Design, Evaluation and Techno-Economic Analysis of a Hybrid Solar-Wind Power Generation System in UAE

تصميم, تقييم وتحليل تقني-اقتصادي لنظام هجين لتوليد طاقة بإستخدام الطاقة الشمسية و طاقة الرياح

By
Chaitanya Bipin Kulkarni
Student ID: 90019

Dissertation submitted in partial fulfillment of
MSc. Sustainable Design of the Built Environment

Faculty of Engineering & IT

Dissertation Supervisor
Professor Bassam Abu-Hijleh

November 2011

DISSERATION RELEASE FORM

Student Name	Student ID	Programme	Date
CHAITANYA KULKARNI	**90019**	**Sustainable Design of the Built Environment**	**November 2011**

Title:

Design, Evaluation and Techno-Economic Analysis of an Integrated Solar-Wind Power Generation System in UAE.

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that the content of this dissertation is the direct result of my own work and that any use made in it of published or unpublished copyright material falls within the limits permitted by international copyright conventions.

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

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

I understand that The British University in Dubai may make that copy available in digital format if appropriate.

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

Signature

ABSTRACT

With the recent turn of events globally, there has been an increasing awareness to drive the earth through sustainable energy means with renewable resources. The use of conventional fossil fuel used for centuries not only has adverse effects but are also fast depleting giving birth to other natural and cleaner alternative power production means for high energy consumption building industry sector. The “Sun and Wind” have by far been proven as the most natural, free and abundant resources on the earth. Also they have received tremendous attention in the recent time as large fractions of these recourses are available at peak power/electrical load production. One of the most important aspects of using Sun (Solar PV) and the Wind turbines (WT) energy resources as an integrated system is that they share most of its components, backup systems and infrastructure to produce power as advantageous technically and economically in this research process. The dissertation aims at exploring the benefits and future potential of using this integrated (solar PV and wind WT) system in relation to the power loads required of the household units in the UAE, Dubai from varied and opposite weather and time conditions i.e. sunny and windy conditions. The research is thus split into two modes of study which are technical and economical.

The computer based simulation methodology proved to be instrumental in the design and modeling of the household to analyze the potential of photovoltaic’s (PV’s) and wind turbines (WT’s) with their common balance of system components. A step by step progression of the various identified case configuration with the use of PV’s first, WT’s second and finally their hybridization HYPW’s from 25%, 50%, 75%, 100% grid connected and standalone renewable energy resources, laid the foundation of the results evolved as technically and economically optimized via the simulation methodology.

The technical results evaluated that till 25% all case configuration, the individual PV’s and WT’s were more suitable to the household due to the low expected power demand from the renewable resources. But beyond the 25% all case configuration, the HYPW system of renewable energy proved as a better solution in comparison to the individuals of PV’s and WT’s due to its higher electrical load demand and potential. The optimized results were a good combination of hybridization of HYPW with their respective contribution of solar and wind energy efficiencies by the PV’s contributing higher and the WT’s maintaining a constant supportive contribution by the electrical production of 1,638kWh/yr respectively for all the 50%, 75%, 100% grid connected and standalone renewable energy resources case configurations. There was reduction in the requirement of PV panels in the case of HYPW configuration from 2kW to 1.4kW PV panels (50% case), 5.4kW reduced to 4kW PV’s (75% case), 7kW reduced to 5.2kW PV’s (100% and Standalone case) hybridized with 1kW 1 number WT’s along with a subsequent support from a correctly evaluated size of the batteries and inverters capacities.

The economics was based on the net present cost (NPC) over the projects 15 years lifetime, in relation to the technical optimization. Similar to the technical result except till all 50% case, the HYPW system was more cost effective as compared to the other two PV’s and WT’s individual system. The minimal 25% and 50% renewable energy grid connected all case configurations proved more economical with only PV’s system. This was essentially due to the lesser operating cost with minimal use of number of components involved in electrical production for household. However the HYPW system was economical for 75%, 100% grid connected and standalone case configurations. This was due to reduction in the number of PV panels in the HYPW system leading to lesser initial capital cost, with the balance electrical production taken care by the 1 number 1kW WT being comparatively cheaper than number of PV’s required otherwise. The reduced number of components led to lowering of the operating cost of the replacements and O&M costs in the HYPW system. Finally the HYPW integrated system proved to be technically better and economically cost effective than the installation of PV’s or WT’s as individual, with increasing demand of electrical production for the household from renewable energy resources with less dependence on the fossil fuel based local grid connection.

الملخص

الأرض إلى استخدام وسائل منذ بداية الإنعطاف الحالي للأحداث على الصعيد العالمي ، كان هناك وعياً متزايداً لتوجيه كوكب سلبية على كوكب الأرض و الطاقة المستدامة من الموارد المتجددة . إن الوقود الأحفوري التقليدي المستخدم منذ قرون ليس فقط له آثاراً سكانه و لكن أيضا هو السبب في تسريع وتيرة تدمير طبقة الأوزون الحامية لهذا الكوكب و بالتالي كان لابد من إعطاء الفرصة لبزوغ أنواع أخرى بديلة من الطاقة النظيفة و المُنتجَة من مصادر طبيعية لاستخدامها بالمنشآت الصناعية كثيفة الإستهلاك للطاقة . لقد ثبت منذ يلقيا زمن أن "الشمس و الرياح" مصدران من مصادر الطاقة الطبيعية النظيفة الغير مكلفة و الأكثر وفرة على كوكب الأرض . كما أنهما اهتماماً كبيراً في الآونة الأخيرة حيث أن الجزء الأكبر من هذين المصدرين يكون متاحاً أثناء ذروة الحاجة لإنتاج الطاقة أو أثناء ذروة الأحمال الكهربائية . أحد أهم جوانب استخدام الطاقة الشمسية (الخلايا الكهروضوئية) و طاقة الرياح (توربينات الرياح) كموارد للطاقة أنهما يشكلان نظاماً متكاملاً حيث أنهما يتشاركان في معظم المكونات و أنظمة حفظ الطاقة بالإضافة إلى البنية التحتية اللازمة لإنتاج الطاقة هذه الطرح يهدف إلى استكشاف الفوائد هذا البحث . بواسطتهما مما يعود بالنفع من الناحيتين التقنية والإقتصادية كما يتضح من خلال والإمكانات المستقبلية لاستخدام هذين النظامين المتكاملين (الطاقة الشمسية و طاقة الرياح) وربط ذلك باحتياجات الوحدات السكنية في مدينة بناءاً على ذلك يتم تقسيم دبي بدولة الإمارات العربية المتحدة من الطاقة في الظروف المتقلبة للطقس و توقيت وجود الشمس أوالرياح . البحث إلى نوعين من الدراسة و هما الدراسة التقنية و الدراسة الاقتصادية.

لقد أثبتت طريقة المحاكاة باستخدام الكمبيوتر أنها أداة مفيدة في تصميم ونمذجة المسكن لتحليل إمكانات الألواح الكهروضوئية و توربينات الرياح مع ما يشتركان فيه من توازن في مكونات النظام و أن الحالات المختلفة التي تم تحديدها عند تطويرها خطوةً بخطوة بدايةً باستخدام الألواح الكهروضوئية أولاً ثم استخدام توربينات الرياح ثانياً وأخيرا تهجين النظامين معاً (نظام تهجين الألواح الشمسية مع توربينات الرياح) بدءاً من نسبة تهجين 25 % ثم 50 % ثم 75 % وصولاً إلى نسبة 100 % تهجين لشبكة متصلة و مستقلة تعمل كمورد من موارد الطاقة المتجددة تكون الأساس الذي تقوم عليه عملية تطوير النتائج على النحو الأمثل تقنيا واقتصاديا من خلال طريقة المحاكاة.

النتائج الفنية التي تم تقييمها أوضحت أنه حتى نسبة 25 % من الحالات المتكونة كان استخدام إما الألواح الشمسية أو توربينات الرياح بشكل منفصل يعد أكثر ملاءمةً للمسكن نظراً لانخفاض الطلب المتوقع على الطاقة المُنتجَة من الموارد المتجددة. بينما قد ثبت في ما نسبته أكثر من 25 % من الحالات المتكونة أن النظام الهجين للطاقة المتجددة يعد حلاً أفضلً بالمقارنة مع استخدام إما الألواح الشمسية أو توربينات الرياح بصورة منفردة و ذلك بسبب ارتفاع الطلب على الأحمال الكهربائية و الطاقة . لذا كانت النتائج الأمثل هي توليفة جيدة من تهجين الألواح الشمسية مع توربينات الرياح مع ما يساهمه كل منهما بناءاً على كفاءة الطاقة الشمسية وطاقة الرياح من خلال الخلايا الكهروضوئية التي تسهم بنسبة عالية من الطاقة و توربينات الرياح التي تحافظ على المساهمة بنسبة ثابتة داعمة لإنتاج كمية من الطاقة الكهربائية تصل نسبياً إلى 1683 ك.و.س / سنة لجميع الحالات المتكونة بنسب 50 % و 75 % و 100 % لشبكة متصلة ومستقلة كمصدر من مصادر الطاقة المتجددة . لذلك كان هناك انخفاض في الطلب على ألواح الطاقة الشمسية في حالة تكوين نظام تهجين الألواح الشمسية مع توربينات الرياح حيث أنه مع خفض قدرة النظام الهجين من 2.0 ك.و إلى 1.4 ك.و إنخفض الطلب على الألواح الشمسية بنسبة 50 % و مع خفض قدرة النظام الهجين من 5.4 ك.و إلى 4.0 ك.و إنخفض الطلب على الألواح الشمسية بنسبة 75 % و عندما تم خفض قدرة النظام الهجين من 7.0 ك.و إلى 5.2 ك.و إنخفض الطلب على الألواح الشمسية بنسبة 100 % و هي الأنظمة الهجين التي تشتمل على تربينة رياح واحدة ذات بقدرة 1.0 ك.و بالإضافة إلى ما يلحق بذلك من وسائل دعم من البطاريات و العواكس ذات سعات مقييمة تقيماً صحيحاً.

الدراسة الاقتصادية تم فيها الإستناد على التكلفة الصافية الحالية للمشروعات ذات العمر الإفتراضي الذي يقدر بـ 15 عاماً و ما يتعلق بها من أعمال التحسين التقني . إن النتيجة تشبه نتيجة الدراسة التقنية عدا أنه حتى ما نسبته 50 % من الحالات وجد أن النظام الهجين أكثر تأثيراً على التكلفة بالمقارنة مع غيره من أنظمة الألواح الشمسية أو توربينات الرياح عند إستخدام أيٍ من هما بشكل منفرد .لقد ثبت أن الشبكات المتصلة بشبكة الطاقة المتجددة بحد أدنى 25 % و 50 % لجميع الحالات المتكونة تكون أكثر اقتصادية مع استخدام نظام الخلايا الشمسية فقط . وكان ذلك بناءاً على تكلفة التشغيل الأقل مع استخدام الحد الأدنى من عدد من العناصر المشاركة في إنتاج الطاقة الكهربائية للمسكن . إلا أن النظام الهجين من الألواح الشمسية و توربينات الرياح كان إقتصادياً للشبكات المتصلة بشبكة طاقة متجددة بنسبة 75 % و 100 % لتكون شبكة اتصال قائمة بذاتها . ويعزى ذلك إلى انخفاض عدد الألواح الكهروضوئية في النظام الهجين و بالتالي أدى إلى تكلفة أقل من رأس المال الأولي ، مع التوازن المطلوب لإنتاج الكهرباء و الحرص على معرفة أن توربينة رياح واحدة تنتج 1 ك.و تكون أرخص نسبياً من عدد الألواح الكهروضوئية المطلوبه بخلاف ذلك . كما أن انخفاض عدد من المكونات أدى إلى خفض تكاليف التشغيل و الإستبدال وتكاليف التشغيل والصيانة في النظام الهجين . هذا و قد ثبت أخيراً أن منظومة متكاملة من الأنظمة الهجين من الألواح الكهروضوئية و توربينات الرياح تكون أفضل من الناحية التقنية و أكثر فعالية في التكلفة الاقتصادية من تلك الأنظمة المركبة من الألواح الكهروضوئية أو توربينات الرياح و التي تعمل بصورة منفردة ، و ذلك مع تزايد طلب المسكن على الطاقة الكهربائية المنتجة من موارد الطاقة المتجددة و تراجع الاعتماد على الشبكة المحلية المعتمدة على الوقود الأحفوري.

ACKNOWLEDGEMENT

Firstly, I would like to thank my supervisor, Dr. Bassam Abu Hijleh, for his kind support, enthusiasm, and continuous guidance. I have gained excellent knowledge as a researcher of renewable energy resources specifically related to solar and wind energy pertaining to the building industry. Also his supervision led to a holistic approach towards a sustainable future in the current times of worldwide climate change.

Most importantly I would like to express my gratitude towards my family (Dr. Dhanashree and Arnav) for their patience and encouragement all throughout the duration of this research.

I would also like to thank my senior, Mr. Anil Dani for his contribution and support to source all the right products and suppliers for the simulation work in this dissertation.

To all my friends and well wishers for making this work memorable and a joyful experience with their time and support when I needed the most.

Above all, my parents (Neelam and Bipin Kulkarni) for their blessings, love, kind words and making me capable of striving for the best throughout my academic and professional path so far and always.

My sincere thanks to all…………..

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

BTU	British Thermal Units
CO2	Carbon Dioxide
COE	Cost of Energy
EAHE	Earth Heat Air Exchanger
EIA	Energy Information Administration
GCC	Gulf Council Countries
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GWEC	Global Wind Energy Council
HAWT	Horizontal Axis Wind Turbines
HYPW	Hybrid/Integrated Photovoltaic's and Wind Turbines
IEA	International Energy Agency
IPCC	Intergovernmental Panel Climate Change
IRENA	International Renewable Energy Agency
LPSP	Loss of Power Supply Probability
MPT	Maximum PowerPoint Tracking
NPC	Net Present Cost
NREL	National Renewable Energy Laboratory
OPV	Organic Photovoltaic's
ppm(v)	Part per million (volume)
PV's	Photovoltaic's
REN21	Renewable Energy Policy Network of the 21^{st} Century
STC	Standard Test Condition
UN	United Nations
US DOE	United States Department of Energy
VAWT	Vertical Axis Wind Turbines
WT's	Wind Turbines

CHAPTER 1: INTRODUCTION

1.1 GLOBAL SCENARIO

Humans have existed on earth and its climatic conditions for centuries and relatively co-existed using its natural resources as a part of the eco-system successfully by adaptation for decades. But the changing global climatic conditions and its warming has been the most controversial topic since decades and if not now then surely down just few years require at most attention. Many claims have been made by various organizations and international governing bodies of its potential effects and occurrences which are caused by human activities and behavioral pattern as detrimental to future generation if we need to survive for further centuries to come by. Although one can decide to neglect them as information used for vested interest, but for sure the changes that we all have noted such as average rise in temperature, increasing sea levels, melting ice caps and series of events like tsunami, earthquakes, wild fires, heat waves cannot be neglected. The debate on the climate changes was carried to the Kyoto Protocol in 1997 by various governments and targets were set to reduce the greenhouse emission emitted by human activities resulting from industrialization. Though very few results were met till again in 2010 the Copenhagen Climate Council initiated a serious concern arising due to the rise in temperature by 2^{o}C whereby it was agreed by the various governments to reduce the green house emission by 80% till 2005 (baseline the year 1990 or more recent years). But it all started with the oil boom in the late 1970's where the use of fossil fuel was instigated a massive boom in industrialization. Since then the use of fossil fuels for power consumption resulting in CO2 emission have been increasing substantially as shown in Figure 1.1

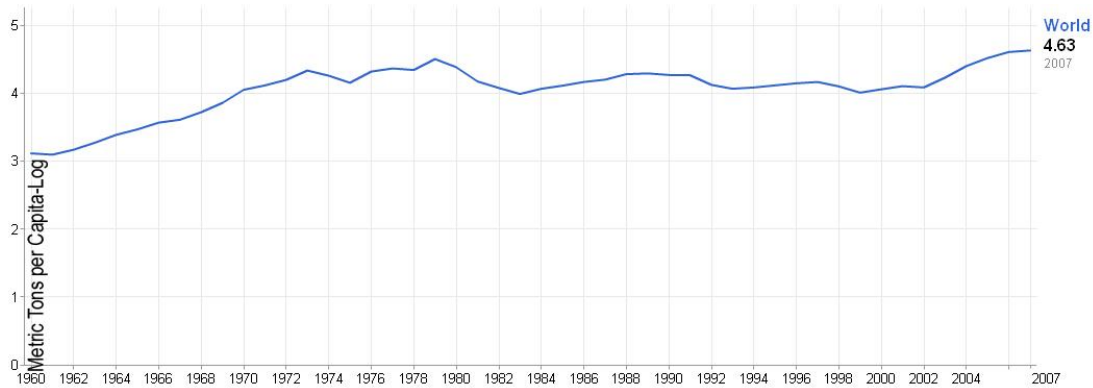


Figure 1.1: World Bank CO2 emissions in metric tons (World Bank, 2011)

Also there are statistics indicating that if we continue to emit greenhouse gases at such fast pace which has already reached 490ppm then there is no point of return as the equilibrium global average temperature shall also follow a similar rise as per Figure 1.2 which could have adverse and catastrophic effect.

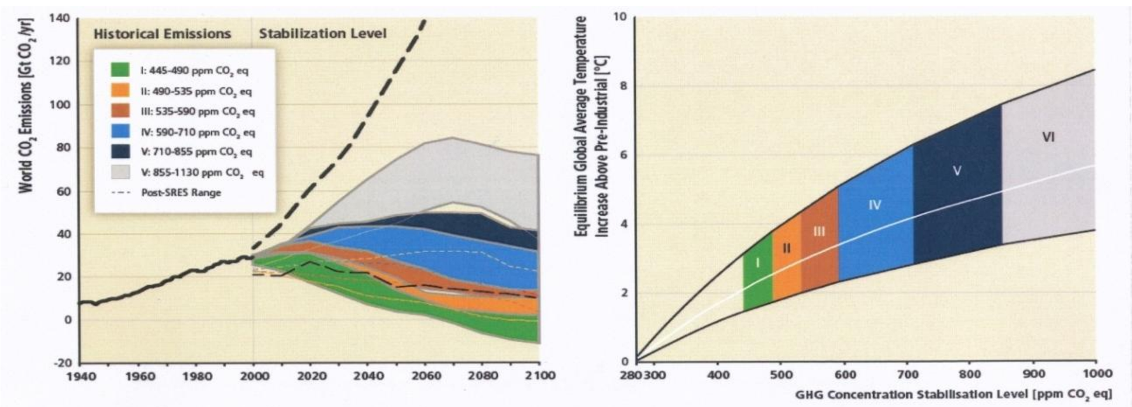


Figure 1.2: IPCC Special Report on Renewable resources and Climate Change (IPCC, 2011)

Though fossil fuels such as gas, oil, coal etc have been the back bone of fast civilization growth and improvement in lifestyle, however they are also natural resources and there is a limitation to its sources as always. So here by we have 2 challenges which is the resource depletion of fossil fuels and the hazardous effects which emit green house gases harmful to the atmosphere. Thus now it is imperative that we need to divert our attention to resources which can produce clean energy and can negate the problems created by the usage of fossil fuels to add value to the global climatic movement to secure our future civilization. Such mitigation is required to bring back a balance in the ecosystem which has been disturbed by mankind in the recent years. In response the increase in the use of renewable energy has been tremendous in the recent years with solar and wind being one of the most researched due its conversion of infinite availability in energy sector and the relative absence of harmful emissions. Thus Figure 1.3 clearly indicates the world energy consumption graph depending on renewable energies with solar and wind as front runners.

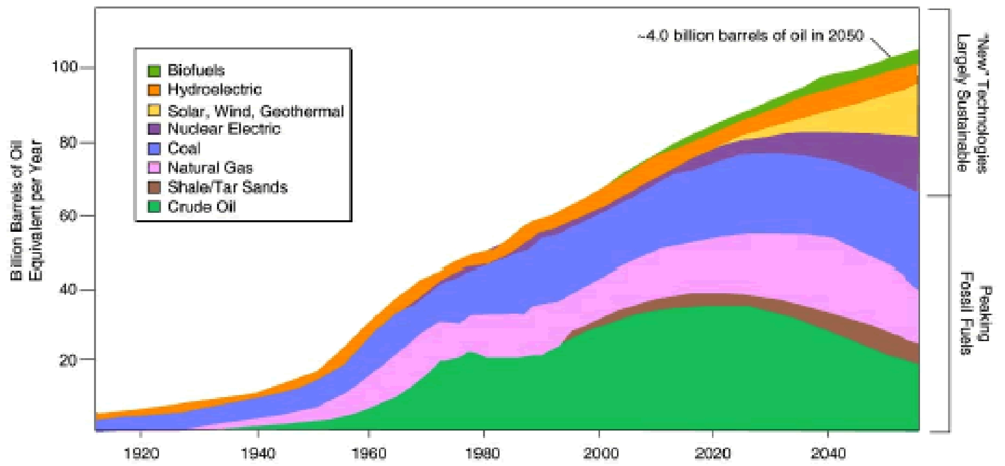


Figure 1.3: Changes in world energy system consumption by source matrix (Orr et al, 2010)

It is interesting to know that if the Solar/PV energy is converted to electricity at a efficiency of 10% (much less as compared to today's commercial module) then a mere 0.7% of the world desert area would be required to generate the total 2005 world electricity consumption of about 18,500TWh (Harvey, 2010). Similarly the world wind energy market grew by about 23.5%/year from 1995-2003, while the installed capacity grew at an average rate of 24.9% reaching 4267GW by 2005 (Harvey, 2010). Thus one can only imagine the great potential of these renewable energy resources and its hybridization as to why it has reached enormous research and development areas. The building sector is known to have higher energy consumption and also potential for energy efficiency in various components and areas related to buildings. It has a very high resource consumption graph right its design, execution, maintenance and operation phase. Figure 1.4 illustrates the building electrical energy consumption has increased almost 3 folds since 1973 till 2008.

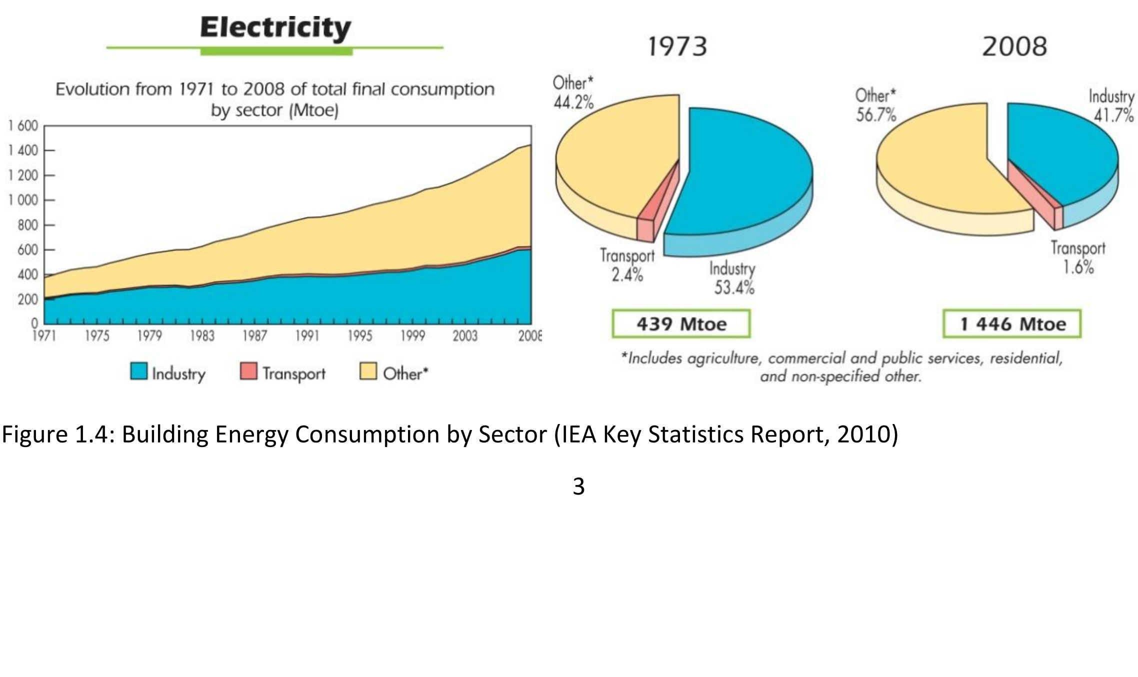


Figure 1.4: Building Energy Consumption by Sector (IEA Key Statistics Report, 2010)

Also as per the US Department of Energy published in the Building Energy Data Book buildings consume almost 40% of all energy use and total electrical consumption of 74% at various stages (US Department of Energy, 2009). Most of the energy is used in lighting, heating, ventilation, cooling and dehumidification as it accounts for about third of the primary use in OECD countries. Table 1.1 illustrates that US leads in the world with total primary consumption overall and in comparison the Middle East accounts for only 5% of that amount. But this if one compares to the per capita basis then the United Arab Emirates and Qatar shall lead way ahead of the US and other Arab Worlds as the Middle East has the highest annual growth rate of any of the other African regions (World Bank, 2011) as per Figure. 1.5. All this has been due to rapid growth and expansion that has been witnessed till 2008 due the heavy construction activity in the Middle East and especially in Dubai. Thus it is time that not only UAE but all nations take a note of this grave problem which mankind faces due to lack of proper monitoring, design approaches, construction methods and processes of the building industry which has put a heavy burden on the built environment by means of renewable, sustainable design and resources here after.

Table 1.1: World Primary Energy Consumption (EIA, International Energy Outlook, 2010)

World marketed energy consumption by country grouping, 2007-2035 (quadrillion Btu)

Region	2007	2015	2020	2025	2030	2035	Average annual percent change, 2007-2035
OECD	**245.7**	**246.0**	**254.2**	**263.2**	**271.4**	**280.7**	**0.5**
North America	123.7	124.3	129.4	134.9	140.2	146.3	0.6
Europe	82.3	82.0	83.0	85.0	86.5	88.2	0.2
Asia	39.7	39.7	41.8	43.3	44.8	46.3	0.5
Non-OECD	**249.5**	**297.5**	**336.3**	**375.5**	**415.2**	**458.0**	**2.2**
Europe and Eurasia	51.5	52.4	54.2	56.2	57.8	60.2	0.6
Asia	127.1	159.3	187.8	217.0	246.9	277.3	2.8
Middle East	25.1	32.9	36.5	39.1	41.8	45.7	2.2
Africa	17.8	20.8	22.5	24.6	26.5	29.0	1.8
Central and South America	28.0	32.1	35.5	38.7	42.2	45.7	1.8
Total World	**495.2**	**543.5**	**590.5**	**638.7**	**686.5**	**738.7**	**1.4**

[6]For consistency, OECD includes all members of the organization as of March 1, 2010, throughout all the time series included in this report. Chile became a member on May 7, 2010, but its membership is not reflected in *IEO2010*.

U.S. Energy Information Administration / International Energy Outlook 2010

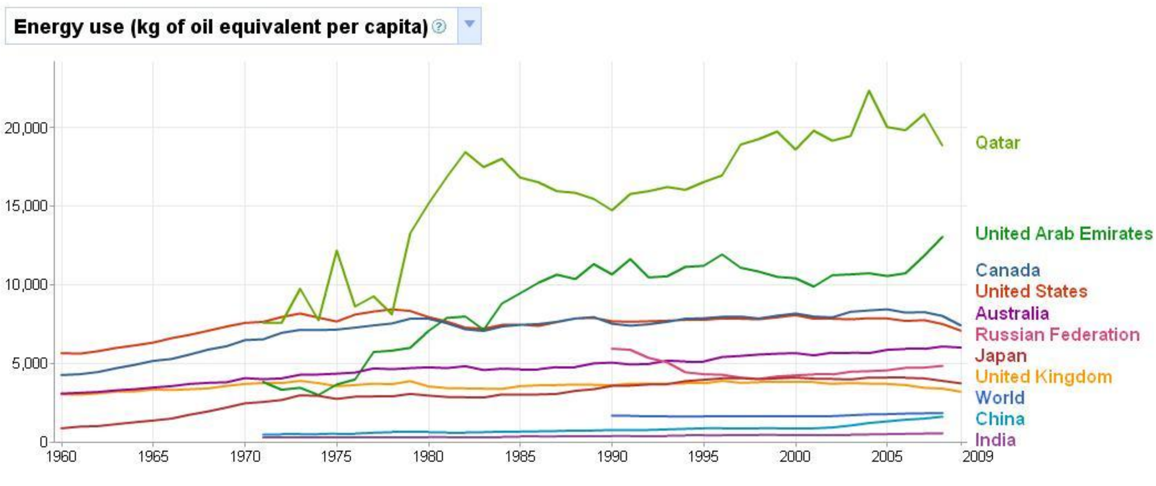


Figure 1.5: World Bank CO2 Energy use per capita (World Bank, 2011)

1.2 BUILDINGS INDUSTRY AND ENERGY RELATION

At first mankind adapted to climatic conditions, but as technology advanced they started designing buildings to adapt to climatic conditions. This evolution lead to the criteria of form, function and space which designers used as keys to design adaptable buildings which was followed by the boom of fossil fuel and the era of mega industrialization. The fast industrialization brought about the important topic of climate changes, warming and research in it. Most of the early publications have been essentials categorized in three main groups. Firstly issues leading to human thermal comfort which utilize passive design techniques to formulate buildings. Further more emphasis on solar access, daylight penetration and passive heating ways by solar energy. Thirdly the major changes in city climatology due to heavy urbanization and its effects. Most research followed more or less similar backgrounds (Okeil, 2010). Slowly but surely results raised concern over supply difficulties, depleting energy resources, conservation and a cap to energy utilization on building energy demands. Glass introduction to building industry was a good solution to daylight penetration but it is not a very good material for controlling thermal exchange due to its comparative poor insulation properties. The global energy contribution from buildings towards energy consumption has increased exponentially from 20% to 40% for both residential and commercial sector and has even exceeded other major sectors such as industry and transport. But apart from the material use the Table 1.2 demonstrates population growth is also responsible for increase primary energy consumption with a per capita value of 15.7% over the last 30 years. Electricity being one of the prime consumers leading to a percentage increment of 18% and the efficiency in exploiting energy resources has declined by 7% points due to the higher rate of GDP growth (Lombard et al, 2008).

Table 1.2: Building Energy Consumption versus Population and Annual Growth Rate (EIA, 2010)

	Energy Consumption (Quad)				Population (million)				Annual Growth Rate			
									1990-2000		2000-2008	
Region/Country	1990	2000	2008		1990	2000	2008		Energy	Pop.	Energy	Pop.
United States	84.9	99.3	99.5	20.2%	250	282	304	4.5%	1.6%	1.2%	0.0%	1.0%
China	27.0	36.4	85.1	17.3%	1,148	1,264	1,317	19.7%	3.0%	1.0%	11.2%	0.5%
OECD Europe	52.2	76.8	81.2	16.5%	402	522	545	8.1%	3.9%	2.6%	0.7%	0.5%
Other Non-OECD Asia	12.6	26.3	35.7	7.3%	781	1,014	1,142	17.0%	7.7%	2.6%	3.9%	1.5%
Russia (1)	61.0	27.2	30.4	6.2%	288	147	141	2.1%	-7.7%	-6.5%	1.4%	-0.5%
Central & S. America	14.5	20.8	25.8	5.2%	359	422	469	7.0%	3.7%	1.6%	2.7%	1.3%
Middle East	11.2	17.3	25.5	5.2%	135	173	205	3.1%	4.5%	2.5%	4.9%	2.1%
Japan	19.6	22.8	22.3	4.5%	124	127	127	1.9%	1.5%	0.3%	-0.3%	0.1%
India	7.9	13.5	20.0	4.1%	838	1,006	1,141	17.0%	5.5%	1.8%	5.0%	1.6%
Canada	11.0	13.1	14.0	2.8%	28	31	33	0.5%	1.8%	1.1%	0.9%	0.8%
Oth. Non-OECD Europe	24.1	12.0	13.2	3.3%	154	128	124	1.9%	-6.8%	-1.8%	1.2%	-0.4%
Africa	9.5	12.0	16.1	2.7%	631	804	970	14.5%	2.4%	2.4%	3.7%	2.4%
South Korea	3.8	7.8	9.9	2.0%	43	47	48	0.7%	7.4%	0.9%	2.9%	0.4%
Mexico	4.7	6.4	7.3	1.5%	85	100	110	1.6%	3.1%	1.6%	1.7%	1.2%
Australia & N. Zealand	4.4	5.7	6.6	1.3%	20	23	25	0.4%	2.5%	1.2%	2.0%	1.2%
Total World	**348.4**	**397.4**	**492.6**	100%	**5,287**	**6,089**	**6,701**	100%	1.3%	1.4%	2.7%	1.2%

Building sector ranges from commercial, residential, public, private, etc and each has its own rate of consumption of electricity due to the varied time and purpose of usage. It is very difficult to calculate electricity consumption for each of the above building sectors but a broad range can be adopted. The service sector such as commercial and public buildings with a wide variety uses and energy services (HVAC, domestic hot water, lighting, refrigeration etc) has expanded from 11% to 18% from the 1950's while the UK service energy accounted for around 11% in 2004 (Lombard et al, 2008) In the residential sector with the change in lifestyle of developed countries the need for indoor comfort conditions and large expanse of per sq ft of area per person incremental brought about installation of new appliances such as air conditioners, computers etc. In USA the consumption in residential sector accounted for 22& and in the UK the figure expanded to 28%, well above the EU nations (EIA, Euro stat, BRE, 2009).

Table 1.3 and Figure 1.6 estimates the HVAC consumption of domestic buildings to be around 42% to about 50% in USA creating a serious concern of supply during peak load periods. While office and retail are the most intensive typologies accounting for 50% of the overall energy consumption with HVAC leading followed by lighting 15% and appliances to about 10% (EIA, Euro Stat, BRE, 2010).

Table 1.3: Energy consumption by end uses in residential sector (EIA, 2010)

Energy consumption by end uses in the residential sector

End uses in the residential sector (%)	Spain	UE	USA	UK
Space conditioning	42	68	53	62
Domestic hot water (DHW)	26	14	17	22
Lighting and appliances	32	18	30	16

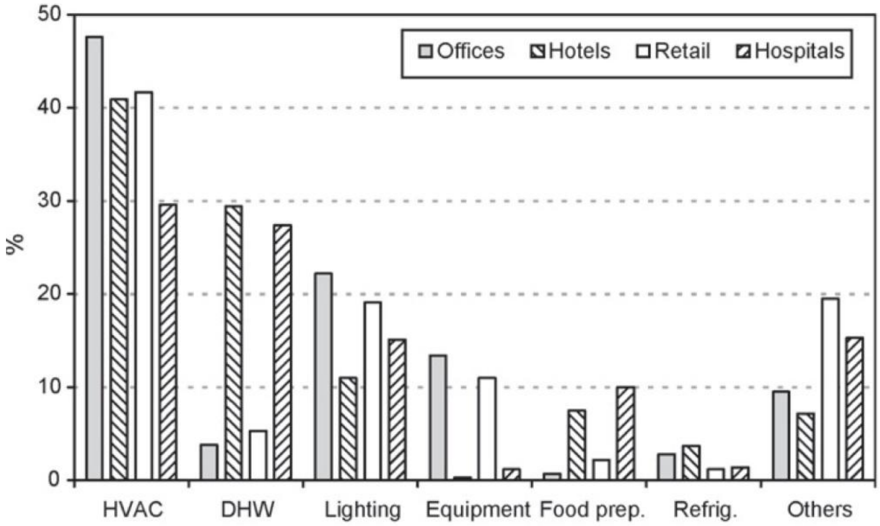


Figure 1.6: Consumption by end uses for different building types (EIA, 2010).

Further studies and research emphasized on energy demand with variations in building forms, orientation, solar pattern, urban heat islands, green roofs, wind/air flow etc in urban and rural set up. The major difference in use of material to achieve better thermal comfort conditions, passive ventilation techniques etc without increasing energy and electricity demand is evolving. Statutory bodies, governments, designers have now become more conscious of this phenomenon and the role the building industry has to play in conservation of climatic conditions. More stringent codes and construction practices have been in place in most of the countries with every nation setting targets to contribute to this event.

1.3 UAE's SCENARIO

UAE (United Arab Emirates) obtained its independence in 1971 and in a very short span of 35 years was recognized as one of the fastest growing economy due to its urbanization, infrastructure and construction industry. The recent years also witnessed a great boom in the real estate industry sector which also led to large pit fall due to the global economic crisis. Consequently oil and natural gas consumption quadrupled in the past two decades resulting high carbon emission amounting to 10 times higher than the developed nations. All this grew exponentially in the recent few years whereby previously traditional building designs prevailed such as small window sizes to avoid heat gain, wind towers such as Badgir but as modernization took over was replaced by mechanical ventilation and large glass panels adding to the heat gain and energy consumption. Vernacular architecture was dependent on high building thermal mass and natural ventilation techniques taking wind tower directions for inlet and outlet.

Least of all the hierarchy and dominance of housing the world's largest building structure prevailed with the Burj Khalifa mounting 838 meters flanked by all glass façade around the Business Financial District which already started housing the 300 odd offices spaces. Similarly retail sector was flanked by the largest malls such as Dubai Mall and Emirates Mall. These solely were depended on mechanical ventilation, particularly the air conditioning, lighting etc due to the low cost of fuel consumption and peak summer load periods in the country.

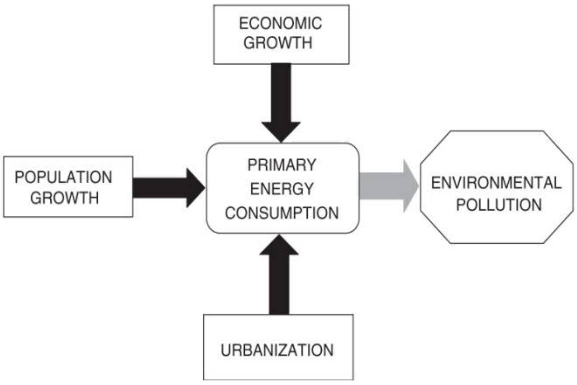
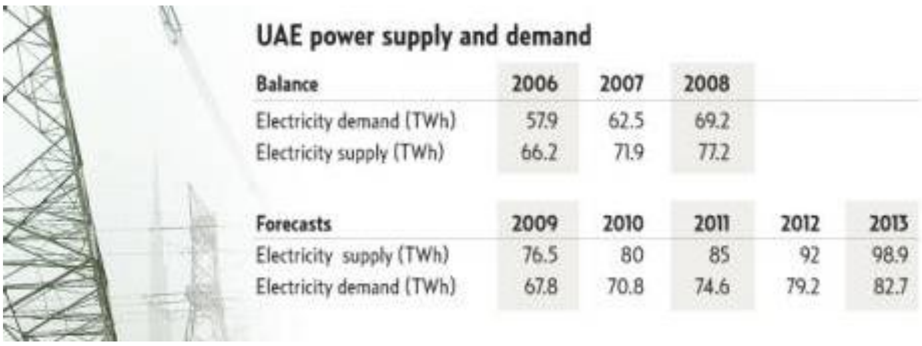


Figure 1.7: Factors contributing to UAE high energy consumption (Kazim, 2007)
Accordingly the UAE maximum crude oil capacity is estimated to be around 2.2-2.5 million barrels per day and natural gas production estimate reached 4bcf/d till 2005 (Kazim, 2007) Subsequently the electricity demand has risen from 57.9TWh in 2006 to 69.2TWh in 2008 with simultaneous incremental in electricity supply from 66.2TWh in 2006 to 77.2TWh 2008 (Dubai Chamber of Commerce based on Ministry of Economic Data, 2009) Refer Figure 1.8. Also the installed capacity of electricity generation till the year 2009 was 20,696MW. (UAE Ministry of Energy, 2010)



UAE power supply and demand

Balance	2006	2007	2008
Electricity demand (TWh)	57.9	62.5	69.2
Electricity supply (TWh)	66.2	71.9	77.2

Forecasts	2009	2010	2011	2012	2013
Electricity supply (TWh)	76.5	80	85	92	98.9
Electricity demand (TWh)	67.8	70.8	74.6	79.2	82.7

Figure 1.8 UAE Power Supply and Demand (UAE Ministry of Economic Data, 2009)

But UAE as a country is also quick in trying to find remedial measures, with effect such as enhancing public awareness through the Federal Environmental Agency (FEA), department of environment and protection areas (DEPA), local municipalities and other nongovernmental organizations. One of the important additions is the $1 million Zayed International Prize aiming to promote sustainable development through various environmental protection initiatives (www.zayedprize.org.ae 2011). In residential sector, Dubai Municipality has started a mandate to use insulated material to suit climatic conditions in addition to the cap of 40% electrical energy conservation. Furthermore the use of energy efficient lights and device such as windows, energy audits, A/C controllers as well as district cooling technologies (Dubai Municipality, 2009). A lot of emphasis is being given to solar technologies due to the apt UAE location and climate as renewable resources, where even oil companies such as Abu Dhabi National Oil Company (ADNOC), ETISALAT have incorporated solar technologies in their system. Dubai Municipality has installed solar parking meters as well as road signages in the city.

One of the major initiatives is the Masdar City located in the out skirts of Abu Dhabi is set to be the first carbon neutral and zero waste city in the world which feature 10-mgawatts of solar power plans, being the largest in the region. Also recently DEWA announced the plan of commissioning of the first private sector power plant, privatizing 1,500 MW of the Hassyan power plant (Gulf News, 2010). UAE government awarded a $20 billion contract to Korean Electric Power to build nuclear reactors, each with a capacity of 1,400 MW and free up domestic production for export (EIA, 2011).

Figure 1.9 Carbon Neutral and Zero Waste Masdar City (Gizmodo, 2010)

All in all as UAE grew faster and approached problems much deeper, it's now initiative to conserve energy, sustainable design approaches and renewable energy future is strong and shall be surely implemented.

1.4 STUDY RATIONALE

The purpose of this study is to review the implications of integrating the two most powerful and abundant natural resources available on earth such as solar and wind energy. The integration of these two renewable resources via solar PV's and wind turbines WT's in order to evaluate their respective potential in harnessing/producing power useful to the building industry. The study strives to be a step towards sustainable built environment and as a cleaner alternative to conventional means of power production. Majority of the research carried out have been more oriented towards improving and examining the potentials of these resources as individuals. This research aims as integrating the two to form a better support system to the building industry with most of their common balance of system components in spite of the varied nature and availability of these two solar and wind energy resources.

Furthermore, since most research for these two renewable energy resources has been conducted by previous studies in various countries such as UAE, Europe, North America etc, but more inclined towards them as individuals. Predominantly such as wind turbines have been researched more often in Europe due to the high wind energy potential where as solar PV's are evaluated on a larger scale in the Middle East but very few papers indicate an integration of the two systems. Hence the study of these two via integrations could prove to be beneficial considering they both are available in various ratios in almost all parts of every countries climatic condition. More so, it is important to evaluate and question the criteria such as:

- Considering the unpredicted nature of the two resources and weather dependence, will they prove to be potentially integrated successfully to smoothen the power production by overcoming each other's weakness is to be researched technically?
- Will economic parameters favor the two integrations in bridging the gap between technology and reality needs to be evaluated?

1.5 DISSERTATION OUTLINE

The dissertation is divided into six chapters essentially as follows:

Chapter1: This chapter gives an insight about the current global scenario as regards to energy and the power sector. The growing problems of harmful levels of CO2 gaseous emission and it effects leading to global warming with contribution from building industries conventional methods of power production dependent on fossil fuels. The current UAE's situation and it energy sector with certain mitigations for future stances is researched progressing towards the need to use renewable energy resources as sustainable means for future generations.

Chapter 2: A step to towards renewable energy resources with various available forms of natural means of power productions ranging from solar, wind, geothermal etc researched literature review. This chapter forms the back bone of dissertation whereby previous research done to specific renewable energy resources are studied and documented. The current stances, details and progress is discussed step by step formulation of every renewable energy resources which specific emphasis in solar and wind energy, backed by systems which harness this naturally abundant energy to lead a sustainable goal towards power production.

Chapter 3: Every research needs to adopt a specific methodology and this chapter lays emphasis on the various research methodologies adopted for this specific dissertation topic of hybridization of solar and wind energy harvesting systems. With the use of paper from various journals, papers, documentations etc. the process of adopting an appropriate methodology is achieved.

Chapter 4: The details of the simulation model methodology are detailed and specified in this chapter. The various case configuration which lead to step by step progression of the dissertation and finally the selection criteria of PV's and WT's are justified to form the model household renewable energy system.

Chapter 5: The technical evaluation and progression of the various case configurations of the PV's WT's and HYPW systems are followed by results from the simulation methodology are noted and discussed. The various questions which are formulated by the aim of this dissertation are answered in this chapter technically with their advantages and disadvantages of every system.

Chapter 6: The second part of this dissertation supportive to the technical results is compared to the economic results and assessment. The prime focus being the economics involved in the success and failure of each and every renewable energy resource is validated here.

Chapter 7: A complete comparative summary and conclusion leading to further works is noted in this chapter for both parts, technical and economic evaluation of renewable energy use.

CHAPTER 2: LITERATURE REVIEW

2.1 BACKGROUND

The potential of renewable resources is enormous and can meet the world energy demand in principle to multiple times. With developing nations such as India, Brazil and China growing at an alarming rate, there will be always demand for oil, gas, fuel etc, but these conventional forms of energy tend to be cynical in nature, due to the effects of oligopoly in production and distribution apart from facing due pressure on numerous environmental fronts. Thus it is becoming clear that the future of economic and policy making lies greatly in the new regime of renewable to sustain longer terms of progress, security and stability. This is further elaborated with different renewable energy forms in the building sector and research literature on two of most fast growing and renowned natural resources.

2.2 RENEWABLE FORMS OF ENERGY PRODUCTION

Numerous renewable resources such as biomass, hydropower, geothermal, wind and solar can provide sustainable energy services in abundance due to the free availability of the main source. The mindset of consumers is looking into the other means of obtaining energy such as heating, cooking, steam generation and power generation for the movement and further for electricity production. Earth is general has great potential in its formation with its eco-system and surrounding atmosphere such as its isolation of the sun and geothermal energy of the earth.

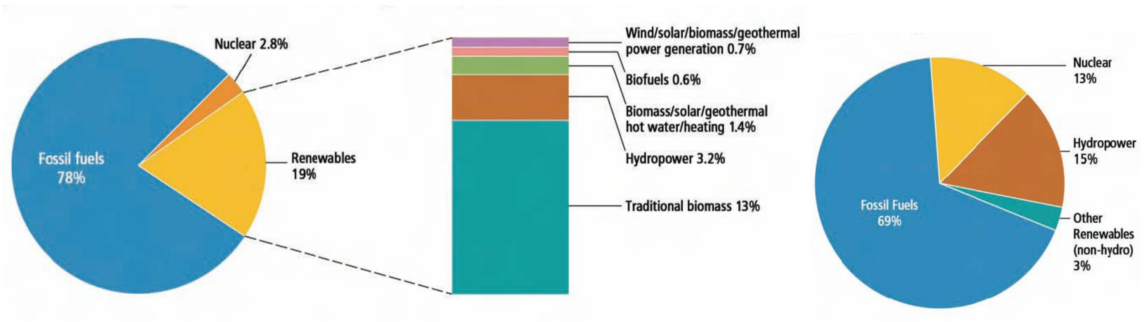


Figure: 2.1: Global Share of Final Energy and Electricity Consumption from Renewable Sources (REN21, 2010 Report)

The current worlds total energy current supply is around 19% with traditional biomass accounting for almost 13% due to the developing countries such as Africa, Asia, Latin America using mostly fuel woods for cooking, heating etc. But when it comes to electricity generation large hydropower is dominant with a large scale of almost 15% which is due to the huge dams, reservoirs in most of the developed countries leaving with only 3% for other non hydro resources. Thus as an alternative to custom, on site construction of centralized power plants, renewable system based on PV arrays, small hydro, wind mills, biomass can be mass produced with energy appliances capable of being manufactured at low cost and tailored to meet specific needs of the service industry to match specific energy loads. Though existing power capacity worldwide has reached 1,230 GW in 2009, the renewable energy comprises only ¼ of global power generating capacity and supplies 18% of the global electricity production (REN21, 2010)

But apart from actual renewable resources there are various researches currently ongoing to reduce electricity loads such as passive ventilation design techniques, façade technologies to control solar gain and losses, energy efficient lighting system, indoor air quality and controls, energy audits, energy measurement gadgets, renewable use of wood (FSC certifications), water usage efficiency etc. Thus not in the field of actual usage of renewable resources, there are measures taken to control building industry by proper construction techniques, testing and commissioning and finally enlightenment of the occupant behaviors is important for success.

2.3 ALTERNATE RENEWABLE ENERGY RESOURCES

In the below sub section we investigate the potential of alternative renewable resources which have their due share in the world energy and electricity generation market such as biomass, geothermal, hydroelectric and ocean. And finally an in-depth literature review on the solar and wind energy resource which is the main topic of research for the author

2.3.1 Biomass Energy

Biomass energy is the conversion of the organic material originating from plants including algae and trees and crops with the collection and storage of sun's energy through photosynthesis. It is useful form of energy such as heat, electricity and liquid fuels which has been used by civilization since cave man where he used wood and other organic products to keep his cave warm and cook food. Energy is extracted from biomass such as woods, paper, dung, straw, sugarcane, domestic refuse, commercial waste, grass, vegetable oils, ethanol etc in the form of heat when it is burned. Hoogwijk et al, 2003 have identified seven categories of biomass as follows such as agricultural land conversion to yields, degraded land which is suitable for reforestation, agricultural residue, forestry residue, animal manure, organic waste and finally biomaterials. Figure 2.2 gives an estimate of traditional biomass usage (Cooking, heating) and for commercial energy used as part of market economy around the world.

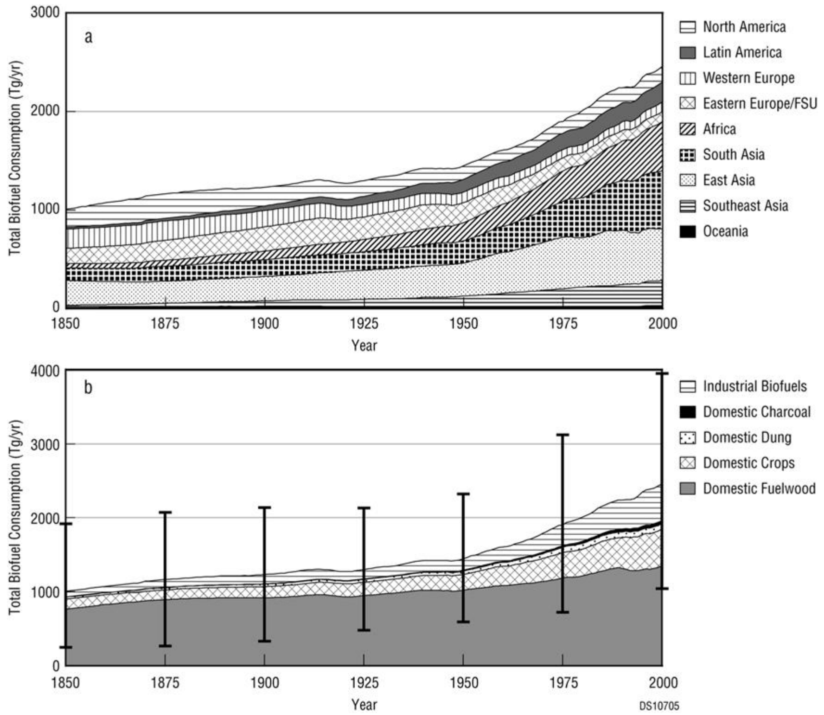


Figure 2.2: Global biomass consumption trends, 1985–2000, by (a) world region and (b) fuel type, (Fernandes et al, 2007).

It has currently an annual primary production of 4500EJ with a bio-energy potential of 299EJ of which 270EJ can be considered to on sustainable basis (Herzog et al 2009). In general terms a good yield in Northern Europe would be around 200GJ and would be sufficient to heat 2-3 houses annually given a floor area of between 60-100m2. There are various technologies for conversion of biomass energy carriers namely electricity, liquid fuels which can be used for households, community and industrial scale.

Direct combustion is a very common technique used in colder countries such as Scandinavian, Austria and Eastern Europe with techniques such as domestic fired heating system which are automated and use standardized fuel such as pellets and has a heating efficiency if over 70% with greatly reduced harmful emissions. For electricity generation the steam-Rankine technology is used in commercial, industrial sector with a capacity of from 1-50MWe where heat from steam turbine is recovered using combined heat, power system which provides greater energy services with an overall efficiency of greater than 80% (Herzog et al 2009).

Gasification is produced with high temperature thermo chemical process of the biomass and one such interesting technology is the integrated gasification combined cycle (IGCC) with a combined heat and power generation in the range of 5-00MWe. Several countries such as UK, Italy, Brazil are trying to contribute and in Sweden the very first completed biomass fueled (IGCC) has been operated over 1500 hours on forest residue generating 6MW of electricity and 9MW of heat for the local district system (Herzog et al, 2009). Also the US.NREL is funding small bio-power projects whereby it can provide power in the range of 5kW-5MW that are fuel flexible and simple to operate (NREL, 2009).

Other forms include anaerobic digestion from biomass through low temperature biological process which commonly named as Biogas whereby methane is produced through digesters or in landfills. India and China lead in this sector of small scale digesters. Also liquid bio-fuels are successful where immediate energy form can be obtained from biomass. This has real potential to replace petroleum based fuels used in transportation. Ethanol production can be combined with efficient electricity production from lignin with an efficiency of 70% (low heating value). Thus the scope biomass is huge and can be endless as technology advances and a in the building industry can be explored from large scale to small scale depending on the land availability and the surroundings. See Figure 2.3 for bio-fuelled combined heat and power project used in BedZED by Arup architects.

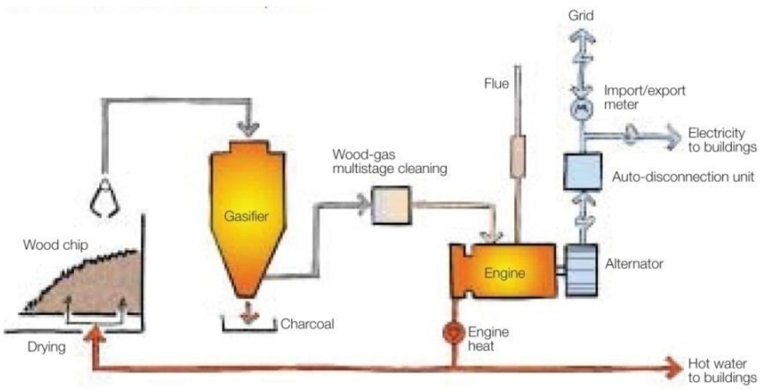


Figure 2.3: Bio-Fuelled combined heat and power at BedZED housing project in UK by Arup (Arup Journal 2003)

2.3.2 Geothermal Energy

Geothermal energy is the natural heat within the earth due to the ancient heat storage in the Earth core, along with the decay of radioactive elements which occur naturally in all rocks and friction from the continental plates which slide beneath each other. Again this form dates down centuries back where people have used this heat in form of hot springs, vents to cook food, heating etc. Today's technologies allow this earths heat energy to be converted to electricity by drilling into hydrothermal reservoirs, which pipe the hot water or steam to the living surface which can be used for space heating, aquaculture and industrial processes. Researchers claim that only 1% of the heat containment in just the uppermost 10km of the earth's crust is 500 times the energy available in oil and gas resources (Harvey et al 2010). But in practice it is seldom concentrated and depths sometimes are greater to be exploited for commercial and economical purpose due to its uneven nature. The total installed capacity is growing at a rate of 12.33% with current status at 2009 estimation of 50,583MWt, with a 78.9% increase in comparison to 2005 (Lund et al, 2011 & World Geothermal Congress, 2010). Countries such a USA, China, Sweden, Norway and Germany alone are holding almost 60% of the world installed capacity. This has been solely due to the increased awareness and popularity of ground source heat pumps (GSHP) used directly as geothermal energy source. Figure 2.4 illustrates the capacity and usage of geothermal heat pumps to account for almost 69.7% and 49% respectively in relation to other geo-sectors.

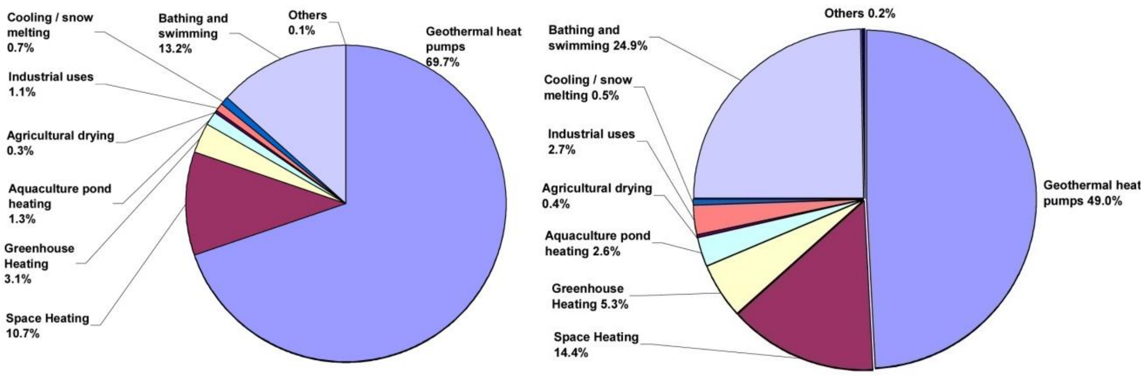


Figure 2.4: Geothermal direct application worldwide of total installed capacity and total energy use (Lund et al, 2011 & World Geothermal Congress, 2010)

Geothermal heat extraction can be classified by various methods ranging from borehole heat exchanger using heat pumps from ground as well as aquifers/ponds with the help of loop pipes depending on the temperature of the ground, hydrothermal for electricity production from high pressure steam fields and similarly dry hot rock beds depending on availability etc. Also various studies have been conducted for earth-air heat exchanger (EAHE) for passive ventilation techniques using ground temperature source whereby (Maerefat, et al 2010) used a combination of solar chimney and EAHE to cool a building modeled by buried pipes and reading of the ground temperature in rationale to the length and width of the loop pipes in the ground. Similar technology can be derived by forming a loop in aquifers or ponds as open water loop or surface water loop to maintain thermal temperature in buildings to avoid heavy energy loads consumed by conventional cooling methods.

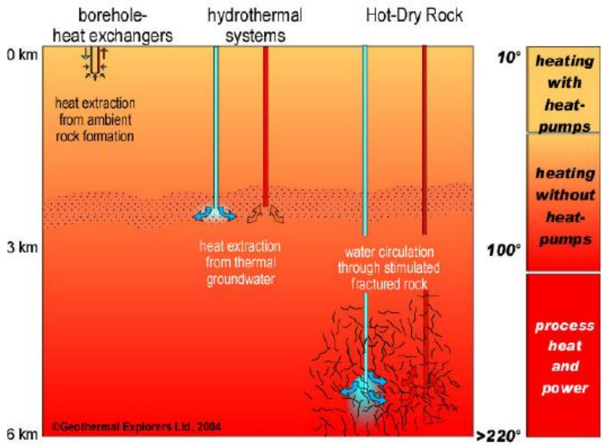


Figure 2.5: Geothermal heat extraction technologies (Geothermal Explorer Ltd, 2004)

Four main technologies have been used to generate large capacity of electricity from geothermal source depending on nature of resource mainly, dry steam, single flash steam, binary cycle and double flash steam power plant. Currently US leads the world geothermal electricity production with 3,086MW capacity from 77 power plants located at “The Geysers in California” followed by Philippines with a 1,904 MW capacity which account to 18% of the country’s electricity generation(Wikipedia 2010).

Figure 2.6 The Geyser Geothermal Power Plant in California, (Calpine Corporation, website, 2010)

Hot dry rock or enhanced geothermal systems (EGS) are also explored within 10km depth of the surface since they require enhance porosity and permeability as name suggests. It is estimated that EGS and other geothermal resources could provide 100GW of electricity in the US by 2050 (MIT, 2006) but countries like France and Australia have actively pursued geothermal options more than US especially in EGS techniques. A good example is Soultz, France connected reservoir well with an active volume of 2km at a 4-5km depth has been created. But due to the high initial and O&M cost for larger production purpose this resource is lacking behind though having enormous potential in the world market.

2.3.3 Hydroelectricity and Ocean Energy

Electricity generated by hydropower, which can be divided by river based or reservoir based including dams etc. Most of the run of the river power is regarded as C-free with no GHC emissions but not true for reservoir based power as the later involves emission of CO2 emitted during cement production. Hydropower supply of global electricity production estimates to about 15% with an addition 31GW each in year 2008-2009 totaling to 980GW including 60GW of small hydro (REN21, 2010). China is foremost leader in hydropower production with an estimate of 197GW followed by US, Canada, Brazil etc. This growth in China is contributed to the “Three Gorges Dam” with an operating capacity of hydroelectricity power station at 22,500MW (Wikipedia, 2011). Figure 2.7 illustrates the world hydroelectric generation by region till 2008.

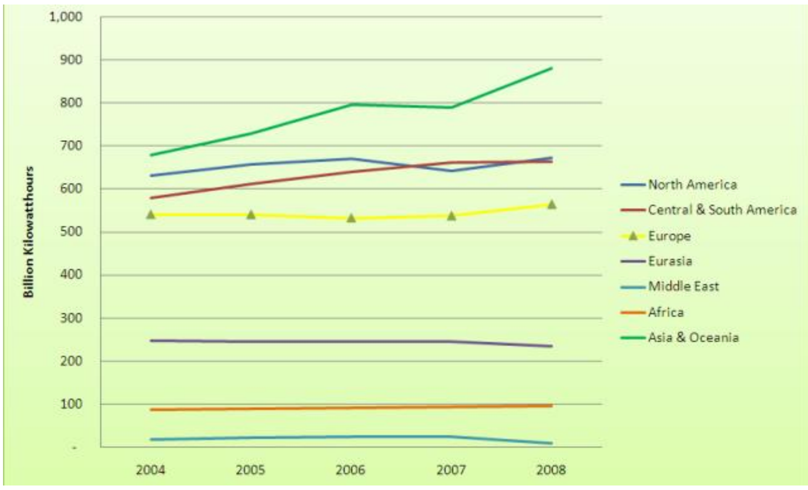


Figure 2.7: World Hydro-Electric Generation by Region, (EIA, 2009)

But there are possibilities with small hydro power generations as well and a lot depends on the type of turbines used ranging from low head, medium head and high hydraulic heads. The designs of the turbines can be categorized by the propeller type such as Pelton, Francis and cross flow turbines. Depending on the type of the turbines and the hydro source one can yield good capacity of electricity generation right form single household to large grid connected as shown in Table 2.1.

Table 2.1: Classification of Hydroelectric Schemes, Capacity and Main Application (Allsaintpreston.org, 2010)

Usual term	Capacity	Main applications
Pico-hydro	few tens of Watts - 5 kW	single household
Micro-hydro	5 kW - 100 kW	mini-grids, small communities, rural industries
Mini-hydro	100 kW - 1 MW	mini-grids, villages, industries, or grid connected
Small-hydro	1 MW - 15 MW	usually grid connected
Medium-hydro	15 MW - 100 MW	grid connected
Large-hydro	> 100 MW	grid connected

Though large dams have become much riskier investment there is still great potential in the hydropower technology but it expected grow at a much slower rate compared to the 70’s and 80’s and may even decrease in the coming future due to much research in other energy sources for larger reservoirs or dams. But there can be possibilities of small hydro power ranging up to 5MW capacity as shown in Figure 2.8.

Figure 2.8: Pico hydroelectricity in Cambodia (Wikipedia, 2011)

Ocean energy can also be termed as Marine energy/power and is based on the ocean wave, tidal course, salinity and the temperature differences. The origination lies in the principles of kinetic energy or energy in motion of the oceanic graph. Though ocean energy is the least explored or so to say less matured as compared to other resources, it definitely has potential and is growing with technology advances. Currently no commercial use is in operation but a few countries are making effort to harness such form also such as South Korea which completed a 1MW tidal current project in 2009 with a construction of 260MW tidal plant followed by Europe in a small capacity of 0.4MW ocean power capacity (REN21, 2010). But the ocean thermal energy (OTEC) which uses the temperature between surface water in tropical regions at a depth of 1km sure has potential in ocean power. A number of research and study is carried on OTEC where by Straatman and van Stark, 2008 proposed using floating solar pond that would create a temperature differential which would increase the efficiency of the electric generation. Yamada et al 2009 also proposed solar plate collectors to boost the surface water temperature to increase electricity output by 50%. The OTEC can be an open cycle or closed cycle process such as Rankine Cycle or combination of both depending on the water temperature, wave depth, etc. A few technologies for OTEC conceptualization which could produce energy of 250MW at Energy Island designed by architect Alex Michaelis see Figure 2.9.

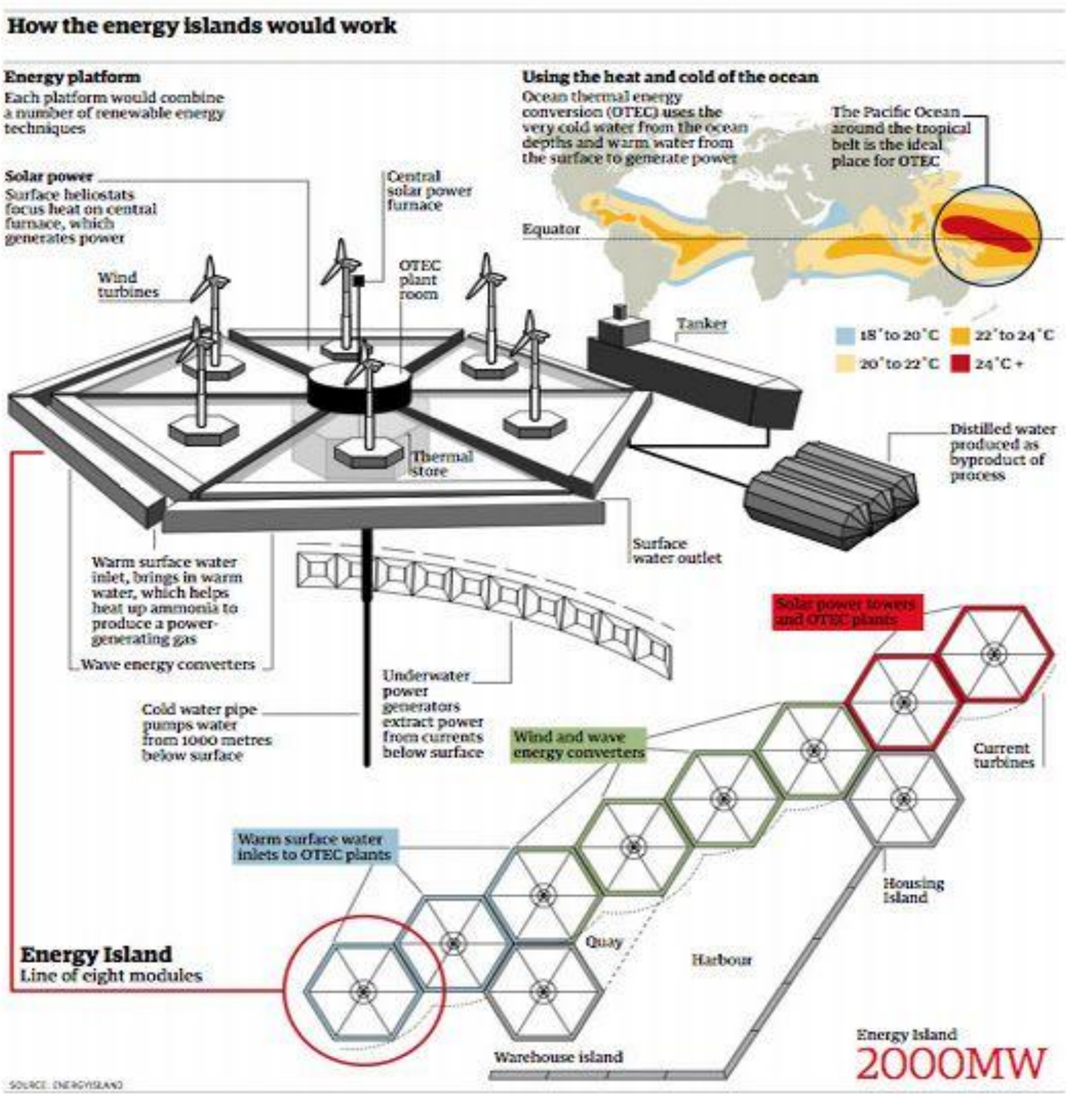


Figure 2.9 Ocean Thermal Energy Conversion (OTEC) Concept at Energy Island (Alfin BlogSpot website, 2008)

2.4 SOLAR ENERGY

2.4.1 Solar Potential

Solar energy attention is growing at a lightning speed due to the diversion towards renewable resources. Researchers, scientist, manufacturers are investing more time and money into solar energy efficiency and simultaneously balance its economy since the sun is part of the universe and it cannot be disassociated from earth which receives 11,000 times of solar radiation given its surface area. The amount of solar radiation received by the earth globally is given in Figure 2.10 which shows the enormous reach of sun and abundance of recourse one can gather from it with dark spots such as North America, Latin America, Africa, Middle East, China and Australia receiving almost sum total of 18TWe.

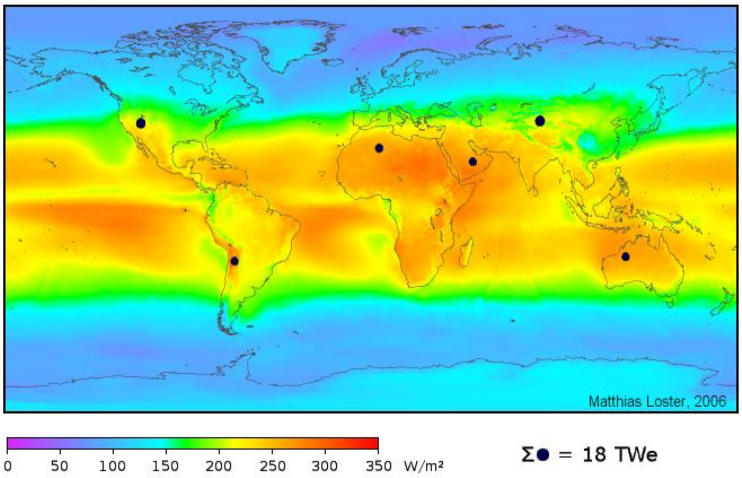


Figure 2.10 Total Solar Radiation of Earth's surface in W/m2 (Wikipedia, 2011)

The popular misconception that solar radiation is dominant in the deserts of the Middle East is false as various countries have similar reach and can harvest better solar potential as seen from the above figure. The photovoltaic's (PV) market has come a long way from its initial start used in space application to power satellites in the late 1950's much later before it was discovered by Henry Becherel in the late 1838 through photovoltaic effect. The market share of PV today is seen in Figure 2.11 with Germany leading the way followed by US and others accounting for almost 90% of the 3705MW of installed PV capacity. This has been predominant since PV's actually work better in cooler temperature since they require light for power output rather than heat (Sullivan, 2008).

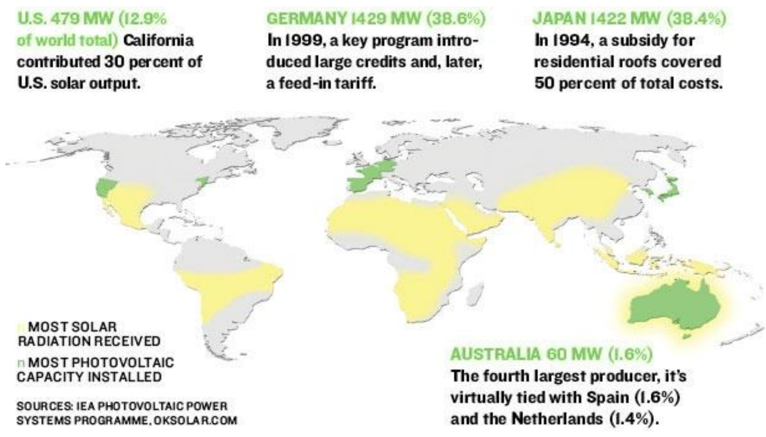


Figure 2.11: PV Hot Spots, (IEEE Spectrum, 2007)

2.4.2 Solar Energy Systems

Solar Energy Technologies are categorized in three basic modes such as the Flat Panel Crystalline Silicon, Thin Film and Concentrators. They are further sub-divided into various categories thereon based on these genres whereby various research, development and modern innovations are underway. Photovoltaic's (PV's) is a process of converting light energy (solar radiation) into direct electric current using semiconductors which work on the principle of photovoltaic effect or quantum mechanics. Solar panels which are composed of number of cells to form a simple play of electrons, protons and neutrons to generate electricity. Concentrators on the other hand as named are forms of concentrating solar radiation to a point (single, multiple) to produce power from heat, steam from fluids, solar cells etc to produce electricity.

Flat Panel PV Systems:

The most commonly used type of PV systems are the flat panel which most common people associate themselves with in their houses and buildings. There are two types of cells predominant in the market namely mono crystalline (pure silicon cell wafers) and poly or multi-crystalline (impure form of silicon cells). Due to their varied composition they emit different efficiencies during production of electricity whereby a mono crystalline offers a cell efficiency of 16-22% as compare to multi crystalline of 14-16%. But they are placed in arrays and come in modules where by the grid formation reduces the efficiency by 2-3% respectively in addition to load power loss due to other accessories such as batteries, inverter etc. (Montoro, 2010). Also since mono crystalline being pure form of silicon is more expensive due to the availability of raw natural resource. Vitanov et al investigated the cell efficiency by varying the emitter thickness of the mono crystalline solar cells with porous cells in relation to the photovoltaic properties. Lipinskiet al. investigated double porous silicon (d-PS) layers formed by acid chemical etching on a top surface of n+/p multi-crystalline silicon solar cells with the aim to improve the performance of standard screen-printed silicon solar cells, the PS layer serving as an anti-reflection coating with the efficiency of the solar cells with this structure is about 12%. Figure 2.12 gives as clear identification of the mono versus multi crystalline in terms of efficiency and visually where by mono crystalline silicon cells look more uniform as compared to shattered look of poly crystalline.

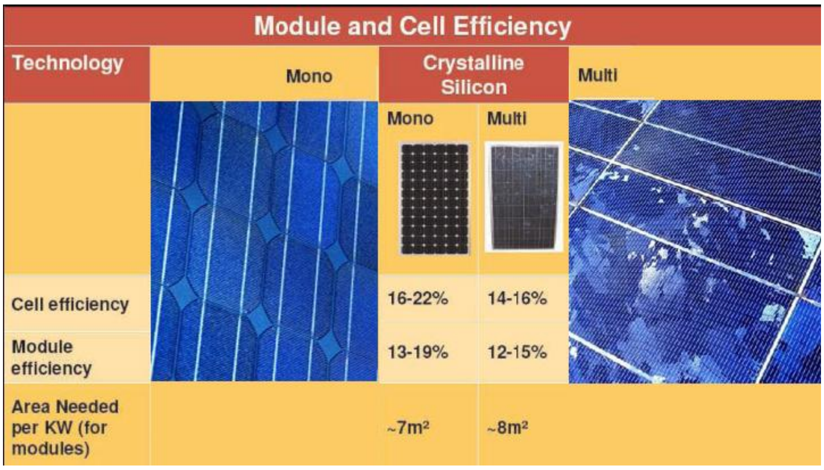


Figure 2.12: Flat Panel PV Systems (Montoro, 2010, Modified)

As time and development advances the multi-crystalline form are catching up in performance with a nominal efficiency of 15% in comparison to 17% of mono crystalline in commercial market with a added advantage of being cheaper than mono crystalline. But by far the most reliable has been mono crystalline silicon cells due to their longer production duration since years and research with almost 25 years of performance guarantee. Another technology which is very competitive is the amorphous silicon ideally known as the Thin Film Technology and has slowly but surely holding greater market value due to its overall flexibility and cost.

Thin Film Solar System

Most promising of the latest technologies and possible future of photovoltaic cells are made by deposition of one or several thin layers of photovoltaic material on a substrate which is mostly metal or even known as nanotechnology using thin cell layers on solar conversion materials. Amorphous silicon (un-crystallized) is the popular one out of all thin film technology with cells efficiency of 5-7% and can be further improved by adding double or triple junction design to an efficiency of 8-10 %. (Parida et al, 2011). Since thin film are processed by adding tiny holes to the cells, the solar transmittance can be adjusted but at the same time the power output is reduced as the value of solar transmittance increases. This is solely due to increase in surface area of solar cells, give larger power output and more the gap in the cells to make it flexible or transparent will reduce power output. But due to fragility of the material and purity they are also more prone to degradation with a wide variety of thin film available in the market such as a-SIC, amorphous germanium (a-SiGe), amorphous silicon nitride (a-SiN) and micro-crystalline silicon (c-Si), (Cd-Te), etc. The entire above have various efficiency levels as shown in Figure 2.13.

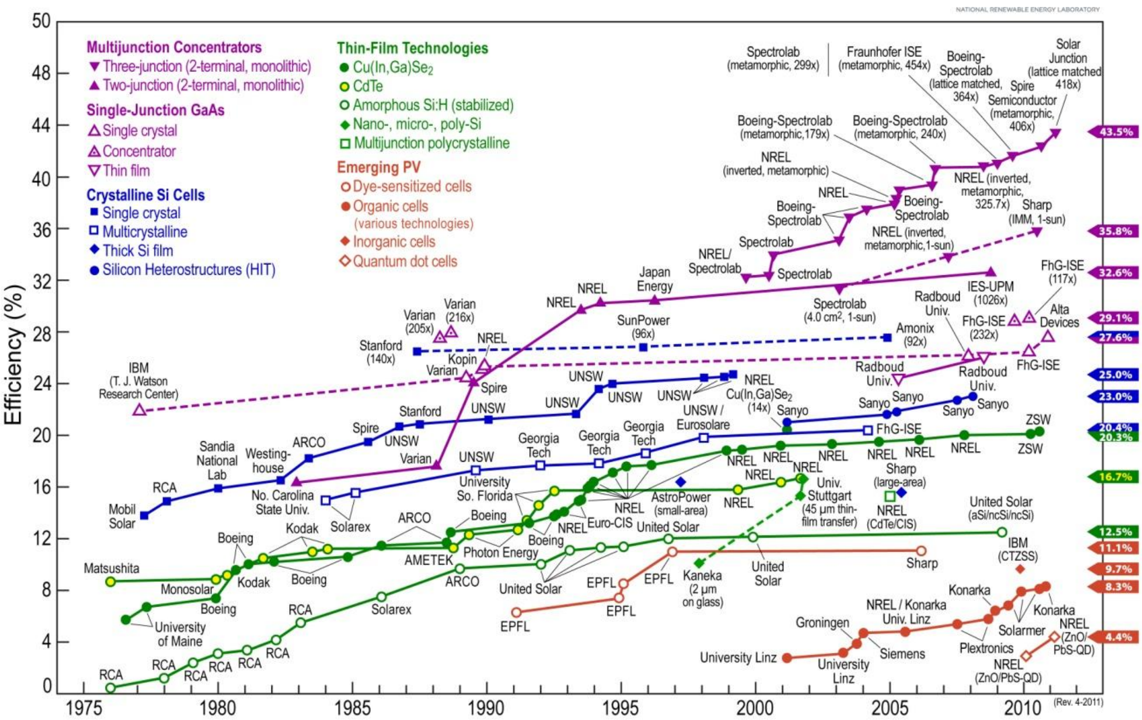


Figure 2.13: Solar cells Efficiency Levels till 2010 (NREL, 2011)

Researchers have been more upfront on thin film and its advantages in relation to efficiency versus actual output. Yang et al discussed the advancement of amorphous thin film which led to the success of an AM13, with cell efficiency up to almost 13% stable and set the ball rolling for the spectrum splitting triple junction structure for manufacturers by the roll-to-roll continuous deposition process. Lund et al estimated by field and laboratory studies that cells are affected by different operating conditions and proposed numerous ways to reduce Staebler-Wronski effect in the Si-H solar cells. Yoon et al, 2011 conducted a practical building monitoring system for 2 years using amorphous silicon transparent thin film cells and derived that the building azimuth and shading plays an important role in the output power efficiency by almost 47%. But the same is true for all PV cells technology as they greatly depend on the amount of solar radiation fall on the surface of the cells. The initial reading gave him a performance almost half of the tested efficiency of the BIPV over the 2 year period. Further analysis lead to the fact the azimuth and the shading factors of the building via simulation on the southwest and building mass shading gave the reduction in the cells efficiency. From the simulating influencing factor such as azimuth and shading the measured energy efficiency in tested conditions improved by 47% due to the better solar radiation allowance on the PV modules. Figure 2.14 illustrates the improved efficiency of the PV modules southwest with better shading building mass leading to better solar radiation on the panels.

Figure 2.14: Transparent Thin Film on building in Korea improved through building monitoring and simulation. (Yoon et al, 2011)

<u>Concentrator Solar System</u>

They can be categorized in two basic systems such as “Concentrator Photovoltaic’s (CPV)” and “Concentrator Thermal Collector” (CTC). As the name suggests they are concentrators of the solar/sun energy by means of reflectors like mirrors, glass etc where by the CTC are mainly used to generate and retain heat which is being reflected on the media such as water, fluids, air etc which in turn produce steam to run the generators for electricity production. The previous CPV in general run on the same principle of PV’s but use less cells or surface area of the panels to concentrate the sun’s energy on the solar point/line focus cells. By this they consume fewer raw materials and less of installation hazards which can be systems using single or dual axial tracking enhancing performance and can be referred as Heliostat Concentrators. The most common use of CTC is the water heaters and space heating and more advance being air-conditioning though the principle is the production of steam to generate electricity directly or use fluids to heat domestic water or space heating in colder countries. Figure 2.15 illustrates the CTC dish system which eliminates the need to transfer heat to a boiler by placing a “Stirling Engine” at the focal point.

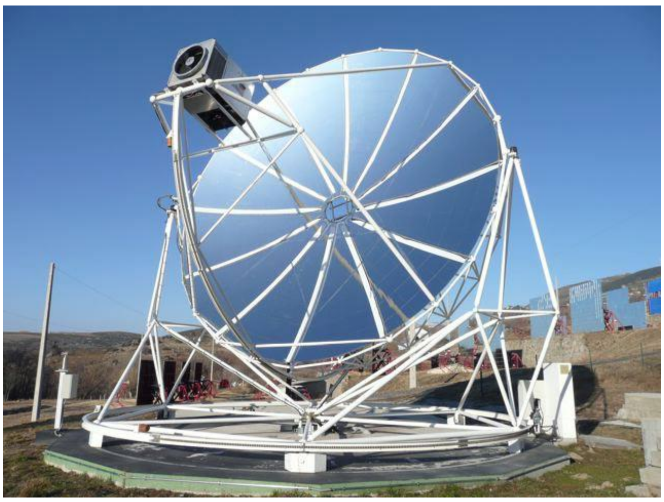


Figure 2.15: A Euro Solar Thermal Concentrator using a Stirling Engine, (PROMES-CNRS, 2011)

Quaschning, 2004 performed detailed technical and economic analyses by means of computer simulation to differentiate non-tracked and two axis tracking PV system of the CPV and noted that the balance in economy brings better results by adding tracking system. At IBM the technique used to cool computer chips is also used to cool solar cells since intense heat degrades the power output of the cells where by a adaption of a liquid metal cooling technique can remove three-fourth of the heat generated by CPV system, La Monica, 2008. The CPV ideally are in three categories such as the Fresnel lens which consist of a series of concentric zones rather than curved surface and requires less material than conventional lens. Second is the point focus plastic lens by Amonix Corporation and third one is the FLATCON with a two junction cell which yields a module efficiency under operating condition of 23% and 36% for three junction cells. (Harvey, 2010) A new concept still under development is the quantum dot or fluorescent dye concentrator which can work on direct and diffuse beam radiation without tracking as compared to other CPV's (Currie et al, 2008). Figure 2.16 illustrates different CPV in market.

Figure 2.16: Different types of CPV's Fresnel lens, Plastic Lens, FLATCON (Kurtz, 2011 NREL)

Solar PV grew at the fastest rate from the year 2004 to 2009 especially in the gird connected world market with an annual average rate of 60% making it a total of some 21GW and some 3-4GW still to be added. Germany was the primary driver of PV installation to reduce the cost down with installation of 9.8GW to the existing capacity leading by almost 47% by 2009. But the concentrated solar power are entering into the small market with France and Italy could have an target of 200MW online by 2010 along with the UAE, Abu Dhabi, Algeria, Egypt and Morocco plants under construction of 100MW. (REN21, 2010) See Figure 2.17 for world statistics of the Solar PV capacity and countries contribution.

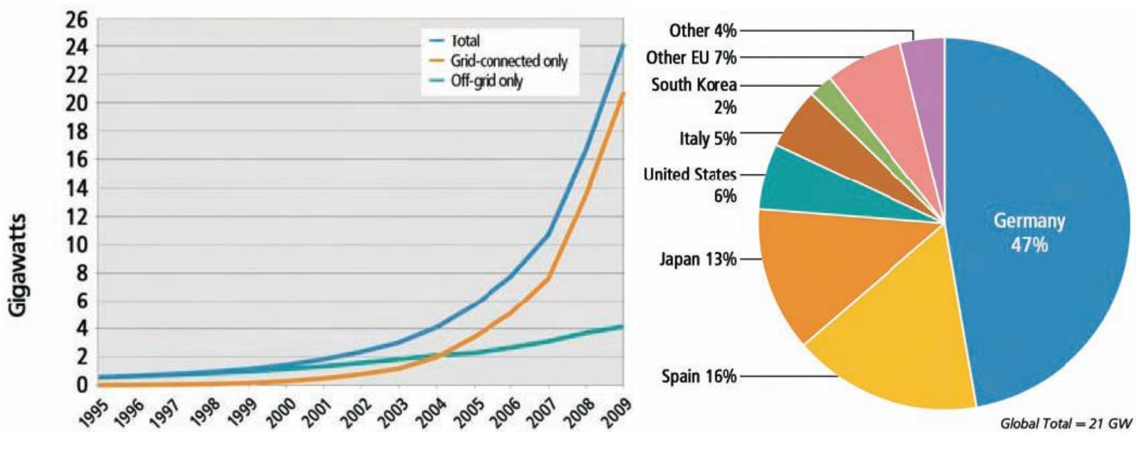


Figure 2.17: Solar PV Existing World Capacity by Type and Country. (REN21, 2010)

Apart from the general PV market there are other factors which govern the PV application on buildings such as performance, cost and integrations of the same. Though thin film PV are more adaptable to the integrations of the building especially due its visual appeal, variety, transparency and uniformity, the crystalline form become a little rigid in its amalgamation with building form. But all the same a perfect balance is important in its utility, capacity, pay back, policy and application use on comparative basis. Wiemken et al studied with monitoring mechanism the effect of 100 PV systems that reveal a considerable decrease in power fluctuation compared to an individual system and the energy spectrum of combined power generation and concluded that there is reduction is almost 65% in produced energy output to the overall installed power. According to Kurtz, 2010 report to NREL the factors that will enhance the solar market is breakthrough in the higher efficiency in comparative to the current cost reverse graph, enhancement in the material with use of plastic wrap and PV spray on paints rather than use of glass, tax incentives, renewable policy improvements and more research and innovation leading manufacturers to invest in better cost efficient material payback period. Rourke et al and research analyst from Deutsche Bank has researched an interesting graph as to which year electricity generation from solar PV would achieve "gird parity". He has estimated the cost price of PV generation will start completing with local retail electricity prices by 2015 in the US. This was purely by estimating the current improvement graph in PV market to the current rate of escalation the retail electricity market in the US and that to without government incentives.

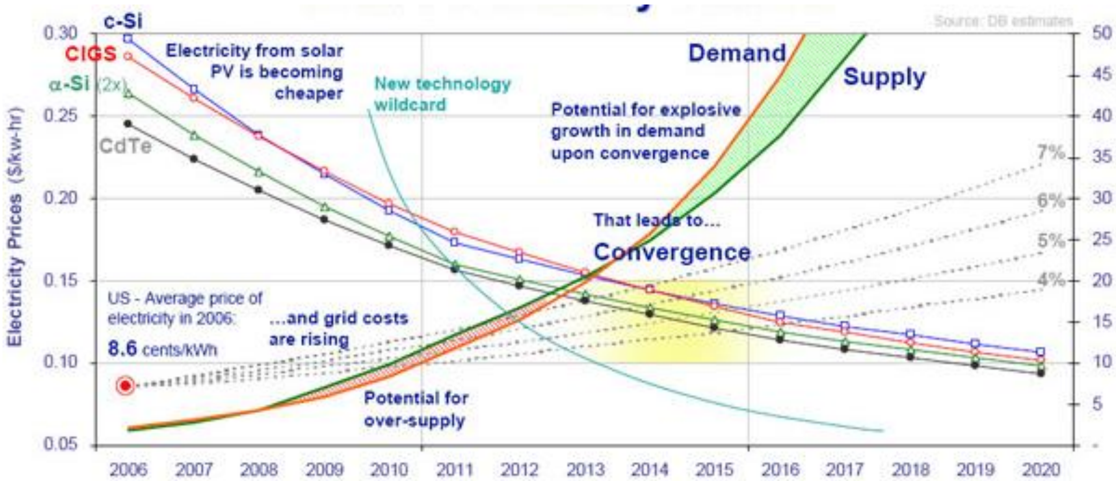


Figure 2.18: Achieving Grid Parity of PV and Retail Electricity Generation till 2020. (Rourke, for Deutsche Bank, 2009)

2.4.3 PV Applications and Design Considerations

PV applications on buildings are greatly dependent on the exposure to solar radiation factors and hence have to be installed on spaces to maximum exposure such as roofs ideally, facades, balcony railings, external shading devices, awnings etc. From the older concept of PV application only on building roofs, the market has emerged innovatively with increase in the PV efficiency, forms and architectural aesthetics allowing its integration on various building types such as residential, schools, commercial, hospitals etc to generate energy via its optimization. The concept of PV's has now become multi-functional beyond only the generation of electricity which includes weather protection, thermal insulation, noise control and modulations of daylight. Figure 2.19 illustrates the various locations of PV installations on buildings with better efficiency areas in terms of its power output.

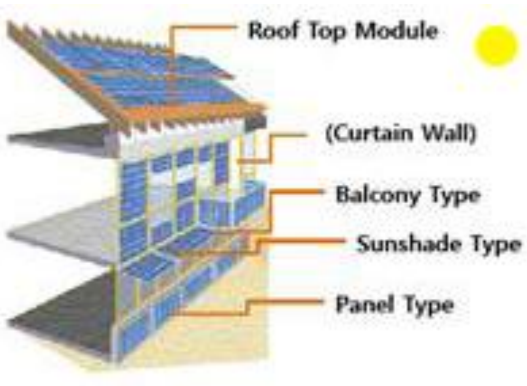


Figure 2.19: Application of PV on buildings (Montoro, 2010)

Key factors which determine the application of PV on buildings is the adequate access to solar radiation either direct or indirect and this solely depends on the location, usage and design parameters. Climatic conditions such inclination angles, longitude, latitude, orientation and the urban settings are critical with solar variation daily, seasonally movement of the sun path, azimuth etc determine the output variable of power and the efficiency of the PV cells to it optimum are important. But the greatest advantage of PV's application on buildings is its incremental capacity output of power is optimum during peak grid supplied power duration. (Radhi, 2010) illustrated via his research in PV application on buildings in UAE that relation between the incident irradiance and the delivered PV power is linear and south orientated, particularly the tilt angle is equal to the latitude of the site and produces a larger amount of output power which in the case of UAE, Al Ain is 24°. Figure 2.20 illustrates the optimum angle tilt and orientation for UAE.

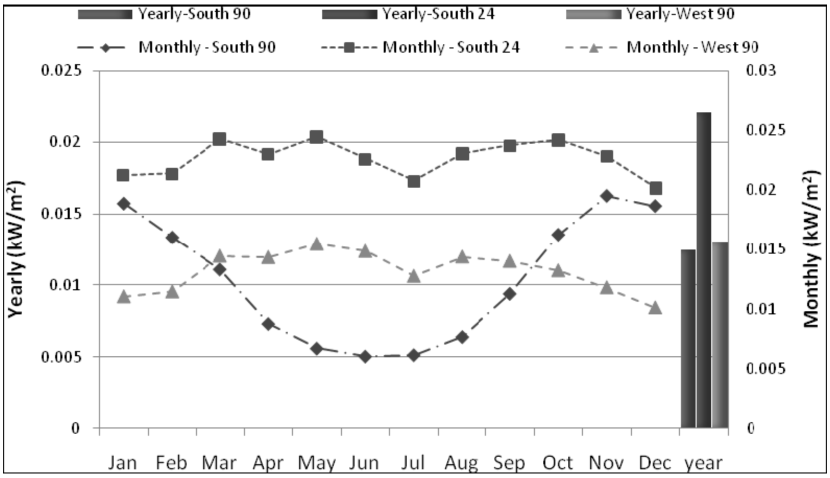


Figure 2.20: PV power output dependent on Orientation and Tilt angle in UAE, Al Ain based on standard test conditions, (Radhi, 2010)

Similarly Modol et al, 2007 validated by simulation results that the roof mounted PV system at a latitude of 54_N in the UK with a south facing surface inclined at 20deg was maximum while on other facing surfaces the output was lower by 1.6% and 18.1% respectively then the maximum value. Other factors which determine the sizing of the PV system is the temperature, precipitation, wind speed and land topography. Nearby structures, plants and objects could lead to undue shading and reduce the PV performance. PV modules and arrays are rated in terms of their electricity output and that corresponds to the standard test conditions (STC) when the solar radiation is near to its maximum 1000Wm2 and the cell temperature is 25degC. Figure 2.21 shows the output reduction based on a temperature dependent scenario of PV cells. Usually the efficiency drops by approximately 0.5% for every 1degC rise in temperature.

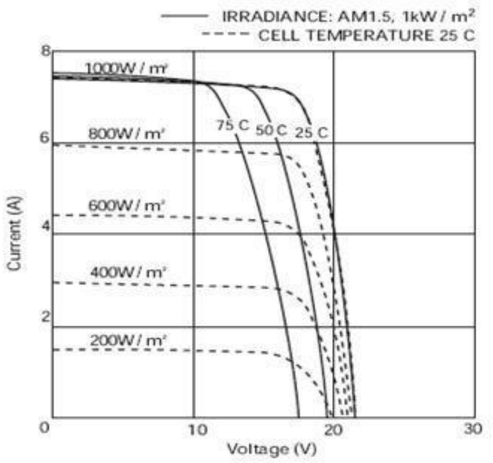


Figure 2.21: Intensity and Temperature dependent behavior of PV cells. (Clean Energy, 2010)

Table 2.2: PV system losses can be due to various factors apart from the above (Parida et al, 2011)

Source of loss									Reference
Reflection (%)	Temperature (%)	Inverter (%)	Low irradiance (%)	Shading (%)	Soiling (%)	Ohmic (%)	Mismatch (%)	MPPT (%)	
–	3.0	7.8	–	7.1	–	–	3.8	–	Sugiura et al. (2003)
–	8.0–17.0	10.0–16.0	–	–	3.5–5.0	1.0–1.5	0.15–0.17	2.0–5.0	Mukadam et al. (1995)
–	–	15.0	–	–	–	2.5	2.0	–	Decker et al. (1992)
–	–	–	–	–		–	–	15.0	Caamaño and Lorenzo (1998)
–	–	–	–	35.0	10.0	–	–	–	Becker et al. (1997)
3.1	7.6	4.0	0.9	0.3	–	1.2	5.7	–	Iliceto and Vigotti (1998)
–	3.3	5.3	–	3.5	–	0.24	–	–	Steinhardt et al. (1998)
–	3.8	17.5	4.6	11	–	1.2	5.7	–	Baltus et al. (1997)
–	2.8	13.2	–	1.7	–	2.1	9.8	4.5	Schaub et al. (1994)
–	2.2	6.9	–	4.1	–	–	5.1	–	Kurokawa (1998)
–	4.0	8.0	–	7.0	–	–	6	–	Kato et al. (2002)
–	3.3	5.3	–	3.5	–	–	–	–	Jahn et al. (1998)
–	–	–	–	–	4.0	1.2	0.2	0.6	Durand et al. (1990)
–	–	10.0	–	–	3.0	–	5.0	–	Lloret et al. (1998)
2	4	15	7		1.5	1.0	1.0	2	Mondol et al. (2007)

2.4.4 PV System Configurations and Components

Above all the sizing of the PV system also depends on the system configuration such as "Standalone PV system", "Grid Connected: or a "Hybrid System". All these systems are finally weighed by the total load profile of the building in relation to the achievable PV system to be installed. The output of the PV system of different sizes and applications can be compared by normalizing them with the actual system size (kWp of PV arrays) and comparing their monthly mean value of their daily final yields. A standalone PV system requires an accurate system sizing than a grid connected and the final result should meet the load profile of the building, structures which ultimately underline the performance ratio of the standalone PV system. But the grid connected system may be designed at different times to meet the fraction of the total electric load while the remaining or the fraction can be taken care by the main power grid of the building. But PV panels alone cannot produce electricity by themselves and require ancillary support system and components to make the power output viable to user. The following are the components which are required to complete the configuration of the system:

- PV Modules of solar arrays (Crystalline or Thin Film, Transparent, Semi-Transparent or Opaque etc)
- Charge Controller which can have optimal features and the function is to maintain the batteries proper charge level and avoid over charging
- Inverter for converting DC power to AC for building equipment usage
- Balance of System which provides the interconnection and standard safety features required for power output such as array combiner box, sizing cables, fuses, switches, circuit breakers and meters.
- AC and DC loads appliances such as lights, equipments, pumps etc which are the final consumers.
- Back up supplies such as diesel generators etc

Apart from the sizing of the PV modules it is critically important that the sizes for components are also calculated to optimize the performance. Nowadays inverters produce a modified sine wave as compared to earlier square wave and are not quite the same as power company electricity as they take care of most of the problems encountered earlier. Inverter sizing is according to the watts they can deliver and are capable of sustaining much higher loads and can run continuously for accurate power rating as per its specifications. The controller apart from maintain adequate flow of charge to batteries also takes care of reverse flow and is the lifeline for batteries. Hua et al 2006 discussed the behaviors of lead acid batteries during three cycling test and procedures and concluded that lead acid batteries display the best cycle life and could be successfully used for standalone PV applications.

2.4.5 PV Future Outlook

The future of solar PV as one of the fastest growing industry lies in the growth rate of new developments such as material use, consumption efficiencies, and reliability in relation to the current initial high cost investment ratio. Most of the investors are discouraged due to the high initial cost and the payback periods. Though new technologies are advancing to balance the cost to efficiency ratio it is still in its initial stages but one has to also understand that the fossil fuels prices are also escalating and a period will come when the payback time will be practically met to cost of the fossil fuels market rate. Munner at al 2005 has already described the modular approach to solar PV electricity shall meet the demand in the year 2025 in six major cities in India and suggested that solar hydrogen based energy network has the capability of providing the energy requirement. But till then the PV market will be dependent on incentives such as government subsidization, policy making and renewable energy goals to step closer to meeting the energy demands. Grid connectivity or smart grids can be the immediate solution to the current cost problems but cannot be meet without the government initiatives.

Innovations in technologies such as organic PV’s (OPV) which replace the use of glass with plastic is already in its application stages. OPV whereby in 2007 German Federal Government announced its support for the industrial partners working on OPV with 60 million Euros within the framework high tech strategies along with companies like BASF, Bosch, Merck are already going ahead with OPV full throttle to scale of 300 million Euros (Henemann at al, 2008). Also Konarka has promised to have products such as Bifacial Cells which will convert electricity on both sides of the glass façade and windows.

Lastly but surely the policies and cost factor for further technologies need to be enhanced. For e.g. in France the BIPV tariffs are higher as compared to the non integrated solutions by almost Euros 9.596 €ct/kWh but additional investment subsidies are also available as tax credits where as in the USA financial incentives are built in for a tax credit savings of almost 30%, but for residential and advances need to be on the businesses as well. While Germany has come forward as a force since models have been developed around the world and one can already see a shift in the market with increasing fossil fuel inflation (Henemann et al 2008). UAE as a country has already initiated (IRENA) International Renewable Energy Association by winning the bid to be the host country to house its headquarters. Almost 149 signatory countries and 76 members have agreed to be the part of this formation to meet energy targets.

2.5 WIND ENERGY

2.5.1 Wind Potential

Wind energy similar to Solar is also one of the leading resources which are not exhaustible, and can produce energy with little or no polluting emissions. According Van Wijk et al the estimated potential to produce electricity from land based wind energy is 20,000TWh per annum along with a possibility of installing 450GW of wind turbines capacity by the year 2020 globally. Figure 2.23 illustrates the wind energy potential globally at 5km wind map at 80m height where dark red signifies potential above 9m/s wind speed in countries such as South America, Europe, China and East African region.

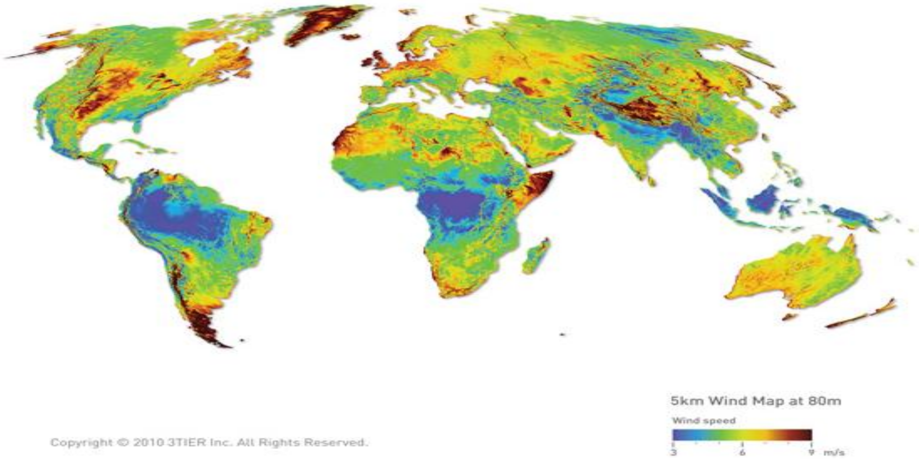
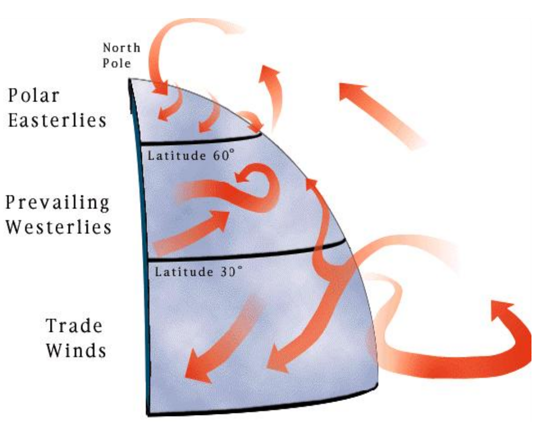


Figure 2.23: Global Land Wind Energy Potential 5km Wind Map at 80m (3TIER Inc, 2011)

Wind is simply air in motion and the power contained in the wind is the kinetic energy (KE) of the flowing air mass per unit time. This KE of mass air in motion is equal to half actual mass (m), of the air time the square of its velocity V and represented as KE=1/2 mV2. Wind is the product of the temperature fluctuation of earth's surface which is comprised of continents and oceans which absorb heat at different times, rates causing temperature differential. It day and night heat movement cycle which is caused by movement of lighter heated air upwards and colder heavy air downwards during day and night from earth to water surfaces. This is also possible in deep mountain valleys with a similar hot and cold air movement. Although there are many factors involving wind pattern, there are three major wind belts in the world namely "Doldrums" near the equator, "High Pressure 30deg latitude" towards the equator and pole and finally "Polar Front" at 60deg latitude. Figure 2.24 indicates the global wind circulation and classes of wind power density at 10m and 50m wind class 2 has wind power density between 100-200W/m2 at 4.4m/s at 10m height. Most wind turbines are installed for class 3 due to better efficiency (Chinchilla et al, 2011)



WindPower Classes	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density (W/m^2)	Speed $^{(b)}$ m/s (mph)	Wind Power Density (W/m^2)	Speed $^{(b)}$ m/s (mph)
1	0	0	0	0
	100	4.4 (9.8)	200	5.6 (12.5)
2				
	150	5.1 (11.5)	300	6.4 (14.3)
3				
	200	5.6 (12.5)	400	7.0 (15.7)
4				
	250	6.0 (13.4)	500	7.5 (16.8)
5				
	300	6.4 (14.3)	600	8.0 (17.9)
6				
	400	7.0 (15.7)	800	8.8 (19.7)
7				
	1000	9.4 (21.1)	2000	11.9 (26.6)

Figure 2.24 Global Wind Circulation and Classes of Wind Power Density, (Wall et al, 2006)

The world wind energy market and technology has come a long way since its initial concepts through simpler wind devices which date back 1000 years back with vertical windmills found in Persian-Afghan border around 200BC and horizontal axis wind mills of the Netherlands and Mediterranean much later in 1300-1875AD, not to forget the Badgirs of the Iranian-Middle Eastern architecture (Kaldellis et al, 2011). As of today the wind energy market has slowed down with the overall annual market shrunk by 0.5% to 38.3GW in 2010 as compared to 38.8GW in 2009.But in spite of the slump the global installed wind power capacity now stands at 197.0GW with the main market drivers being Asia and Europe which installed 21.5GW and 9.5GW respectively in 2010. China due to its continued boon in infrastructure has alone accounted for half of new global wind installations with 18.9GW in 2010 totaling up to 44.7GW and has surpassed US to claim the top spot. Overall it is notable that the total investment was accounted for by China and large European off shore wind farms by 2010 (GWEC, 2011). Figure 2.25 represents the growing market in wind power installed capacity by region spanning from 2003-2010 with the largest share improvement in Asia especially due to China followed by Europe.

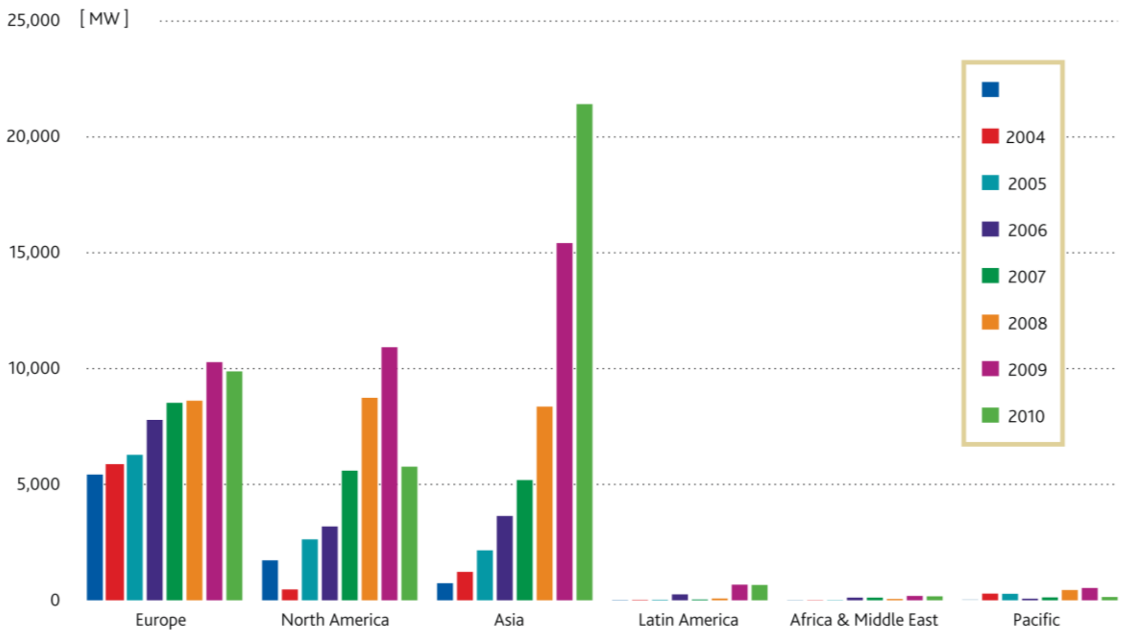


Figure 2.25: Global Wind Power Installed Capacities by Region 2003-10 (GWEC, 2011)

Though the Middle East is way behind in wind power there is definitely potential to invest in this sector as per Prof. Mohammed Yagoub, a researcher from the UAE University in Al Ain, where wind farms can be established along the north western area with a wind speed ranging from 4.18-5.28m/s in certain identified area through the GIS, weather and satellite imagery with a close proximity to centre of demands such as urban and agricultural hubs, refineries, airports and transmission lines. From collected information through 34 meteorological stations in the UAE the maximum gust ranges between 8-14m/s and this speed together with the average speed can be put to account in the turbine design cut-in and cut-out speed (Kazmi, Gulf news, 2009).

2.5.2 Wind Energy Systems

So far we have looked into the wind energy potential but this energy need to be converted to usable power and for the conversion wind turbines are used along with its components. By definition wind turbines is a rotary device that extracts energy from the wind which can be converted into electricity and if the same energy is used for machine purposes then it is defined as windmill and wind pump if used for pumping water. Wind turbines are broadly classified in two categories such as “Horizontal Axis Wind Turbines” (HAWT) and “Vertical Axis Wind Turbines” (VAWT) respectively. The important thing to note is that these wind turbines essentially are designed based on the flow axis of the wind and maximization of the wind energy to power conversion factor. Though both wind turbines exist in the market with the majority share taken by HAWT and almost 90% turbines in use are HAWT for several reasons (Rosa, 2009).

Horizontal Axis Wind Turbines (HAWT):

The HAWT is a rotary device which harnesses power from the wind energy which flows at higher speeds above ground surface. It is a device which is driven by main rotor shaft and electricity generators which are placed at the top of the tower. The HAWT has a design specifically which demands that it should be pointed towards the wind velocity to capture maximum power. This process is called yawning. The turbine shaft is generally coupled to the shaft of the generator through a gearbox which turns the slow rotation of the blades into a quicker oration that is more suitable to drive the electrical generator. Figure 2.26 represents the general design of the HAWT and the internal equipments. The “Nacelle” is the cover which houses the gearbox and the generator along with other components of the HAWT.

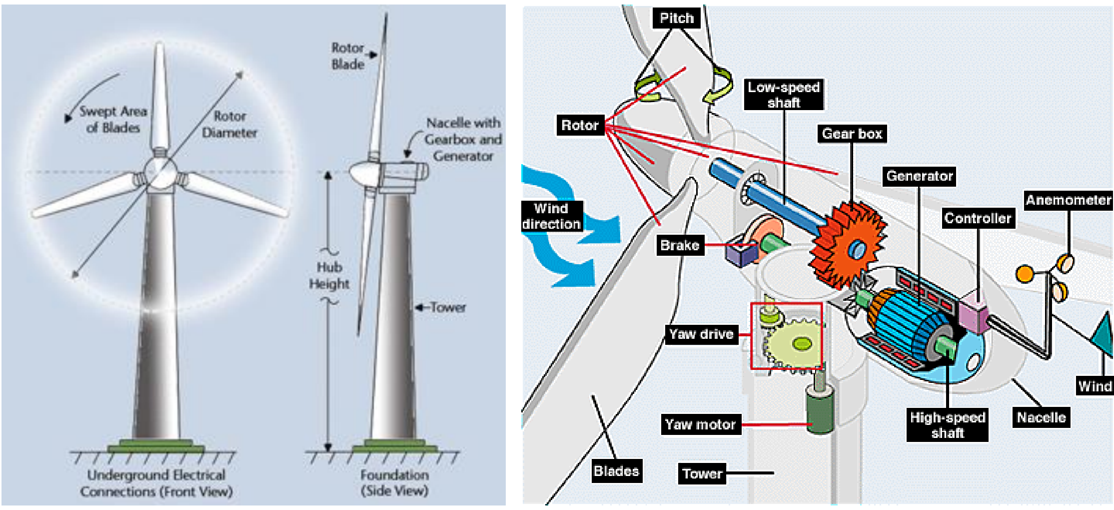


Figure 2.26: HAWT Design and Internal Equipments (ESN, 2011 and Wikipedia, 2011)

The HAWT generally has 1-3 numbers of blades depending on the rotor diameter and the swept are of the blades to capture maximum wind power, and could possibly have larger number of blades with disc like solidity which is termed as “High Solidity Devices”. Similarly the lesser the number of blades with less solidity is termed as “Low Solidity Devices” with much larger void in the swept area of the rotor. Furthermore the HAWT can be divided into three types such as “Dutch Windmills”, Multi-blade Water-pumping Windmills” and “High Speed Propeller Machines”. The Dutch windmills were the more widely used across Europe for grinding grains and they operated on thrust exerted by wind with blades inclined at an angle to the wind direction initiating rotation. Whereas the Multi-Blade as the name suggest more number of blades is used to pump water and since they are more located based on the water availability they are designed to function on low wind speeds. Finally the High propeller machines are more adequate and widely used to generate electricity and instead of working on the thrust of the wind force as compared to former cases these turbines operate on the aerodynamics forces of the wind. It is found that the turbines which operate on thrust forces are of lower efficiency than the ones which operate on the aerodynamic forces. (Vijay and Sethi, 2011) Figure 2.27 illustrates the different HAWT types.

Figure 2.27: a) Dutch Windmills b) Multi-Blade Water pumping windmills c) High Propeller Machines

Vertical Axis Wind Turbines (VAWT):

VAWT are less known type of wind turbines with the designs, the air scoops or aerofoil rotate perpendicular to the direction of the wind as in general they can capture wind in any direction as compared to HAWT but various issues arise due to efficiency levels. The VAWT have main rotor shaft arranged vertically for multi-directional wind capture and due to this it harnesses great benefits where wind direction keeps varying. They are also comparatively lighter as the gearbox and generators can be placed near the ground which makes them more easy and accessible. But some design produce pulsating torque which results in fatigue and sometimes becomes difficult to place them higher due to higher pressure resulting in fatigue at higher height wind pressure. They are more preferred at lower base levels where the wind pressure is lower as the sizes of VAWT are restricted to harness lesser efficiency power output at lower output. They are categorized in three types such as “Darrieus”, Savonius” and “Giromill Rotor”. The Darrieus type is named after its French inventor Greoges Darrieus and had features such as good efficiency, produces large torque ripples, and starting torque is very less with external superstructures are needed to hold them up. (Vijay et al 2011). The Savonius type is shaped like to cup drums cut into half vertically and are drag type turbines which work entirely on thrust of the wind force with the two cups attached opposite each other on the vertical shaft to scoop wind force. While the Giromill types are quite similar to the Darrieus except that they have straight blades and have cyclo-turbine variety which has variable pitch to reduce the torque pulsation and is self starting. The advantages being high starting torque, lower blade ratio, a wide relatively flat torque curve with a higher coefficient of performance. Figure 2.28 illustrates the different types of VAWT

Figure 2.28: VAWT Types a) Darrieus Rotor b) Savonius Rotor c) Giromill Rotor. (Vijay and Sethi, 2011)

Advantages and Disadvantages of HAWT and VAWT

HAWT Advantages:

- It is more stable due to the blades position being to the turbines centre of gravity
- Turbine blades give best angle of attack due to wing warp ability which gives better control so that the blades can collect maximum amount of wind energy at any time and season.
- Avoids damage to turbine due to ability to pitch the rotor blades in storm
- Taller towers can access better wind speed with wind shear and every 10m up the wind speed increase by 20% and the power output by 34% (Patnaik, 2009)
- Unevenness of land, forest and offshore locations are more feasible with tall tower positioning.
- Most are self starting and can be cheaper for higher production volumes, larger the size higher the capacity and efficiencies with better proven products.

Disadvantages:

- Cannot be placed closer to the ground as they require laminar wind flow and their yaw with smooth blades bearing needs in turbulent winds makes it difficult.
- Blade sizes up to 60m long which are taller and long are difficult to transport on land and sea increasing the equipment overall cost.
- Also installation is difficult with tall and longer blades with skilled operators and cranes.
- Navigation and maintenance of transmission lines with offshore towers
- Fatigue and structural failure caused by turbulence is suffered in downwind variants.

VAWT Advantages:

- Maintenance and servicing is more feasible since moving parts are closer to the ground due to its shape with airfoils, blades just connected to the arm of the shaft that sits on the bearing and drives the generator below.
- Vertical shape of rotor blades avoid yaw device reducing cost and need for bearing.
- Higher airfoil pitch improvises aerodynamics which reducing drag and high pressures.
- More powerful winds at ground levels at hilltops, ridgelines and passes then at higher levels can house VAWT better then HAWT due to the increasing wind velocity as one goes higher up.
- Laws and restricted areas where higher heights not permitted can benefit from VAWT
- Ease of transportation and installation cost due to the VAWT scales.
- Due to lower tip-speed ration damages are less at high wind situations.

Disadvantages:

- Limitations in height due to the VAWT mechanics and doubts as to rise in swept area at higher positions.
- Efficiency for most VAWT are 50% of that of HAWT in larger parts because of the additional drag that they have as their blades rotate into the wind.(Vijay and Sethi, 2011)
- Not all devices are self starting as Darrieus type has self starting difficulty in normal wind regimes.
- Limitations in higher power production due to lower wind power regime device structures.
- Historically VAWT are higher cost to power output ratio.

2.5.3 Wind Turbine Design Considerations and Applications

The design of the wind blades is critical in design of the wind turbines and even more complicated then aircraft wings as the air movement around the blades has wind forces moving towards and also from the relative motion of the blade. Since the air pressure at the airfoil on top is lower than the pressure below due to the upward lift and the angle which is formed at the lower portion of the airfoil is the “angle of attack”. This angle is cause due to the resultant wind which moves towards the blade. Increasing the angle can improve the lift of the blades at the expense of the increased drag but heavy air pressure will stall the wings and airflow will have turbulence and damage the turbine blades. This specific design of blades in wind turbines is known as the aerodynamic blade design to harvest maximum power output in the rotation of the rotor in the swept diameter of the wind turbines. The tip speed ratio (TSR) of a wind turbine is defined as the ratio of the speed of the blade tip to the speed of the wind and dictates the rotor efficiency, expressed mathematically as follows:

$$TSR = \frac{2\pi RN}{V}$$

Equation2.1: Where R= Radius of the swept area, N= Rotational Speed and V= Free Wind Speed

Power coefficient of the wind turbine is the instantaneous efficiency of the conversion of energy into mechanical energy of the shaft and in high speed HAWT the maximum power coefficient is given by the betz limit which is 59% or 0.59 (Yao et al 2009) and is given as follows:

$$Cp = \frac{\text{power output from the wind turbine}}{\text{Power contained in the wind}}$$

Equation 2.2: Where Cp = Power Coefficient

But the wind turbines do not start generating power by just the blow of wind through it and there is a control mechanism such as “Cut in Speed” which is the minimum speed at which the wind turbines will generate usable power as the wind speed is not sufficient to overcome friction in the drive train of the turbine and is typically between 7-10mph for most turbines. In many modern designs the aerodynamic torque produced at standstill conditions is quite low and the rotor has to be started (by working the generator in the motor mode) at the cut in wind speed (Bhadra, 2010).Similarly there is a “Rated Wind Speed” at which the wind turbine will generate its designated rated power. This is the speed at which the wind turbine will optimize its rated power output. But there are situations when the wind turbine will be subjected to very high wind speed pressure and may rotate much beyond the rated speed. In such a situation there is “Cut out or Furling Wind Speed” beyond which the turbine will shut down to avoid damage to the turbine. This shut down may occur in several ways such as automatic brakes, pitching the blades to spill the wind and others such as spoilers etc. Most of the wind turbine manufacturers provide a graph called the “power graph” showing the wind turbine output with wind speeds as mentioned above. Figure 2.29 illustrates an example of the power curve in relation to the power output versus wind speed.

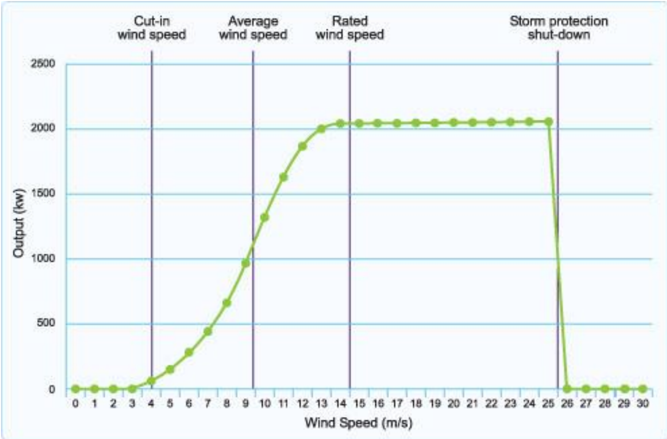


Figure 2.29: Power curve graph for Wind Turbines (PFR, 2011)

There are various factors affecting wind power such as wind statistics, load factor, seasonal and diurnal variation of wind power. The later has a significant effect on wind power and can be reduced by increasing the height of the wind power generator tower. As we all know air is heavier at the bottom of the surface of the ground earth and hence there is more friction at the ground surface and is generally termed as roughness ratio of the earth from bottom to top. It is know that “Power in the wind is proportional to the cube of the wind speed, so even the modest increase in wind speed will cause significant increase in the wind power. Hence the air friction is critical to get smoother wind speed which gets better as we move up and above the earth’s ground surface. As we look into good location to house the wind turbines generators such as availability, power connection system around, site, terrain, soil, lightning strokes, and the very next factor is the friction coefficient of the location to maximize power output. Figure 2.30 illustrates the friction coefficient of various terrains and height variation in wind tower which leads to better power output graph.

Terrain characteristics	Friction coefficient α
Smooth hard ground, calm water	0.10
Tall grass on ground	0.15
High crops and hedges	0.20
Wooded countryside, many trees	0.25
Small town with trees	0.30
Large city with tall buildings	0.40

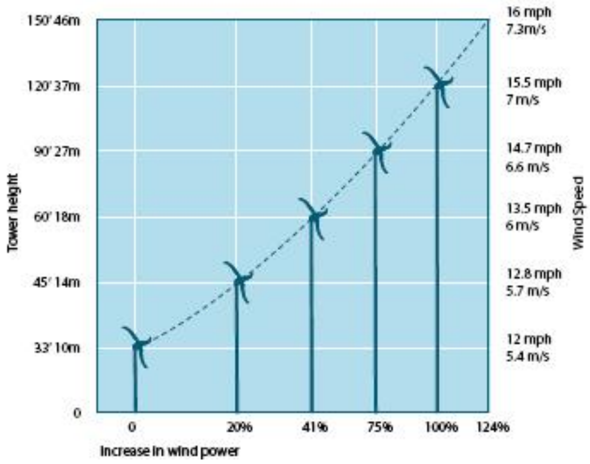


Figure 2.30: Various terrain friction coefficient and Tower height to wind power ratio (Yao et al 2010 and SWBET, 2011)

Other factors are also critical to maximize power output such as wind rose, Weibull distribution function, long term wind records used to select the rated wind speed for wind electric generators, pitch control , stall controls which include systems such as passive and active stall controls, yaw control which helps to continuously orient the turbines along the direction of the flow. But yaw control often produces loud noise and it is desirable to restrict the yawing rate in large machines to reduce noise (Bhadra, 2010). Application of wind energy in building is not new and the concept of standalone wind turbines for urban power generation started with power generation system in rural areas especially due to heavy cost involved in laying heavy transmission lines and losses. A lot depends of various factors especially in an urban environment as we have mentioned earlier as regards to terrain and turbulence, obstructions. However apart from physical aspect, the building also has to be seen through aesthetical point of view. There are different methods adopted worldwide to integrate wind turbines in building and the most common amount them being “Roof Top Mounted on Buildings”. This is usefully to harness maximum wind speed without any physical obstructions if possible with the surroundings and creates high turbulence at the top of the roof due to upward draft movement of the wind on the building structure. This upward draft could also be harmful if not pitched at an adequate angle and can cause fatigue to the blades in no time. But the “VAWT Turby” is designed specifically on building to counter such turbulence problems as per manufacturers. However studies have revealed that wind flow acceleration occurs on the roofs to multiple times of the ambient wind speed and could be helpful in high wind power production (Walker, 2011). Another method is “Ducted Wind Turbines between Windward side and Leeward Side or Roof”. This is based on the positive pressure built up on the windward side and negative pressure built up on the leeward side due to the wind past blowing the buildings. This air pressure differential has potential as air moves from front to back or other sides which experiences wind acceleration (Frechette et al 2008). With a connection via ducts placed with wind turbines inside between the windward and leeward sides multiples again as compared to ambient wind speeds improving wind power. But this has to be carefully studied as in case the air flow is perpendicular to or at angle to the duct no pressure differential is induced along the two sides and no wind energy is generated Some researches and engineers have specially formulated building shapes in aerodynamics specifically to gather better wind speeds and with this can gather wind power at different angles or more parallel to the turbines axis such as HAWT. Wind turbines in such aerodynamic arrangement of building forms are known as “Building Augmented Wind Turbines” (BUWT). A very good example of this is the Bahrain World Trade Centre” and test models built such as “WEB Conference and Research”. Various wind turbines location and design methods are illustrated below in Figure 2.31

Figure 2.31 a) Roof Mounted WT, 5MW Turbine; 10MW Tower (Studied Impact Architects, 2010)
b) Ducted WT, 8% of Building Electricity Demand, Castle House Tower (Hamilton, 2010)
c) BUWT, 11-15% of Building Electricity Demand, Bahrain WTC (Atkins, 2009)

2.5.4 Wind Energy System Configuration and Components

Depending on the load generation needed from wind energy profile the system can be either a "Standalone (Non Grid Connected)" or a "Grid Connected". Nowadays a single turbine is just used for a particular site such as off grid rural places or in off-shore areas. In cases where the wind speed is good there are numerous wind turbines which are often termed as "wind farms". The advantage of such wind farms is that they reduce site development cost, simplified connection to transmission lines and more centralized access for operation and maintenance. Today turbines capacities have grown significantly with the latest 5MW turbine in 2006. Figure 2.32 shows the wind turbine wind farms and progression in maximum turbine sizes and capacity over time.

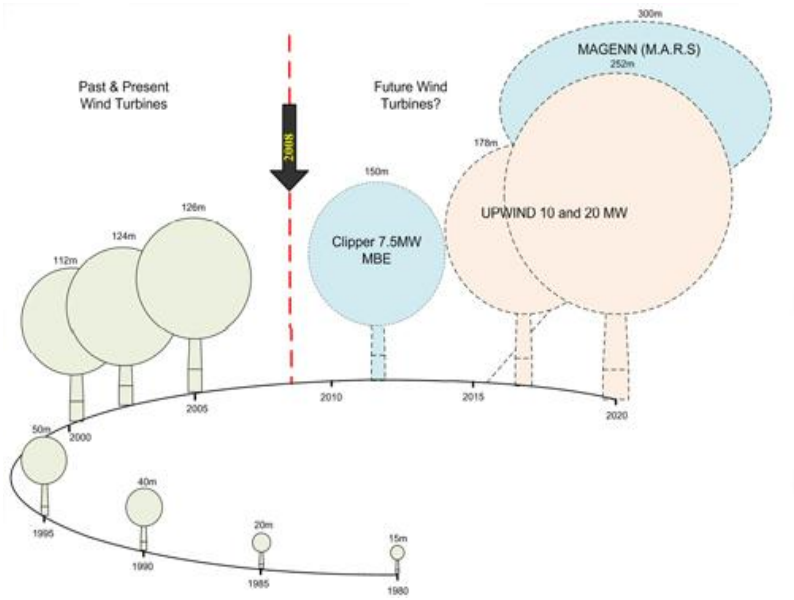


Figure 2.32: Turbine Sizes and Capacity over time (Wind Energy Facts, 2010)

The Standalone wind turbines or non grid connected turbines can produce electricity or mechanical energy and often have methods of storing energy such as batteries when wind conditions are not good. The come in range of power output systems such as "Micro-Systems" with 100W or less used for small appliances, remote lights, small communication systems etc, "Mini Systems" with 100W to 10kW are useful for pumping water for irrigation, navigational aids waste water treatment etc and finally "Small Systems" with 10kW to 50kW and are large enough to supply electricity to farms or business, remote camps or communities. Whereas large wind turbines that feed electricity into the utility grids (Grid Connected) are commercially available such as wind farms above and are in the range of size from 300kW to 1.5MW. The following components are required to complete the wind energy system configuration:

- Foundation and Towers: They are critical as they have strong enough to hold the turbine and its components. Some of the ones used are "Guyed Tower" as they are strong and economically viable, "Tilt up Tower" are used for smaller systems as they are safe on maintenance of turbines, "Simple Rigid Poles" are used for micro systems home or cottage installations.
- Rotor: This consists of blades specifically shaped for aerodynamic surfaces. Turning of the rotor causes the rotation of the drive train and generator. Diameter of rotor blades determines how much power is generated from wind.
- Nacelle which houses the gearbox, a generator which is generally induction (asynchronous)generator, electronic system which monitors the condition of the turbine and controls the yaw mechanism, yaw mechanism which turns the rotor face towards wind direction, cooling unit, and an anemometer and wind vane to measure the speed of wind and direction.
- Batteries such for storage of power from wind energy with charge controller to control discharge and reverse flow.
- Inverter which converts DC to AC usable electrical power and balance of system such as wiring, cables etc

2.5.5 Wind Energy Future Outlook

It is estimated that wind power in many countries is already competitive with fossil fuels and nuclear power if social/environmental costs are considered (REN21, 2010). As the maintenance cost of the wind system is normally very small and annual maintenance costs is about 2% of the total system cost. (Yao et al 2010). But a lot of efforts are still made in reducing the cost of wind systems by design improvements, better manufacturing technologies, site issues, better control strategies, development policies and instruments etc. Moreover , according to the long term plans 400GW of wind power in Europe and 20% of US electricity demand covered by wind till 2030 is planned, along with China requesting 150GW installed by 2020 (Kaldellis et al 2011). Figure 2.33 illustrates the expectation to meet the 230GW target by countries.

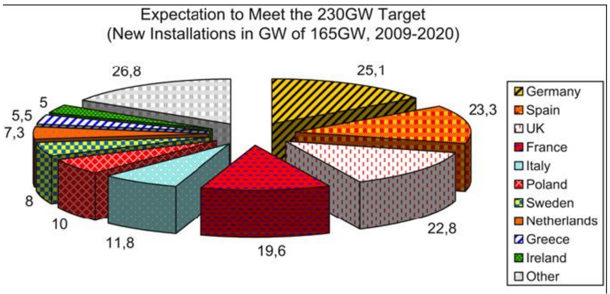


Figure 2.33: Future Wind Energy Targets and Expectation from Countries till 2020 (Kaldellis et al, 2011)

But to achieve such target the R&D for wind energy systems must also look at the following points to achieve sustainable, economic aspects such as:

- New wind turbines to reduce overall cost, assess efficiencies, reliability in wind turbines, innovative logistics with improved design considerations.
- Achieve grid integrations for even greater wind energy penetrations
- Government subsidies, policies and infrastructure, resource assessment and planning with governmental incentives etc.

Innovations such as the new rooftop turbines developed by “WindTronics”, Michigan which is only six feet in diameter and can generate wind energy at just 2mph on contrary to 6-8mph to produce electricity. This is possible as the power generating parts where placed outside the wheel whereby the blades can turn faster reducing bulk at the centre in traditional wind turbines and produce a power output of 2,000kWh of electricity annually. This would be almost 18% of the average household use with a cost of $5,499 only. (WindTronics, 2010) Other companies such as Katru Eco-Energy have developed a new type of HAWT called the “Implux” which can capture air from all directions which stands on a vertical axis but has horizontal blades facing up. The main innovation is that it can streamline and accelerate from any direction into the central chamber where the rotors generate electricity such that the centre piece is a fluid dynamic gate which prevents air from escaping the turbine and can generate up to 2kW of electricity with future plans of improving it to 4-10kW. Some realistic innovative designs are shown in the below Figure 2.34 as per today’s market in R&D sector.

Figure 2.34: a) Implux Turbine (Katru Eco-Energy, 2011) b) Energy Ball (Home Energy, Sweden, 2011)

2.6 STUDY OF PREVIOUS RESEARCH PAPERS

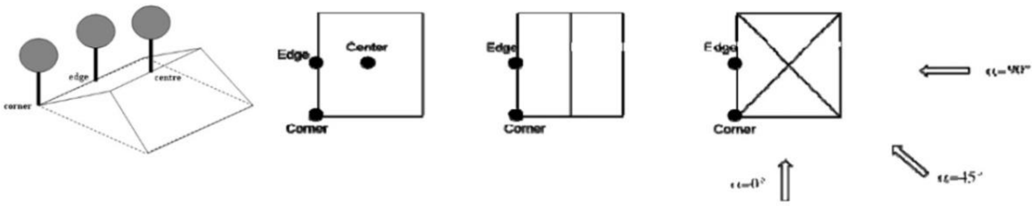
The below section investigates further research and finding by some scientific paper from various sources. The key aspects that are studied in the papers are in relation to solar and wind energy system along with factors such as orientation, scale, control mechanisms and techniques to maximize/optimize power output from the given system. By means of such study the author intends to utilize these finding in the current research and compare results by finding positive and negative aspects that have been noted in such research papers. Initially findings of each sector of energy generation i.e. solar and wind shall be investigated individually and further paper shall be based on issues and solutions related with integration of both the systems as a way ahead.

2.6.1 Studies on Wind Energy Systems

Ledo et al (2011) investigated the effects of wind flow characteristics in three suburban landscape characterized by houses with different roof profile such as pitched roof, flat roof and pyramidal roof. By the use of such analyses the author has produced reading which will assist in the integration of micro turbines on building in a suburban housing profile with factors such as low wind speeds, building forms, turbulence intensities, turbine heights and perception of potentially high level of aerodynamic noise generated by turbines. The use of numerical equations accompanied by computer fluid dynamics (CFD) has been used to simulate the wind flow in such environment and to find the optimum micro-turbine mounting location. Placing turbines where turbulence intensity is high causes early fatigues failures of the blades while it will be subjected to low wind speeds in separated zones is the main objective to study this research paper and hence Ledo et al has investigated situation where the density of the such suburban housing is more closer .The model of closely knit housing in Spain (Figure 2.35) with houses spaced 6m apart having a profile flat, pitched and pyramidal roof, plan of 8mx10m scale, finally height of 10m for flat roof and ridge at 12m for other roofs.

Figure 2.35: Housing in Spain a) Pitched roof b) Flat roof c) Pyramidal roof (Ledo et al 2011).

Use of a semi-log wind profile which is a logarithmic profile is adopted above the mean building height and an exponential wind profile is used below the building height instead of using the wind velocity based on roughness of the ground. Based on the this semi log wind profile the pitched roof at height of 10m the wind velocity calculated is 6m/s. Similarly the placement of wind turbines is considered with variable locations and the boundary conditions for the model in a rectangular domain of height equal to three times the actual building height are positioned. Hereby to investigate the effect of wind directions simulation is run as three different angles such as 0deg, 45deg and 90deg with recommendations of turbine mounting locations based on turbulence intensity level the following reading are obtained Figure 2.36



	Corner	Edge	Centre
Pitched roof	x	x	x
Flat roof	√	√	√
Pyramidal roof	x	√	x

Figure 2.36: Results of Turbine Mounting Locations based on turbulence intensity levels (Ledo et al, 2011)

Further studies were done on wind velocities at different angles as mentioned before by mounting turbines as again different locations to derive a power density using mathematical equation. As the turbulence intensities where more stable above the flat roof with stable wind velocities due to the formation of buildings the flat roof had wind power higher than the pitched roof as the wind power is sensitive to wind direction in all cases studied. Figure 2.37 illustrates the power densities of all forms of buildings at different angles in relation to wind directions and power availability.

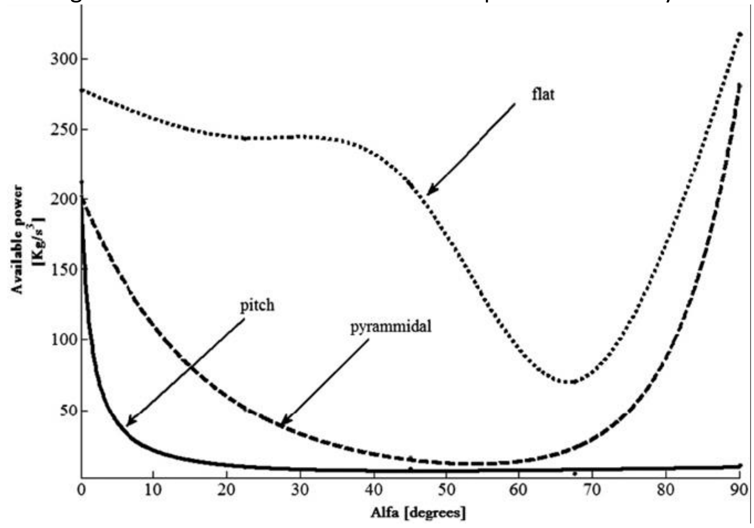


Figure 2.37: Power densities for a turbine hub height of 3m for all roofs as a function of wind directions in all cases. (Ledo et al 2011)

Final results led to the conclusion that turbulence intensities strongly depends on roof profile as well as wind directions, however the flat roof showed more stable turbulence intensities as compared to other but even beyond the roof decreases rapidly due to structure and space formations. While slow down in wind velocities are noted at 55deg for pyramidal roof, the pitched roof slow wind velocity was obtained at 67deg. But overall the flat roof was the more desired roof form in such dense suburban low structures with better power densities and normalized wind velocities to generate optimum power energy output.

James et al (2010) presented papers with key findings using filed trial monitoring method on 39 HAWT in urban, suburban and rural locations in the UK. The objective of the paper was to compare the technical and economic aspects of the installed horizontal micro-wind turbines with the data provided by the manufacturers in relation to the actual power output achieved on site. The performance of all the wind turbines (<2kWp) components of the UK micro-wind trials undertaken by the Energy Saving Trust in 2008/09 was assessed over a period of 12 months with 5 min average data collection on date and time, turbine output, turbine consumption, available wind speeds and directions. A Vaisala ultrasonic anemometer (WMT50) was installed on each site, fixed into position by a local TV aerial installer and as closer as possible to the turbine hub height while maintaining lateral separation sufficient to minimize interaction/distortion effects. For estimating the wind resource database (NOABL) numerical objective analysis boundary (BERR, 2007) was developed to predict wind speeds at 1km grid square level at 10, 25, 45m above ground level. New micro generation tariffs were analyzed in relation to the grants given by UK policies to find a realistic output of the wind energy system to overcome economic problems in future wind turbine installations ranging from <1.5kW-15kW capacities. Basis of site selection was to provide a wide range of manufacturers and wind regimes as possible. Table 2.2 illustrating the wide range of sites and turbine types selected as per manufacturers.

Table 2.2: Fully monitored building mounted HAWT sites for trial (EST, 2009)

Turbine	EST+*WWT*	Diameter (m)	Rated power (W)	Rated power per m^2 swept area (W/m^2)	Rated wind speed (m/s)	Cut-in speed (m/s)	Cut-out speed (m/s)
Airdolphin	1+*4*	1.8	1000	393	12	2.5	50
Ampair 600	0+*14*	1.7	600 (231[a])	264 (102[a])	12.5	3.5	None
Eclectic D400	0+*4*	1.1	400	421	15.5	2.5	None
Swift	4+*1*	2.1	1500	433	12.5	2.3	None
Windsave, WS1000	34+*6*	1.75	1000	416	12.5	4.5	15

Careful analysis was done on the manufacturer's data available such as power curves, annual energy production graphs, wind speeds and coefficient of performances (COP), estimated annual generations based on wind speeds and finally a comparison of the measured meteorological wind speed data with a 10 years average data set was established. Further all sites were subjected to trials and data collection based on measured annual and average wind speeds, estimated shape and scale factor, wind speed predictions, turbine type and height, annual generation per m2 swept area and finally load factor was recorded. Evaluation of economics of the wind energy system in relation to the current electricity tariff structure and the payback time within its lifetime in the UK was graphed. All factors such as initial costs, maintenance and annual operation cost were taken into consideration and were even compared to the PV output ratio were estimated in general. Finally Figure 2.38 illustrates the generation tariff required for payback in fixed number of years (p/kWh) and the discounted rate evaluated.

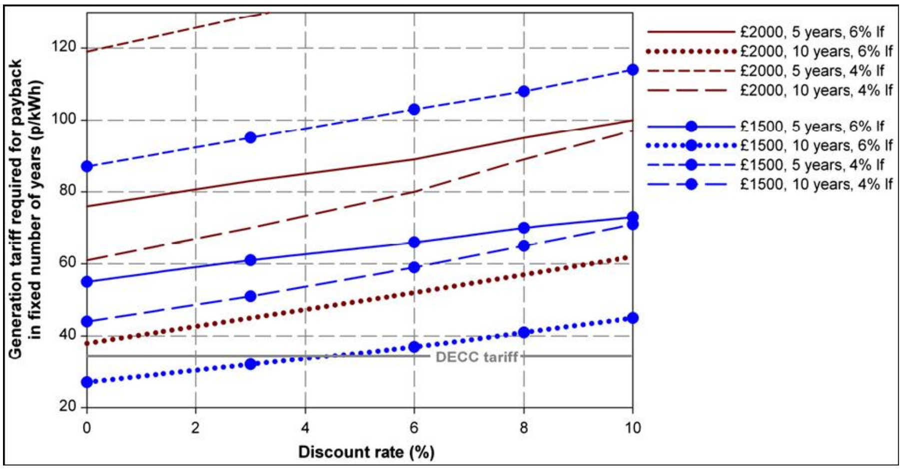


Figure 2.38: Tariff generation required for 1kW micro-HAWT to achieve a payback as a function of load factor, period and discount rate. (James et al 2010)

The performance of micro-HAWT was generally poor due to the realistic wind resource around the buildings in comparison to the available database and manufacturer's product information as none of the site recorded an average wind speed above 4m/s while it must average a wind speed of 5m/s minimum correspond to an annual generation per m2 swept area of 10% load factor approximately. Thus resultantly a comparison between NOABL database and measured wind data, the NOABL database overestimates the wind resource and a higher threshold of 5.8m/s was suggested for future potential wind energy market across UK. Also to achieve a 10 year lifetime payback period at a zero discounted rate would require an annual load factor of 7% which is higher than the measured at the fully monitored sites in trial.

Muller et al (2009) analyzed the oldest known form of wind energy system, "Sistan Type Windmill" (Vertical Axis) and conceptualized the adaptation of this type of drag force windmill converter in to modern design of building integrations architecturally. The Sistan Windmill absorbs wind energy with its individual blades and moves slower than the wind on its drag coefficient. After the studying the older concept mathematically the modification was done whereby the drag coefficient was improved to 1.2 to 2.0 by adding a disc at top and bottom of the wheel that increased the efficiency by 29.6% theoretically. Further improvisation was done to the geometry to the leeward side with modifications to the rotors, walls and top and bottom to obtain low pressure zone and high pressure zone on the side of the obstacle facing the flow direction. Mathematical equations derived for both functions i.e. ratio of average blade and wind speed. Modeling the equation as simple box with vertical axis and a friction wheel over the side wheel after which the wind speed was measured with a hand held anemometer and ten revolutions of the wheel were timed with a stop watch. The same concept was modeled in Archicad on a building with rotor blade area of 5x8m, wind speed of 15m/s, converter efficiency of 50% which would result in maximum power output of 36kW. Figure 2.37 shows the older concept of sistan windmill and the newer version modeled to obtain results by mathematical equations.

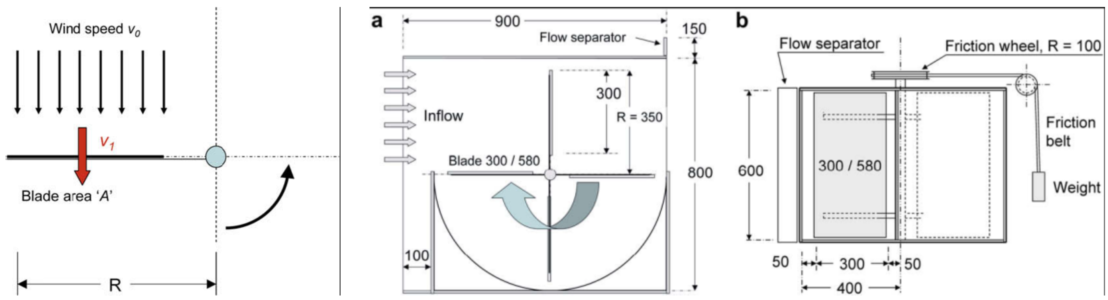


Figure 2.39: a) Principle concept of Sistan Windmill b) Modified Concept of Resistance VAWT.

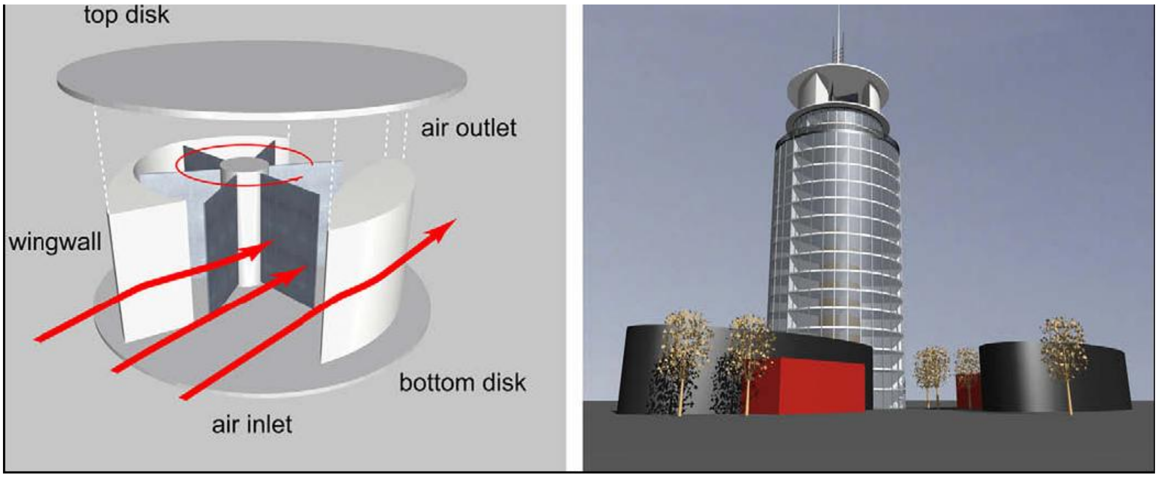


Figure 2.39: c) Artist Impression of large scale resistance type VAWT on high rise (Muller et al 2009)

In conclusion it was derived that theoretical development of this geometry change with induced 2D flow field indicated a maximum converter efficiency of 48-61% with test conducted on theory the highest measured power output determined was 42% with low pressure induction of wind on the leeward end. Loop holes such as actual magnitude of pressure on the front and back and effects were not investigated, nor are the optimization in the number of blades and effects is considered with details of in and outflow of wind energy on the drum.

Sharpe el al (2010) also developed a radical new design concept based on the Darrieus turbine form which is type of vertical axis wind turbine on building integrations. Investigation was done to find a balance in building integration forms and to avoid reduction in output which are unable to maximize the potential of the augmented airflow around buildings. Factors which create issues as regards to HAWT large output models such as loads on larger buildings, maintenance or repair, noise and vibrations and finally visual acceptance has been the key focus of this new modular design. With this in mind the "Cross flex" design is researched specifically to respond to demands for turbines in urban situations. Though the new design works on the Darreius turbine principle it brings innovations to counter balance the negativities of the original concept by mounting the frame with the shaft held on both ends so as to enable the operation within the axis of rotation aligned either horizontally or vertically which reduces the loads on the bearing and shaft. Points of innovation that follow are

- Blade design such as to achieve maximum efficiency with low solidity and low inertia mass design and flexibility of blades which naturally assume troposkien shape at rated speeds which minimizes bending stress.
- Design of blade roots which can solve problems in limitation in rotational speed in high wind conditions.
- Distribution of loads which will help in reducing loads on buildings and no rotor tip blades which help in noise reduction.
- Capabilities which can draw wind from all directions and cope with turbulence around buildings

Further use of mathematical modeling which calculates torque, resultant stream wise force, variation in angle of attack versus azimuth and finally power output potential is analyzed. Flexibility in blade design also helps in possibilities of a dynamic pitch angle with inclusion of linear springs to gradually increase the magnitude of the negative pitch angle with increasing rpm and via graph plotting the best angle is derived for even high torques. Issues such as over speeding are solved by modification in braking system or release mechanism by addition of loop of wire or chord which retrains each blade by looping through a pin in the blade. During high speed conditions the loop breaks and all blades are released from the slot. Building integration models are worked at different angles of the building and location as shown in Figure 2.40.

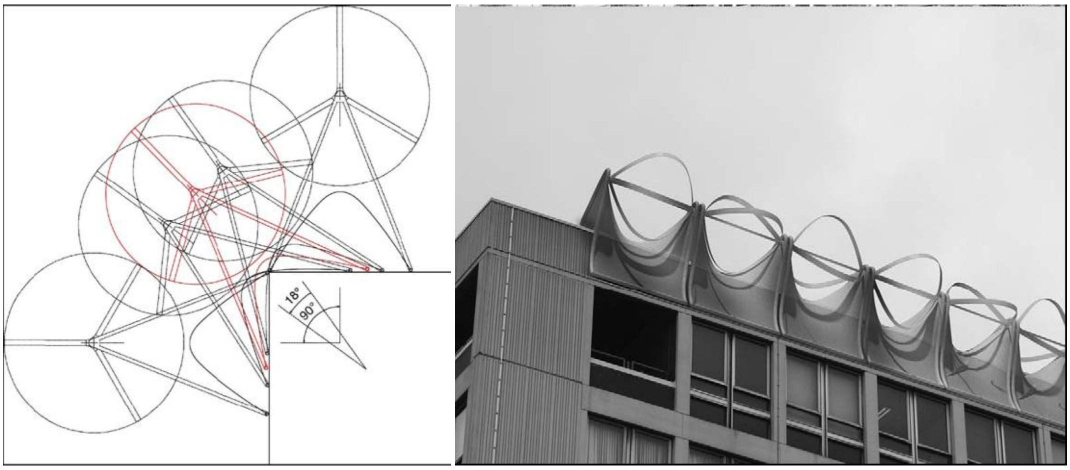


Figure 2.40 a) Variable placement angle b) View of Building integration on parapets (Sharpe et al 2010)

It has been concluded that such modular system the capacity of the power output can be increased with addition of number of modules and can be placed at building tops, edges, parapets and all possible location which can benefit from the urban building augmented air flow. Being light weight and specifically designed to suit urban environment the installed capacity could be between factors of 4-6 times greater if favorable mounting conditions are met. Also modularity could lead to economic manufacturing cost benefits and efficient power output as per following power curves obtained by modeling of the cross flex design.

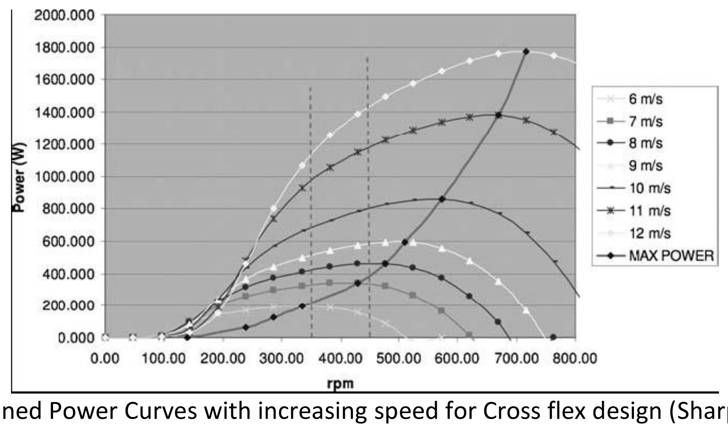


Figure 2.41 Obtained Power Curves with increasing speed for Cross flex design (Sharpe et al 2010)

Zghal et al (2011) presented papers to optimize and manage the energy produced by wind energy systems with new methods of sizing and techno-economics with a given load distribution for a specific site with analysis on the impacts of different parameters on the system. Since the main sub-systems of a wind energy system are generators and unit of storage the paper present the lack of energy to generate probabilities (LEGP) in relation to the percentage of surplus of energy produced (PESP) and the cost of kilowatt-hour produced. Mathematical and simulation code has been used to carry out the optimization in sizing of the system coupled with a case study to satisfy the residential house requirement (5kWh/day) in Tunisia is analyzed. It is critically important to select a correct regime of the HAWT to predict the performance of the energy output with the different components so as to enable an optimization in the system which is done by determining the aerodynamics power efficiency, mechanical transmission and tower height with the most important elements such as rotor, gearbox and generator. In series a mathematical model is used to determine the quantity of energy that can be produced by the HAWT, secondly the capacity of the nominal power of the generator is determined with possibilities such as that wind turbine does not produce any current, power dependent on wind, constant power output and high speed condition braking of the wind turbine is evolved mathematically. Further modeling of storage systems such as batteries which depends on previous state battery energy, quantity and finally user consumption. During optimization criteria it was noted that total energizing system can meet the daily load demands which leads to situations such as lower production, equal production and excess production. For all the above mentioned choices the paper represents a variable limitation with a balance in system power reliability and system cost. Case study evaluation of wind turbine using these case optimization leads to the following curves resulting that only increasing the height of the wind turbine increases energy produced by the wind generator which shows growth of the PSEP and reduction in LEGP. The upper line i.e. 2sky, C3+C1, 4C1 represent turbine types.

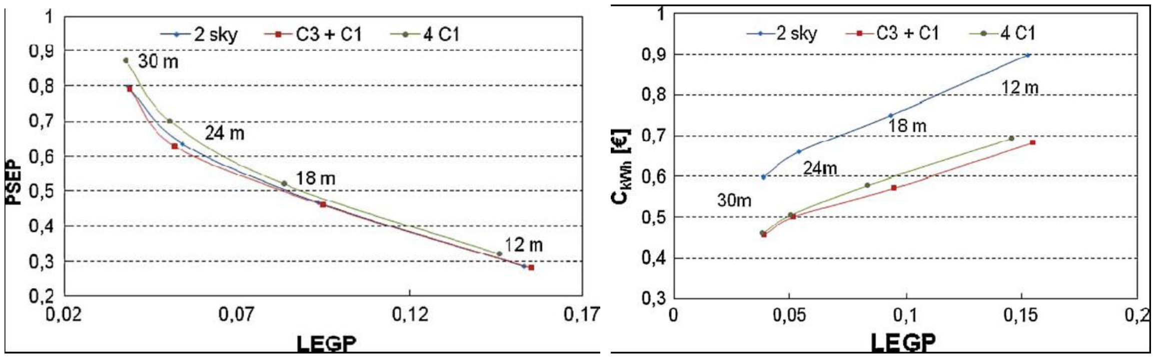


Figure 2.42: a) LEGP and PSEP evolution for different system configurations. b) Impact of LEGP on the cost of energy (C-kWh) (Zghal et al, 2011)

Further simulation results lead to the clarification of the impact of the LEGP on the cost of energy C-kWh. Results indicate that based on the configuration the C-kWh values decrease when the LEGP decrease which is due to increase in the height of wind turbines which increases energy output. Since increase in the size of the wind generator or number of batteries the LEGP value did not attain zero, it was indicated to use complementary systems such as PV's, diesel etc to meet user energizing needs and loads for the case study model in Tunisia.

Muyeen et al (2011) investigated the use of current controlled voltage source inverters with variable speed wind turbines systems. Considering recent wind farm grid codes modeling the control strategies for overall system was developed to augment the low voltage ride through abilities of a variable speed wind generator. This analysis is carried into real wind speed data measured in Hokkaida Island, Japan to avail the dynamic characteristics using standard power system simulation packages, with verification of results of voltage control voltage source inverters in comparison to power failure literature. In series the modeling of the wind turbine is done with maximum power point tracing graph and range of rotor speed variation approximately ranging from 5-16rpm and care is taken that magnetic synchronous generator output does not exceed the rated power. Inverter model is a standard 3 phase two level units six IGBT and anti-parallel diodes and frequency controller which consist of a rectifier, boost converter with grid inverter as mentioned earlier. Diagrammatic models of the sinusoidal pulse width modulation (PMV) and based on the inverter switching function inverter simulation model is developed along with the boost converters purpose to control the rectifier output current and power. Strategies for the variable speed inverter (VSI) are obtained with three phase electrical quantities and are related to each other by reference frame transformation. Figure 2.43 illustrated the diagrams that have been evolved with the above set of formations to carry simulation results.

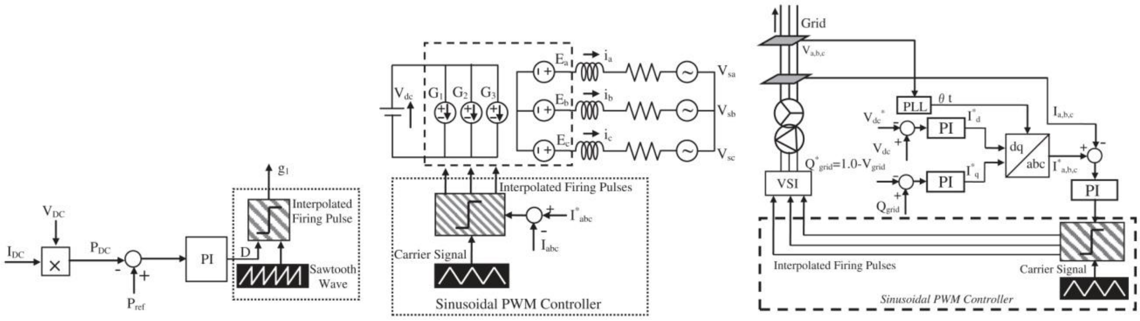


Figure 2.43: Diagram Models, a) Boost Converter b) PMV-VSI c) Current controlled VSI (Muyeen et al 2011)

Further circuit breakers of symmetrical 3-line to ground fault, unsymmetrical 2-line to ground fault and 1-line to ground fault are considered for network distribution and from simulation results is was analyzed that the unsymmetrical faults of VSI improves the system performance considerably. Dynamic characteristic of the model is run on varied range of wind speeds as obtained from the site and was noted that wind generator terminal voltage could maintain a constant desired level of transmission system operator under the proposed control strategy. The system runs smoothly under random and quickly varying wind conditions during both symmetrical and unsymmetrical fault conditions with effective operation conditions of the variable speed wind turbine- permanent magnetic synchronous generator in both dynamic and transient conditions.

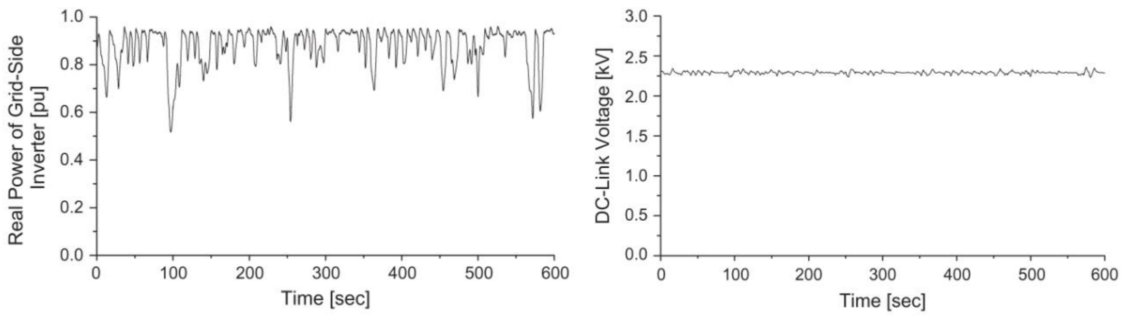


Figure 2.44: Stable Simulation results by use of control strategies a) Real power supply to grid b) DC-Link voltage frequency converter (Muyeen et al, 2011)

2.6.2 Studies on PV Energy Systems

Omer et al (2003) conducted monitoring results for two building integrated PV's (BIPV) systems in the UK with thin film module apt for commercial use and other crystalline PV roof slats appropriate for domestic buildings. The criteria for building selection was clear such as usage, sizes, construction, occupancy and design where on the selection of PV system was based. The roof areas considered for commercial building spanned almost 160m2 inclined at 16.5deg to the horizontal and wall of 50m2 suitable for solar installation. Out of the complete roof 50% was dedicated for solar thermal collectors to meet the building heating loads and 50% was allocated for BIPV which was monitored for field tests along with its components. Various simulation packages were used for energy analysis and positioning of the PV system along with the appropriate selection of type and components. Care was taken for the vertical installation of the PV panels to make sure that they project out on the upper floor from the roof overhang and avoid overhang shading and further projects helped in maintaining an air flow between walls and panels to avoid overheating of the cell temperature. Use of a-Si cells encapsulated between glass and Tedler backing supported by aluminum framing with a tilt angle of 58deg horizontal with the whole PV array facing 30deg south as seven parallel strings of 4 modules with standard test conditions open circuit 264V, short circuit 1A and peak power of 952Wp. Finally a Sunny Boy inverter of appropriate size and modulation was attached to the main system. Similar studies to the domestic PV system were carried out and south facing application was zeroed down into roof mounted PV slats replacing roof tiles was used. Here a Mono-crystalline technology was more suitable to ensure maximum power output owing to the higher conversion efficiency as compared to the a-Si with a final south facing tilt angle of 52deg in 14 rows installed. Electrical connection followed as 2 parallel sub-arrays of 66 series connected 11.88Wp with nominal STC open circuit voltage 235.6V and short circuit of 8.9A with peak power of 1568Wp along with appropriate inverter similarly. Figure 2.45 shows the selection of buildings and PV systems installed for filed monitoring.

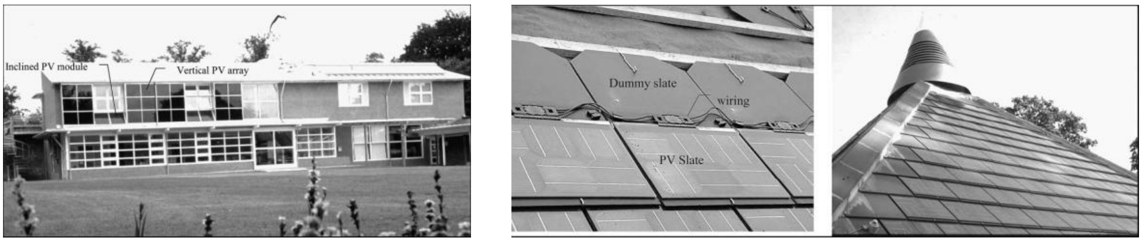


Figure 2.45: a) Commercial building with a-Si PV system b) Domestic building with mono-crystalline PV system installations. (Omer et al 2003)

Continuous monitoring of the PV systems for both the building brought about the following result:

- Low efficiency of the PV system as compared to original simulation output due to effects of shading on part of arrays, reduction in module peak power with associated effects on inverter power ratio, maximum power tracking failure and suspected defective PV modules on the commercial installation in addition to poor orientation of array and power losses due to system components.
- Even the domestic building showed similar signs of low efficiency; though no inverter problems were associated, the PV arrays were subjected to partial shading due to close proximity of trees. But one of the main reason for failure was the cell temperature which was due to the integration of PV slates and their multi-layer structure overlapping each other with can resulting in mid day cell temperature rising in an excess of 70deg while the roof space was only 33deg. Again not only the overlap but low gaps/spacing along with roof fixing components was an additional cause.

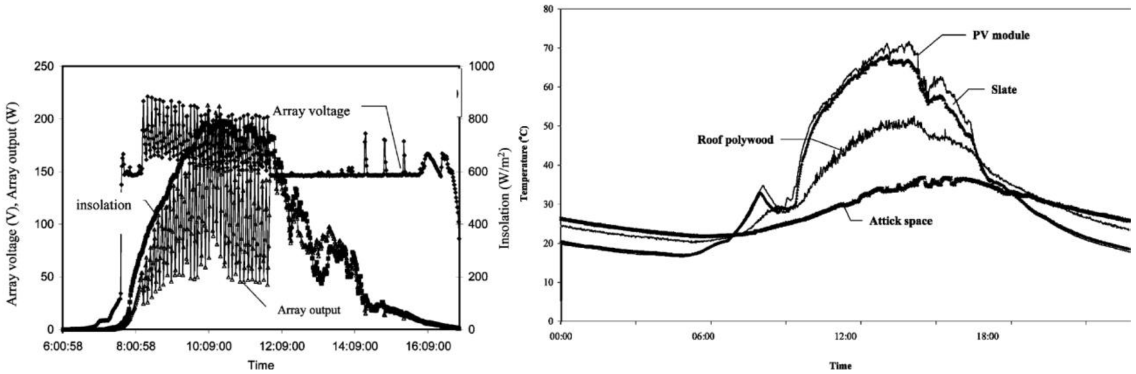


Figure 2.46: Graphs showing problems associated with PV Installations: a) Commercial building MPPT issue b) Cell Temperature issues in domestic buildings (Omer et al 2003)

Economic assessment of both the buildings yielded a result such in case of commercial building was that initial cost would be substantially reduced if the panels were more integrated in the structure rather than further addition of frame work while in case of domestic installation this was not the case due to roof integrations possibility. Though the commercial installation is higher than the domestic cost there are possibilities of full integration into window systems. Finally both the buildings did not prove to be cost effective at the current market prices of energy while the basic aim of the paper was to bring the technology to a wider audience and attention to potential reduction in CO2 emissions. In conclusion it is noted that appropriate information should be provided at an early stage which include principles of BIPV operations, manufacturer’s data, and sizing of components such as inverters, available climatic site situation, and degradation criteria of amorphous PV cells consideration, shading problems and finally controlling cell temperature.

Radhi (2010) evaluated variation of the total energy of BIPV as a wall cladding system applied in UAE commercial sector and provided comparison of viability of such technology against other forms using the concept of embodies energy payback time (EPBT). Analysis of the EPBT of the solar energy system was done in terms of four main sections i.e. silicon production and purification, production of silicon wafers, cell fabrication, packaging into PV panel modules and finally the balance of the system (power conditioning, control equipments, storage, load equipments etc). Three major cities of UAE were zeroed down to study the climatic conditions such as Dubai, Al Ain and Abu Dhabi as comparatives. Detailed studies involving temperature, humidity, average irradiance on the horizontal plane and tilted planes showed different characteristics, which were derived using MeterNorm Software. All PV panels were assumed to be integrated into the building envelope with 90deg tilt envelope supported by an aluminum frame leaving an air gap of 12-15cm from the walls. Energy-10 software utilized for the analyzing the PV system performance hour-by-hour which estimates the efficiencies, operating temperature with exact energy balance methods between building and its system. Most important the calibration of the simulation was done based on monthly utility bills and building design and operations with first real weather data based in Al Ain and then same run for Dubai and Abu Dhabi.

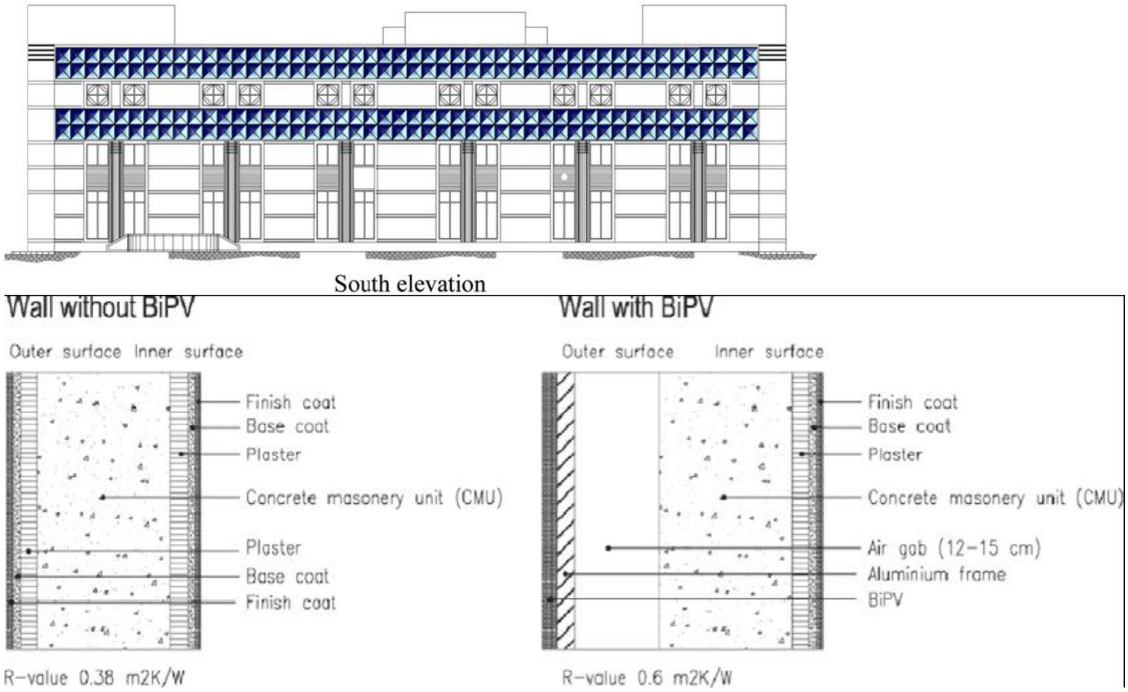


Figure 2.47: a) Building in Al Ain with PV panels windows on all directions (e.g. South Elevation) b) Composition of existing wall and with PV installation used for research (Radhi, 2010)

At first the PV systems energy payback time is done without any considerations for the reduction in operational energy and then the impacts of PV panels as a wall cladding, so as to explore the embodied energy and performance of the PV façade, only then the estimate of the total energy saving was derived. Literature review led to various factors of energy requirement in the production of PV system. Detailed process showed that ratio between PV output and saving in energy due to PV panels was within a range of 1:3-1:4 and the most energy efficient direction were southern and western facades with a embodied energy payback time for the PV system within a range of 12-13 years and when a reduction in operational energy is considered it reduces further by 3-3.2 years. Also detailed research led to the fact that optimum tilt angle for the south facing surface in the UAE is 24deg but the western 90deg surface tilt generates larger output in spite of intensive solar radiation on the south face predominantly due to the rise in cell temperature which degrades the efficiencies. Also Radhi, (2010) finally encourage the use of PV system as also thermal insulators to stop heat transfer which reduce cooling loads including wall insulation as an added advantage and alternative in the UAE apart from its capabilities to produce electricity for the building.

Norton et al (2011) evaluated in depth the various factors which enhances the performance of PV systems sizing on buildings theoretically. By emphasizing range of key systems which would improvise the solar energy potential in terms of efficiency, overall performance and finally help in the economic viability factors such as use of inverters, concentrators, thermal management and storage systems were detailed in research with various up-to-date advanced techniques of the PV system installation and operations.

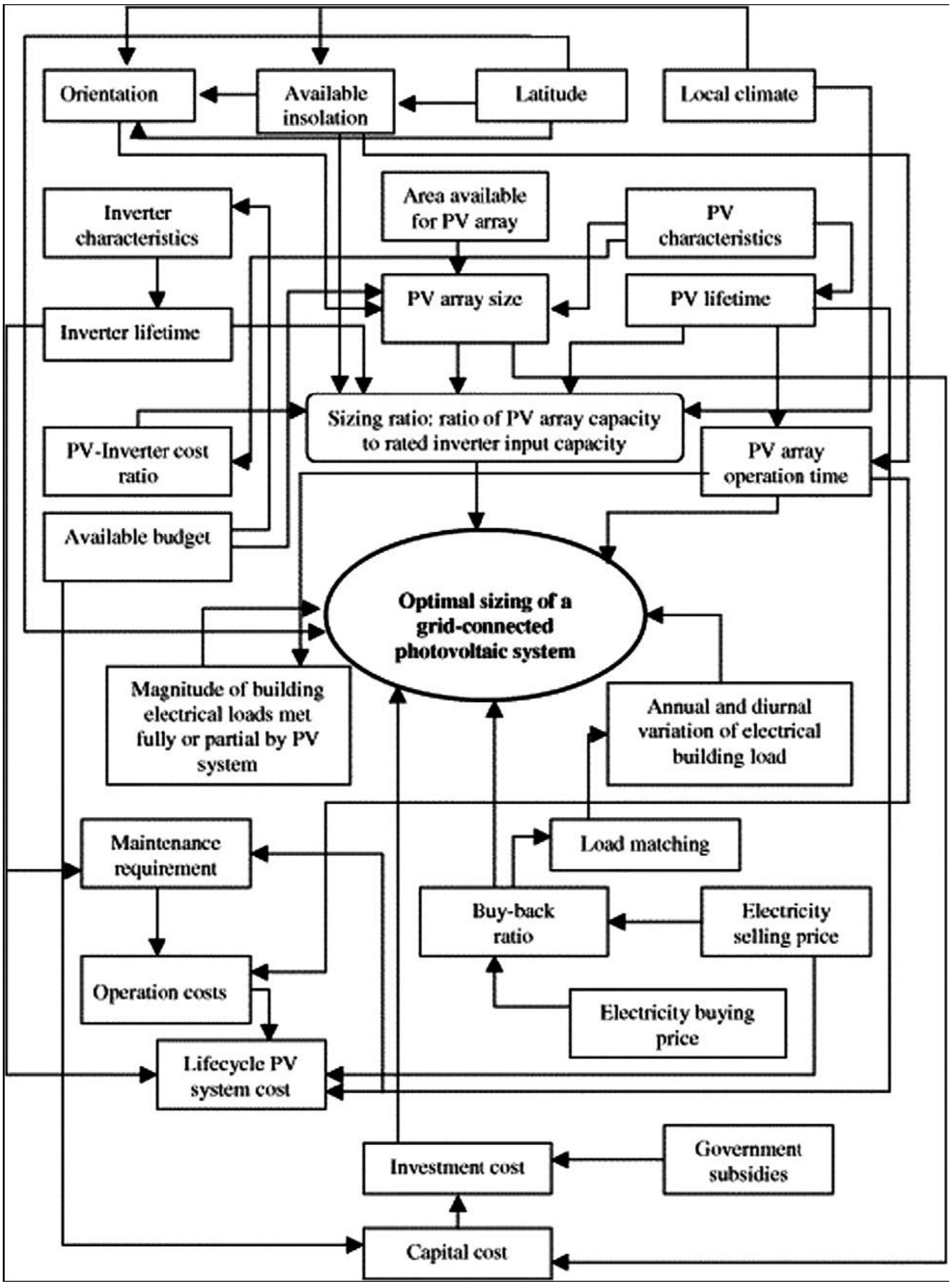


Figure 2.48: Interaction of influences on PV system sizing (Mondol et al 2006a)

The above chart is a excellent formation of all measures involving optimal sizing of the PV system grid connected matrix which not only looks at basic parameters of initial PV design criteria but also emphasis the need for appropriate study based on post installation maintenance and costs associated with the final outcome.

Toledo et al (2010) presented a review of the energy storage and distribution associated with PV energy by using the Sodium Sulfur (NaS) batteries which help improve the load factor, back up energy and supply side management. One of the most important components of the storage mechanism which in most cases is batteries and the basis of the system to generate sufficient energy to attend demand at accessible prices and to provide clean, safe and reliable electricity. Battery applications require energy discharge ranging from fraction of a second in high power systems to hours in high energy applications. Various technologies are available in the market for energy storage and it is important find out their graph related to efficiency and durability in charge-discharge cycles with at least 80% depth discharge. Accordingly the discharge time and rated power are to be analyzed. Figure 2.49 compares most of the energy storage mechanism available in the market and their properties critical for appropriate storage selection and sizing.

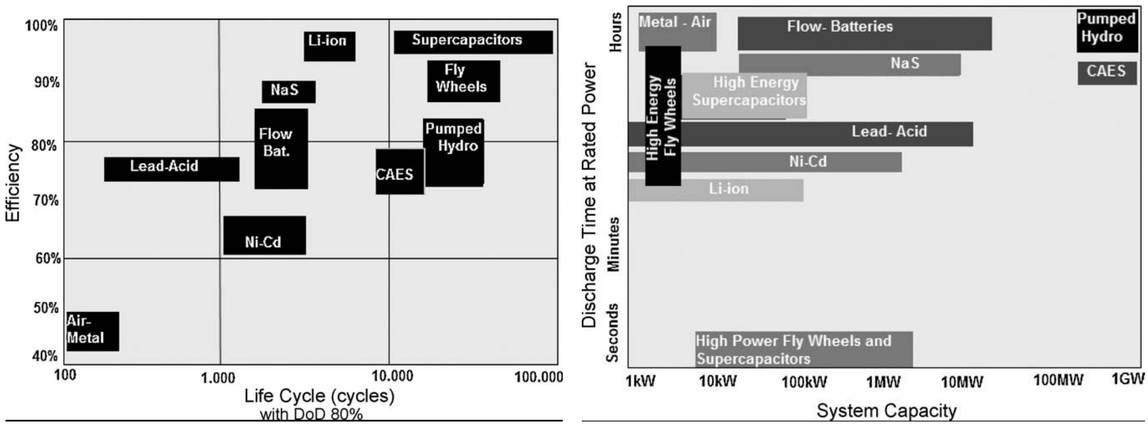


Figure 2.49: Diverse energy storage technologies with a) efficiency and reliability in discharge rate b) discharge time and rate power comparison. (Toledo et al, 2010)

In cases where distributed generation system are often of a smaller case and require small scale storages of a few MW for a few hours in different locations the NaS provides a excellent solution but in cases where storage capacity is fairly less with supply to particular smaller homes, cottage the lead acid batteries are also viable economic solutions as seen from the above graph which involves second best to NaS batteries. The important parts of battery selection that need to be considered are noted in spite of emphasis given to NaS batteries which is a point to be taken such as:

- Reversibility ratio of charging and discharging with expected duration in number of years considering number of cycles for at least 80% Depth of Discharge.
- Output voltage modules, power and energy for peak shaving application.
- Rapid response time, high energy density, unaffected by ambient temperature with capabilities of being installed in protected or unprotected environment.
- Possibilities for remote monitoring with minimal maintenance, no emissions or vibrations, low noise and finally recycling capacity.

Also the peak hour encountered during the day in peak summer due to air conditioning should increase in storage capacity whereby increasing the aggregated value of photovoltaic’s. Battery selection and storage performance ratio/efficiency for both grids connected or direct connection to load demand can add value to the system by:

- Allowing load management, for consumer by shedding load utility from other sources i.e diesel, main electrical power stations etc when associated with demand side controls.
- Avoid energy interruption by increasing the capacity of utilities.
- Enable consumer and main power grids to support local critical loads by attending to their own energy demands in case of system failure and excess demand during peak hours.

Overall the best battery selection reduces the high cost of photovoltaic installations which can be minimized by proper battery load management and energy storage power whereby bringing the PV market more closer to the concept of clean, reliable and economic solution in renewable energy drive in today’s times.

Chaar et al (2008) discussed the effects of wind-blown sands and dust on PV arrays in the UAE. Especially in the UAE in spite of the excellent solar conditions to harness PV system installations there are prevalent problems due to high temperature with occasional strong winds which lead to sandstorms in additional to the humid weather during summer season. With accumulation of such sticky sand and dust on the PV leads to poor performance energy output as compared to the tests conducted in the laboratory or manufacturers catalogue output graphs. Dust or sand collection on the PV arrays leads to poor solar radiation reach on the cells which invariably affect the overall efficiency of the cells and is no different than similar cases of shadowing of the cells due to other factors. Also if the weather conditions are harsher the occasional large sandstorms could further damage the cells of the PV arrays if occurred regularly. Chaar et al also mentions that a poor link is formed due to the complete damage cause to a single cell in an array which further degrades the overall module efficiency which not only stops its power output but also acts as a high resister and reverse action by other associated cells. Figure 2.50 illustrates the effect of one cell that is 75% under shade conditions on a module of 36 mono crystalline formations of PV arrays.

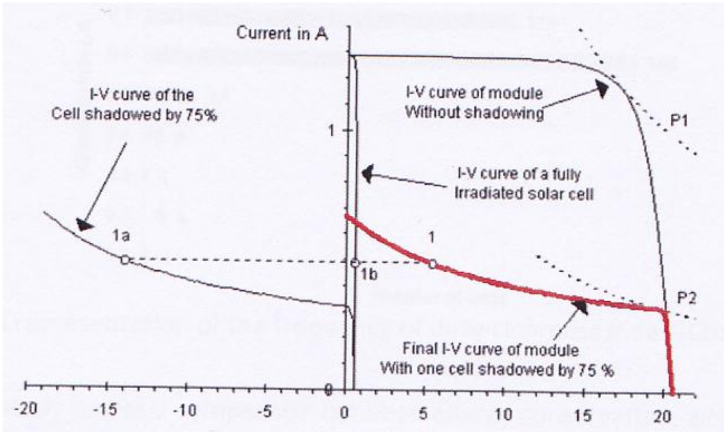


Figure 2.50: I-V curve of module with one cell shadowed by 75% (Chaar et al, 2008)

Chaar et al (2011) based on the above paper also has discussed mechanisms which can prove a solution to such sand particles, dust and bird dropping problems which cause PV cell degradation and affect overall output efficiency by adequate cleaning and maintenance methods. Various methods of cleaning are mentioned with their advantages and disadvantages in below Table 2.3

Table 2.3: Selection of PV cleaning system and comparisons. (Chaar et al 2011)

Comparison of a selection of cleaning systems.

Cleaning System	Advantage	Disadvantage
Manual	Cleaning only when required	Cost varies depending on location and manpower Time consuming and inefficient
Transparent Shield [15]	No mechanical movement to scratch the protective surface	Requires high voltage for good performance. Causes shading when used on a PV panel Cannot be directly powered from the panel
Electro-Dynamics Screen (EDS-PV) [19]	Efficient and can be used to remove dust from a variety of surfaces	Requires 3-phase high voltage amplifier which is a problem in remote locations
Integrated Electro Dynamic Screens [20]	Efficient with and without use of external power supply	Requires a Digital Signal Controller (DSC) which is costly Requires switching devices for converters hence more maintenance is required
Standing Wave Electric Curtain [21]	It is highly efficient at high gas pressure	Removal is difficult when gas pressure is below a certain limit Dust removal capability depends on the size of the particles deposited
Solarbrush PV Robot [18]	Automated robot	Heavy weight and has a high initial cost Requires human intervention
CleanAnt [17]	Self regulating and flexible uninterrupted cleaning operations	Heavy and large Requires external source for charging
Over-dimensioned PV Array	More power available hence possible onshore implementation Acceptable initial investment	Limited space offshore Requires larger battery bank therefore higher losses

Apart of the above methods two other cleaning systems are analyzed and emphasized in details namely the PIC system and the PLC system which are micro controlled systems deploying mechanical movement and electrical components and are simple in operation with photo-detectors attached to the panels and initiates daily cleaning operation, more like mechanical wipers on PV arrays. Birds are prevented during day by a buzzer with motion a sensor which detect bird movements and during night green light is emitted to frighten them away. Although these mechanisms add to the initial investment with payback period of 2 years they considerably improve the overall efficiency of the cells by better power output ratio.

Chaar and Lemont (2010) investigated the climatic condition in the UAE in particularly Abu Dhabi to implement OV technologies by measuring solar radiation of five different geographical locations. The hourly, daily, and monthly global horizontal irradiation were collected and processed via statistical methods especially in the summer periods. Also the clearness index was calculated to investigate the number of cloud days which resulted in maximum clear day conditions in a year. Figure 2.51 and Table 2.4 illustrates the high 82% clear days in a year maximum number being 165 days of 0.6k clearness index with maximum day light hours occurred from the month April to September which is most summer season in the UAE.

Table 2.4 Average daylight hours in Abu Dhabi (all locations) (Chaar and Lemont, 2010)

Month	Average daylight hours
January	10.6878
February	11.20107
March	11.88231
April	12.59827
May	13.19577
June	13.47368
July	13.33593
August	12.82337
September	12.10818
October	11.39402
November	10.80012
December	10.53767

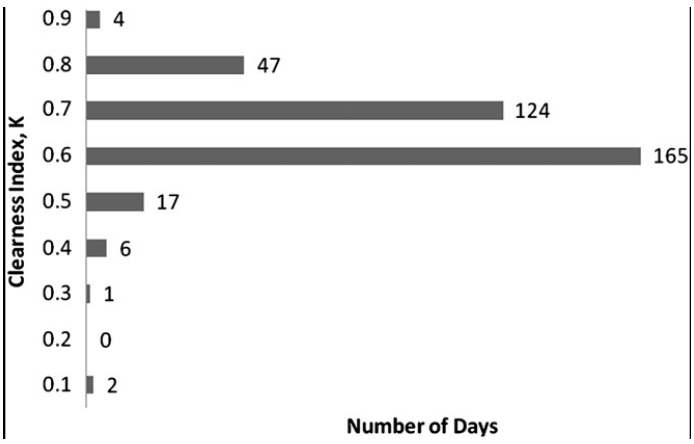


Figure 2.51: Graphical representation of the frequency of daily clearness index in Abu Dhabi (Chaar and Lemont, 2010)

The overall results of total solar horizontal irradiation, daylight hours and clearness index showed that PV applications in Abu Dhabi are a promising solution to energy expansion the UAE as a country.

2.6.3 Studies on PV and Wind as Hybrid Energy Systems.

Hongxing et al (2009) presented papers for recommending an optimal design for a hybrid solar-wind system employing optimal battery banks for calculating the system optimum configuration and ensuring the annualized cost of the system is reduced while meeting the custom requirement of loss of power supply probability (LPSP). The key factors which were evaluated to optimize the hybridization of the system were, number of PV modules, Slope angle, wind turbine number, turbine installation height and the battery bank capacity. All the above was put to test for a telecommunication relay station in eastern coast of China to find the success ratio of the complementary nature of solar and wind hybridization system. In order to find the performance of the various components of the hybrid system, a generic algorithm was used particularly in multi-modal and multi-objective optimization problems. The model for PV arrays was based on five factors namely, non linear effects that the photocurrent depends on, PV module technology related to dimensionless coefficient, non linear temperature-voltage effects, power rated series and finally the maximum power point tracking under different working conditions. Similar for wind modeling factor such as cut-in speed, power output incremental ratio to wind speed and finally the rated power were calculated. Batteries such as lead acid type elected and evaluated based on the state of charge and floating charge voltages were considered. Loss of power supply probability is important as analysis of the issues when the power supply cannot meet the load demand is critical and the all the above led to the chart optimization process illustrated in Figure 2.52.

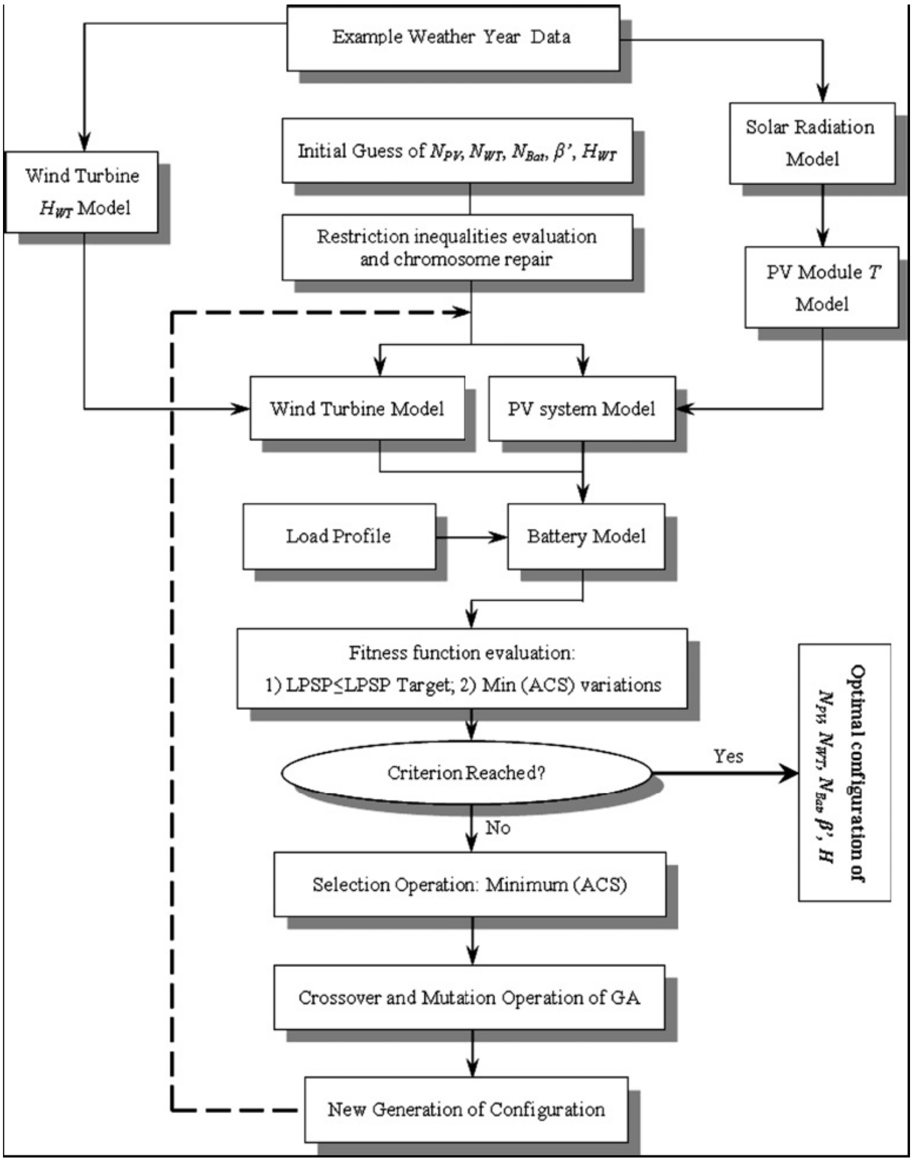


Figure 2.52: Optimization of the Hybrid system flow chart using genetic algorithm (Hongxing et al, 2010)

Further discussion based on the normal operation mode of the telecommunication stations in China led to the desired LPSP of 2% but this was due to limited space in the installation of PV modules which less by 35 modules and the wind turbine height restricted to 20m above ground due to severe typhoon scenario in summer season. Hourly measured field measure data for a year noted an energy contribution variation greatly for each month throughout the year. The batteries state of charge were in a good working condition though with nearly 90% opportunities for its SOC with the LPSP well controlled with less than 2% as required. Table 2.5 and Figure 2.53 shows the final optimal design configuration with an annualized system cost of 9708 US$ in addition to the adequate monthly energy contribution of solar and wind energy.

Table 2.5: Optimum sizing results of the hybrid system and annualized cost (Hongxing et al, 2009)

Configuration	N_{WT}	N_{PV}	N_{bat}	β' (°)	H_{WT} (m)	ACS (US$)	LPSP (%)
1	2	82	8	23.2	25.5	12,536	0.64
2	1	98	5	23.2	32.5	9116	2.95
3	1	106	5	25	31	9421	2.19
4	3	116	3	23.2	25	12,717	1.71
5	1	118	8	22.3	25	11,215	1.23
6	1	114	4	23.2	25	8998	3.14
7	1	114	5	24	32.5	9708	1.96
8	3	242	5	24.5	35	18,740	0
9	1	54	4	26	20	6532	19.25
10	2	82	4	23.2	40	10,910	1.8
Revised result	2	78	5	24	20.0	10,456	1.98

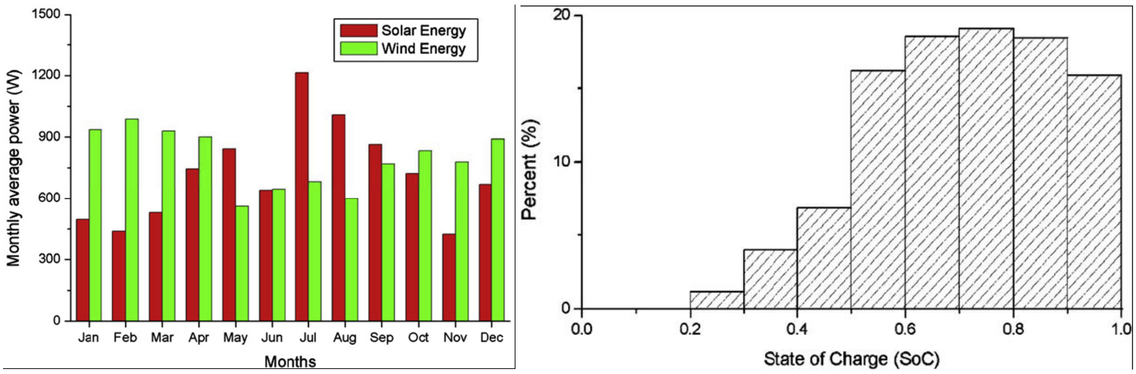


Figure 2.53: a) Monthly energy contribution b) Revised configuration of the Battery SOC (Hongxing et al 2009)

Prasad GVT et al (2010) presented methods of improvising the efficiencies of the solar wind hybrid system by altering the design parameters. A small prototype creating a power load of 120W was design and tested based on the alterations and additions to basic design of solar wind energy system. Additions to PV panels involved reflectors along with sun tracking systems and similarly windmills were equipped with wind sensors and micro-controller to detect maximum flow of wind directions. 80W/12 volts mono crystalline module was preferred for PV system with aluminum sheet reflectors fitted at an optimum angle of 60deg inclined to the plane of the PV panel. The sun tracker ensured that plane of the panels is always perpendicular to the sun's rays and the position of the reflectors enabled the light to fall at the tip of the reflector to reach the edge of the panel with all rays directed maximum to the width of the PV panel. Figure 2.54 shows the arrangement of the reflector design in relation to the PV panels.

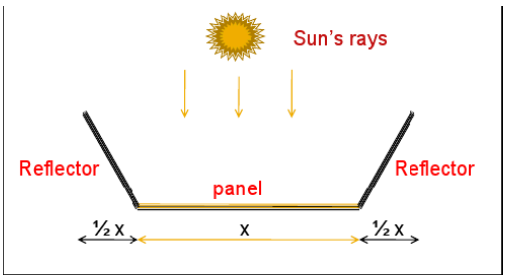


Figure 2.54: Design modification to PV panels by addition of reflectors to increase the light collection potential. (Prasad et al, 2010)

Factors for selecting a wind sensor involved such as, no moving parts, digital and analog output, time proven design, sensor emulation and 16 point wind tunnel calibration. Tests were conducted in two modes i.e. auto mode and manual mode and final output of the solar and wind energy evaluated in comparison to the basic concept and value addition/alterations to the same design and parameters as indicated in Table 2.6 and Table 2.7.

Table 2.6: Final Tested Output of Solar Panels (Prasad et al, 2010)

Open Circuit Voltage = 19.75 V

TIME	FIXED PANEL (Watts)	WITH REFLECTOR AND TRACKING (Watts)
11 AM	31.67	36.68
12 NOON	32.43	38.98
1 PM	29.51	39.32
2 PM	27.09	36.86
3 PM	19.18	18.43
4 PM	11.87	25.80

Table 2.7: Final Tested Output of Wind mill (Prasad et al, 2010)

TIME	WIND DIRECTION AND SPEED	FIXED WITHOUT TRACKING (Watts) (↖)	WITH WIND SENSOR AND TRACKING MECHANISM (Watts)
Morning	↗18 km/h	0.671	1.452
Afternoon	↑ 13 km/h	0.561	0.992
Evening	↖ 27 km/h	4.148	4.148
Night	↖ 25km/h	2.452	3.705

Conclusions read the improvement by alterations to design of PV system to enhance the collection efficiency by 68.5% and for wind mill by an overall margin of 50%.

2.7 DUBAI-UAE: GEOGRAPHY AND CLIMATE

Dubai is a part of the United Arab Emirates which is a federal of seven emirates (Dubai, Sharjah, Ajman, Ras Al Khaimah, Um AL Quwain, Fujairah and Abu Dhabi) with Abu Dhabi as its capital city as seen in Figure 2.55 with the constituency formation in 1971 by the late H. H Sheikh Zayed Bin Sultan Al Nayhan. Dubai is geographically located at 25.2697° North and 55.3095° East and covers a land area of 4,110 km2 situated on the Persian Gulf coast of UAE and is roughly at sea level 16m above (Wikipedia, 2011). Though Dubai's economy was based on the back bone of oil industry revenues such as oil and natural gas, they are comparatively less now and expected to diminish in the coming years. With this in mind the economy is now being diversified into real estate and construction, tourism and trade, financial services as a larger contribution to the UAE economy as a country. The weather conditions in Dubai are hot arid temperature conditions with warm winters and very hot summers due to its direct association with the Arabian Desert. Most of Dubai is on an island largely due to sea reclamation with now urban and suburban main lands. The highest point is the city garden of Al Ain with a height of 1,340m above sea level. Known for its 21st century architecture and modern infrastructure only 30% of the emirates are inhabited and rest form large deserts spanning miles of land area.

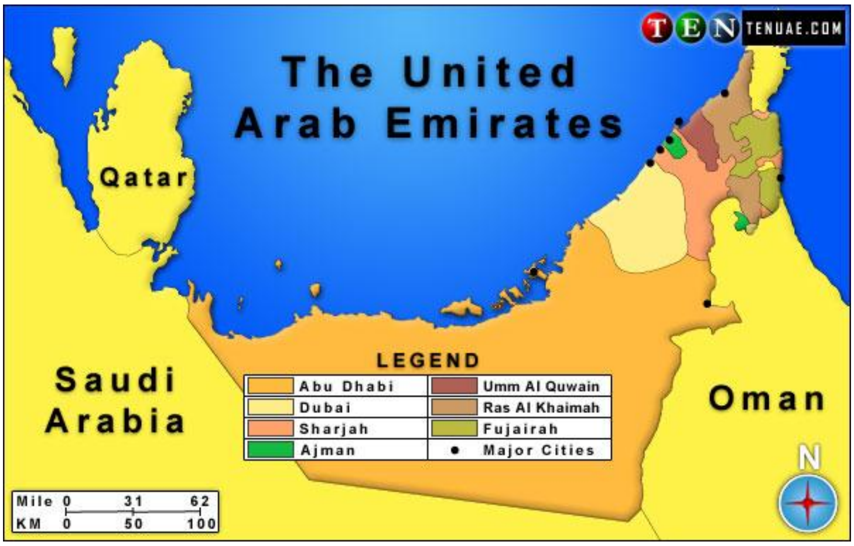


Figure 2.55: Map of United Arab Emirates (Ten Guide, 2011)

Figure 2.56: Map of Dubai (Google Maps, 2011)

Weather data extracted from Autodesk Ecotect Analysis© software and Dubai Meteorological Office (DMO) Database:

Note: Most of the data collected from NASA SSE Methodology is based on average over a period of 22 years (Jul 1983-Jun 2005) and Dubai Meteorological Office Database over 25 years period from 1985-2009.

Temperature

As per Figure 2.57 the temperature various throughout the year ranging from peak temperature during the month of June to August which reaches above 40° C on most of the occasions with 19th August recorded as the hottest day peak. The temperature from September onwards to October starts dipping down with a daily average of above 26°C. As winter slowly progress from the month of November to February the temperature averages between the ranges of 15°C with close to 10°C on a few occasions with the coolest day peal recorded as 14th February. The central blue line indicates the comfort zone averaging between 22°C-26°C throughout the year.

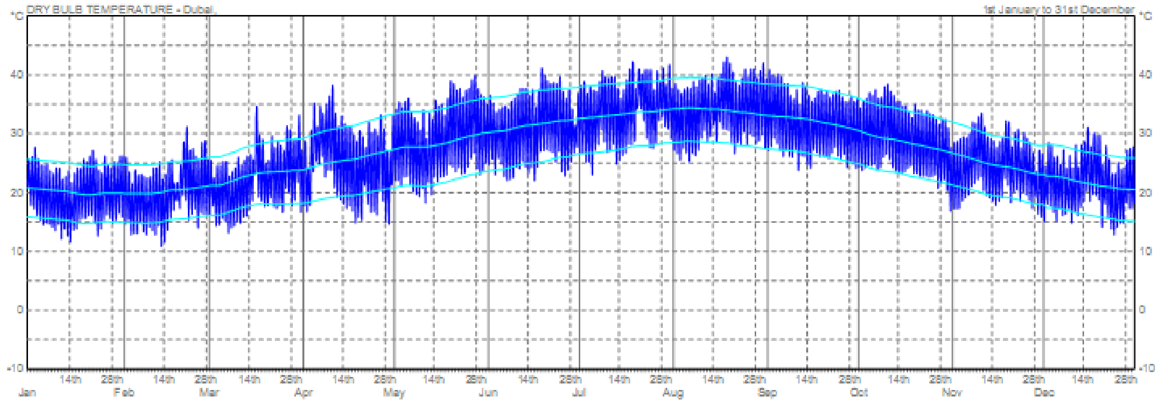


Figure 2.57: Dubai Annual Temperature (Ecotect Database)

Relative Humidity

Due to the hot desert air and the cooler evenings Dubai is subjected to high humidity levels throughout the year. Highest humidity levels are above 90% in the month of February on certain occasions with lowest humidity levels in Al-Ain (DMO, 2011).

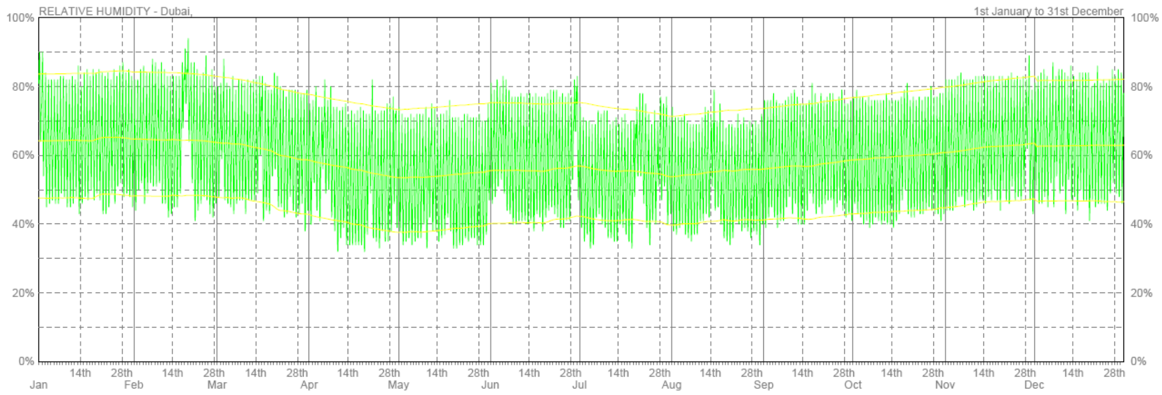


Figure 2.58: Dubai Annual Humidity Levels (Ecotect Database)

Precipitation

Rainfall is almost negligible in the UAE-Dubai with some rainfall in the months of December to February with mean reading of 25.0mm maximum rainfall in February with occasion cloud bursts. Numbers of mean rain days are in March with 5.8 days only as seen from Table 2.8. But sunshine days are plenty with 11.5 hours/day in the month of June.

Table 2.8: Dubai Climate Information (Dubai Meteorological Office, 2011)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Maximum Temperature °C (1984-2009)	23.9	25.4	28.4	33.0	37.7	39.5	40.9	41.3	38.9	35.4	30.6	26.2
Average Minimum Temperature °C (1984-2009)	14.3	15.5	17.7	21.0	25.1	27.3	30.0	30.4	27.7	24.1	20.1	16.3
Mean Rainfall (mm) (1967-2009)	18.8	25.0	22.1	7.2	0.4	0.0	0.8	0.0	0.0	1.1	2.7	16.2
Mean # of Days with Rain (1967-2009)	5.5	4.7	5.8	2.6	0.3	0.0	0.5	0.5	0.1	0.2	1.3	3.8
Sunshine Hours / day (1974-2009)	8.1	8.6	8.7	10.2	11.3	11.5	10.7	10.5	10.3	9.9	9.3	8.2
Mean Sea Temperature °C (1987-2009)	20.9	20.6	22.3	25.0	28.5	31.2	32.2	32.8	31.9	29.7	27.1	23.3

Solar Radiation

Figure 2.60 a) indicates that the direct solar radiation is high in Dubai throughout the year. It reached a maximum level in the month of February and October at 12.00pm with a reading of 904W/m2. The diffuse solar radiation is high in the summer period from mid-May to mid-August with maximum reading of 410W/m2 in the month of July at 12.00pm.

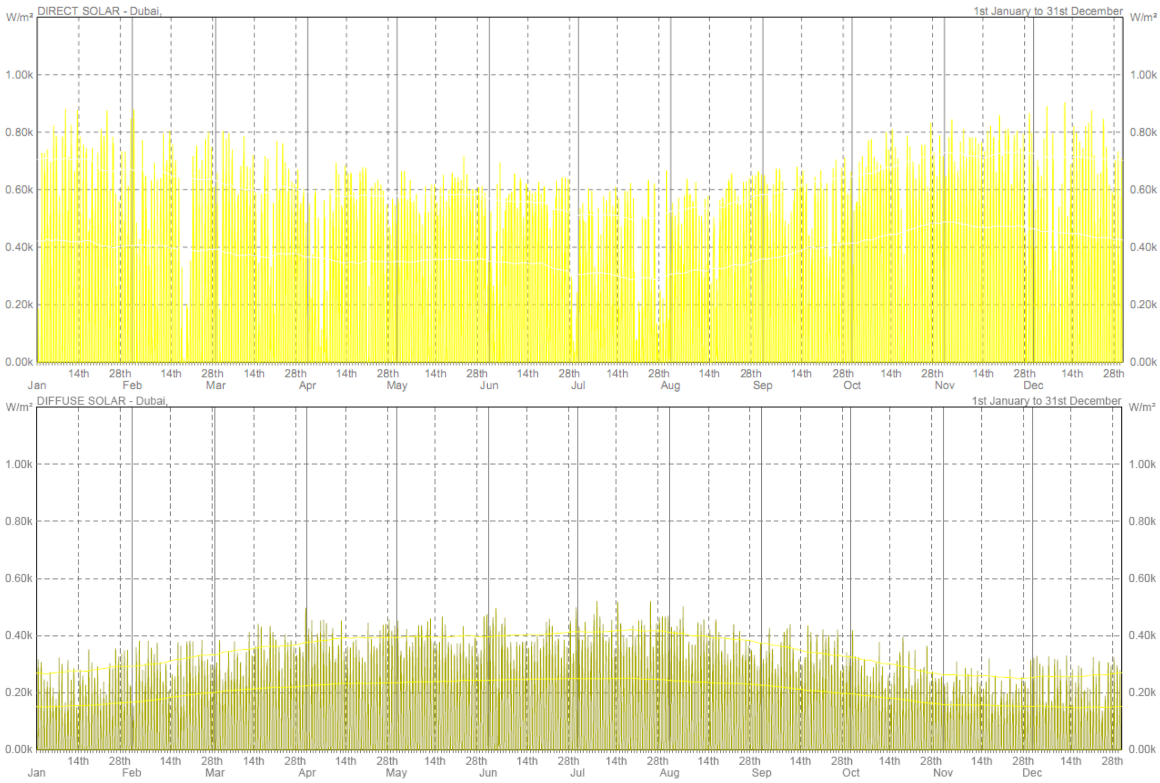


Figure 2.60: Dubai Annual a) Direct and b) Diffuse Solar Radiation (Ecotect Database)

Table 2.10 indicates the readings as obtained from the NASA SSE Database as maximum daylight hour in the month of June with 13.6 hours a day average and average maximum solar angle relative to horizon ranging from 41.8deg to 87.8deg. As mentioned earlier in the literature review, *"PV panel tilt angle equal to the site latitude produces largest amount of power output"* can be clearly seen with the optimized tilt angle in Dubai being 25.2deg.

Table 2.9: Solar Geometry based on Latitude and Longitude (NASA SSE Database, 2011)

Solar Geometry:

Monthly Averaged Daylight Hours (hours)

Lat 25.27 Lon 55.309	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	10.7	11.3	12.0	12.7	13.3	13.6	13.5	13.0	12.3	11.6	10.9	10.6

Parameter Definition

Monthly Averaged Maximum Solar Angle Relative To The Horizon (degrees)

Lat 25.27 Lon 55.309	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	43.9	52.3	62.9	74.4	83.5	87.8	85.9	78.5	67.8	56.2	46.5	41.8

Parameter Definition

Maximum Radiation Incident On An Equator-pointed Tilted Surface ($kWh/m^2/day$)

Lat 25.27 Lon 55.309	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
SSE MAX	4.65	5.64	6.33	7.52	8.22	7.84	7.14	7.00	6.61	5.99	5.09	4.34	6.36
K	0.69	0.71	0.68	0.71	0.74	0.69	0.64	0.66	0.68	0.72	0.73	0.69	0.69
Diffuse	0.79	0.91	1.33	1.40	1.45	1.78	2.00	1.76	1.40	0.96	0.71	0.75	1.27
Direct	6.76	7.41	7.02	7.96	8.80	8.21	6.98	7.13	7.54	7.86	7.38	6.48	7.46
Tilt 0	4.52	5.60	6.26	7.37	8.18	7.81	7.11	6.90	6.52	5.94	4.93	4.24	6.28
Tilt 10	5.26	6.28	6.65	7.51	8.03	7.56	6.94	6.91	6.80	6.55	5.69	5.00	6.60
Tilt 25	6.10	6.99	6.93	7.37	7.43	6.86	6.39	6.63	6.92	7.15	6.56	5.89	6.76
Tilt 40	6.59	7.30	6.82	6.83	6.47	5.83	5.53	6.00	6.65	7.33	7.03	6.44	6.56
Tilt 90	5.40	5.34	3.97	2.79	1.92	1.74	1.86	2.30	3.44	5.01	5.60	5.46	3.73
OPT	6.70	7.31	6.94	7.52	8.18	7.81	7.11	6.93	6.92	7.33	7.11	6.60	7.20
OPT ANG	51.0	43.0	28.0	12.0	0.00	0.00	0.00	6.00	22.0	39.0	49.0	54.0	25.2

NOTE:	*Diffuse radiation, direct normal radiation and tilted surface radiation are not calculated when the clearness index (K) is below 0.3 or above 0.8.*

Sky conditions are also important for the production of power output from PV panels since the direct solar radiation is scattered due to heavy cloud conditions which obstruct rays from reaching the cell. Large clouds form shadow effect on the ground which also affect cell efficiency. As per Table 2.11 the monthly average amount of total solar radiation incident on a horizontal surface of earth when cloud cover is less than 10% is maximum in May with 7.64kWh/m2/day. The clear sky insolation clearness index is high between Jan to April with an average reading of 0.70

Table 2.10: Clear Sky conditions based on Latitude and Longitude (NASA SSE Database, 2011)

Monthly Averaged Clear Sky Insolation Incident On A Horizontal Surface ($kWh/m^2/day$)

Lat 25.27 Lon 55.309	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	4.73	5.63	6.51	7.33	7.64	7.57	6.88	6.71	6.31	5.72	4.88	4.36	6.19

Parameter Definition

Monthly Averaged Clear Sky Insolation Clearness Index (0 to 1.0)

Lat 25.27 Lon 55.309	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
22-year Average	0.70	0.71	0.70	0.70	0.68	0.67	0.61	0.63	0.65	0.68	0.70	0.69

Parameter Definition

Monthly Averaged Clear Sky Insolation Normalized Clearness Index (0 to 1.0)

Lat 25.27 Lon 55.309	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
22-year Average	0.64	0.65	0.63	0.64	0.63	0.61	0.56	0.57	0.59	0.63	0.64	0.63

Wind Speed and Direction

The wind speed in Dubai-UAE is highest in the month of May measuring 5.22m/s and lowest being in the month of November measuring 3.69m/s at 10m above the earth surface from terrain similar to airports. Also the wind speed increases with increase in height above earth's surface can be seen with wind speed measurement as per Table 2.12 at 50m height above earth's surface. Overall the wind speed averages maximum at 57% with measurement between 3-6m/s wind speed. Maximum prevailing wind speed is available between 324deg to 352deg which lies in the North West direction.

Table 2.11: Wind Speed and Direction Statistics in Dubai-UAE (NASA SSE Database, 2011)

Monthly Averaged Wind Speed At 10 m Above The Surface Of The Earth For Terrain Similar To Airports (m/s)

Lat 25.27 Lon 55.309	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	4.22	4.84	4.66	4.69	5.22	5.05	4.76	4.55	4.42	4.09	3.69	4.18	4.53

Monthly Averaged Wind Speed At 50 m Above The Surface Of The Earth (m/s)

Lat 25.27 Lon 55.309	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	4.93	5.67	5.45	5.49	6.10	5.91	5.57	5.33	5.17	4.79	4.32	4.88	5.29

Minimum And Maximum Difference From Monthly Averaged Wind Speed At 50 m (%)

Lat 25.27 Lon 55.309	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Minimum	-14	-16	-11	-19	-13	-5	-8	-11	-17	-17	-8	-20	-13
Maximum	16	23	12	10	11	8	10	20	18	20	9	20	15

It is recommended that users of these wind data review the SSE Methodology. The user may wish to correct for biases as well as local effects within the selected grid region.	***All height measurements are from the soil, water, or ice/snow surface instead of "effective surface", which is usually taken to be near the tops of vegetated canopies.***

Parameter Definition *Units Conversion Chart*

Monthly Averaged Percent Of Time The Wind Speed At 50 m Above The Surface Of The Earth Is Within The Indicated Range (%)

Lat 25.27 Lon 55.309	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0 - 2 m/s	16	11	10	9	7	9	11	12	14	18	22	16	13
3 - 6 m/s	60	55	59	57	46	48	54	57	59	60	63	62	57
7 - 10 m/s	21	28	27	32	44	40	33	29	24	18	14	19	27
11 - 14 m/s	2	5	3	1	2	2	2	2	2	2	1	2	2
15 - 18 m/s	0	1	0	0	0	0	0	0	1	1	0	1	0
19 - 25 m/s	0	0	0	0	0	0	0	0	0	0	0	0	0

Parameter Definition

Monthly Averaged Wind Direction At 50 m Above The Surface Of The Earth (degrees)

Lat 25.27 Lon 55.309	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10-year Average	324	347	334	329	328	329	336	341	346	350	350	352

2.8 AIMS AND OBJECTIVES

The dissertation aims at comparing the benefits of using this integrated (solar PV and wind turbines WT) system in relation to the power loads required by the household units from the local/govt. authorities as an objective to offset the overall building electrical consumption so as to function as a standalone renewable energy system which gains its power outputs from varied and opposite weather conditions i.e. sunny conditions and windy conditions. But before we embark onto the standalone analysis, a step by step progression is necessary and hence the research will progress with balance percentages split from 25%, 50%, 75% and 100% provision of electrical demand by the renewable energy system with the rest supplied by local grid connection respectively.

The research is thus hereby split into 2 modes of study which are technical and economical and aim to resolve the below mentioned questions:

- What are the benefits of using solar PV's and Wind turbines as sustainable and renewable resources individually to the production of power loads?
- What are the derived benefits of deploying an integrated system in relation to the overall predicted/calculated power loads to the production system?
- What are the barriers of using both the resources in harvesting power as individuals and whether these individuals function better in integration technically and economically to smoothen out power production?
- Can the unpredicted nature of 2 resources and weather dependence smoothen out the power production by overcoming weakness of each other?
- What is the cost of investment and related payback period of such an integrated system in comparison to the baseline supply and investment of power which is required by the residential unit from the local/govt. authorities?
- What are the feasibilities of using the integrated system which can be either grid connected or functions as a standalone system or combination of both for a yearly net zero outcomes?
- Can this integrated system be beneficial in other regions and what impacts does it have locally in the UAE climate and simultaneously in other regions?

CHAPTER 3: RESEARCH METHODOLOGY

3.1 RESEARCH PARAMETERS

The previous chapters we have studied the various concepts of building and producing renewable energy through solar and wind power potential via equipments like PV panels, wind turbines and its balance of component systems. The intention being to built clean, save and conserve energy in buildings which is majorly dependent on fossil fuel consumption which one day will lead to slow depletion and increase economically in cost of living. The purpose of such research finally is to evaluate the electrical performance of the modeled house and develop appropriate design methods and procedure to make the house as much as possible self sufficient with efficient solar power, battery storage and supplementary wind power with its varied advantages and disadvantages.

It is hereby necessary that one develops as common parameter to compare the benefit of the two most naturally available abundant resource (solar and wind) technologies. Accordingly a design of a basic house (Ground + One + Roof) model be created to set a benchmark for comparison. By manipulation of certain variables the efficiencies of each system for various configurations will be analyzed to find the potential electrical production as individuals and hybrid system. The energy production benefits of PV and Wind energy systems will be based primarily on the energy consumption of the house as modeled.

The following are the main variables based on the literature review of research methodology:

<u>Orientation</u>

This study is important to examine the effects of orientation since solar and wind power are heavily dependent on the energy output based on directions, angle etc, in order to maximize solar radiation or wind speed for PV's and wind turbines. The energy output benefit can be thoroughly optimized with the use of correct orientation techniques which is suitable for each system technology. It guides to decide the appropriate inclination of PV array, sizes, distribution of the light absorbent cells and similar wind speed orientations for wind turbines in relation to the proposed house model.

<u>House Profile (Design and Primary Load)</u>

The design of the house post it relation with orientation to climatic conditions is vital in terms of the materials used and the choice of openings, direction of windows to maximize daylight and minimize solar heat gain, overhangs. Though we are not analyzing the thermal performance in accordance to comfort conditions in the house it is vital in terms of energy use since an in-appropriately designed house in terms of material use (insulation) or orientation can lead to high power consumption and higher energy use dependent on mechanical power consuming equipment. As the house will be formatted to utilize energy 24 hours, the distribution of energy load profile needs to be carried out to analyze the renewable energy output of each system hourly, monthly and yearly in comparison to readings obtained from the primary load consumption audit of the house. Thus the correct primary load audit such as lighting, equipment, secondary loads and cooling loads will formulate the research parameter and outcome of each system sizing, efficiency and performance.

<u>PV Power Generator</u>

The selection of appropriate PV types will have effects on the total electricity production, as they are specified by the open circuit voltage and short circuit current and finally the Operation point called "Maximum Power Point" (MPT). For each type of PV panel selected there is peak MPT graph or the operating point at which it operates the loads most efficiently and ultimately the production of electricity/power lighting demand and cooling loads. By specifying the number of PV cells to be used and spacing between each cell, it is possible to control amount of electricity generated. The selection and configuration will be based on simulation study and will be explored later in further chapter based on only two types namely “Higher Output Mono-Crystalline Cells” and comparatively “Lower Output Thin Film Cells”

Wind Power Generator

Energy produced from a wind generator depends primarily on the average wind speed, distribution of wind speed on site and swept area of the wind generator rotor blades. The power output of a wind turbine varies directly with the blade swept area. But the size to be considered has limitation to the placement on houses as large rotor blade diameter is not feasible on the modeled house, nor is it recommended due to the large foundation it requires plus the economics of initial investment. Hence by assumption the size of the wind turbine is considered to be within a range of 2.5-5.0m diameter rotor blades to keep it a low profile and manageable. Further manipulations to the placement and direction shall be studied in detail in relation the type of wind turbine selection in the chapter to come with products available and their vital study in suburban environment having a reasonable cut in speed, rated speed and cut down speed. Point to be considered is that since wind turbines in this research are more complementary resources to the PV modules in the UAE region, high investment in such systems is avoided.

Batteries

Storage system is the heart of each of the selected systems in this research and hence careful manipulations and selection is important to consider issues like Depth of Discharge rate, voltage equalization charge to reverse the sulphation in case of discharge, voltage type, power rating etc. Similarly cost of the batteries, number of batteries and optimization of the units to avoid over sizing, under sizing and best suitability to residential house model needs to be validated. The relation of the energy produced by the systems hourly, monthly, yearly is directly related to the battery selection as storage device will provide further renewable stored energy to the consumer. Batteries nowadays are specifically designed to store renewable power system and are different from automotive batteries and hence specifics of them such as “lead acid type”, sodium sulfur” type etc in critical to validate design.

Charge Controller

The job of a charge controller is to protect the batteries from overcharging and avoid the flow of reverse current that would discharge the batteries into the system at night. But since the model house is a 24 hour operation the role of charge controller is more vital since with more charge to battery which is full will cause overheating and degrade the batteries leading to power losses. Careful manipulation in selection of some charge controller with ON/OFF control or gradual reduction flow current know as “Pulse Width Modulation” (PWM) is vital to hold voltage more constant. Also aspects such as “Maximum Power Point Tracking” which enables the device to track the MPT of the system and few which come with devices such as battery monitoring status, voltage and current could help the model efficient storage and production of the hybrid system.

Inverter

Inverters convert low voltage DC power to higher voltage standard household 110vac power. Today’s technology enables the inverters to allow house owners to operate regular household appliance as they are wired directly to the household’s distribution panels effortlessly with improved viability to cater specific needs of residential renewable energy power system. Careful selection into the type of inverter in terms of size, capacity and conversion rate has to be studied with improved efficiency as per today’s market availability. Feasibility of grid tie inverters which can be programmed to connect to grid to supplement renewable energy or sell back the power to utility when produced in excess needs to be analyzed. A balance of the inverter selection is critical for different type of system connections such as off grid or grid connected hereby. Modern sine wave inverters used for household applications and their efficiency levels to operate under varied conditions needs manipulation.

Off Grid and Grid Tied Power Connections

The primary load profile of the household will determine the amount of energy that needs to be produced by each or hybrid system, but this is a permutation and combination ratio to reach to closer to the desired power load demand of the modeled house. In a scenario where the renewable system does not meet the desired loads it is imperative that the household be connected to supplementary power supply by the utility. Thus a grid connected system is to be validated to reach a more and more closer to the goal of a self sufficient house. As research is carried out at further stages feasibility of the house to be off grid can also be validated but not before step by step progression from certain percentage of loads from renewable production and rest from grid utility and finally to full dependency and hence the paper looks into both the options of grid connected sizing, optimization, economics reaching to standalone parameters.

NOTE: All the above also needs to be weighed in terms of economics of the initial investment, annualized cost of the system and payback period with return of investment to prove the true competence of each system and hybridization of the two renewable energy producers.

3.2 REVIEW OF PREVIOUS RESEARCH METHODOLOGY.

After selection of individual parameter to validate, there need to be a proper platform or methodology to investigate all parameters individually and as a composite system. The below section review the methodology adopted by various other research papers with similar guidelines and parameters to form the basis of this research paper to validate and select the correct methodology useful for step by step analysis.

Observational Research (Field Monitoring)

O.A. Soysal (2007) conducted a experimental field monitoring assessment of the grid tied residential size hybrid system combining solar and wind power generation to supply power through net metering. Figure 3.1 illustrates the system configuration used for monitoring considering the actual load demand characteristics in relation to the power output capacities of each of the system based on the manufacturer’s product details. Care was taken to analysis the appropriate actual site to avoid as many constraints as possible that would lead to power losses from the hybrid system. Assessment of the site solar and wind potential was done based on the locations available data with reading ranging from average monthly to yearly predictions. Similarly the output characteristics of each of the system was calculated based on the site potential and the tables were formed to estimate the predicted final output with software’s such as NREL. The system monitoring results were regularly obtained for PV using a data logger to record voltage, current, power, efficiencies, energy and frequency values on a Excel sheet with 10s interval. Similarly wind potential was monitored using an internal data transmitter and a remote monitor power logger to record wind turbine output data with same interval as PV system. The recorded data was collected very quickly and the system analyzed which led to conclusions as the power output of PV was better in summer while the wind turbine output was significant in the month of November (winter). But overall the wind potential was not excellent for the selected location but was quick to mention that assessment was based on hourly average wind speed and might underestimate the real potential and could mislead. Thus it was proposed to evaluate the whole system with a one year cycle for better evaluation of the overall system power output potential.

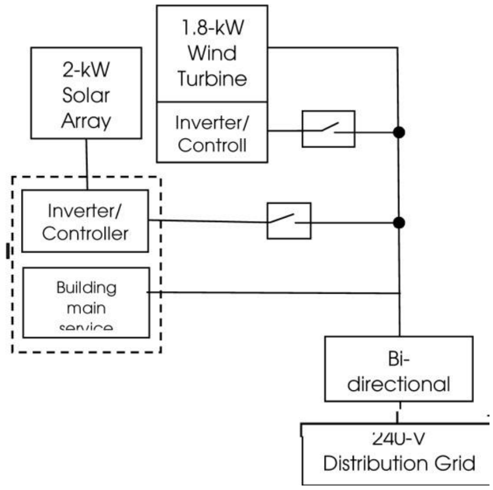


Figure 3.1: The hybrid system configuration used for monitoring purpose (Soysal, 2007)

Hongxing et al (2009) also conducted an observational field monitoring assessment of a hybrid system, solar and wind power in China. Prior to proceeding with filed measurement the optimization of the hybrid system was done by employing battery banks calculating system optimization with loss of power supply probability using genetic algorithm method. But here the goal was to obtain a standalone hybrid system as compared to the previous paper and the bases was to assess the best annualized cost of the system. A detailed algorithm mathematical process was adopted to analyze the complete system performance ranging from PV panels, wind turbines, battery banks and loss of power probability with the economic model based on annualized cost. The obtained results were applied to actual site assessment and the sites weather data was considered with solar and wind energy potential. Figure 3.2 shows the optimized sizing results for the hybrid system which was subjected to site measurement assessment.

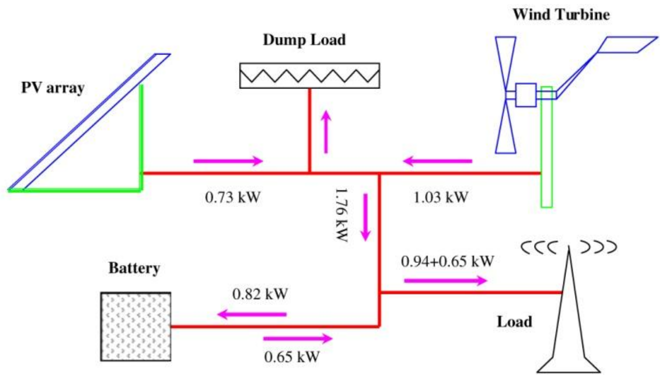


Figure 3.2: Optimized Annual average energy balance system for site assessment. (Hongxing et al 2009)

With one year hourly measured field data of the analyzed project the monthly average contribution of each PV and wind turbine components and subsequent battery working states it was recorded that the production each of the systems vary greatly from one month to the next but they were mostly complementary with each other. The batteries also showed a good opportunity of 90% battery state of charge conditions and the discharge rate was minimal throughout the year. The annualized cost of the system optimized was around 9708US$ with a loss of power supply probability in the range of 1.96-2% which was considered fairly good in the hybridization of the system within a lifetime of 25 years.

Experimental Studies

Dali et al (2010) presented an experimental result from the operation of a test bench constituted of a grid connected hybrid system. The study used wind and PV physical emulators, batteries, loads and controlled interconnection to the LV grid with system units connected to the weak AC gird via 1-phase inverter and lead acid accumulator. The flexibility of the grid power inverter is used to permit the operation in an interconnected LV grid or also in a standalone mode with seamless transfer of connections. Figure 3.3 shows the diagram and equipments manipulated for the laboratory tests conditions.

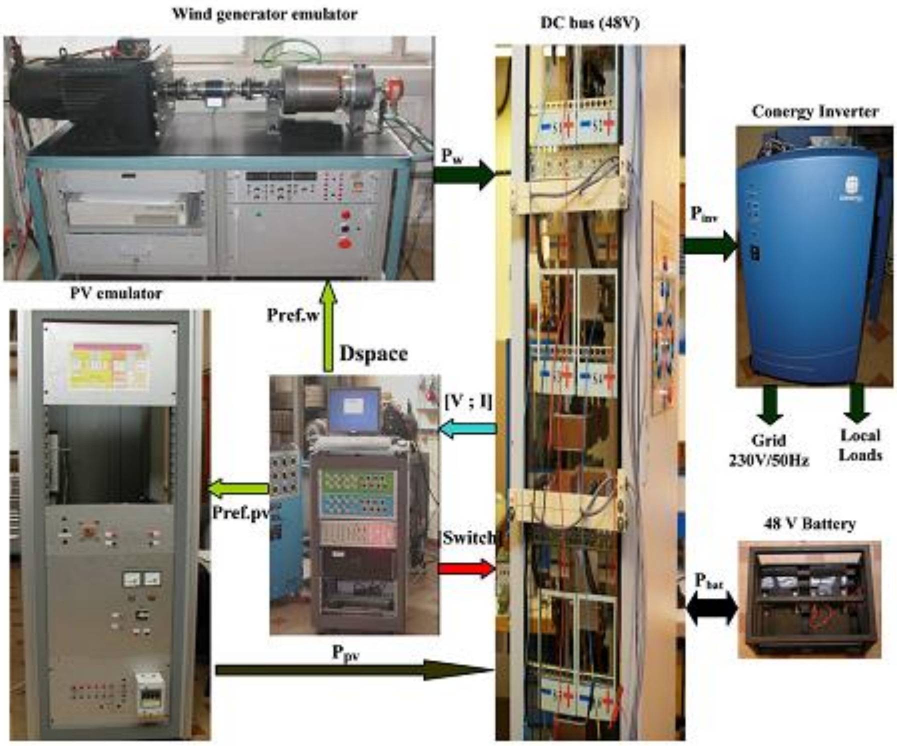


Figure 3.3: Laboratory experimental test conditions for grid connected hybrid PV/Wind system. (Dali et al, 2010)

The detail description of the system components is given primarily along with the control principles. The system is introduced by the need of energy management to control the energy fluxes between the grid/local loads and the storage elements together in order to maintain a stable flow for the entire system in both sources to avoid any disturbances or interruptions. By experimentally running the operation it is provided that the system runs smoothly in parallel to the gird or in autonomous mode. Finally is it concluded that the grid inverter guarantees an uninterrupted electric power supply using the PV and wind energy system even in conditions which favor power cuts or fluctuations. Whenever there is shortage or outage of utility power supply the inverter smoothly switched to the alternate circuit output over to separate emergency output circuit with true sinusoidal output voltage.

Hoicka and Rowlands (2011) carried an investigational experiment to analyze climatic conditions for complementary solar and wind resources to generate desired electricity in various regions in Ontario: Canada. The study was conducted over a period of three years of synchronous, hourly measurements of solar irradiance and wind speed from the countries data weather database on four major locations with graphical representations, percentile rankings and use of theoretical maximum as proxy for capacity. The aim of the study was to evaluate the possibilities of using the combination of solar and wind in different locations, as whether they smooth out the operations and improvise the overall concept of hybridizations. Figure 3.4 shows the results for capacity of the theoretical maximum for the combination of both the resources and locations over a period of three years.

Table 3.1: Study results of the combination of resources over 4 major locations in Ontario based on capacity percentile. (Hoicka and Rowlands, 2011)

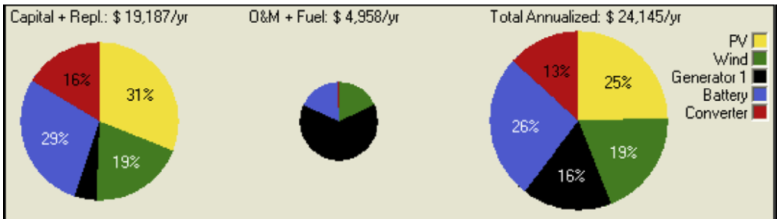
Year	2003				2004				2005			
Location	Ottawa	Sault Ste.Marie	Toronto	Wiarton	Ottawa	Sault Ste.Marie	Toronto	Wiarton	Ottawa	Sault Ste.Marie	Toronto	Wiarton
Solar												
80 percentile	236.0	222.0	240.1	222.5	233.2	214.7	228.7	221.2	232.5	224.9	243.3	236.8
50 percentile	7.9	7.7	9.0	8.5	7.7	7.7	9.6	8.8	7.4	8.3	8.7	8.7
20 percentile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wind												
80 percentile	165.6	176.2	142.8	176.7	168.7	201.2	147.4	163.2	175.1	202.7	153.9	163.0
50 percentile	33.1	35.2	32.3	28.4	40.3	37.8	33.3	33.1	35.0	29.9	37.4	30.8
20 percentile	6.5	3.2	5.0	4.7	7.3	4.0	6.0	5.1	6.9	1.2	5.8	3.9
Combination A[a]												
80 percentile	211.9	214.5	210.7	211.9	220.9	215.6	212.5	205.1	215.5	216.4	212.4	218.2
50 percentile	55.6	57.6	54.5	55.0	58.2	59.2	56.3	57.9	59.2	60.0	58.4	62.1
20 percentile	8.0	4.9	7.0	8.5	8.4	4.4	8.0	8.6	9.0	4.0	6.9	4.8
Wind and solar, mixed locations												
Combined locations and resources	Combination B[b]	Combination C[c]	Combination D[d]	Combination E[e]	Combination B[b]	Combination C[c]	Combination D[d]	Combination E[e]	Combination B[b]	Combination C[c]	Combination D[d]	Combination E[e]
80 percentile	218.2	211.4	213.4	212.4	216.6	204.2	207.6	209.2	217.4	214.3	211.6	211.2
50 percentile	63.4	57.0	67.8	67.6	64.9	60.2	71.6	73.2	60.3	63.0	68.1	72.4
20 percentile	5.5	8.3	11.5	13.4	5.1	9.2	15.2	19.5	4.0	4.8	8.0	14.3

[a] Combination A: solar and wind combined for each location.
[b] Combination B: Ottawa solar, Sault Ste Marie wind.
[c] Combination C: Toronto solar, Wiarton wind.
[d] Combination D: Ottawa and Toronto solar, Sault Ste. Marie and Wiarton wind.
[e] Combination E: all locations and resources.

The overall study found that the combination of the two resources yielded less variability in power production in two locations as compared to the total of each of the resources in the given locations. Also addition of two resources in two locations smoothens out the power production flow. Such permutation and combination of resources and locations if carried out could further improvise in a better format to stabilize power flow. The study though clearly misses out certain limitations with the information available as compared to the actual monitoring since based only theoretical studies. Also restriction in monetary economics to combine two locations is not calculated depending on the transmission distance and final output of the power in relation to the payback time and return of investments.

<u>Simulation Studies</u>

Bekele and Palm (2010) conducted a software based simulation to assess the potential of solar and wind hybrid energy system for a small community detached from the main electricity grid in Ethiopia. The performance evaluation was based electrical loads demand of the community which housed a few structures with a detailed load profile of the lighting, water pumps and some clinical equipment. By use of the HOMER software the annual load profile with the primary loads and deferrable loads was studied monthly. Similarly the monthly average solar radiation and wind speed data is collected from NASA weather data base and fed to the software. Selection of PV's and wind turbine is based on sensitivity analysis of the software with the use of a backup generator and storage capacity batteries. Economics of the system is also conducted as part of the software by feeding in the initial cost and calculating the annualized cost of the hybrid system based on the optimization results. Figure 3.5 illustrates the cost summary of the renewable energy resource. Results were obtained based on the percentage utilization of the renewable energy source. Since the location was not connected to electrical grid the base cost using generator and batteries was calculated and a comparison by use of 51% to 81% renewable energy of the total energy is run by the software. It is noted that the current cost of renewable resource is higher by almost 20% as compared to the total of net present non renewable cost. But there is also an excess of 11% percent of electricity produced which can be further utilized for additions in the community phases. Though the net present cost has to be balanced against the design to move towards the use of renewable energy the benefits of these cannot be expressed in cost but the future climatic benefits by comparatively less emission of pollutants such as CO2, CO, SO2 etc.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
PV Array	72,000	5,996	0	0	0	5,996
Generic 20kW	45,000	3,747	0	900	0	4,647
Generator 1	11,000	916	-57	327	2,831	4,017
Battery	49,980	4,162	1,361	900	0	6,423
Converter	28,000	2,332	730	0	0	3,062
Totals	205,980	17,153	2,034	2,127	2,831	24,145

Figure 3.4 Cost summary for an 81% utilization of renewable resources by simulation of HOMER software. (Bekele and Palm, 2010)

Gadkari (2009) presented paper with the use of software simulation modeling a new concept of hybrid solar and wind energy system. The use of parabolic trough concentrator basic concept was modified to integrate a wind turbine for generating wind energy during high wind speeds and focus light energy on sunny days onto the high intensity multi junction (VMJ) cells. Few number of software's tools were used to study key mechanisms such as optics, cooling of the system cells and airflow through the developed model. Figure 3.6 shows the prototype model developed to harness solar and wind energy by a single instrument to calculate the benefits in the levelized cost of energy.

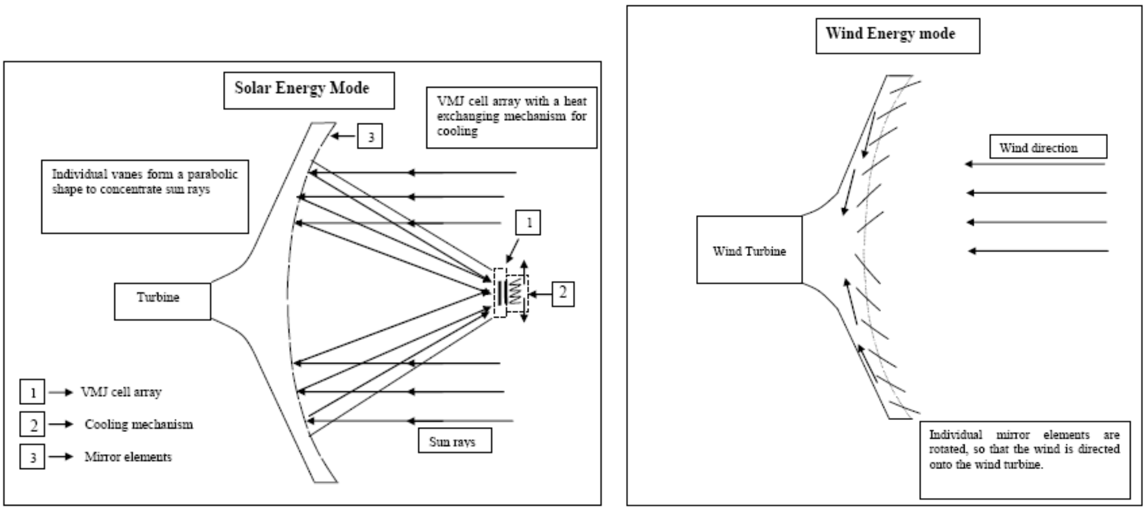


Figure 3.5: Proposed prototype design system a) Solar energy mode of operation b) Wind energy mode of operation. (Gadkari, 2009)

Detailed study of the characteristics of the model design with software tools such as "Light tool 5.40" for calculating the incident solar power and the power densities achieved by the VMJ receiver and CFD to study the air flow mass through the available space was carried out. Results concluded that individual vanes do not cause any significant losses in the optical concentrator. Similarly the wind concentrator turbine evaluated a wind acceleration of about 1.5 times the inlet air velocity. The economic evaluation resulted in the levelized cost of the completed system was higher than the current utility supplied energy but mention of the system use in a remote location or grid isolated site to be cost competitive feasible for standalone concept could be possible.

3.3 CHOOSING AN APPROPRIATE RESEARCH METHOD

The below section are a brief outline of the four different methodologies relevant to the current research paper. By means of description of each of the methodologies the paper will form the basis and appropriate reasoning to select the suitable method for further study.

<u>Experimental:</u>

By means of an experimental or laboratory approach, the study can lead to smaller scale demonstration to obtain benefits from each of the system. It is comparatively difficult to form experimental methods for such scale of energy production system as there is involvement of more than one energy system. One method which can be adopted with an actual small scale setup of solar PV panels and wind generators model of appropriate scale. The PV panels can be tested irrespective of the location with its balance of system components subjected to particular weather conditions and measuring the output on the voltmeter along with the digital panel meter. Figure 3.7 illustrates a small diagrammatic model to set up an experiment to measure the PV output and wind turbines by generic wind tunnel test.

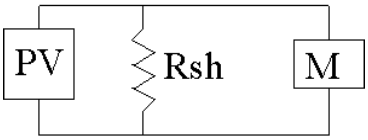


Figure 3.6: a) PV represents the panel subjected to sunlight, M is the voltmeter and Rsh is the resistor through which most of the current flows across and will measure the voltage. (Chuck Wright Consultant LLC, 2011) b) Test apparatus for wind turbines in wind tunnel test method. (Gregg, 2011)

By setting a general goal of 100mVolt reading in the digital meter in full sunlight so that the meter will read 1nVolt per 10 Watts/m2 the basic output of the panel can be measured with such baselines through instrumentation. Also permutations can be done by tilting the PV panel at various angles and measuring the output with measuring readings through a few peak hours in open locations exposed to sunlight. But this cannot be full proof as this is just a basic fundamental output on laboratory open test which only gives few variables. Similar test can be done by wind turbine model in a wind tunnel test with data parameters set to local conditions, see Figure 3.7. Also the system balance of components can be tested as mentioned by Dali et al (2010) to measure the flow stability of current through controller, battery storage and inverter control mechanism.

Second experimental method based on mathematical genetic algorithm which could be robust in optimization with multi modal and multiple objectives. A thorough study of various proven equations is required to model the PV array model, wind turbine performance model and system components. By formation of equations for each component the results of optimization can be met by setting variables for each type of system operation i.e. PV and wind turbine separately etc. But a constant measure needed to form the basis of comparison such as for e.g. loss of power or annualized cost of the system to check the compatibility of the hybridization. This constant could be anything otherwise also such as PV panel angles, battery type, wind turbine sizes, height etc. This method could lead to both approaches herby such as quantitative (overall cost saving) and qualitative (stabilized and desired optimized energy production) results.

Modeling

By means of computer modeling the hybrid system of solar and wind can be tested under varied conditions, combinations, and optimizations by both ways in terms of technical and economic aspects. Firstly the model can be used to test the optimum orientations to produce higher electrical output by placing the solar PV panels to harness maximum solar radiation and the wind turbines to face the maximum wind speed directions. Each system can be tested individually to bring out the best in each of them and could be compared as obtained results from each with hybrid concept of the research paper. The model can be further analyzed by manipulating the output ratios of each of the system and optimizing them to find the best combination of solar and wind to compare the same with the economic output.

But first a bench mark needs to be set to form the parameter of the model house with its size and load requirements. The size, orientation, and demand electric load profile will govern the permutation and combination of the system sizing and output potential of the model house. Also the number of PV panels and the size of wind turbine along with its balance of systems numbers and requirements can be determined by sizing the house to an appropriate scale. The software could evaluate numerous aspects such as demand load profiles, orientations, capacities, best combination individually and combined along with economic variables to present the optimized permutation of current cost versus break down of annualized cost with payback period. But the most importantly the software must be fed with the correct and closest approximate data such as weather, current costs, correct equipment uses in the house. All the necessary data is required to be collected with appropriate validation and authentication from the industry developed prototypes.

Field Monitoring

A field monitoring method can be carried out for period of at least one year to measure the performance of the solar and wind energy systems individually and compare the benefits by combination of the both. The longer the period the better the study as one year will allow the system to run through various season pertaining to the geographical location under varied conditions. But before the complete system is set up studies of the weather data needs to be collected by two ways, either from the local weather station or field monitoring equipments such an anemometer for wind speed and directions. Again if this is to be implemented then a few months of reading is necessary to come closest to appropriate approximated measurements. Then the urban, rural or suburban environment needs to be studied to find the setting around the installation of setting such as if any shading by associated structures or trees etc to manipulate the position of the system. Since every set up has its advantages and disadvantages for the "Heat Island effect" which will also govern the environment that the field monitoring will be subjected too.

It is important that the PV panels be subjected to proper orientation and placement angles with the angle of solar radiation and similarly the position of wind turbine be correctly facing the maximum wind speed direction based on the above mentioned criteria. Selection of balance of system components needs to be validated based on certain assumption calculated from the energy output of each system and combination. Sizing of the components shall be based on the output characteristics of the renewable energy systems in comparison to the demand electrical load profile of the selected house on the geographical location. Building renewable energy output measurement equipments are critical in this case to give the correct reading from the system and also the rate of flow of current from the system to the house. Further manipulations could be possible based on the initial limitation adhered from the site and if the load losses occur due to any particular reason ranging from either PV panels or wind turbines, also from the equipments if any. Upon obtained stabilized results from the complete set up the economic viability of the complete filed monitoring method could be derived and explained in relation to the current cost of electricity as the baseline for comparison and return of investment period. An example of field monitoring set up given by Hongxing et al (2009)

Figure 3.7: Field monitoring set up for a hybrid solar wind power generation (Hongxing et al, 2009)

Historical or Theoretical Review

The above method would allow the current research to be based on the research parameters already studied by other papers on similar topics. By relying on studies conducted by others the efficiency of each of the system and components could be analyzed based on the success and failures of the project. Similarly a comparative review could be conducted based on different geographical locations using a common system parameter of the hybridization of the renewable energy resources. By using a constant of the energy system installation the study of the various conditions and backgrounds of locations with its disadvantages and advantages of the energy output could be measured as a research bases. It is important that although comparison can be made for the efficiency of the system for different regions, the success of the project will depend on the correct selection of the geographical location that will harness both solar and wind to the closest achievable possibilities i.e. the selection of location cannot be based on diametrically opposite environmental and climatic conditions in spite of being in different regions.

Though a comparison can be done for each of the system based on hot and cold climatic conditions, balance of the system needs to be maintained to measure a desired output ratio for solar and wind complementary. Also failures and success could be compared with varied reasons based on technical issues or economic issues based on the region. Regulatory compliances or incentives, current cost of energy and final output could be compared. The overall results of the research approach should indicate the best combination of the system as a better alternative to the regions solar and wind potential hybridization

3.4 COMPARISON OF METHODOLOGY AND SELECTION CRITERIA

Based on the review of the precious research methodologies adopted with its limitations and pros associated with the current subject, the modeling approach was deemed most appropriate considering the scale and number of factors involved to analyze. However this modeling approach as already been complimented with the literature review that we have covered in the previous chapter. The literature review noted has enabled a broader knowledge and requirements of detail analysis required when it comes to application of PV and wind energy potential individually and as a hybrid system. Also the areas which require in depth study and cons have been understood to form a balance platform for this paper. Furthermore the comparisons and contrasts between the four methodologies that will complement an additional method in support to this modeling approach as per the below paragraphs to follow.

In laboratory test which we have mentioned earlier, the process is very time consuming as the test prototype model has to be built in a suitable environment. Comparatively it is more earlier to build simulation model using software's which could be tested in a 3D environment which is less time consuming. Finer details of the model can be manipulated in the 3D environment much quicker to simulate results. Also the laboratory method requires numerous equipments; instrumentations which will involve high cost, time and the result will be only on small scale with few constants and subject to actual losses in energy conditions on larger scale which might not be visible at this current scale of research. The concept of laboratory methods is quite similar to the 3D environment except the tools are of smaller scale and the later can produce results for the entire building and the environment around as well. Today's technology in software simulation allows the researcher to build advance analysis methods and computational power, with proper feed-in to the software which can simulate most closest parameters and results to life like digital built environment. Also instead on relying on the outdoor environment to be built on equipment based on indoor instrumentation to dictate the outcome of results, it is simpler to control parameters and flexibility of the software tools to allow increased opportunity to get more comprehensive output results via computation. Ultimately the software allows the researcher to play with more permutations and combination.

For a field monitoring technique, one of the most disadvantageous criteria is that the researcher might be influencing the data while collection due to its presence in the environment. The flexibility of using the research on a broader spectrum is lost in this method due to the limitation that the environment which is decided to observe field test. Since each building has its own requirements, setup, environment, load demand characteristics etc the field monitoring can form a basis to such wide variety building sectors i.e. if a residential building is selected then the same format might not hold true for PV and wind energy output or scale in a commercial buildings, which makes the research more difficult. Also there might be restriction with the accessibility, timings to the building, which could lead to errors in monitoring due the current research of solar and wind which would require 24 hrs readings or results. The adjoining factors of the building such as shadings from other buildings, trees, objects might not be a similar factor with building monitoring results in other locations even if the environment is the same. This will affect the output parameters of the PV and wind turbine especially as the wind pattern is also majorly governed by the local set up of forms. The same holds as an advantage in the simulation model as the building can be placed in different environment and association with other limitations around as discussed better. The external elements are under the control of the simulator or even modifications to the locations of systems possible to counter balance this limitation.

The method of literature review is limited to research parameters studied by previous papers by others under varied conditions and environment. In most of the case studies the data provided might not be suitable to form a basis for the current search and dependence on bit by bit information from various researchers could lead to unjustified results of the hybrid research system. Especially in the wind potential in the UAE very limited research has been conducted and would be certain assumption from other locations to find suitability to current environment. Also some of the information from earlier database research study could be outdated and might produce wrong results. The precious research literature review might be sometimes highly influenced by the researcher and towards certain direction of results which might not be deemed accurate enough to follow. Though quite a few papers are written on PV solar potential in the Middle East but since the current research is based on actual site location subjected to surrounding suburban environment only partial information might hold good after verification. Also the most important factor such as the demand load profile of the house will govern the output the set up based on literature review would be quite loose to analyze and to form a bench mark true simulation analysis would be more prudent. Here to say it is best to study and analyze the parameters by self simulation rather than influential literature review by other.

Altogether it could be concluded that the control of the research parameters in simulation by software based model would be more beneficial to avoid undue dependence on experimental, field monitoring or pure literature review methods. The software could be managed to reflect the closest construction parameters and test conditions along with true demand electricity load profile. The flexibility, cost and time factor in software based simulation modeling could benefit in more in depth analysis with varied combination profiles to study the true environment in terms of location latitude, orientation, PV panels factors, wind energy factors, balance of system components to suit the performance output factor of the hybrid system.

3.5 CHOOSING A SIMULATION SOFTWARE

For the current research procedure it would be ideal to use more than one software, which would split the format in two parts, such that one package could be used to build a model and study the parameters related to the house and the environment associated with it. Also this would form the basis of selecting the solar PV panels (latitude, tilt angle etc.), wind turbines with wind speeds and directions. Proper demand electrical profile would be done using an appropriate software based calculator. Second package would be used for simulating the correct sizing for PV panels, wind turbines, hybrid formation of both, balance of system components and finally optimizing them with the technology aspect and economics of the system computed. There are variety of programs available in the market which could offer such capabilities, some of which are Autodesk Ecotect Analysis©, Integrated Environmental Solution or IESve©, Energy Plus© etc. Figure 3.9 illustrates the process of "Building Performance Analysis Software integrations by describing various data transfer steps with capabilities of different software's.

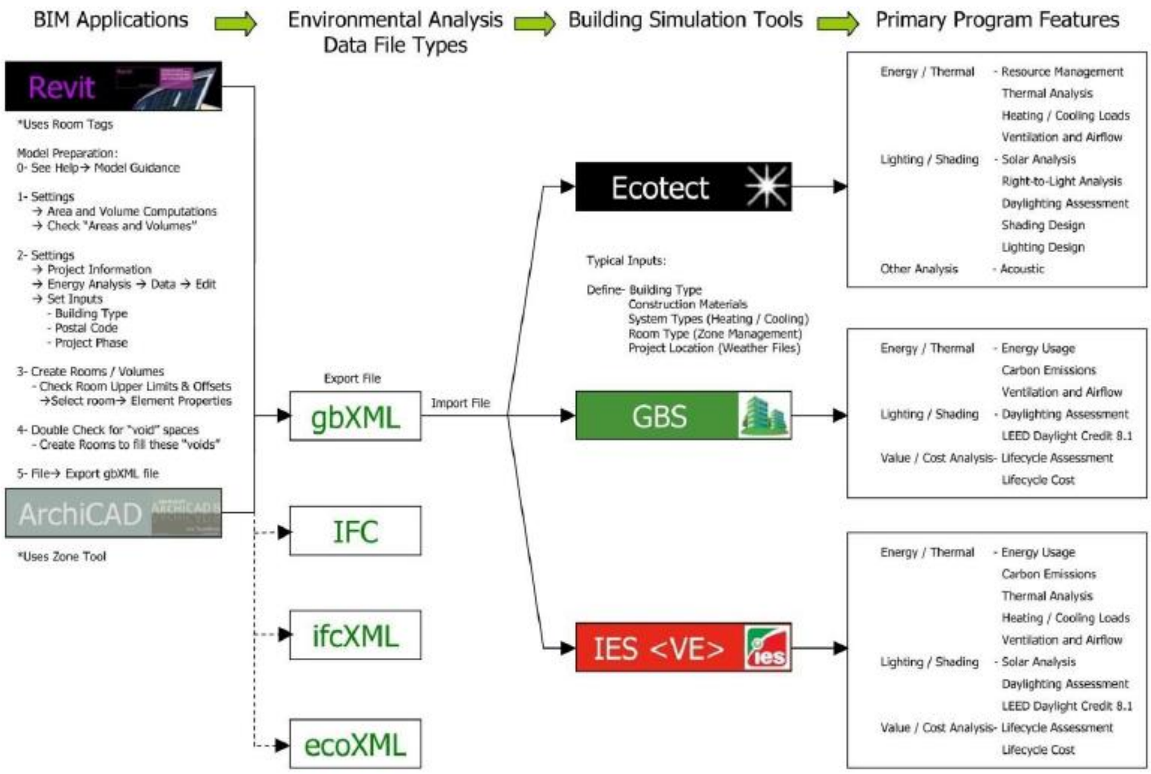


Figure 3.8: Basics and Integration of Building Performance Analysis Software (Azhar et al 2009 and HCC, Atlanta, GA)

There are several important criteria in choosing the correct software for study depending upon the research objectives, scope and potential expectation of output. Now a day's software's are becoming more and more advanced with interlink parameters associated with each other such as direct transformation of files, 3D models into BIM analysis for smooth transition and efficiency in time and avoidance of errors. The following are the advantages which can aid the aspects of sustainable design:

- Building Orientation (Aids in minimizing energy costs)
- Building massing (Optimizing building forms and envelope to minimize energy consumption)
- Daylight Analysis
- Water Harvesting
- Energy Modeling (reduce energy needs and analyze renewable options such as solar and wind energy)
- Sustainable Material (Recycled Materials) etc.

All the above can be simulated seamlessly in a user friendly interface, reliability with use of these by other research papers and easy configuration of model operation profiles and schedules.

Secondly since the paper would involve not only integration building environment and the model but also integrations and hybridization of two different renewable energy resources such as wind and solar. Software's such as Homer Energy Saver, RET Screen international, BGW2004 are more efficient in simulating hybridization of such renewable energy systems and components. Finally the selection process also includes consultation with other professionals and colleagues which have previous experience in using such different simulation software's. A comparison of some important software's useful in the current research is given to analyze the potential of the various sustainable features as evaluation tools is given in Table 3.2.

Table 3.2: Building Performance Analysis Software Evaluation Matrix (Azhar et al 2009 and HCC, Atlanta, GA)

Sustainable Design Features	Weighting (1-10)	Ecotect™	GBS™	VE™
Energy	6			
Energy Usage		1	3	3
Carbon Emissions Calculations		3	3	3
Resource Management		3	1	0
Total Score		**7**	**7**	**6**
Thermal	7			
Thermal Analysis		3	1	3
Heating / Cooling Load Calcs		3	1	3
Ventilation and Airflow		3	3	3
Total Score		**9**	**5**	**9**
Solar				
Solar Analysis	2	3	1	3
Right-to-Light		3	1	1
Total Score		**6**	**2**	**4**
Lighting and Daylighting	3			
Daylighting Assessment		3	1	3
Shading Design		3	1	1
Lighting Design		3	1	1
Total Score		**9**	**3**	**5**
Acoustic	2			
Acoustic Analysis		3	0	1
Total Score		**3**	**0**	**1**
Value and Cost	8			
Lifecycle Assessment		0	3	3
Lifecycle Cost		0	1	3
Total Score		**0**	**4**	**6**
LEED	8			
LEED Integration Tools		0	1	1
Total Score		**0**	**1**	**1**
Total Weighted Score		**150**	**130**	**180**

Even though IESve© scores the highest among the famous BIM software's it is interesting to know for our current research which is related to solar and wind Autodesk Ecotect© is quite competitive and comparatively with better visual characteristics user friendly tools. Also similar to IESve© it has an integrated plug in to import model from simple software such as Google Sketch which is especially useful for architects and less time consuming.

3.6 SOFTWARE INFORMATION (AUTODESK ECOTECT AND HOMER ENERGY SAVER)

Software Description (Autodesk Ecotect Analysis©)

The use of this software enables the researcher to study the complete building design with the environmental analysis function tools to cover a full range of simulation required to understand as to how the building design will operate and perform. Tools such as "Weather Manager" allow feasibility study of the location where the project is entitled to be conducted with the "*creation, conversion and management of tightly formatted weather data used by Ecotect and other software".* The site conditions with respect to the weather can be analyzed using such tools which give information related to temperature, humidity, rainfall, cloud cover, wind resources and radiation with hourly, monthly and yearly readings. Similarly the solar tool guides the site with respect to the sun path, daylight savings in the form of stereographic, BRE sun path, tabular etc. The use of such tools prepares the initial setup and study which help the designer to design the building in a more passive manner to save and conserve building energy. Further primary program analysis by building the house model with its material characteristics enables the study of energy, thermal and lighting/shading analysis.

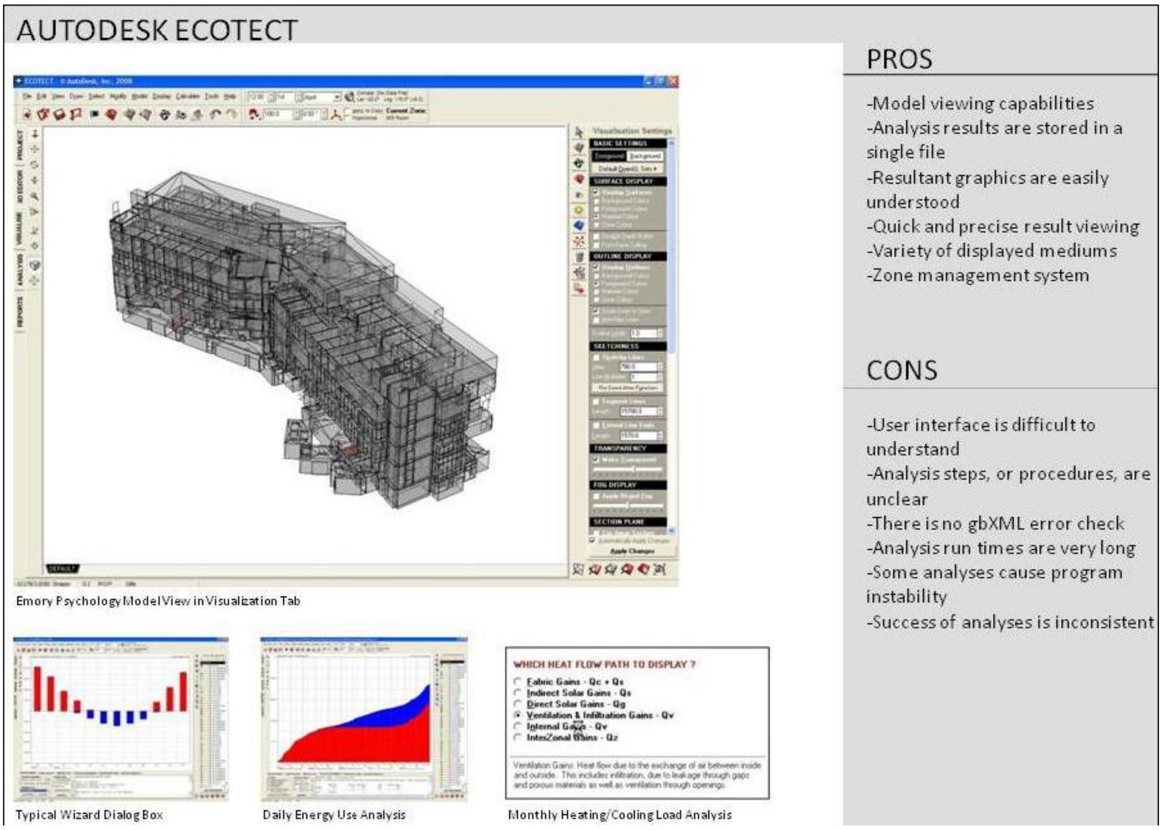


Figure 3.9: "Autodesk Ecotect Analysis" Pros and Cons (Azhar et al 2009 and HCC, Atlanta, GA)

Apart from the above, the features which are important for the current research are noted below:

- Calculate Solar Availability Using Point: This tool will guide us to calculate the reading of solar availability on a selected surface (say roof of the house) using point objects on the roof surface model.
- Cumulative Insolation Analysis: By display of distribution of solar radiation over entire model house, it will be useful to consider shading requirement or assessing the best location to place photovoltaic panels for optimum energy collection.
- Solar Analysis Using Model Grid: Similar to the point based system as mentioned above this tool enables the calculation of solar availability by modeling the house in a surface miniature grid to display incident, direct, diffuse radiation etc in grid tile formation. For this the surface could be vertical (external walls, windows) or horizontal (ground, terraces, and roofs).
- Shadows and Reflection: This tool help study of building with respect shadows on or from building adjoining, self forms, trees etc to avoid such energy losses from PV panels by keeping them away from shadow or high temperature reflection which could increase cell temperature.
- Wind Rose: This tool allows the study of wind speeds and directions of the prevailing wind at different times of the year with respect to the site and buildings within it. A guiding tool to place the wind turbines appropriately to maximize wind speed orientation for efficient wind energy output for the model house.

<u>Software Description (HOMER Energy Saver)</u>

HOMER software simulates the operation of the system by calculating energy balance for each of the 8,760 hours in a year. It compares the electric and thermal loads in the hour to energy that the solar and wind hybrid system can supply in that hour. It function in both types of modes such as “Off Grid” and “Grid Connected” with the feasibility of use of batteries or generators to decide for each hour to operate either ways, whether to charge or discharge the batteries. It performs the energy balance calculations for each of the configuration that are considered which are either feasible or not feasible to meet the energy demand of the house and estimates the cost of installation and operation of solar and wind in our case over the lifetime of the project.

After the configuration variables it displays the list of configurations sorted by net present cost that can be used to compare system design options to optimize the model. A sensitivity analysis tool enables optimization of the configurations for each sensitivity variable that are specified for the system. Finally the software helps in answering the following questions that could be validated for the system configuration used:

- *Is it cost-effective to add a wind turbine and solar PV panels to the diesel generator in my system?*
- *How much will the cost of diesel fuel need to increase to make photovoltaic’s and wind turbine cost effective?*
- *Will my design meet a growing electric demand?*
- *Is it cost-effective to install a micro turbine or additional PV panels to produce electricity and heat for my grid-connected facility?*

The chronology of events to be simulated in the software are basic and involve three main steps for the formation of the system to be validated to match the energy demand profile of the project in the order as shown in Figure 3.12.

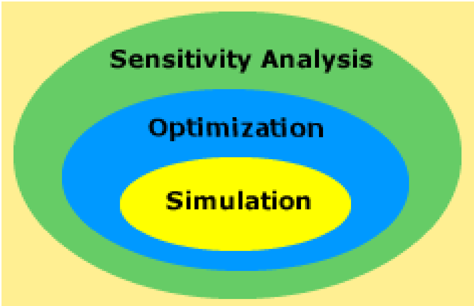


Figure 3.10: Conceptual Relationship between steps involved in the HOMER software (Tom Lambert-Mistaya Inc. and Paul Gilman, Peter Lilienthal- National Renewable Energy Laboratory- 2011)

<u>Software Validation and reliability</u>

Autodesk Ecotect Analysis©: Initially developed by Andrew Marsh for Square One Research Lab which was funded by Centre for Research in Built Environment, UK and later brought by Autodesk in 2008 with earlier validation from:

- ☐ CIBSE TM33 (Macdonald et al 2004)
- ☐ IEA Task12
- Envelope BESTEST (Judkoff and Neymark 1995a: also ANSI/ASHRAE Standard 140, 2001)
- ☐ ISO 13791

HOMER Energy Saver©: It was incorporated in 2009 to commercial Hybrid Optimization Model with development from National Renewable Energy Laboratory (NREL) which is a division of the US Department of Energy.

More information about the validation of software can be obtained from the below mentioned website:

http://usa.autodesk.com/adsk/servlet/ps/dl/item?siteID=123112&id=14576143&linkID=13734494

http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=425/pagename=alpha_list_sub

List of papers using HOMER simulation software are noted below for validation:

Bekele, G. & Palm, B., (2010). *Feasibility study for a standalone solar–wind-based hybrid energy system for application in Ethiopia*. Applied Energy, Volume 87, Issue 2, February 2010, Pages 487-49. http://www.sciencedirect.com.ezproxy.aus.edu/

Nandi, S.K. & Ghosh, H.R., (2010). Prospect of wind–PV-battery hybrid power system as an alternative to grid extension in Bangladesh. Energy, Volume 35, Issue 7, July 2010, Pages 3040-3047. http://www.sciencedirect.com.ezproxy.aus.edu/

Hongxing, Y., Wei, Z. & Chengzhi, L., (2009). *Optimal Design and techno-economic analysis of a hybrid solar-wind power generation system*. Applied Energy, Volume 86, Issue 2, February 2009, Pages 163-169. http://www.sciencedirect.com.ezproxy.aus.edu/

CHAPTER 4: SIMULATION MODEL

4.1 MODEL DESCRIPTION

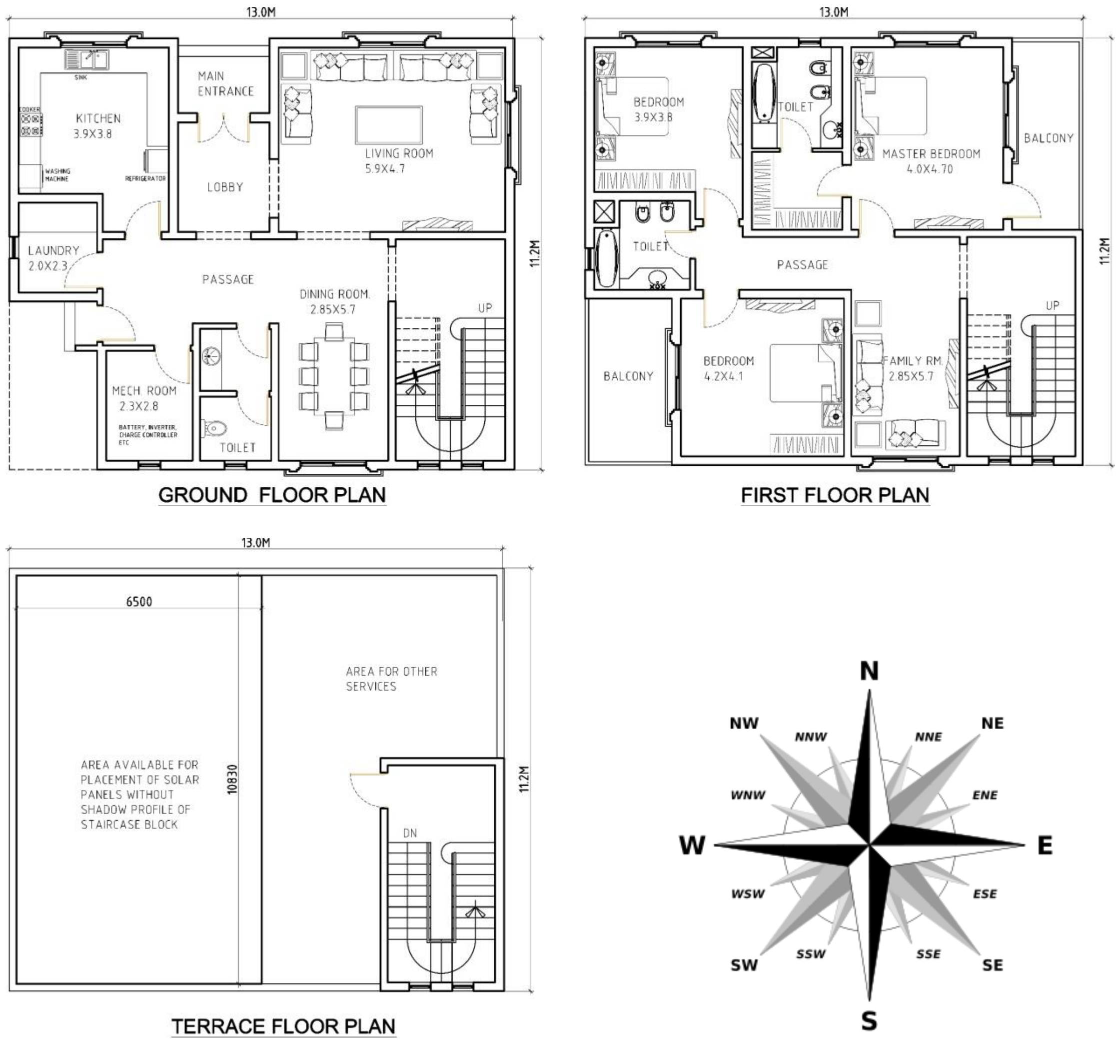
Since the project is based in Dubai-UAE it is necessary and imperative that the house model is analyzed on the parameters and generic regulation set by the Building Governing Authorities in UAE, "The Dubai Municipality". All necessary regulation stipulated by the authority shall be followed as per material specification and sustainability program "Estidama" set by the local UAE authorities. Although the authority is not specific about the usage of renewable energy systems like solar PV panels and wind energy system, we shall use the literature review section to form the basis of our simulation setup. For instance the use of PV panels to generate electrical output for the model house shall be placed on the roof to maximize the output potential considering the solar radiation optimal position with respect to its exposure to sunlight. Similarly the wind energy system "wind turbines" shall be positioned to suit the highest wind speed direction related to the location of the site. But so as to minimize the load on the power demand load profile of the house, the design needs to be characterized to consume less power by means of passive design technologies and comfort conditions reliant on mechanical systems. For example care is taken to avoid unnecessary heat gain inside the house exerting load on HVAC system or lighting loads by proper orientation design of the house as can be seen further. The house is designed as a compact bare minimum necessity but adequate in terms of space, equipment, lighting and livable space rather than just emphasis on minimizing demand load. The following are the basic description and design of the model house and its parameters.

4.1.1 House Model

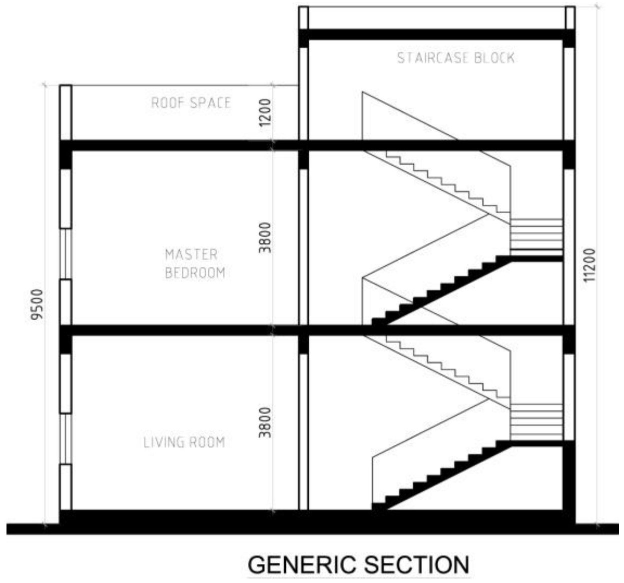
The simulation house model is developed on a suburban site located at Dubai-Land in Dubai, UAE with orientation co-ordinates of North 27.76° longitude and East 50.32° latitude with elevation of 32.89m. The plot size is 20.5m x 33.0m and the house dimension are (width) 13.0m x (depth) 11.2m with an area as per design of total 255 sq.m (Ground Floor Area = 130 sq.m and First Floor Area = 125 sq.m) as shown in Figure 4.1. The height of the house is considered as 4.2m Floor finish to Floor Finish (FFL) with a plinth of 0.3m for better circulation of natural ventilation during external comfort condition considering the minimum habitable room dimensions of 3.0m and maximum dimension of 4.5m. As hot air tends to move upwards and hence a better volumetric height above 2.1m human habitat level will ensure better comfort conditions as seen in Figure 4.2. Similarly care has been taken with location of the windows and its ratio with respect to the floor area to minimize heat gain during peak summers as per north eastern hemisphere. Figure 4.3 illustrates the elevations and window to floor area ration with the following description:

- South facing Glass: 2.5-3% of the floor area of the house
- West facing Glass: 1.5% of the floor area of the house (avoid over heating during summers)
- East facing Glass: 1.5-2% of the floor area of the house
- North facing Glass: 5% of the floor area of the house (maximize daylight with important rooms design windows facing north)
- Overhangs should cast a comparatively less shadow effect on the south facing window during winter solstice (December 21) with complete shadow during the summer solstice (June 21).

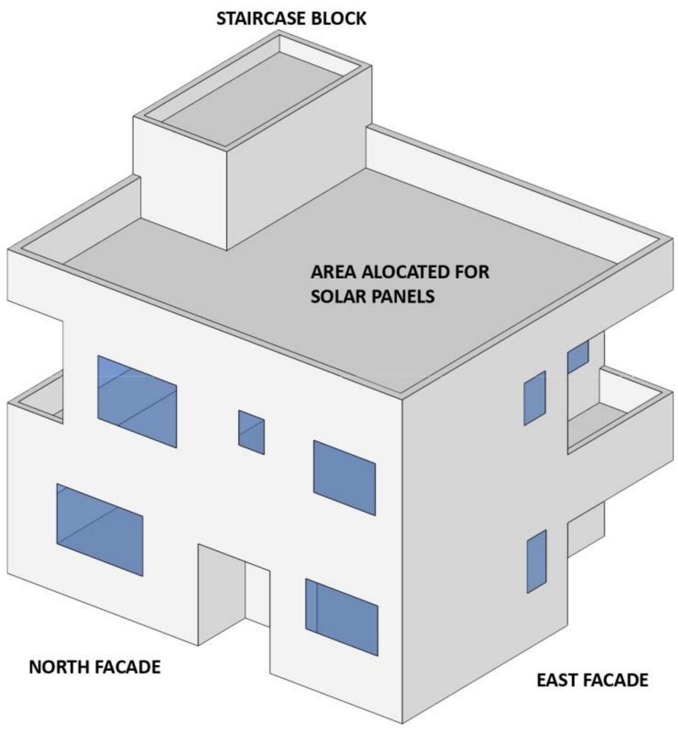
Passive energy saving strategies with the use of insulated material specification as per Estidama and selection of windows is a tradeoff between achieving high solar gain and high R value (insulation factor) to prevent heat losses during night time ventilation. Basic requirements of the house such as furniture and finishes with low VOC materials specifications need to be considered as guidelines also for sustainable design parameter. Note that these are generic strategies for reducing energy loads to achieve better thermal comfort conditions though no simulation will be run to validate these assumptions but based on mere literature review points as followed.



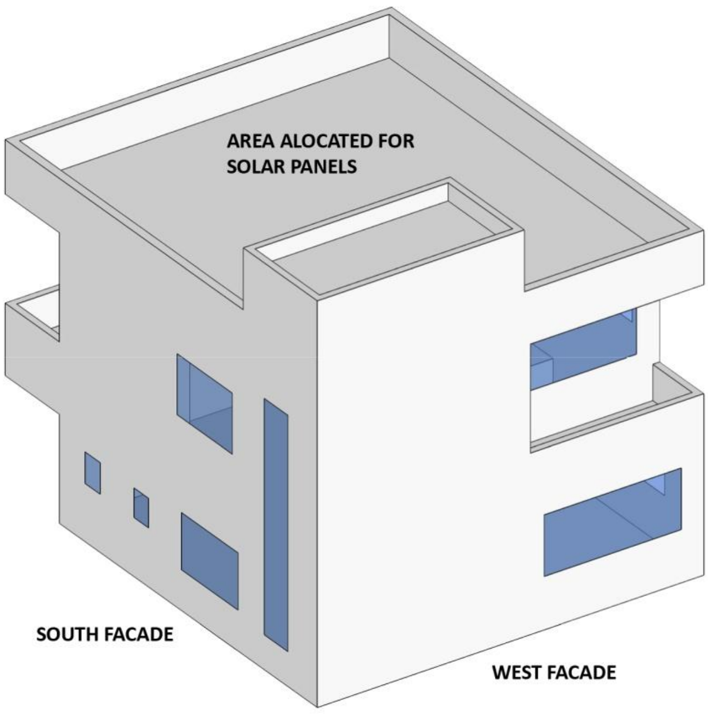
4.1 Model House Plans a) Ground Floor b) First Floor c) Roof Floor d) North Sign as per site



4.2 Generic Section indicating heights



4.4 North East Axonometric Elevation View



4.3 South West Axonometric Elevation View

4.1.2 House Model Finishes

The below mentioned finishes for the model house are based on the Estidama Villa Product Database (EVPD) complaint for the Pearl Villa Rating System (PVRS). Since Abu Dhabi has recently formulated a sustainable energy efficient design guideline and Pearl rating system based on the region, it is used as a baseline for setting energy efficient goals, which is crucial for the UAE 2030 vision. Table 4.1 shows a list of materials which are approved by the EVPD panel based on the certain values as listed below with "RE-2" requirement where the house model aspires to a higher Pearl rating and has targeted for "Cool Building Strategies" product database.

Table 4.1: House Model Material Specification (Estidama and Ecotect, 2011)

Product	Material	Thickness (mm)	Thermal Conductivity (W/mk)	Density (kg/m3)	Category	U-Value
External Wall (Emcon LLC)	External Render	13	0.5	1300	Plaster	0.21
	Concrete Block	70	1.24	2000	Concrete	
	Polystyrene	160	0.0365	25	Insulation	
	Concrete Block	70	1.24	2000	Concrete	
	Internal Render	10	0.5	1300	Plaster	
Internal Wall (UPC)	Internal Plaster	10	0.5	1300	Plaster	0.55
	Internal Precast Concrete Wall	80	1.85	2500	Concrete	
	Polystyrene	50	0.28	32	Insulation	
	Internal Precast Concrete Wall	70	1.85	2500	Concrete	
	Internal Plaster	10	0.5	1300	Plaster	
Internal Floor and Ceiling	Tiles	10	0.309	1900	Tiles	0.92 (Ecotect)
	Screed	50	0.41	1200	Screed	
	Cast Concrete	250	1.4	2100	Concrete	
	Ceiling Cavity	500	-	-	-	
	Ceiling Tiles	10	0.056	380	Tiles	
Main Roof (Roof Care LLC)	Reinforced Concrete	150	1.9	2400	Concrete	0.12
	Polyurethane Spray	180	0.022	50	Insulation	
	Polytex UV Protection	600 microns	-	-	Liquid	
	Polyfab layer	120gsm	-	-	Geotexile	
	Screed	180	1.3	2500	Concrete	
	Polyflex layer	-	-	-	Cement	
Doors	Pine (20% moist)	40	0.14	419	Timber	2.2967 (Ecotect)
Product	**Material**	**Thickness (mm)**	**Transmittance**	**Out Reflect.**	**Inside Reflect.**	**U-Value**
External Glazing	Pilkington Glass	6	0.23	0.39	0.1	2.06
	Air Cavity	12	-	-	-	
	Clear Glass	6	0.73	0.09	0.1	
Shading Coefficient: 0.27, SHGC (center pane):0.23						

4.1.3 Electrical Load Profile of House

The house is considered for a single family ratio with a dwelling capacity of 4 persons. All necessary equipments are considered for habitable conditions as per UAE household livable standards. The house shall operate on necessary mechanical systems such as water pump since drainage and supply line is provided by the Government (hence no septic tank pump required), independent HVAC system, house appliances, and generic office and entertainment devices. The house is designed with a power system of 220V loads for most of the appliances, equipments and the same needs to be simulated by the hybrid power generation system in terms of its inverter and battery storage capacities. A demand load analysis needs to be conducted for the house energy consumption i.e. the amount of energy in kWh used by the chosen selection of household equipment loads. A load analysis table 4.2 lists the electrical loads of the house with rated power requirement of each device and the number of hours per day that are expected to operate. The energy required to operate the load for a day can be calculated in (Wh) as:

$$E(Wh)=\sum IVH$$

Where I and V are the current and voltage respectively of the loads and H is the daily duty cycle of the loads in hours/days. Hence values are listed in more common units of kWh/day.

In order to analyze the load profile of the house in kWh/day the selection of equipments in done based on their respective wattages and an assumption is taken as workable average usage hours/day. For the purpose of identifying the wattages for various equipment and appliance the use of database as researched by the “U.S Department of Energy” is taken whereby the “Typical Wattages of Various Household Appliances” is provided in consideration to the “Energy Star” criterion such as A+, A+++ etc where the addition of “+” indicates high energy efficiencies for those appliances.

Most of the equipment and appliances selected are under the A++ or A+++ criteria and the assumption for the appliances and equipments are listed below as:

- Refrigerator, the running time of the compressor is considered as 1/5th of the 24hours of operation. This is due to the fact that power is consumed mostly when the compressor is running which is not 24hours.
- Water pump is designed for 220V pump capacity from the local market specification and a large pressure tank with 15 gallons drawn down is specified for the water system to reduce the frequency of power up conditions that produce a short spike in power demand.
- Domestic storage type water heater is not considered in the wattage table due to it ready availability from the solar water heating system.
- Air conditioning system considered as VAV Ducted Fan Coil Units of 5 ton capacity (Mc Quay Air Conditioning System- Product Code with cooling capacity of 2.9kW-15.8kW) and the kitchen is fitted with room infiltration rate maximum flow of 50 ACH (air changes per hour). The air conditioning unit is designed to have minimum seasonal average COP of 3.4 as per Estidama rating system. Maximum care is taken to provide window natural ventilation air changes during outdoor comfort conditions. Again the running time of the compressor is considered as 1/5th of the 24hours of the operation when running the whole day in peaks summer time.
- Lighting system for internal use is energy efficient LED 15W with average minimum illumination levels considered during operation as 200lux and the outdoor lights again LED with 5W used with daylight sensors. Lighting power densities are designed not to exceed as per figures mentioned in ASHRAE 90.1 Section 9
- Other loads considered can be seen as in Table 4.2

Table 4.2: Load Analysis for the House Model (US. DOE, 2011)

Equipment and Appliances	Total Nos.	Generic Rated Power as per US.DOE (W)	Total Rated Power (W)	Average Hours/day	kWh/day
Mechanical					
Water Pump	1	1100	1100	0.5	0.55
AC (5-Tons)	1	2200	2200	4.5	9.9
Kitchen					
Refrigerator	1	500	500	4.5	2.25
Coffee Maker	1	900	900	0.15	0.135
Toaster	1	800	800	0.15	0.12
Micro Oven	1	500	500	0.5	0.25
Dishwasher	1	1200	1200	0.5	0.6
Slow Cooker	1	110	110	0.5	0.055
Mixer Grinder	1	300	300	0.15	0.045
Lighting					
GF LED lights	18	15	270	4	1.08
FF LED lights	18	15	270	4	1.08
Exhaust Fans	3	100	300	2	0.6
Outdoor Lights	8	5	40	8	0.32
Office and Entertainment					
TV 32"	4	120	480	2	0.96
DVD Player	2	20	40	3	0.12
Music System	2	25	50	1	0.05
Laptop	2	50	100	8	0.8
Printer	1	20	20	0.15	0.003
Modem, Router etc	1	20	20	3	0.06
Laundry					
Washing Dyer Machine	1	500	500	1	0.5
Iron	1	1000	1000	0.5	0.5
Small Power Points	2	6	12	2	0.024
				Total AC Load (kWh/day)	20.002

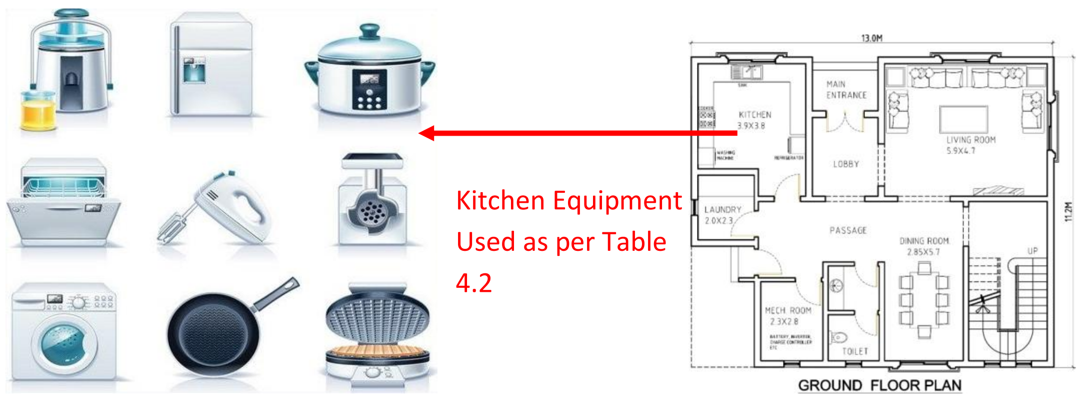


Figure 4.5 Equipment In Plan Diagram

4.1.4 PV Model Selection Strategy

Actual Site Location Solar Potential

In order to specify the type of PV panels it is critical that the solar resource of the exact site needs to be validated in order to optimize the PV module potential. Site specifics as mentioned earlier are latitude 27.76º (27º45' N) and longitude 50.32º (50º19' E). This is important as the information related to solar radiation will be calculated based on monthly average amount of total solar radiation incident on the horizontal surface of the earth for the 12 month period related to exact site locations global positioning. In order to size the solar panel arrays the average of direct and diffuse solar radiation which is the sum of these two called "global solar radiation" on the horizontal surface has to be obtained. For this purpose HOMER uses the NASA SSE data as the average daily solar radiation as specific reading each month along with the clearness index ratio (K). As shown in Figure 4.6

Parameters for Sizing and Pointing of Solar Panels and for Solar Thermal Applications:

Monthly Averaged Insolation Incident On A Horizontal Surface (kWh/m^2/day)

Lat 27.76 Lon 50.32	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	3.67	4.65	5.41	6.65	7.43	7.87	7.76	7.32	6.68	5.68	4.20	3.35	5.89

Location

Latitude 27 ° 45 ' North South

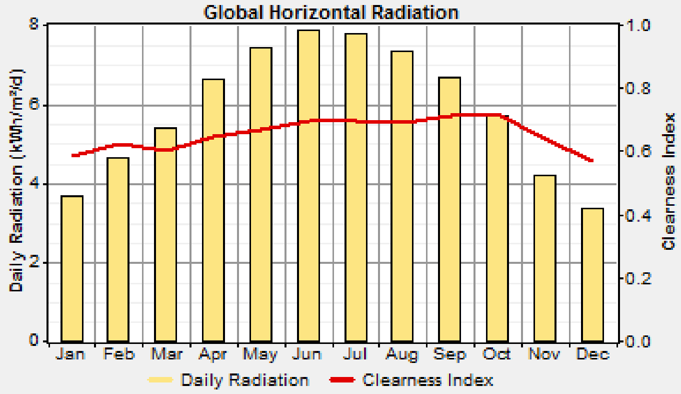
Longitude 50 ° 19 ' East West

Time zone (GMT+04:00) Georgia, Oman, UAE

Data source: Enter monthly averages Import time series data file Get Data Via Internet

Baseline data

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.584	3.670
February	0.623	4.650
March	0.602	5.410
April	0.645	6.650
May	0.670	7.430
June	0.694	7.870
July	0.694	7.760
August	0.693	7.320
September	0.710	6.680
October	0.720	5.680
November	0.643	4.200
December	0.568	3.350
Average:	0.661	5.894



Plot... Export...

Scaled annual average (kWh/m²/d) 5.89 {..} Help Cancel OK

Figure 4.6 Site Specific Solar Radiation Data (NASA SSE Database, 2011 inputs for HOMER software)

Available Space for Maximum Solar Exposure to PV Panels

The entire roof of the house is considered as available area to place the PV panels with a total available space equal to 137 sq.m, including the roof of the stairwell. But to minimize the space with respect to serviceable access the roof except stairwell is more advisable and the area amounts to 120 sq.m. Since the stairwell is bound to cast a shadow on the roof again the entire assessable roof area cannot be considered. Thus based on the model simulated in ECOTECT software which indicated the shadow range for summer solstice (June 21 at 12.30pm) and winter solstice (December 21 at 12.30pm is shown in Figure 4.7 to illustrate the available space exposed to solar radiation with major shadow formation on the roof PV panels. Thus the actual feasible space on the roof for placement of PV panels without formation of shadow on them is roughly 6.5m x 11.5m totaling to 75 sq.m areas of closest approximations.

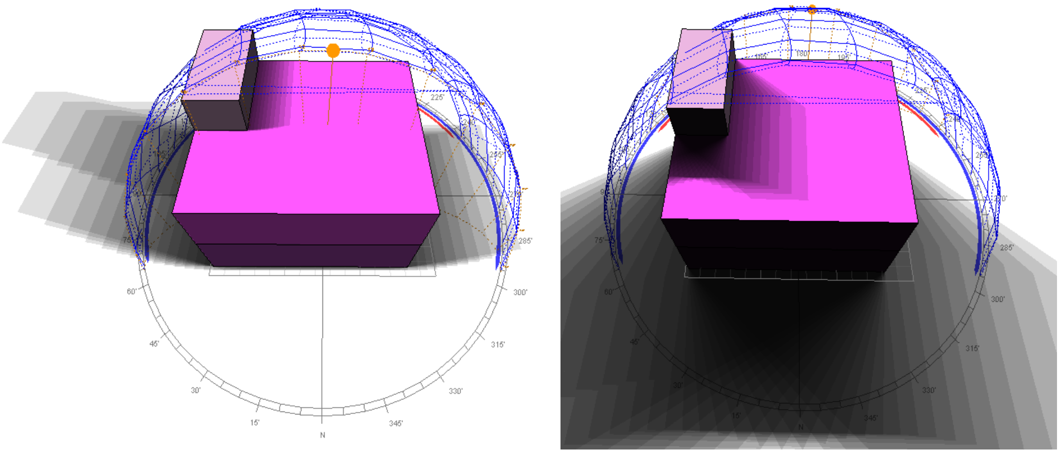


Figure 4.7: Shadow Range Analysis for placement of PV panels on roof of house model (ECOTECT) a) June 21st summer solstice b) December 21st winter solstice

PV panels Optimum Tilt Angle

The optimum tilt angle for maximize the amount of power output is if the PV panels are tilted at an angle perpendicular to the sun's rays. In order to achieve this parameter at all times of the day and days of the year would require a two-axis device which would add considerable cost and complexity to the hybrid system. Thus most residential houses PV panels are fixed at the optimum angle or at two tilt angles that are adjusted to the season. With the use of NASA SSE database we can though obtained the optimized tilt angle suitable to the site which again as mentioned earlier is the same angle equal to the latitude 27.1º of the site location as seen in Table 4.3. Note: No solar tracking device is considered in this simulation procedure in HOMER.

Table 4.3: Tilted Solar Panel indicating optimum angle of 27.1º for the selected site geographical location. (NASA SSE Database, 2011)

Parameters for Tilted Solar Panels:

Maximum Radiation Incident On An Equator-pointed Tilted Surface (kWh/m²/day)

Lat 27.76 Lon 50.32	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
SSE MAX	4.45	5.21	6.19	7.16	7.89	8.11	8.11	7.47	6.83	5.96	4.76	4.05	6.35
K	0.69	0.68	0.67	0.68	0.71	0.71	0.72	0.70	0.71	0.73	0.71	0.68	0.70
Diffuse	0.72	0.99	1.30	1.53	1.62	1.67	1.56	1.51	1.20	0.83	0.72	0.73	1.20
Direct	6.76	6.95	7.14	7.65	8.45	8.87	8.80	8.45	8.36	8.23	7.02	6.33	7.76
Tilt 0	4.34	5.17	6.12	7.01	7.86	8.08	8.08	7.43	6.73	5.91	4.63	3.98	6.28
Tilt 12	5.27	5.95	6.62	7.20	7.71	7.80	7.86	7.46	7.14	6.72	5.54	4.89	6.68
Tilt 27	6.15	6.63	6.91	7.07	7.16	7.08	7.20	7.13	7.29	7.37	6.39	5.78	6.85
Tilt 42	6.66	6.91	6.82	6.56	6.26	6.01	6.18	6.44	7.03	7.58	6.86	6.33	6.64
Tilt 90	5.62	5.21	4.16	2.94	2.15	1.85	1.95	2.57	3.82	5.39	5.62	5.50	3.89
OPT	6.79	6.92	6.92	7.20	7.86	8.08	8.08	7.48	7.30	7.58	6.95	6.50	7.31
OPT ANG	54.0	45.0	31.0	15.0	0.00	0.00	0.00	7.00	25.0	42.0	52.0	56.0	27.1

NOTE:	*Diffuse radiation, direct normal radiation and tilted surface radiation are not calculated when the clearness index (K) is below 0.3 or above 0.8.*

Characteristics of PV module used for study

As per literature review the mono-crystalline PV cells have the best nominal efficiency as compared to other multi-poly-crystalline PV cells available in the market. Though thin films have come comparatively closer to the efficiency of mono-crystalline cells, the previous cannot match up to the parameters yet due to shear purity of silicon crystal which are cut in thin wafers with greater power output based on their composition. Due to no constraints in selection criteria such as transparency and aesthetics it is best advised to use the most efficient cells in the market. Table 4.4 shows the characteristics of the two typical PV module matrix and justification for the selection strategy. The mono-crystalline PV module selected has an efficiency of 14.9% with a positive tolerance 0/+5% for power output reliability. It is also self cleaning anti reflective surface, hydrophobic layer which improves light absorption and reduces surface dust accumulation. The module is 200W with a module of array 72(6x12) no. of cells of 125x125mm each and is completely opaque module formed in aluminum frame as per datasheet.

Table 4.4: Characteristics of PV module used in the study (Suntech Power, 2011)

PV Array Type (Suntech Product)	Nominal Efficiency	Nominal Cell Temp. (NOCT)	Reference Irradiance for NOCT (W/m2)	Temp. Coeff. For Nominal Efficiency	Degradation Factor (%)	Shading Factor	Electrical Conversion Efficiency
Mono Crystalline	15.7%	45ºC	800	-0.38%/ºC	1%	1	80%
Poly Crystalline	13.9%	45ºC	800	-0.44%/ºC	1%	1	80%

Note: STC irradiance is 1000W/m2, module temperature 25ºC
NOCT irradiance is 800W/m2, ambient temperature 20ºC, wind speed 1 m/s

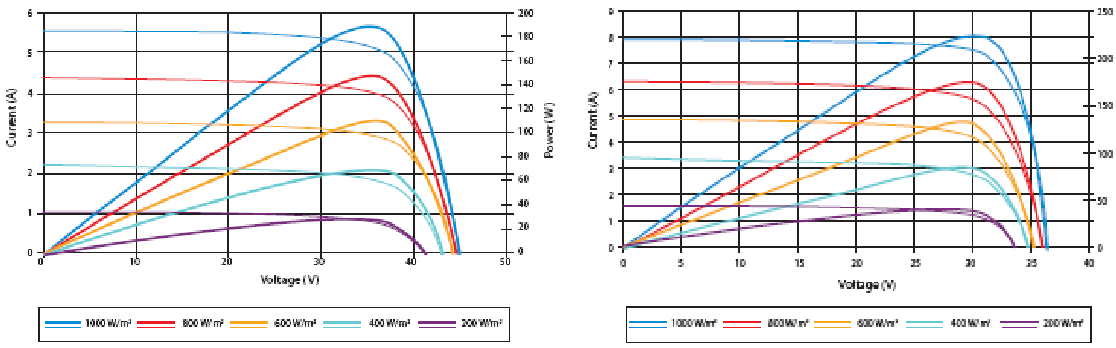


Figure 4.8: Current Voltage & Power Voltage Curves a) Mono-Crystalline b) Poly-Crystalline (Suntech Power, 2011). Refer to Appendix C for manufacturer's datasheet and verification.

Case Configurations

Since solar potential is comparatively better in the UAE in comparison to wind power as reviewed from literature papers, the study shall analyze the use of only PV solar module initially to suffice the demand loads of the house needs to be simulated. In order to do so, the model will be tested first with PV potential with the above selected criteria of poly-crystalline cells due to their very close output efficiency and low cost as compared to mono crystalline. For the purpose of analysis the model will be run in HOMER software with the following case configuration under the conditions of grid connected house and off grid connected house model as shown in Table 4.5.

Table 4.5: Matrix Case Configuration for PV module Only.

Connection Type	**PV power output potential ratio (%) in relation to demand load profile of the house model**				
	25%	50%	75%	100%	100% surplus
Grid Connected	X	X	X	X	X
Off Grid Connection	-	-	-	X	X
Net Present Cost(NPC)	X	X	X	X	X
Pay Back Time	For all the above Case Configuration a Pay Back time of 15 years shall be simulated.				

4.1.5 Wind Turbine Selection Strategy

Actual Site Location Wind Energy Potential

The wind potential at the specific site location is measured with the database location from NASA SSE again similar to the PV module with a wind speed parameter at 10m to 50m height from the surface of the earth. As per literature review the wind speed various with height from surface of the earth due to atmospheric and climatic conditions prevailing in the suburban environment. The average wind speed for any given period is made up of many intervals of varying wind speeds; the average is not good indicator of the actual power output over any given period. Hence due to this even though our wind turbine height is location at 25m which above the general level of the suburban set up of our site the measure difference of wind speeds between 10m-50m cannot be generalized for 25m. Thus for wind speed average per month the reading at 10m above the surface of the earth for the terrain similar to airports is taken into consideration (see Table 4.6) to be fed into the HOMER software as per Figure 4.9.

Table 4.6: Wind Speed Statistics Specific to Site (NASA SSE Database)

Monthly Averaged Wind Speed At 10 m Above The Surface Of The Earth For Terrain Similar To Airports (m/s)

Lat 27.76 Lon 50.32	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	4.57	5.09	4.92	4.67	5.24	5.48	4.66	4.63	4.28	4.04	4.20	4.59	4.69

It is recommended that users of these wind data review the SSE Methodology. The user may wish to correct for biases as well as local effects within the selected grid region.	*All height measurements are from the soil, water, or ice/snow surface instead of "effective" surface, which is usually taken to be near the tops of vegetated canopies.*

Meteorology (Wind):

Monthly Averaged Wind Speed At 50 m Above The Surface Of The Earth (m/s)

Lat 27.76 Lon 50.32	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	5.34	5.95	5.75	5.46	6.13	6.41	5.45	5.43	5.01	4.72	4.91	5.37	5.49

Wind Speed Direction Site Specific and Position of Wind Turbine Location

The erection of wind turbine is based on the maximum wind speed direction available on the site in relation to the maximum number of hours, which can be seen in Figure 4.9 and Table 4.7. Based on the simulation and database the optimized location for wind turbine is North West direction at 346° average approximation.

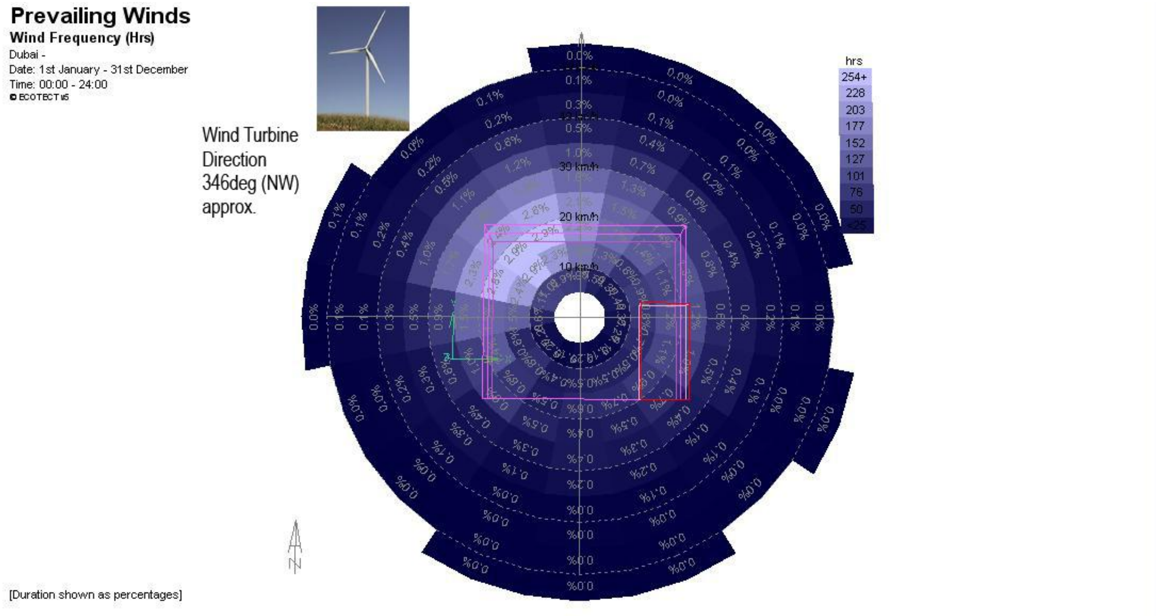


Figure 4.9: Wind Turbine Location at North West Direction (346deg) site specific (ECOTECT)

Table 4.7: Wind Speed Direction in Degrees site specific (NASA SSE Database, 2011)

Monthly Averaged Wind Direction At 50 m Above The Surface Of The Earth (degrees)

Lat 27.76 Lon 50.32	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10-year Average	335	340	344	346	346	341	339	339	341	344	346	346

It is also important to obtain the number of hours of peak wind speed that tend to be windiest, on average as input parameters in HOMER software since it runs an 8760 day wind data simulation to maximize the power output from wind turbines. Figure 4.10 illustrates above 13+ hours of wind speed in the month of June which has the average wind speed of 5.48m/s and hence the assumption of 15 hours of peak wind speed in that month as HOMER input parameters.

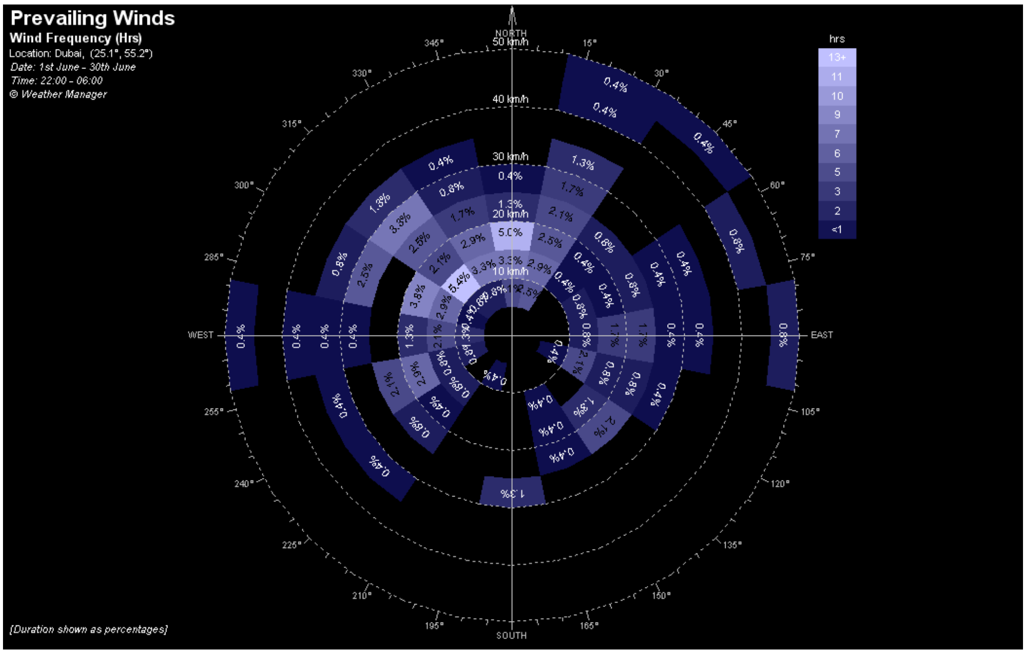


Figure 4.10: 13+ Hours of wind speed in the month of July from NW direction (ECOTECT)

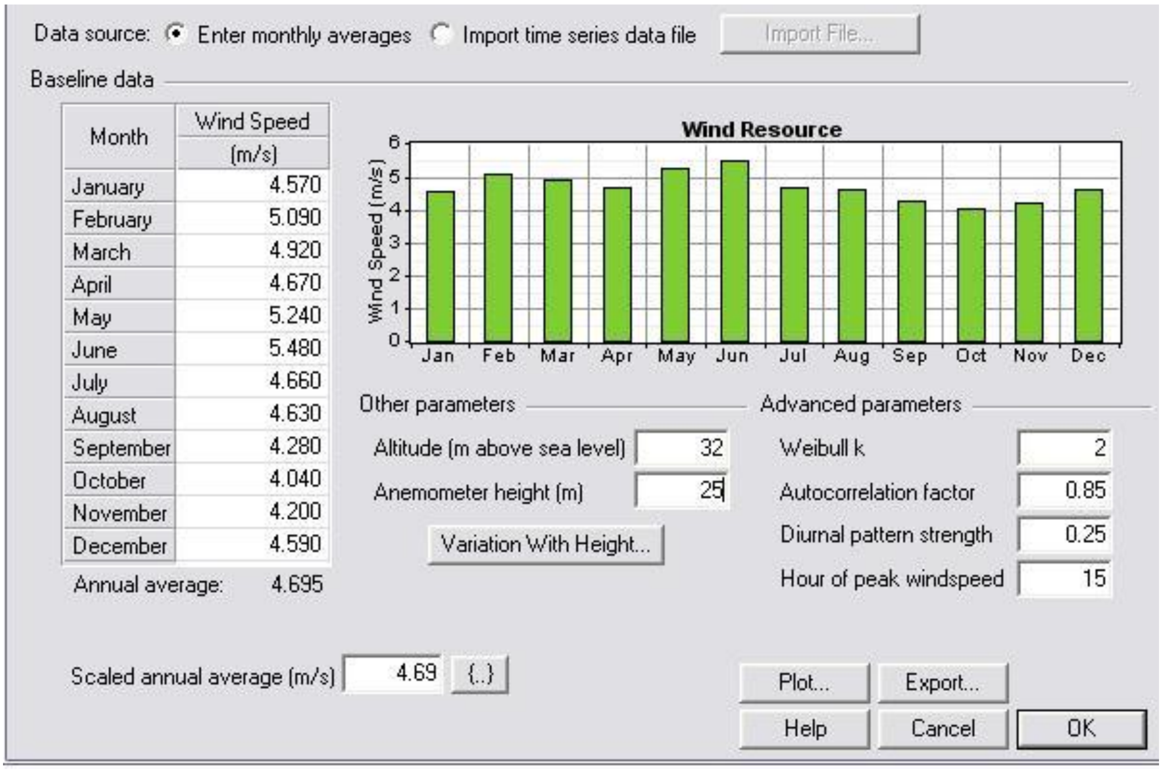


Figure 4.11: HOMER wind speed resource input parameters based on Table 4.6 and Figure 4.10

Note: Actual Altitude of Site= 32m and Anemometer Height = 25m

<u>Characteristics of Wind Turbines Selection used for Study</u>

Based on the literature review we have noted that wind power varies with the cube of the wind speed, i.e. power output increases by a factor of 8 if wind speed is doubled. Thus for comparison purpose we used 2 types of wind turbines from the same manufacturer using them for residential sectors with criteria such as rotor diameter, swept area, rated power and off course the balanced cost based on the available wind speed on the site location. Table 4.8 illustrates the two types of wind turbines with its characteristics. Here it is important to mention that larger the swept area larger the electricity production but in order to increase the swept area the rotor diameter has to increase. If the rotor diameter increases the blades are longer and heavier with higher cut in speed. But on our given site the average wind speed is 4.69m/s which are not very high readings for wind speed to generate power. Thus it is important that a lower cut in speed rotor diameter wind turbine needs to be selected so that the lower rated wind speed produces larger power output given its rated output.

Table 4.8: Matrix for Wind Turbines Technical Specification (Southwest Wind power, 2011)

Wind Turbine (Whisper)	**Rotor Diameter (m)**	**Start up Wind Speed (m/s)**	**Rated Wind Speed (m/s)**	**Rated Power (W)**	**Voltage**	**KWh/month at 4.5m/s (site avg.)**
100	2.1	3.4	12.5	900	12,24,36,48	65
200	2.7	3.1	11.5	1000	24,36,48 (HV)	125
500	4.5	3.4	10.5	3000	24,36,48 (HV)	330

As per the above table all the three are quite compatible to be installed on the site but one important factor is also the initial cost of the three and the Whisper 500 is 2.5 times more expensive than the previous two wind turbines. Since we are not very confident from the wind resource in the UAE we shall prefer to be more conservative in the cost aspects for initial cost of investment. Also the rotor diameter is very high for a suburban environment considering various constraints in the locality. A comparison between Whisper 100 and 200 results in a slightly higher rotor diameter, though manageable but the power output per month is almost twice with comparatively fractional higher cost. Hence a Whisper 200 is selected for larger output potential considering the average wind speed at the specific site. Also the Whisper 200 shows a better overall power output in comparison as seen in Figure 4.12.

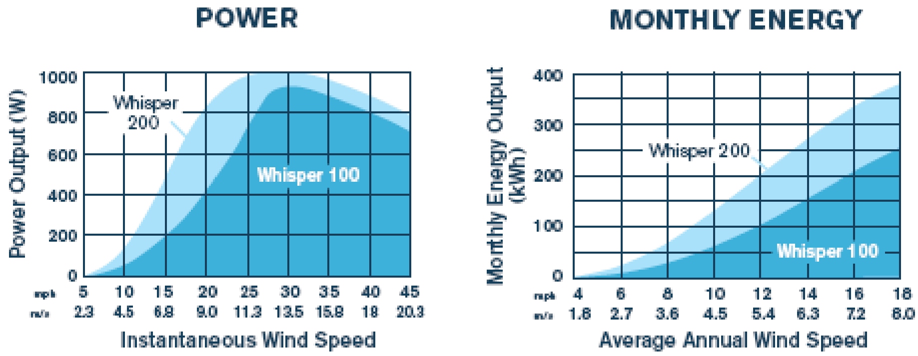


Figure 4.12: Comparison of Whisper 100 versus Whisper 200 (Southwest Wind power, 2011)

Note: Refer Appendix C for Manufacturers Technical Data

Case Configurations

A similar simulation check will be run to find the maximum potential of wind energy at the proposed site location in order to analyze the use of wind turbine. To find out whether the wind energy potential is suitable to be added as hybrid system along with the solar power can be only validated by simulating both the energy systems individually. Once both the systems are validated separately, the optimized results from the HOMER software can be compared to the hybrid model run in the software again to check the feasibility.

Table 4.9: Matrix Case Configuration for Wind Energy Only.

Connection Type	**Wind power output potential ratio (%) in relation to demand load profile of the house model**				
	25%	50%	75%	100%	100% surplus
Grid Connected	X	X	X	X	X
Off Grid Connection	-	-	-	X	X
Net Present Cost(NPC)	X	X	X	X	X
Pay Back Time	For all the above Case Configuration a Pay Back time of 15 years shall be simulated.				

4.1.6 Battery Selection Strategy

The appropriate battery selection is one of the most important criteria for storing renewable energy since they are in charge of storing sufficient energy produce by the hybrid. Also when there is a low period, and the system does not produce enough energy, it is important that the battery is not discharged immediately with its consumption. Most common batteries used in residential sector are the VRLA (value regulated lead acid batteries) which are mostly maintenance free in desired conditions. They should be able to store power enough to regulate the house load for a day minimum or more and provide instantaneous superior power to support the instantaneous motor start supply for appliances such as pumps and refrigerator.

Since most of the residential sector run on a 12, 24, 48 volt charging system in the UAE, it is important that a battery of similar voltage is selected for the model house which supplies and stores sufficient power based on the demand and peak load profile. Thus a battery with 12V of 6 cells is selected with nominal capacity of 357 Ah for 20 hours for a house load of more than 20kWh demand load profile. Also they battery has a hybrid system design for a 5-7 days of autonomy. The depth of discharge (DOD) rate is also important since it is a perpetual value of energy extracted from a battery in a discharge which is in our selection is maximum 80%. All the above parameters are present in a Surrette 12CS11P battery and can be seen for Figure 4.13 as input parameter for HOMER prepared from the manufacturers technical specification. The battery size is around (l) 559mm x (w) 286mm x (h) 464mm and can be kept in a series of number of batteries simulated in the mechanical services room kept separate on the ground floor of the model house.

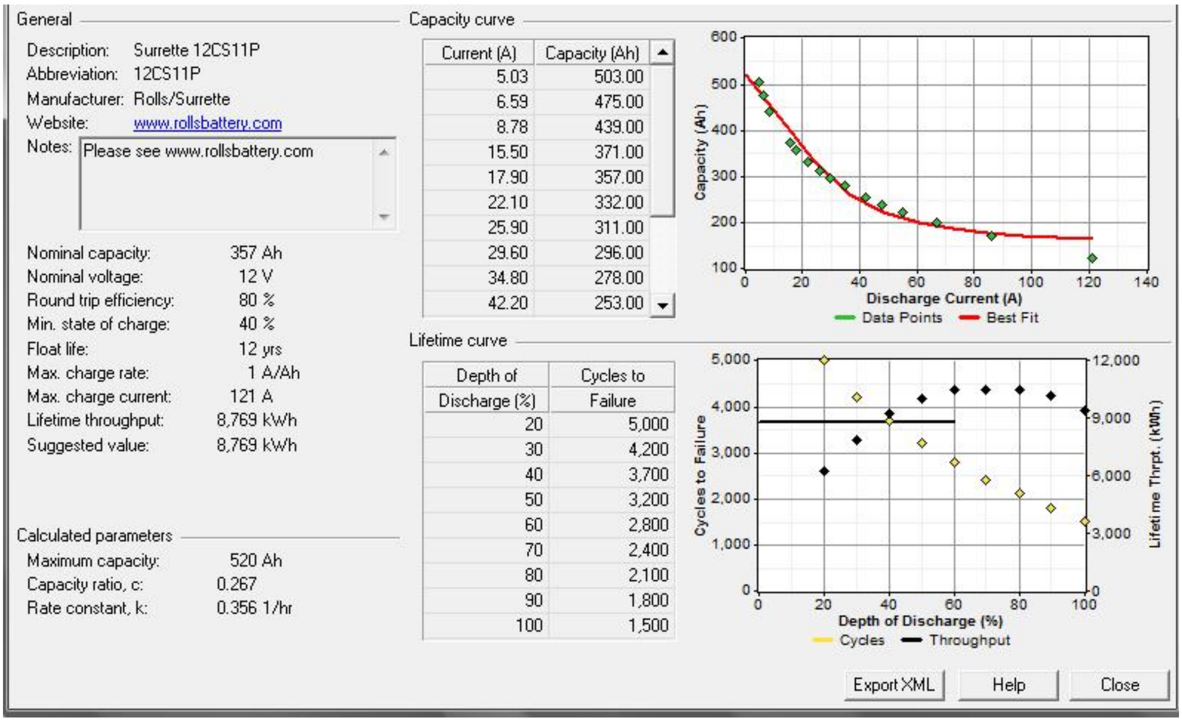


Figure 4.13: Battery Input for HOMER simulation software (Rolls Battery, 2011)

Note: Refer to manufacturers technical specification as per Appendix C

4.1.7 Charge Controller Selection Strategy

As mentioned in literature review, the job of a charge controller is to control the smooth flow of current from hybrid energy to battery and from battery to useful house appliance energy. Usually the charge controller needs to be rated 1.25 times the charging current that is specified by the manufacturer of the hybrid system. The controller must be able to hold the maximum expected charging current in batteries selected which in our case is 121A. Thus charge controller needs to hold about 151.25A charging current for the model house. Figure 4.14 illustrates the selected charge controller for the hybrid system model house.

Xantrex™ XW Solar Charge Controller

Electrical Specifications	
Nominal battery voltage	12, 24, 36, 48, 60 Vdc
Maximum PV array voltage (operating)	140 Vdc
Maximum PV array open circuit voltage	150 Vdc
Array short-circuit current	60 Adc maximum
Maximum and minimum wire size in conduit	#6 AWG to #14 AWG
Total power consumption while operating	2.5 W (tare)
Charger regulation method	Three-stage (bulk, absorption, float)
	Two-stage (bulk, absorption)

Figure 4.14: Charge controller Maximum Power Point Tracking 60-150A (Xantrex XW-MPPT60-150, 2011)

- Note: The HOMER software does not model the charge controller simple due to the fact that it assumes that the flow of current will be smooth based on the appropriate battery selection and its DOD.
- Refer Manufacturer Technical Specification as in Appendix C

4.1.8 Inverter/Converter Selection Strategy

For residential purpose the best choice for appliance is the “modified sine wave” inverter which can support variety of loads and the voltage output is not pure sinusoid as per our literature review. Purely since they deliver power more efficiently and reduce the harmonics and noise that may be problematic during certain load operations. Few factors which are considered while selected our inverter are their capability when there is a sudden splurge in current when supplied for starting of equipment motors or a short circuit that requires circuit cutoff. Better convergence efficiency for instantaneous power with a model that will operate of the times close to its nominal power. Certain loads again such as refrigerator, water pumps do not have control over when they start up and even if they all these loads run simultaneously our load demand shall not exceed or add up to 5500 Watts peak. Inverter performance at 70% of its nominal power at least. The Inverters should have the ability to switch automatically to an alternative source of current (grid, generator, solar) and also charging of batteries simultaneously.

The Xantrex XW6048-120/240-60 is a preferred choice as it has a continuous output power of 6000W, with a surge rate (10sec) of 12000W which can support heavy equipments and high power start up. It has an AC auto transfer switch with capabilities of the inverter being grid independent or grid interactive with 120/240V AC split phase operation. Better harmonics distortion of <5% with better load management by larger number of steps. Figure 4.15 illustrates the technical specification found suitable for the model house hybrid system simulation.

Electrical Specifications	
Model	XW6048-120/240-60
Continuous output power	6,000 W
Surge rating (10 seconds)	12,000 W
Surge current	L-N: 105 Arms (7 sec) L-L: 40 Arms (20 sec)
Waveform	True sine wave
Low-load efficiency	95%
Idle consumption - search mode	< 8 W
AC connections	AC1 (Grid), AC2 (Generator)
AC voltage	120/240 Vac split-phase
AC input breaker	60 A two-pole
Utility interactive	Yes
CEC weighted efficiency	92.5%
CEC power rating	5752 W
AC output voltage	L-N: 120 Vac +/- 3%; L-L: 240 Vac +/- 3%
AC output frequency	60.0 +/-0.1 Hz
DC current at rated power	130 A
Total harmonic distortion	< 5%
Automatic transfer relay	60 A
Typical transfer time	8 ms
DC input voltage (nominal)	50.4 Vdc
DC input voltage range	44 - 64 Vdc
Maximum continuous charge rate	100 A
Efficiency at maximum charge rate	89.4%
Power factor corrected charging	0.98

Figure 4.15: Technical Characteristics of Inverter selected (Xantrex, 2011)

4.1.9 Operation Load Profile for HOMER input

In order to prepare a demand load profile of the house model which is the most important input factors inside the HOMER software, it is critical that a baseline data set for 8,760 values representing the average electric demand be prepared. These values are expressed in kW, for each hour of the year for the period of 12 months. For our house model based in UAE we have prepared a manual load analysis specific to the region and the same has been analyzed in Section 4.1.3 which gives us a kWh/day electric AC load of 20.002kWh/day which we consider as the peak load profile for the day in the month which consumes most energy in the year. The same profile need not be prevalent for each month or each hour of the day in terms of usage and hence needs to be verified further to analyze the usage in spilt of 8,760 values for each hour throughout the year.

<u>Hourly Average Load Profile</u>

To plot the load profile of each month in a year, thus a load profile for each hour is worked out based on typical load profile analysis for a general house working culture for a family of 4 persons. Split in a 24 hour average load profile in a month certain assumptions are taken into consideration as follows ranging from 00:00am to 00:00pm at a 3 hour interval for simplification as per Table 4.10 assumption:

- 00:00am to 03:00am: These hours are most dormant hours when only certain load such as refrigerator, AC and outdoor lighting is under work and hence least load consumption of only 3.75% is taken into consideration of peak.
- 03:00am to 06:00am: Activity starts in the house with important daily works from say 6.00am and the usage of equipment and certain loads are measured at 8.5% approx.
- 06:00am to 09:00am: Before moving to work, the household activities are more for preparation which accounts to almost 13.5% with involvement of daily cores of cooking, bathing, light use in the bathrooms, exhaust fans, cooker, toasters, AC, refrigerator etc.
- 09:00am to 12:00pm: Due to most persons moving out of the house the activities of only certain movement left in the household is taken as assumption with a comparatively lesser activity for non-working class like children, servants etc. with slight reduction in electric load consumption to 12.5% approx though house is occupied at least 1 person and certain working loads.
- 12:00pm to 03:00pm: Due to high summer temperature levels the AC loads peak during this time and the conditioning is required at dormant occupancy conditions with a 14.5% as assumption

with children returning from school and occupying their respective rooms and equipment activities such as TV, DVD or computers working.

- 03:00pm to 06:00pm: Low activity is considered during such dormant house between these hours similar to period from 9.00pam to 12.00pm as it is resting time with only certain operating loads during this phase.
- 06:00pm to 09:00pm: Since the household is full with 100% occupancy and heavy activity including kitchen, living and bedrooms almost occupied with different equipments including high AC loads the assumption is the highest of 25% for these hours considering the return of working class to the household.
- 09:00pm to 12:00pm: Activity slows down with from 9.00pm onwards and hence the percentage gradually reduced from 8.5% onwards close to 12.00pm with dormancy again taking toll.

Note: The load profile is validated with the similar load profile in UAE region by the DEWA government as can be seen in Appendix C for the electricity bills taken from a similar house hold size and works.

.

Table 4.10: Typical Hourly Electric Load Profile Assumption for House Model (Paatero and Lund, 2006)

No.	Hours Per Day	Hourly Load (kW)	3 Hour (%)	3hr Interval Total (kW)
1	00:00 - 01:00	0.21255	3.744493392	0.82875
2	01:00 - 02:00	0.18525		
3	02:00 - 03:00	0.43095		
4	03:00 - 04:00	0.4095	8.370044053	1.8525
5	04:00 - 05:00	0.63765		
6	05:00 - 06:00	0.80535		
7	06:00 - 07:00	1.22655	13.48898678	2.98545
8	07:00 - 08:00	0.9399		
9	08:00 - 09:00	0.819		
10	09:00 - 10:00	0.8385	12.84581498	2.8431
11	10:00 - 11:00	0.96525		
12	11:00 - 12:00	1.03935		
13	12:00 - 13:00	1.34745	14.34361233	3.1746
14	13:00 - 14:00	1.01205		
15	14:00 - 15:00	0.8151		
16	15:00 - 16:00	0.77415	12.89867841	2.8548
17	16:00 - 17:00	0.79755		
18	17:00 - 18:00	1.2831		
19	18:00 - 19:00	2.40045	25.63876652	5.6745
20	19:00 - 20:00	1.95585		
21	20:00 - 21:00	1.3182		
22	21:00 - 22:00	0.936	8.669603524	1.9188
23	22:00 - 23:00	0.585		
24	23:00 - 00:00	0.3978		
	Total AC Load (kWh/day)	**22.1325**	**100**	**22.1325**

Note: The above hourly electric house load profile has been modified to suit the house work profile of UAE, Dubai. The above load profile presents a modified version of load profile model provided by (Paatero and Lund, 2006). Refer the following information for further study details: Jukka V. Paatero and Peter D. Lund. 2006. A model for generating household electricity load profiles.
(http://lib.tkk.fi/Diss/2009/isbn9789522481252/article1.pdf)

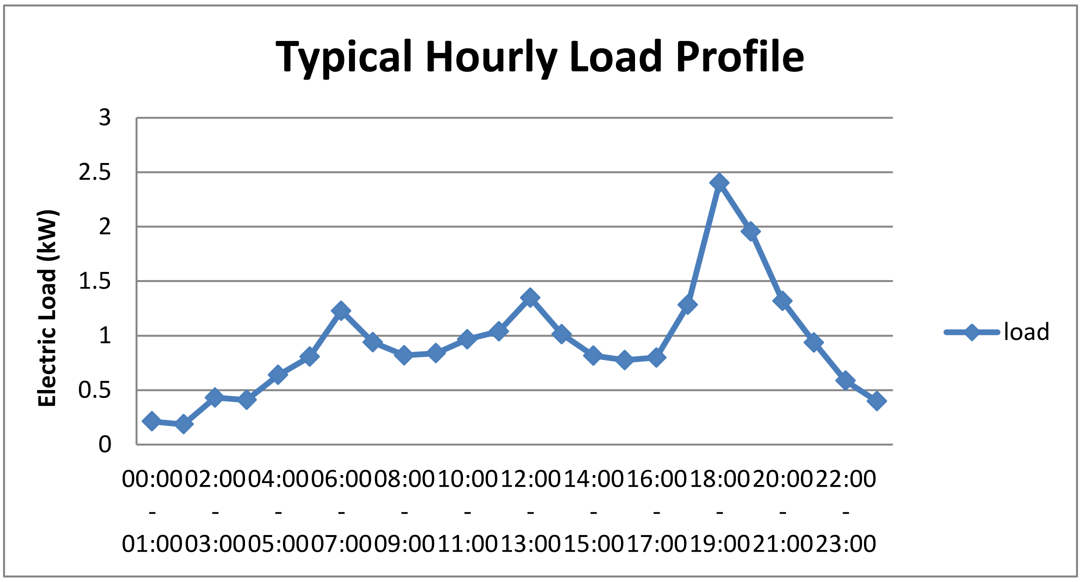


Figure 4.16: Typical Hourly Load Profile Graph

Monthly Average Load Profile

Once the daily load profile is plotted the same is scaled to for the monthly load proflie based on seasonal variation in the UAE reagio for the house model. Considering winter season the moslty in December to January the baseline data is shows a load profile of 14.7kWh/day average. Peak summer season in the months of June, July and August indicates a average monthly peak electrci load profile of 22.1kWh/day. And the rest of the month are scaled proportionately according to the seasonal variation spanning from peak summer to peak winter as indicated from Figure 4.16 with respective average electric load profile reading in kWh/day.

All these monthly profile and hourly data is then fed into the HOMER software with calcuted the hourly and daily noise to accommodate variation in randomness to make it more realistic. Percentage for hourly noise and daily noise can be seen from HOMER input parameters as 20.0% and 15.0% respectively as shown in Figure 4.18 respectively. The data scales the baseline to form a average peak load profile of 18.0kWh maximum and calculates the peak hourly load demand for 3.8kW to 3.9kW. Final graph for realistic load profile can be seen from Figure 4.17.

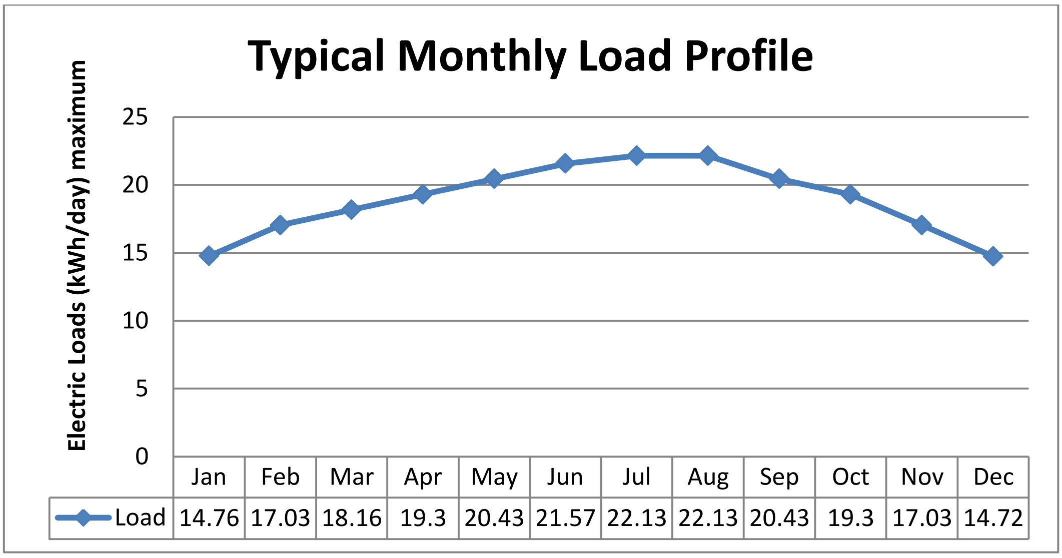


Figure 4.17: Typical Monthly Load Profile Graph Manual Assumption.

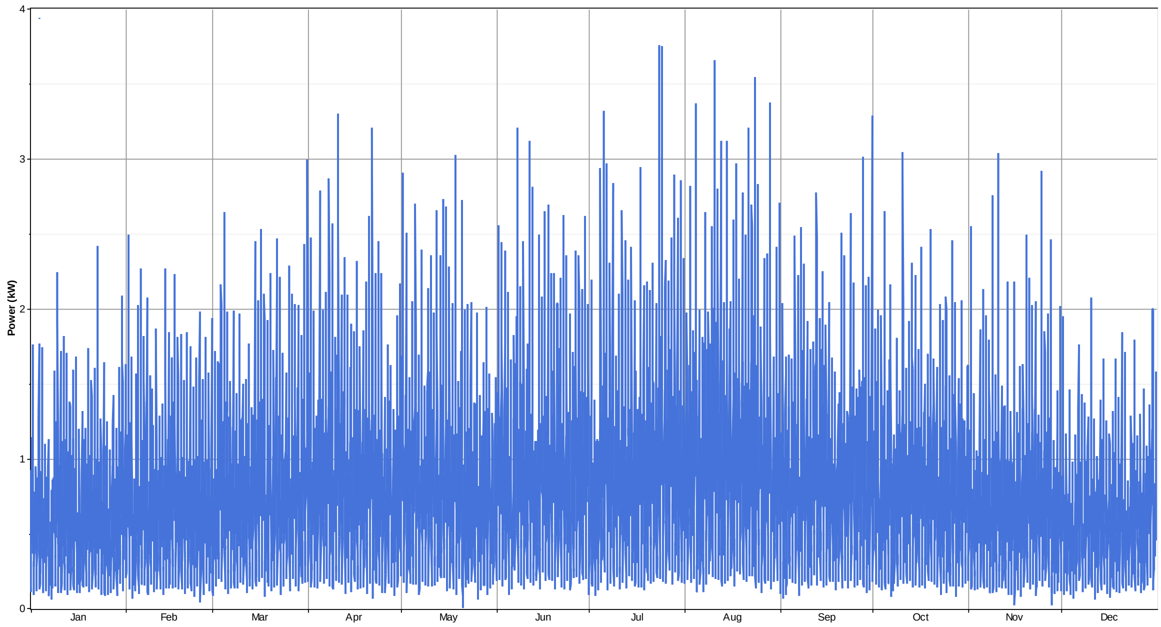


Figure 4.18: Hourly Load Profile as Monthly Average (HOMER software inputs).

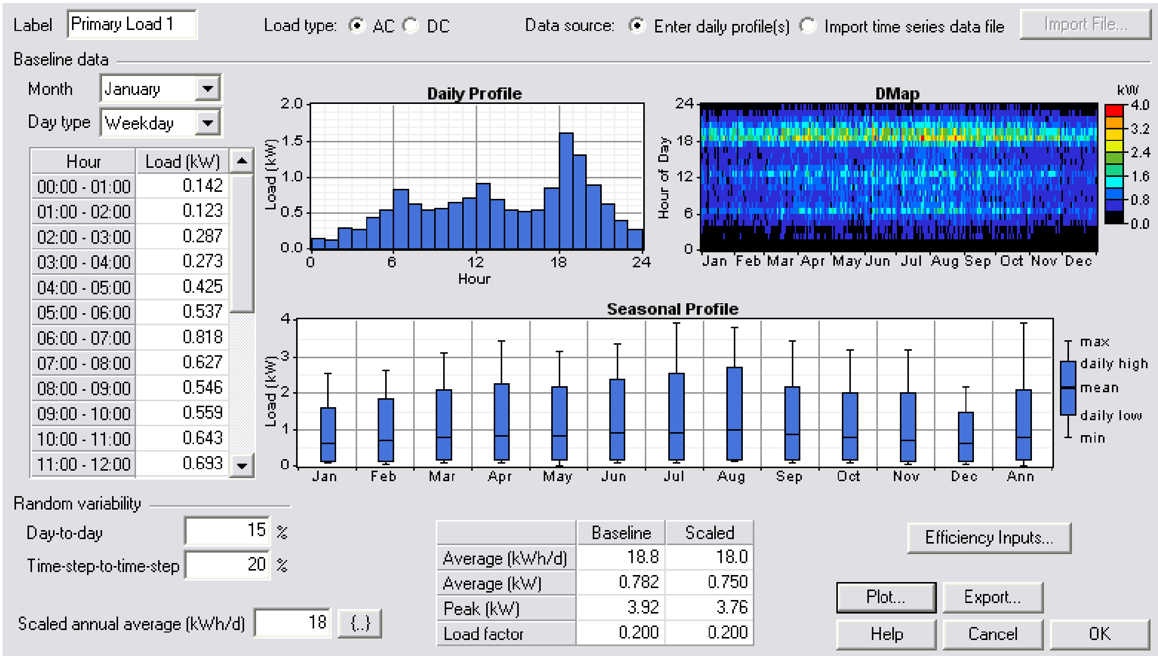


Figure 4.19: Monthly Load Profile as inputs in HOMER software.

4.2 SIMULATION CASE CONFIGURATIONS

The energy output potential of the PV panels and wind turbines needs to be validated separately before putting up a case of hybrid simulation. For this the base case is considered as “No Renewable Energy” for the house model as per Table 4.11 whereby the complete electrical supply energy is provided by the local grid connection.

Table 4.11: Simulation Base Case Study Configuration (No Renewable Energy Systems)

Type of Energy System	**Selection Criteria Reference**	**Output Units**	**Notes**
Base Case: 100% Energy Output to Model House			
No Renewable Energy	See Table 4.10	kW	1. 100% Energy Supplied by Grid or Generator

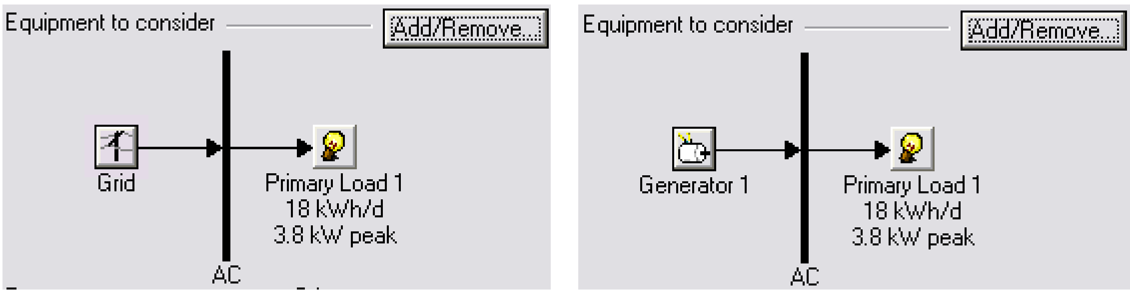


Figure 4.20: Base Case: No Renewable Energy Output to Model House in HOMER software.

a. Primary Load supplied by the available Local Grid Connection
b. Primary Load supplied by Generator incase of non availability of Local Grid Connection.

In case the local grid connection is not available to the site due to non availability of transmission lines or needs more cost to provide long distance from the closest available transmission lines possibility of using of generator could also be explored for comparison purpose. This also one of the problems faced by UAE since development is happening as a far rapid pace and sometimes suburban master planning cannot support long distance transmission lines which require higher cost and are finally to be borne by the developer. This affect the final outcome of final buyers who have to shell extra costs leading to diesel used generators causing more carbon and greenhouse emissions.

Thus in order to analyze this non renewable energy case, the following parameters shall be studied from the HOMER software for validation of the total costs and emissions in comparison to renewable energy usage.

- Off Peak Rates
- Shoulder Rates
- Peak Rates
- Carbon Emission
- Other Green House Gases Emissions

Further to compare the benefits of individual renewable energy output potential prior to combining both, in order to justify the cause of hybridization needs to be simulated. Thus to simulate the individual case configurations as mentioned in Table 4.5, the following "PV Renewable Energy System" as shown in Table 4.12 is tested to its full potential with HOMER input parameters as shown in Figure 4.20 with system connection variation.

Table 4.12: Simulation Case Study Configuration (PV Model Renewable Energy Systems)

Type of Energy System	**Selection Criteria Reference**	**Output Units**	**Notes**
PV Model Case: 25% to 100% Energy Output to Model House			
Poly-Crystalline (PV)	See Table 4.4	kW	1. 75%-25% of Balance Energy supplied by Grid Connection/Generator. 2. For 100% and surplus System to be Standalone.
Batteries	See Figure 4.13	Number	
Inverter/Converter	See Figure 4.15	kW	

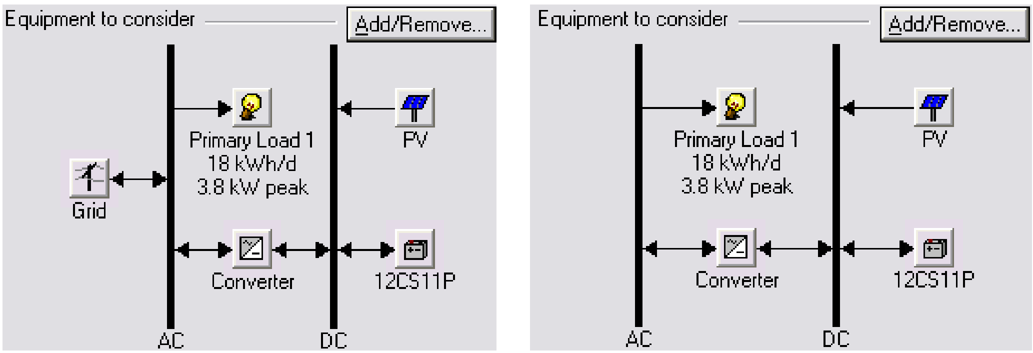


Figure 4.21: PV Model Case: Renewable Energy Output to Model House in HOMER software.
a) PV Model Connected to Grid with variation from 25% to 75% energy output potential
b) PV Model Standalone with 100% and 100% surplus energy output potential

Similarly the "Wind Turbines Renewable System"is simulated by the following HOMER input parameters as shown in 4.21 and case configuration matrix Table 4.13 to verify and validate its full potential in the specified climatic condition with system connection variation similar to PV model.

Table 4.13: Simulation Case Study Configuration (Wind Turbine Renewable Energy Systems)

Type of Energy System	**Selection Criteria Reference**	**Output Units**	**Notes**
Wind Turbine Model Case: 25% to 100% Energy Output to Model House			
1kW Wind Turbine	See Table 4.8	kW	1. 75%-25% of Balance Energy supplied by Grid Connection/Generator. 2. For 100% and surplus System to be Standalone.
Batteries	See Figure 4.13	Number	
Inverter/Converter	See Figure 4.15	kW	

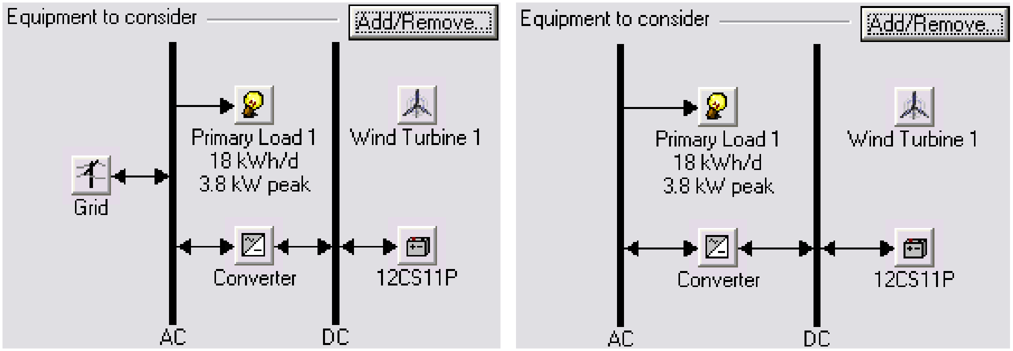


Figure 4.22: Wind Turbine Case: Renewable Energy Output to Model House in HOMER software
a) Wind Turbine Connected to Grid with variation from 25% to 75% energy output potential
b) Wind Turbine Standalone with 100% and 100% surplus energy output potential

Hybrid Case Configuration

Once the individual system are verified and validated the same shall be form the basis of hybridization of PV model and Wind Turbine Model for further case configuration simulation. The optimized results for both individually shall be compared to the reading obtained by the hybrid configuration. Table 4.14 illustrates the final hybrid case configurations for analysis in the HOMER software as seen in Figure 4.22.

Table 4.14: Simulation Case Configuration (Hybrid Model Renewable Energy Systems)

Type of Energy System	**Selection Criteria Reference**	**Output Units**	**Notes**
Hybrid Model Case: 25% to 100% Energy Output to Model House (Figure 4.19)			
Poly-Crystalline (PV) and Wind Turbine	See Table 4.4 and Table 4.8	kW	3. 75%-25% of Balance Energy supplied by Grid Connection/Generator. 4. For 100% and surplus System to be Standalone.
Batteries	See Figure 4.13	Number	
Inverter/Converter	See Figure 4.15	kW	

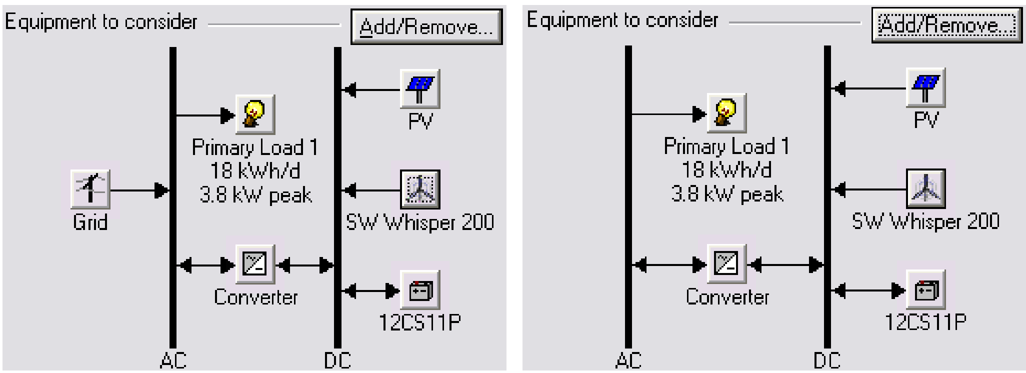


Figure 4.23: Hybrid Case: Renewable Energy Output to Model House in HOMER software
a) Hybrid Connected to Grid with variation from 25% to 75% energy output potential
b) Hybrid Standalone with 100% and 100% surplus energy output potential

The following parameters can be compared by the final outcome of the hybridization for both (solar energy and wind energy) renewable energy systems:

1. Amount of Photovoltaic Panels Required: kW

2. Number of Wind Turbines: Number of turbines

3. Output of the optimized PV panels: kWh/year (monthly and hourly data)
    - Rated capacity: kW
    - Mean output: kW
    - Mean output: kWh/d
    - Capacity factor: %
    - Total production : kWh/yr
    - PV penetration: %
    - Hours of operation: hr/yr

4. Output of the optimized Wind Turbine number: kWh/year (monthly and hourly data)
    - Rated capacity: kW
    - Mean output: kW
    - Mean output: kWh/d
    - Capacity factor: %
    - Total production : kWh/yr
    - Wind Turbine penetration: %
    - Hours of operation: hr/yr

5. Batteries required: Number
    - String size: Number
    - Strings in parallel: Number
    - Bus voltage : V
    - Nominal capacity: kWh
    - Usable nominal capacity: kWh
    - Autonomy: hr
    - Lifetime throughput: kWh
    - Energy: kWh/yr
    - Energy out: kWh/yr
    - Storage depletion: kWh/yr
    - Losses: kWh/yr
    - Annual throughput: kWh/yr

6. Inverter/Converter: kW
    - Hours of operation: hrs/yr
    - Capacity factor: %
    - Energy in: kWh/yr
    - Energy out: kWh/yr
    - Losses: kWh/yr
    - Minimum output: kW
    - Maximum output: kW

4.3 MODELING PROCESS

The following describe the different modeling stages that will be carried out for the study:

- Creating a House Model: Designing an appropriate house design to suit the conditions of the local UAE lifestyle and characteristics shall be built in AUTOCAD with a 3D shall be prepared in Google Sketch up (Refer Chapter 4 Figure 4.1 to Figure 4.4). The same model is studied in ECOTECT to analyze the parameters such as Sun-path and Wind rose to identify the potential of solar and wind energy.
- Passive Design Parameter: Appropriate passive design techniques such orientation, material use and thermal properties are studied using Estidama as baseline with model study in ECOTECT generically and as literature review basis.
- Creating a Load Profile: In order to obtain the electric demand load characteristics of the house model first manually by means of identifying equipment and appliances number, its respective loads, usage per hour so as to calculate the energy demand per day. The same load profile is then analyzed as input parameters in HOMER software to verify the true monthly and yearly final electric loads. Care is taken for appropriate selection of energy efficient alliances and equipments based on literature from US. DOE website for suitable Energy stars ratings.
- Project Profile: The various hourly profile of the house model as described in Table 4.10 is calculated based on lifestyle pattern of a typical household in UAE. Timings for use of equipment, lighting and AC are assumed from literature review of a typical household usage profile.
- Defining Model Parameters: Renewable energy potential is identified from NASA SSE Database for solar and wind energy potential based on the sites latitude and longitude. The same inputs are then validated using software ECOTECT to nullify major reading errors. Finally use of HOMER software input parameters for the solar and wind energy resources is done.
- Build Schematic: The various case configurations can be built as schematics in the HOMER software to test and compare no renewable energy versus use of renewable energy and hybridization with its Add/Remove Component Tool. Options such as inclusion of Primary Loads, Components referring to renewable energy (PV, Wind, Hydro, and Biomass) and non renewable energy such as generators, Balance of system components (batteries, converter) with multi tasking and comparisons leading to Grid Connection, Off Grid is possible.
- Examine Optimization Results: Automatic discard of the results which are infeasible system configuration is done by HOMER and the overall best combination of system configurations are indentified separately to be further sensitized and scrutinized.
- Refining Optimization: It is possible to validate and re-scrutinize the overall systems best configuration with tools such as amount of energy produced charts from each system and excess energy identification which can be re-simulated to further fine tune results.
- Sensitivity Variable: The sensitivity analysis in HOMER allows the user to simulate the variation in different components such as PV module panel values, wind speeds, demand load constraints etc can be further add dynamics to optimized results.
- Final Outcome: HOMER software shall form the basis of final result outcome with its renewable energy validation and hybridization of the same renewable individual energy systems with further for resource inputs from ECOTECT manually.

4.4 MODEL VALIDATION

The HOMER software uses most of its data which are manually fed into, using input resources of various system configurations from the NASA SSE database. In order to verify the same and avoid unwanted resource inputs errors for solar and wind power ECOTECT software is used. Similarly the house demand load profile can be validated using an electronic load profile calculator from the website.

Load Profile Validation

Description	Electricity consumed per month (kWh)
Microwave Oven - 1350W	6.075
Rice Cooker - 600W (2 to 4 persons)	9
Oven Toaster - 600W	2.7
Energy Efficient - 18W	38.88
Energy Efficient - 18W	38.88
Energy Efficient - 9W	12.96
Refrigerator - Frost Free (400 litres)	27
Air Conditioner - System 4	305.1
Electric Fan - 50W (Box Type)	0.75
Colour TV - 26	48
Hi-Fi System (2 x 50W)	18
VCR/VCD/DVD Player - 15W	2.7
Notebook - 50W	24
Printer - 75W	0.3375
Electric Iron (Conventional) - 1000W	15

Figure 4.24: Reading obtained from an “Electronic Web-Based Calculator” for typical house electric load consumption profile (Source: http://services.spservices.sg/cs_services_energy-audit.asp)

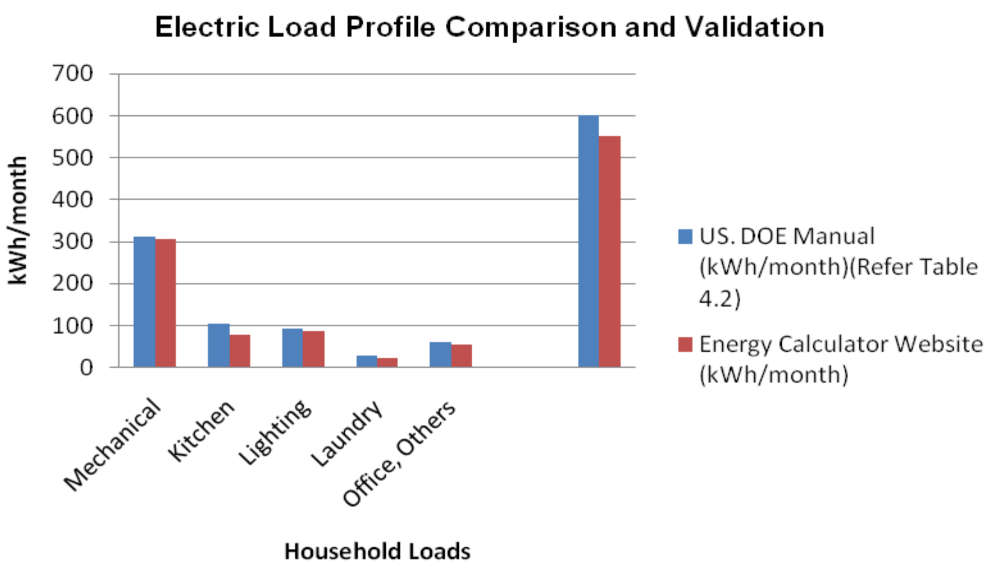


Figure 4.24: Load Profile Validation (Manual Calculation, Ref. Table 4.2 versus Web-based electronic calculator)

The minor variation between the two comparatives is due to the fact that not all equipments are considered by the web-based electronic calculator such as water pump, dishwasher, small power etc. The manual used table is more specific to the usage in the UAE household in terms of capacity and lifestyle where as the web-based calculator generalizes certain criteria's with more basic assumptions. Detailed assumptions in terms of hours of the days are also slightly different as compared to our manual based table.

Solar Energy Resources Validation

Following is the validation and comparison of the NASA SSE database with ECOTECT software based solar resource data:

Table 4.15: Solar Radiation (NASA SSE Database, 2011)

Maximum Radiation Incident On An Equator-pointed Tilted Surface (kWh/m^2/day)

Lat 27.76 Lon 50.32	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
SSE MAX	4.45	5.21	6.19	7.16	7.89	8.11	8.11	7.47	6.83	5.96	4.76	4.05	6.35
K	0.69	0.68	0.67	0.68	0.71	0.71	0.72	0.70	0.71	0.73	0.71	0.68	0.70
Diffuse	0.72	0.99	1.30	1.53	1.62	1.67	1.56	1.51	1.20	0.83	0.72	0.73	1.20
Direct	6.76	6.95	7.14	7.65	8.45	8.87	8.80	8.45	8.36	8.23	7.02	6.33	7.76
Tilt 0	4.34	5.17	6.12	7.01	7.86	8.08	8.08	7.43	6.73	5.91	4.63	3.98	6.28
Tilt 12	5.27	5.95	6.62	7.20	7.71	7.80	7.86	7.46	7.14	6.72	5.54	4.89	6.68
Tilt 27	6.15	6.63	6.91	7.07	7.16	7.08	7.20	7.13	7.29	7.37	6.39	5.78	6.85
Tilt 42	6.66	6.91	6.82	6.56	6.26	6.01	6.18	6.44	7.03	7.58	6.86	6.33	6.64
Tilt 90	5.62	5.21	4.16	2.94	2.15	1.85	1.95	2.57	3.82	5.39	5.62	5.50	3.89
OPT	6.79	6.92	6.92	7.20	7.86	8.08	8.08	7.48	7.30	7.58	6.95	6.50	7.31
OPT ANG	54.0	45.0	31.0	15.0	0.00	0.00	0.00	7.00	25.0	42.0	52.0	56.0	27.1

NOTE: *Diffuse radiation, direct normal radiation and tilted surface radiation are not calculated when the clearness index (K) is below 0.3 or above 0.8.*

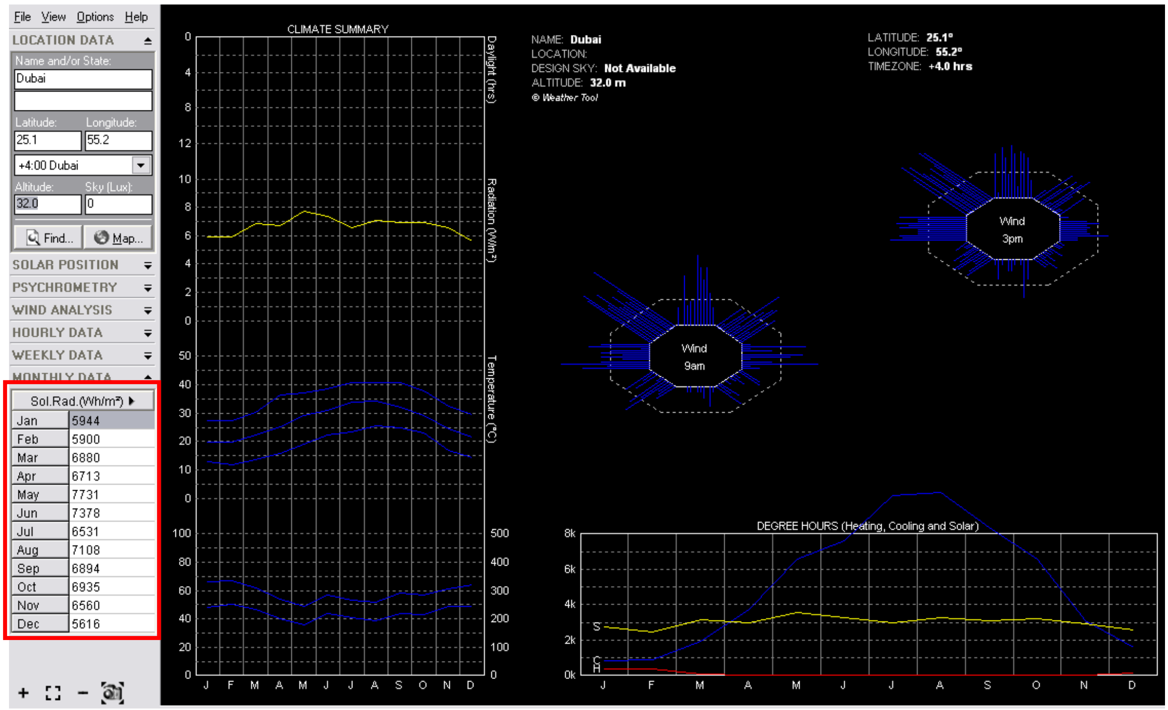


Figure 4.25: Solar Radiation Data (ECOTECT, 2011)

It is important to note that the comparison as per Figure 4.26 has to be done with respect to the maximum solar radiation in ECOTECT versus the optimized solar radiation availabe from NASA SSE Database with respect to the tilt angle. Only this table from the source gives us the optimized/maximum solar radaition which is comparible to ECOTECT maximum solar radiation data as the software already calculated the best oreinetation and tilt suitable to the location.

Also there are variation due to the fact that NASA SSE provides the solar radiation specific to the (latitude 27.76º (27º45' N) and longitude 50.32º (50º19' E) of the site location, where as ECOTECT generalises the reading for the Dubai, UAE as a region with latitude 25.1° and longitude 55.2°.

Note: HOMER software uses 8,760 values from NASA SSE Database which represent the average global solar radiation indicent on the horizontal surface for each year and separate tool and parameter identifies the optimised tilt angle solar radiation data which is scaled to suit the tilt angle with its inbuilt input window.

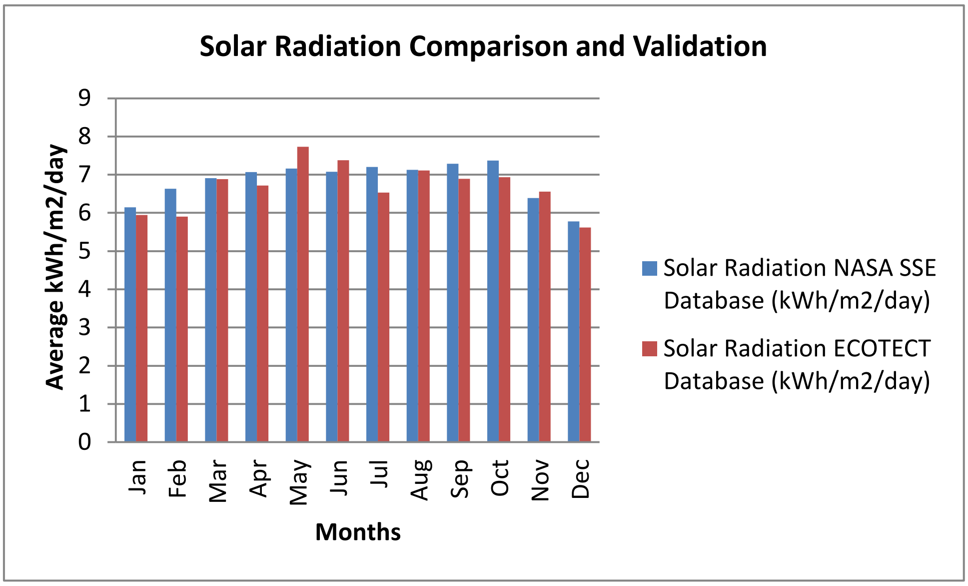


Figure 4.26: Solar Radiation Validation (NASA SSE Data versus ECOTECT software)

Best Orientation

Figure 4.27 indicates the best orientation chart as per ECOTECT software showing angles based on solar radiation received in the coldest 3 months (blue) and the warmest 3 months (red) along with the entire year (green). The objective of this orientation to gain maximum solar radiation as possible in the winter when heating is required and reject summer solar radiation. But since UAE being more in the north eastern hemisphere it is advisable to reject most of the heat gain during summer which is oriented in the 185° south. Hence most of the primary rooms are placed northwards to avoid unnessecary heat gain.
It is important to understand that ECOTECT orientation tool is design for heating purpose towards more southern hemisphere and for northern hemisphere the orientation is more suited for cooling purpose and hence opppsite directions are more suitable as best orientation.

Figure 4.28 illustrates the best location and validation by ECOTECT for placement and tilt angle of PV panels on the roof of the house model.

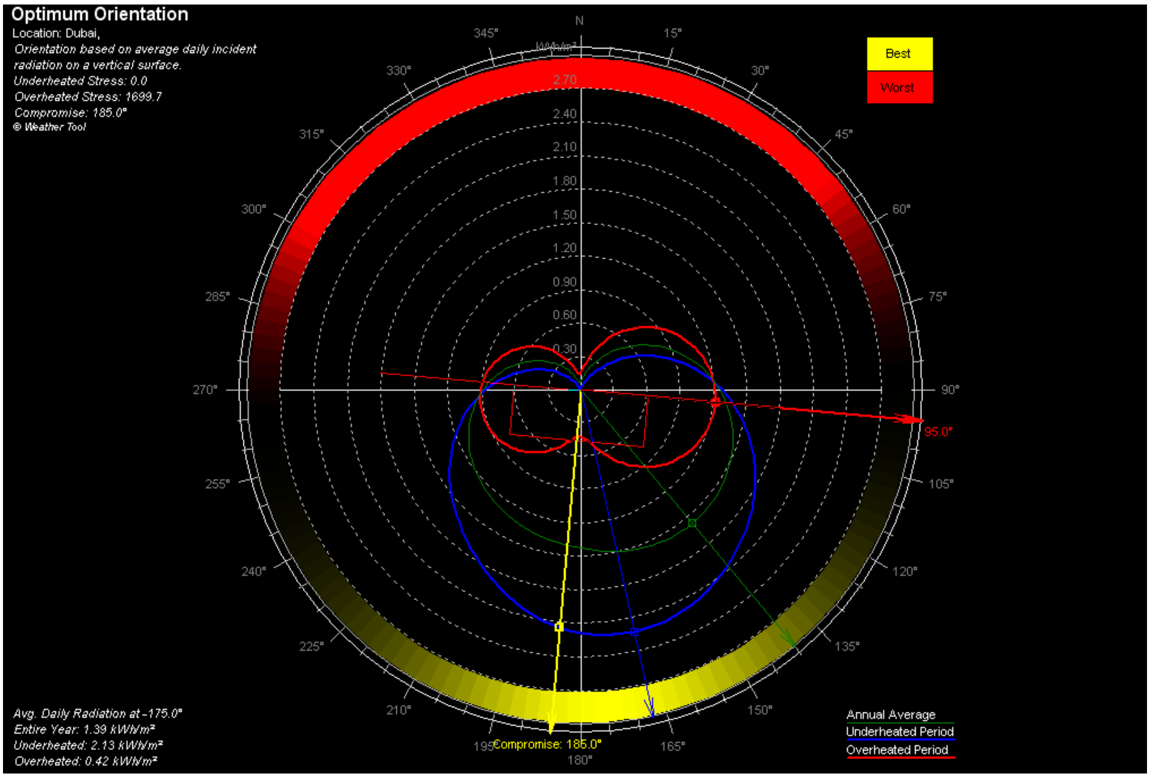


Figure 4.27: Best Orientation (ECOTECT)

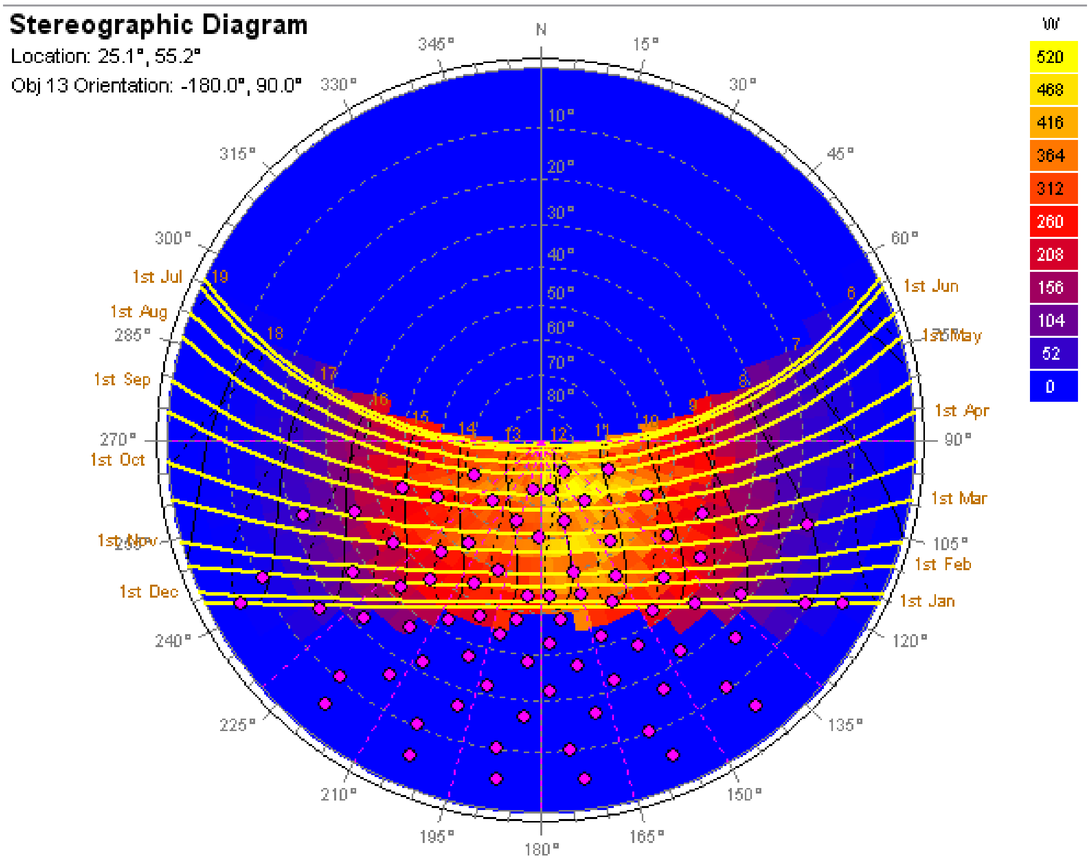


Figure 4.28: Stereographic Sun Path diagram illustrating daily solar radiation and vertical sky factor components on roof surface for PV panels (ECOTECT)

CHAPTER 5: TECHNICAL RESULTS AND DISCUSSION

The following chapter discusses the various simulation results which have been outlines in the previous chapter by the formation of model and configuration. The first section shall outline the supply of power to the house model with a non renewable energy resource which will form the basis of our comparison with various renewable recourse parameters. In order to simulate the supply of electric power for the house model to function as a working household by means of local grid connection and also a diesel generator will provide us the inputs as to how much electric power is taken from the local grid and the generator capacity shall be validated. Following the discussion of these shall be further compared to PV panel and Wind turbine electric energy output to the model house with same demand electric load profile. Finally a hybrid of PV and Wind turbines shall be assessed to compare the feasibility of this system in comparison to the entire configurations and optimized to obtain technical results. Economic analysis of all the configurations shall be done in the next chapter separately.

It is important to note that though simulation software HOMER evaluates results based on economics, the current chapter analysis technical results first, whereby the system is evaluated with most optimum renewable energy mix along with its balance of system components. Factors such as precise provision of complete primary load supply, unmet loads, capacity shortage, number of PV panels in kW, number of WT's, number of batteries and inverter capacity used shall form the basis of technical optimized evaluation.

5.1 BASE CASE CONFIGURATION ASSESSMENT (NO RENEWABLE ENERGY)

The main purpose of assessing the non renewable resource to find the amount harmful gases which are emitted by the use of diesel in power generation plants which supply electric power to the local grid connection or the generators which are used in certain cases where no local grid supply power transmissions is possible. Also the long distance transmission power lines put heavy financial burden to local authorities included power losses in certain cases. Apart from a comparison to the provision of electric supply to the household such technical evaluation harmful to the environment by emission of unhealthy gases is important to the research objective.

5.1.1 Local Grid Connection

<u>Electric Power Supply Assessment</u>

We have already identified the electric demand load profile to be used in the HOMER software in the previous chapter with detailed analysis and validation. As per Figure 4.18 our house model average electric demand primary loads are 18.8kWh/day with a peak of 3.8kW. Based on the peak loads the model shall simulate the supply of power to the household as shown in Figure 5.1.

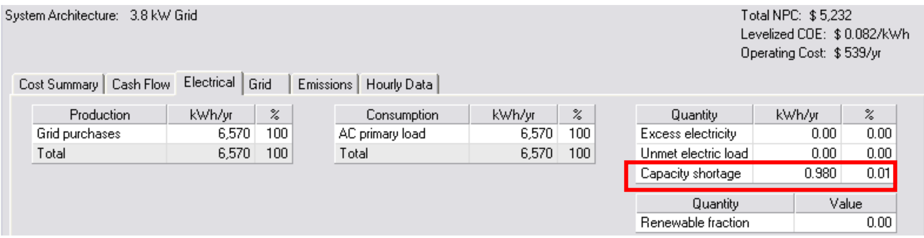


Figure 5.1: Yearly Electric Power Production from Local Grid Connection at 3.8kW peak power requirement.

As per Figure 5.1 results even though the power requirement is 3.8kw peak, it is seen that there is a capacity shortage of 0.0980kWh/yr (0.01%). This could be for various reasons such as certain calculation for startup peak loads for equipments such refrigerator compressor or mainly AC compressors, water pumps etc run by the HOMER software. Also possibilities of certain loads required during the month of July and August which requires more that 22.135kWh/day (Table 4.10), thus would require higher peak power readings for the household in those peak months. Important factor to note here is that even though the software scales the average load profile yearly, the final peak power calculated and run by the software is more realistic. Hence it cannot be generalized that the grid connection output shall be the same as the peak power requirements run by the software but instead it runs a good 8,760 values which are every hour of the year to obtain accurate results.

In order to further assess the realistic grid connection electric power supply the model was run beyond the 3.8kW peak power requirement such as (4.0kW to 4.2kW). The simulation results identified that the capacity shortage was met as 4.2kW as per Figure 5.2 and this results shall form the benchmark peak power requirement i.e. 4.2kW with AC primary load of 6,570kWh/yr for the household electrical demand hereafter in our research parameters.

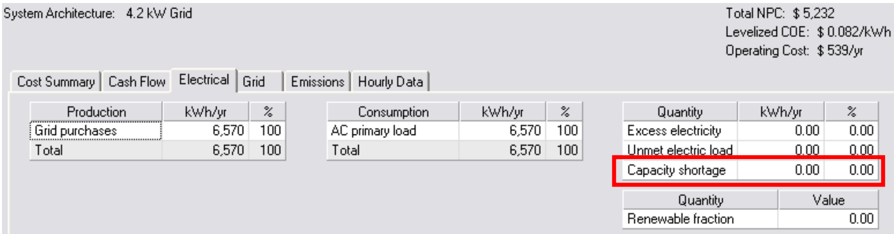


Figure 5.2: Yearly Electric Power Production from Local Grid Connection at 4.2kW peak power requirement.

The following Table 5.1 identifies the average monthly energy produced from the 4.2kW peak local grid connection supply based on the monthly primary electric load power requirement of the household model.

Table 5.1: Monthly Energy purchased from the Local Electric Grid Connection simulated by HOMER.

System Architecture: 4.2 kW Grid

Cost Summary | Cash Flow | Electrical | Grid | Emissions | Hourly Data

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
Jan	430	0	430	2	35	0
Feb	437	0	437	2	36	0
Mar	551	0	551	3	45	0
Apr	556	0	556	3	46	0
May	582	0	582	3	48	0
Jun	621	0	621	3	51	0
Jul	647	0	647	4	53	0
Aug	687	0	687	4	56	0
Sep	591	0	591	3	48	0
Oct	561	0	561	3	46	0
Nov	477	0	477	3	39	0
Dec	431	0	431	2	35	0
Annual	6,570	0	6,570	4	539	0

Figure 5.1 can be validated with Figure 4.16 illustrated, where the average monthly primary load profile has been calculated for maximum electric power requirement for the household in kWh/day.

5.1.2 Harmful Emission by Local Grid Connection

In order to assess the emission levels emitted by the local grid connection supplied by the local electric power plants station run on fossil fuels, it is important to find the typical value of these harmful gases emitted by the power plants. Table 5.2 illustrates the typical reading of harmful gases such as carbon dioxide, carbon monoxide, particulate matters (VOC), sulphur dioxide and nitrogen oxide emitted by the regions power plant station in g/kWh.

Table 5.2: Average Emission from Power Plants using fossil fuels (g/kWh) (EIA, 2010 and EPRI, 2010)

Carbon Dioxide (CO2)	Carbon Monoxide (CO)	Particulate Matter (VOC)	Sulphur Dioxide (SOx)	Nitrogen Oxide (NOx)
842	0.19	0.05	5.1	1.5

Note: Electric Power Research Institute (EPRI)

The above values are fed in the HOMER software to obtain the amount of these harmful gases emitted by the electric power supply from the local grid connection to the power requirements of the house model as shown in Figure 5.3.

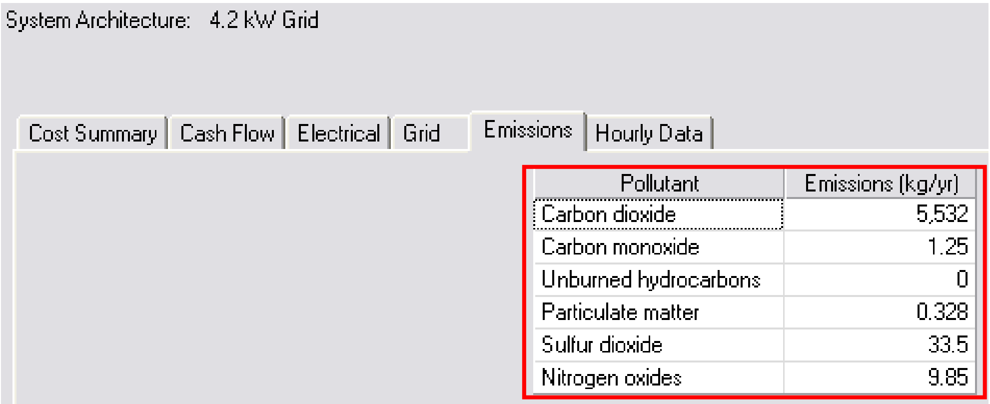


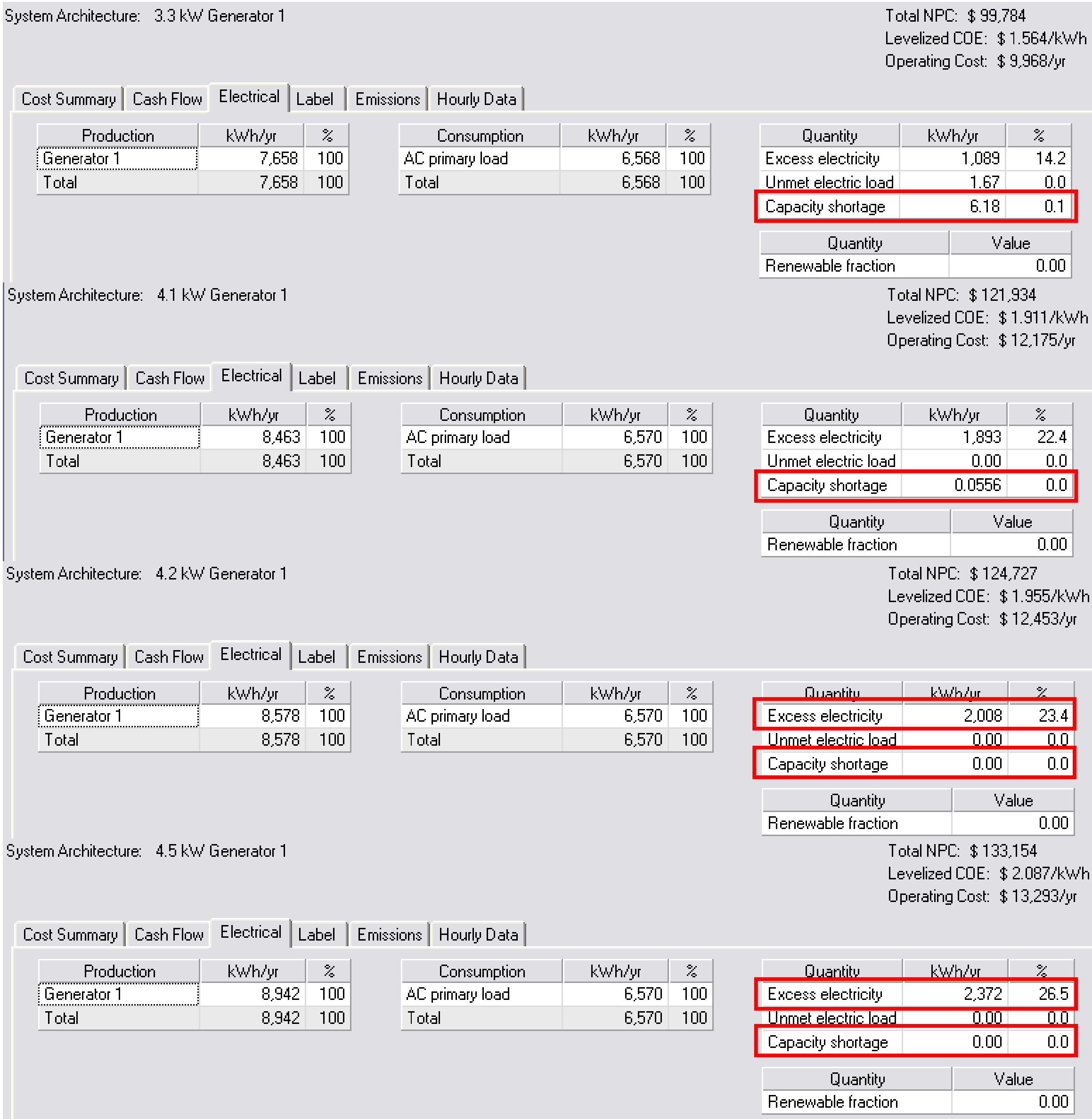
Figure 5.3: Harmful Emission to the environment due to the power supply from local grid connection using natural gas to the household model.

The results indicate that the 4.2kW of peak power output from the local grid connection emits carbon dioxide level of 5,532kg/yr, carbon monoxide of 1.25kg/yr, particulate matters (VOC) of 0.328kg/yr, sulphur dioxide of 33.5kg/yr and nitrogen oxide levels of 9.85kg/yr in to the local environment due to fossil fuel operated local electric power generation plant station.

5.1.3 Independent Onsite Power Generator Machine

<u>Electric Power Supply Assessment</u>

Similar to the case simulation of the local grid connection the assessment of power supply to the house with same electric primary load profile is done using an independent power generator machine which is also a non renewable energy resource run by diesel fuel type. The model was run from supply power requirements to the household ranging from 3.3kW to 4.5kW generator machine which lies between the average peak power requirement of the 3.8kW HOMER yearly load profile. Again since HOMER runs 8,670 values for each hour throughout the year it is necessary that such values are added as inputs to the software. This is to assess the realistic size of the generator machine providing power to the household for peak power requirement from lowest demand hour to the highest demand hour in the year. Figure 5.4 illustrates assessment from 3.3kW to 4.5kW peak power requirement to the household.



System Architecture: 3.3 kW Generator 1

Total NPC: $ 99,784
Levelized COE: $ 1.564/kWh
Operating Cost: $ 9,968/yr

Cost Summary | Cash Flow | Electrical | Label | Emissions | Hourly Data

Production	kWh/yr	%
Generator 1	7,658	100
Total	7,658	100

Consumption	kWh/yr	%
AC primary load	6,568	100
Total	6,568	100

Quantity	kWh/yr	%
Excess electricity	1,089	14.2
Unmet electric load	1.67	0.0
Capacity shortage	6.18	0.1

Quantity	Value
Renewable fraction	0.00

System Architecture: 4.1 kW Generator 1

Total NPC: $ 121,934
Levelized COE: $ 1.911/kWh
Operating Cost: $ 12,175/yr

Cost Summary | Cash Flow | Electrical | Label | Emissions | Hourly Data

Production	kWh/yr	%
Generator 1	8,463	100
Total	8,463	100

Consumption	kWh/yr	%
AC primary load	6,570	100
Total	6,570	100

Quantity	kWh/yr	%
Excess electricity	1,893	22.4
Unmet electric load	0.00	0.0
Capacity shortage	0.0556	0.0

Quantity	Value
Renewable fraction	0.00

System Architecture: 4.2 kW Generator 1

Total NPC: $ 124,727
Levelized COE: $ 1.955/kWh
Operating Cost: $ 12,453/yr

Cost Summary | Cash Flow | Electrical | Label | Emissions | Hourly Data

Production	kWh/yr	%
Generator 1	8,578	100
Total	8,578	100

Consumption	kWh/yr	%
AC primary load	6,570	100
Total	6,570	100

Quantity	kWh/yr	%
Excess electricity	2,008	23.4
Unmet electric load	0.00	0.0
Capacity shortage	0.00	0.0

Quantity	Value
Renewable fraction	0.00

System Architecture: 4.5 kW Generator 1

Total NPC: $ 133,154
Levelized COE: $ 2.087/kWh
Operating Cost: $ 13,293/yr

Cost Summary | Cash Flow | Electrical | Label | Emissions | Hourly Data

Production	kWh/yr	%
Generator 1	8,942	100
Total	8,942	100

Consumption	kWh/yr	%
AC primary load	6,570	100
Total	6,570	100

Quantity	kWh/yr	%
Excess electricity	2,372	26.5
Unmet electric load	0.00	0.0
Capacity shortage	0.00	0.0

Quantity	Value
Renewable fraction	0.00

Figure 5.4: Yearly Electric Power Production from Diesel Generator Machine ranging from 3.3kW to 4.5kW peak power requirement.

3.3kW and 4.1kW peak power supply generator shows a capacity shortage of 6.18kWh/yr and 0.0556kWh/year respectively which occurs in the months of July and August where the peak power supply is 22.1325kWh/day. Even though 4.2kW and 4.5kW peak power supply generator indicates the 0.0% of capacity shortage, the criteria for selecting the most suitable generator shall be based on excess electricity generation which is higher in 4.5kW generator with a reading of 26.5% which is 3.1% more than the 4.2kW generator which would count as wastage of electric generation to the household. The important factor to note here is that there will be excess electricity generated from the generator. Since the household is run on 24hr basis and there is no specific time to shut down the generator and hence the excess electricity generation to provide undivided power supply to the household at all times. Hence the 4.2kW diesel generator is more suitable for the household, which is similar to the peak power supply by the local grid connection as seen in Figure 5.2. Also this shall form the basis to compare the emission levels between the two non renewable resources with similar power supply output values. Figure 5.5 illustrates the efficiency values obtained every hour and month specific to the 4.2kW generator by the software.

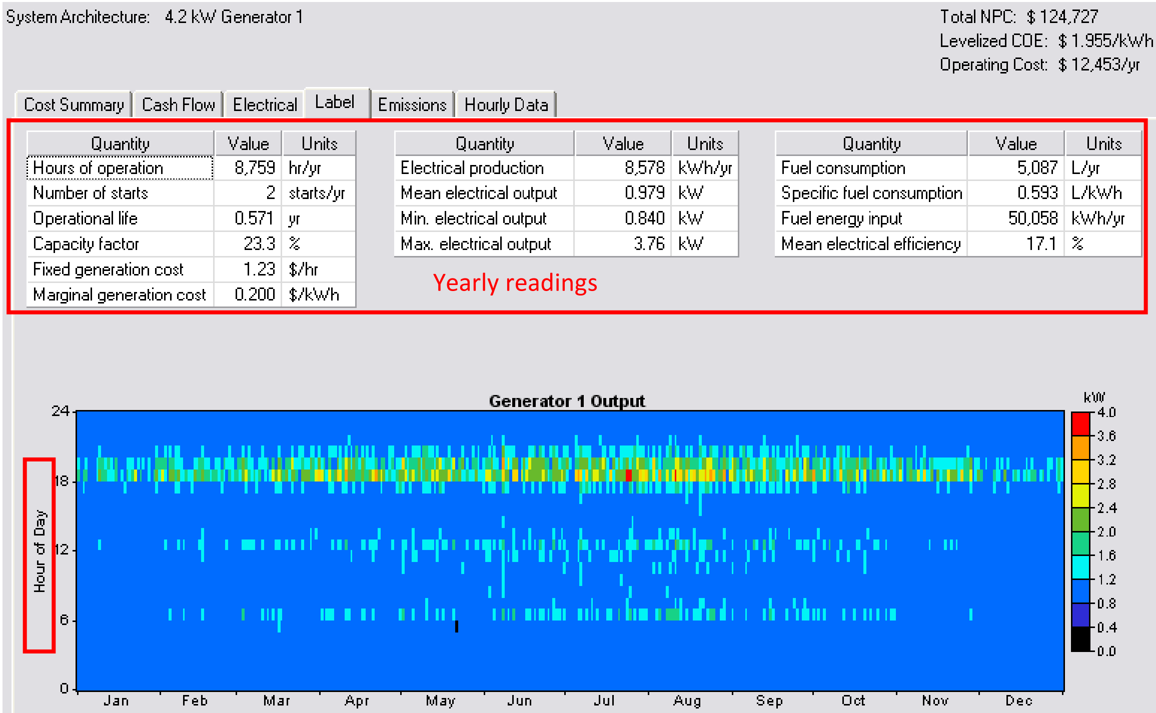


Figure 5.5: Table and Data Map illustrating 4.2kW peak power generator output values with hourly, monthly and yearly performance.

5.1.4 Harmful Emission by Independent Onsite Power Generator Machine

The assessment of the harmful gases emitted by the 4.2kW generator is done in a similar manner as explained during the process of local grid connection.

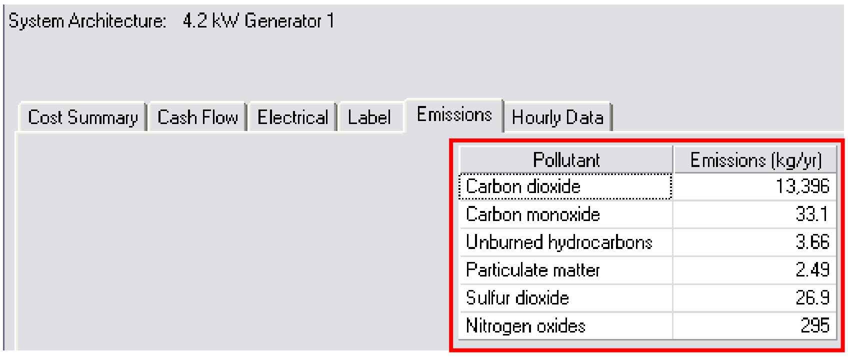
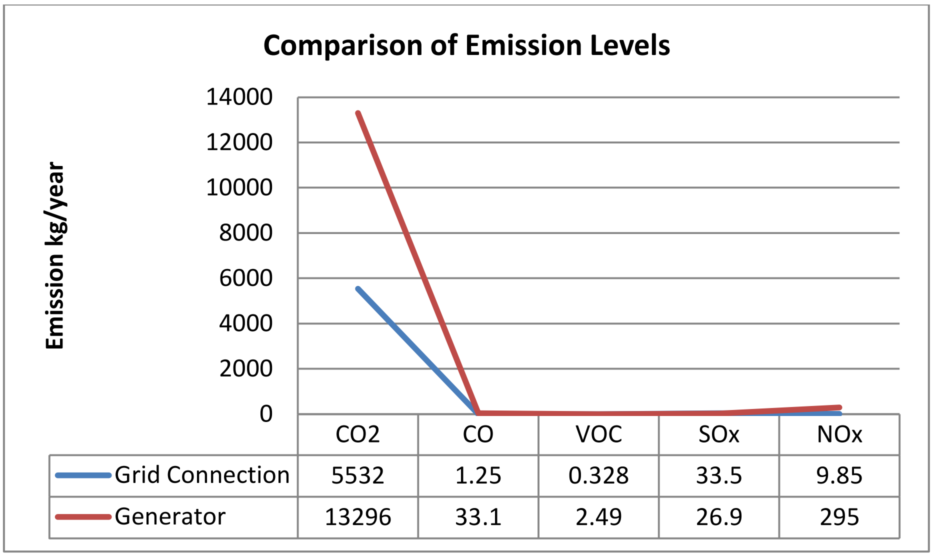


Figure 5.6: Harmful Emission to the environment due to the power supply from independent onsite power diesel generator to the household model.

It is assessed that the emission levels by comparing both the non renewable energy power supply sources, that the generator produces higher values of CO_2 and NO_x gases as shown in Figure 5.7. The CO_2 emission values are almost 13,396kg/yr emitted by the diesel independent house generator which is almost 2.4 times higher than the local grid connection. Similar the NO_x emission from diesel generator amounts to 295kg/yr which is 30 times more than the grid connection. Overall the house diesel generator scores much higher in terms of its typical emission levels emitted to the environment as compared to local grid connection in spite of supplying similar peak power output values of 4.2kW to the household. This is predominantly due to the use of different type of fuel such as natural gas for local grid connection and diesel for onsite power generation machine on remote places.



	CO2	CO	VOC	SOx	NOx
Grid Connection	5532	1.25	0.328	33.5	9.85
Generator	13296	33.1	2.49	26.9	295

Figure 5.7: Comparison of Emission (kg/yr) between local grid connection and generator with 4.2kW peak power supply to the model house.

5.2 PHOTOVOLTAICS (PV) MODULE CASE CONFIGURATION

PV modules shall be assessed based on the study case configurations as mentioned in Table 4.12 where by a step by step method of deriving power output from the PV module ranging from 25% to 100% grid connections first and then comparing it to 100% standalone and its surplus electrical output. The balance power shall be provided by grid connection which shall be run on the software simulation from 75% to 0% grid connection i.e. we have already assessed the maximum peak power required for the household as 4.2kW. Thus the grid connection purchase capacity in the software shall be modulated to assess the output of PV's and its electricity production capacity to the household. The software allows variation with the permutations and combinations for the balance of components such as number of batteries and converter with regards to its capacities and requirement hereby.

5.2.1 PV power output at 25% and balance Grid Connected

In order to evaluate this case the PV arrays were set from a minimum of 0.2kW to a maximum of 1.6kW initially with a step by step increment permutation of 0.2kW considering that the PV polycrystalline panels used are of 200W each single panel. Since the maximum grid connection required was 4.2kW (100%) as assessed earlier, the range of this purchase set to vary for grid connections, such as 4.2kW (100%), 3.15kW (75%), 2.1kW (50%), 1.05kW (25%). By this combination it would be assured that irrespective of the findings the household would be supplied with required primary loads to run smoothly throughout the year. Similarly batteries provision was set to vary from 0(no batteries) numbers to a maximum of 6 numbers initially. Converter also set ranging from 1kW converter with increment to a maximum of 6kW considering the peak power requirement is 4.2kW. The "Renewable Energy Fraction" which is the amount energy required from PV's was set to 25% so as to enable a correct evaluation.

<u>Electric Power Supply Assessment</u>

Figure 5.8 illustrates the best combination obtained from the above permutation and combinations run to achieve optimized results. Optimized results indicate the best combinations such as 4.2kW grid connection and 3.15kW grid connection since the renewable fraction set to minimum 25% as a constraint.

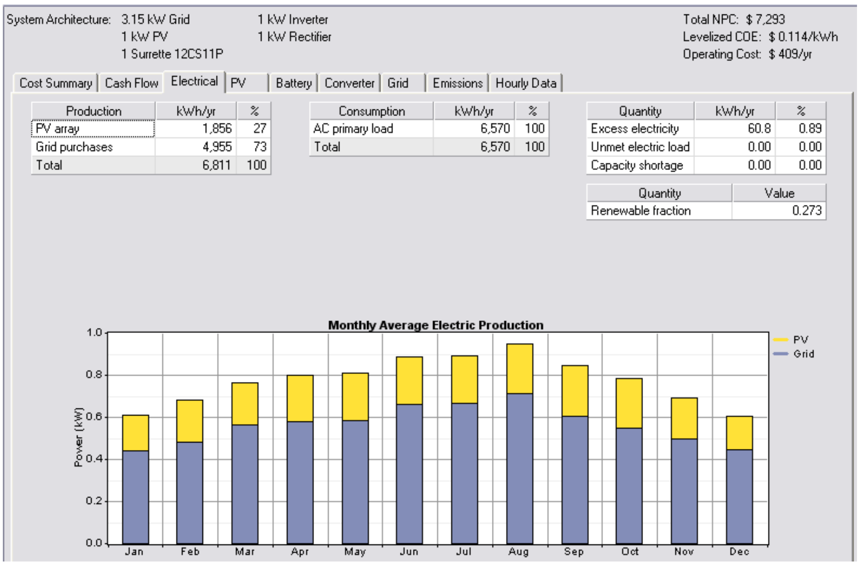


Figure 5.8: Yearly electric power production from 3.15kW (73%) grid connection and 1kW (27%) PV power output.

As per Figure 5.8 in order to achieve a 25% renewable energy fraction the required PV capacity is 1kW with a yearly production of 1,856kWh/yr amounting to 27% and a grid connection of 3.15kW with production of 4,955kWh/yr as balance 73%. The number of batteries required is 1 number, with a converter capacity of 1kW. The AC primary load is met for the household with a minor excess electricity production of 0.89% due to the surplus power produced by the PV's as in certain periods its minimum output exceeds the loads and the batteries are unable to absorb it all. **NOTE:** The software evaluates the readings based on optimized or minimum "Net Present Cost" (NPC) and hence if it economizes better to dump the excess loads in lieu of the cost, the software prefers this option. Though this excess could be captured in extra batteries or sold back to the grid with minor additional cost which shall be evaluated in chapter 6. But the current evaluation is technically analyzed as mentioned in this chapter's first paragraph.

Table 5.3 illustrates that the 27% PV power is optimized during the month of peak power demand such as July and August in comparison to the Table 5.1 showing peak grid power of 4kW each month which is reduced to 3kW whereby reducing the annual average to 3kW apart from similar fractional reduction on grid loads each month.

Table 5.3: Monthly Energy purchased from the grids 3.15kW connection.

System Architecture: 3.15 kW Grid, 1 kW PV, 1 Surrette 12CS11P; 1 kW Inverter, 1 kW Rectifier

Cost Summary | Cash Flow | Electrical | PV | Battery | Converter | Grid | Emissions | Hourly Data

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
Jan	327	0	327	2	27	0
Feb	324	0	324	2	27	0
Mar	418	0	418	3	34	0
Apr	415	0	415	3	34	0
May	436	0	436	3	36	0
Jun	476	0	476	3	39	0
Jul	495	0	495	3	41	0
Aug	531	0	531	3	44	0
Sep	437	0	437	3	36	0
Oct	407	0	407	3	33	0
Nov	358	0	358	3	29	0
Dec	330	0	330	2	27	0
Annual	4,955	0	4,955	3	406	0

Reduction in peak demand in these months

Further optimization is done by the software run, with the system run on a 4.2kW grid connection keeping the same renewable energy fraction.

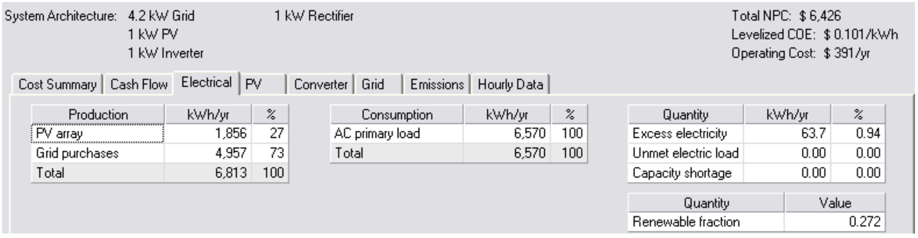


Figure 5.9: Yearly electric power production from 4.2kW (73%) grid connection and 1kW (27%) PV power output.

Figure 5.9 also evaluates the use of PV as grid connection without the need for batteries since the household utilizes a maximum local grid connection. This is due to the fact that household uses PV power directly without storage during its primary load demand timings and the balance is automatically taken care by the local grid connection. The difference is noticed in the minor increment in the excess electricity production which increases from 0.89% to 0.94% which is reflected in the month of April and August for grid energy purchased.

5.2.2 PV power output at 50% and balance Grid Connected

In order to evaluate the above configuration the simulation software was run with the following combination based on the 25% PV grid connection results. PV panels ranging from 1kW till a maximum of 3.6kW with similar 0.2kW increment step wise. Grid connection again from 4.2kW to 1.05kW with reduction every 25% accounting to 2.1kW (50%) also, according to the configuration, except an additional local grid connection purchase criteria of 1.8kW was combined to assess exceptions if any. Battery quantity ranging from 1 to 6 numbers and converter capacities from 1kW to 6kW were considered. Now the renewable fraction constraint was set to a minimum of 50% with the balance left to the local grid connection.

<u>Electric Power Supply Assessment</u>

Primary assessment with the above restricted 2.1kW (50%) local grid connection indicates that the PV power output is 2.6kW panels with 1 number battery and 2kW inverter as shown in Figure 5.10. But even though there is excess electricity produced which is explained earlier there is an overall capacity shortage of 3.04kWh/yr. The most important factor is that there is clearly an unmet load of 0.504kWh/yr in the period and month of June, July and August as seen in Figure 5.11. The is due to the constraints of local grid connection and the PV power not producing enough electricity during a specific time of the period which cannot be stored either with 1 number of battery, also due its discharge and surge characteristics.

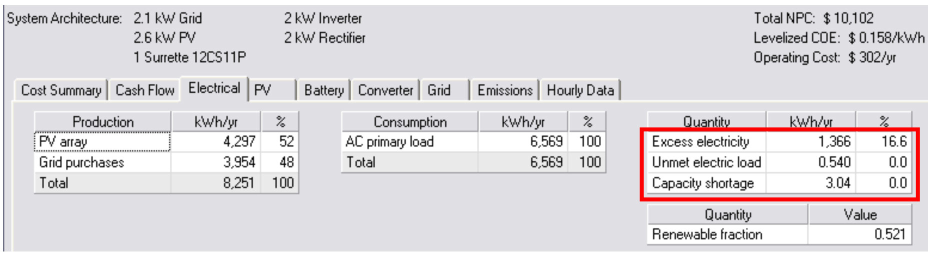


Figure 5.10: Yearly electric power production from 2.1kW (48%) grid connection and 2.6kW (52%) PV power output.

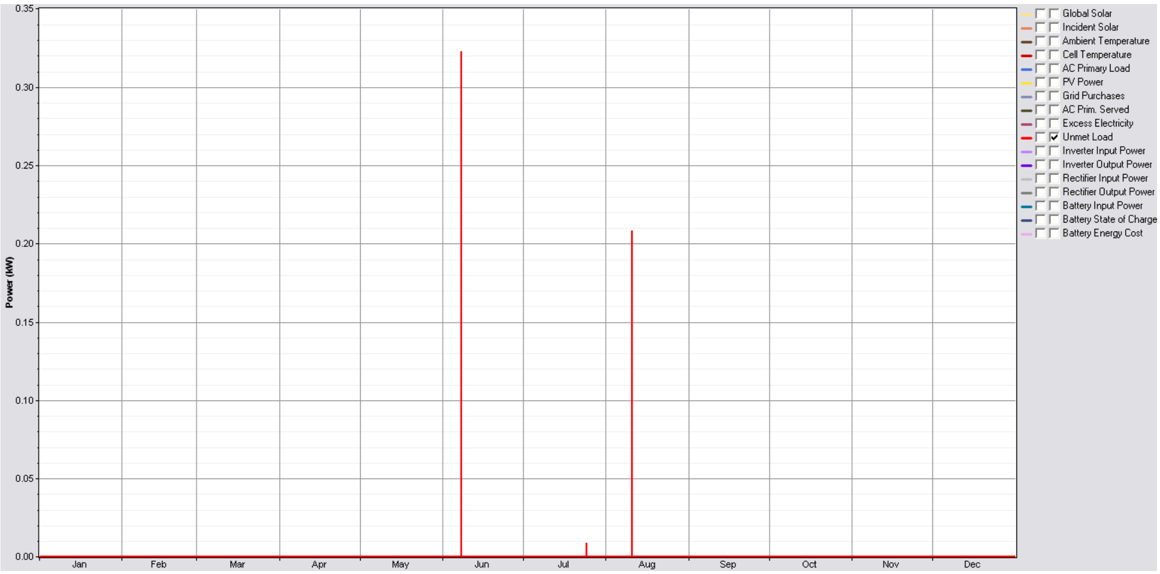


Figure 5.11: Unmet Load in June, July and August with an electric power production from 2.1kW (48%) grid connection and 2.6kW (52%) PV power output.

Further simulation reveals that the best combination for the above case configuration is 1.8kW local grid connection, 2.4kW PV power panels with an increment in storage capacity by 2 numbers of batteries and same 2kW inverter. Also the AC primary load is met with 6570kWh/yr as per our household requirements with a precise 50% balanced grid connection to PV power output ratio. Also now there is reduction in the excess electricity from 16.6% to 12.6% and the unmet load is balanced to zero with a negligible capacity shortage of 0.980kWh/yr as shown in Figure 5.12. The unmet load is now taken care by the addition of number of batteries with a reduction in local grid connection and PV power as compared to Figure 5.10 and Figure 5.11. This implies that though ideal case consideration of 50% (2.1kW) grid connection constraint is always not suitable for better technical result and optimization can be done by probing the variable with further value inputs.

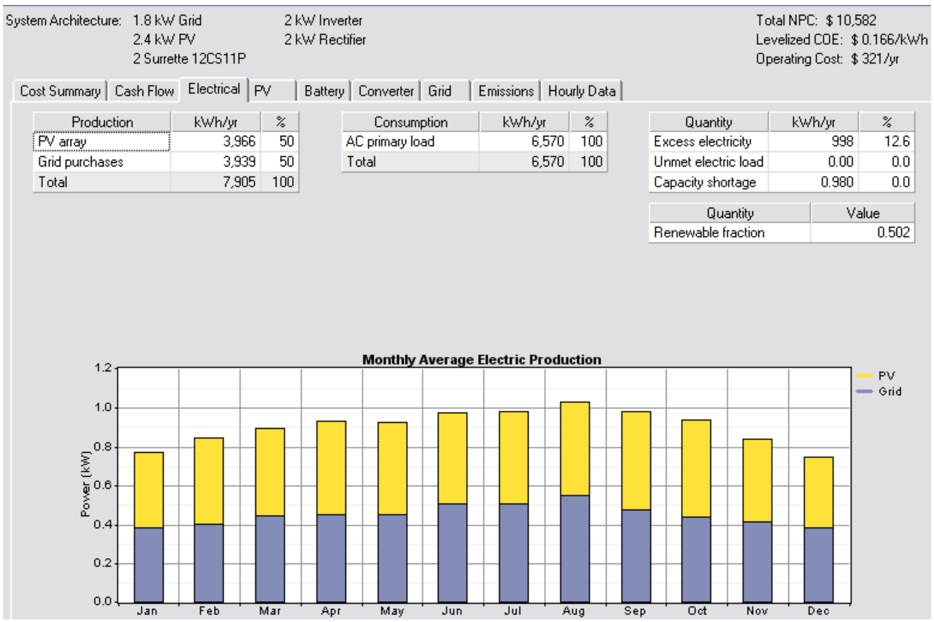


Figure 5.12: Yearly electric power production from 1.8kW (50%) grid connection and 2.4kW (50%) PV power output.

5.2.3 PV power output at 75% and balance Grid Connected

For the above case configuration, based on the earlier results the value inputs of the local grid connection were fed again similarly from 4.2kW to 1.05kW (100% to 25%). Also more addition of 0.8kW and 1.1kW local grid connection based on earlier results of the 50% case configuration was considered. PV power values were set from now 3.2kW to 6.0kW with similar 0.2kW increments and batteries also increase from minimum 2 numbers to maximum of 10 numbers. Inverter set beyond 2kW to a maximum of 6.0kW. Renewable energy fraction set to 75% as a constraint as per case configuration.

Electric Power Supply Assessment

Primary assessment reveals that with a precise 1.05kW (75%) local grid connection, the PV power required is 5.6kW (25%) with 4 number of batteries and a 3kW inverter as shown in Figure 5.13. But there is huge excess electricity generated with 42.2% and a fractional unmet electric load and capacity shortage. This due to the fact that the grid connection produces high supply electric energy amounting to 3,070kWh/yr and the PV arrays also providing excess electricity which is unable to store in the economized 3 number of batteries. It is important to note that the total electrical energy produced by the combination amounts to almost double the capacity of the AC primary load required.

System Architecture: 1.05 kW Grid, 5.6 kW PV, 4 Surrette 12CS11P, 3 kW Inverter, 3 kW Rectifier
Total NPC: $ 18,237
Levelized COE: $ 0.286/kWh
Operating Cost: $ 237/yr

Cost Summary | Cash Flow | Electrical | PV | Battery | Converter | Grid | Emissions | Hourly Data

Production	kWh/yr	%
PV array	9,254	75
Grid purchases	3,070	25
Total	12,324	100

Consumption	kWh/yr	%
AC primary load	6,570	100
Total	6,570	100

Quantity	kWh/yr	%
Excess electricity	5,201	42.2
Unmet electric load	0.00000238	0.0
Capacity shortage	0.156	0.0

Quantity	Value
Renewable fraction	0.751

Figure 5.13: Yearly electric power production from 1.05kW (75%) grid connection and 5.6kW (25%) PV power output.

Thus it is important to factor in lesser grid connection in the values to check if less excess electricity can be produced keeping the local grid connection closer to the 25% potential case configuration. In such a case the 0.8kW local grid connection is added to probe and the results indicate that it still meets the renewable energy fraction of 75% with lesser PV panels of 5.4kW and same 4 numbers of batteries and 3kW inverter. But the output of the PV panels is reduced to 8,924kWh/yr still maintaining the required renewable energy fraction of 75% but comparatively lesser excess electricity from 42.2% to now 38.7% overall as indicated in Figure 5.14.

It could be probed that, reduction in the local grid purchase capacity may reduce the excess electricity. Hence a lesser 0.4kW local grid connection was probed. But in spite of reducing the purchase capacity of the local grid connection the results still indicated a minimum requirement of 0.8kW only. This was due to the constraint set for 75% renewable fraction which in spite of producing required levels by the PV panels, economics could not match to a higher number of storage batteries which could store electric excess but of no avail to the house and hence still needed to be dumped.

Figure 5.14 thus illustrates that the optimized combination for a 75% renewable energy fraction is precise with 0.8kW local grid connection and a 5.4kW PV panel arrays economized with 4 number of batteries and a 3kW inverter with negligible unmet and capacity shortages electric production.

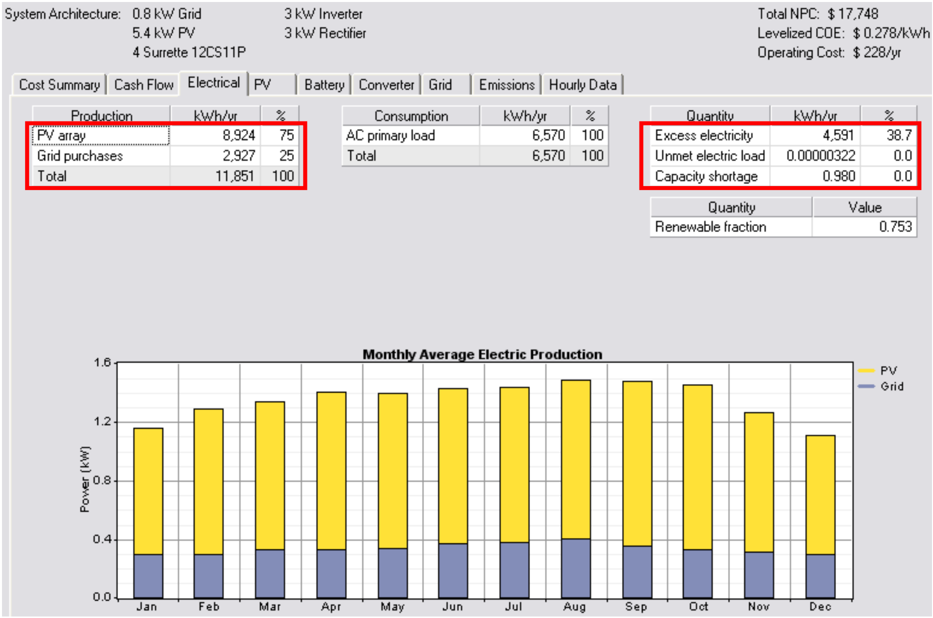


Figure 5.14: Yearly electric power production from 0.8kW (75%) grid connection and 5.4kW (25%) PV power output.

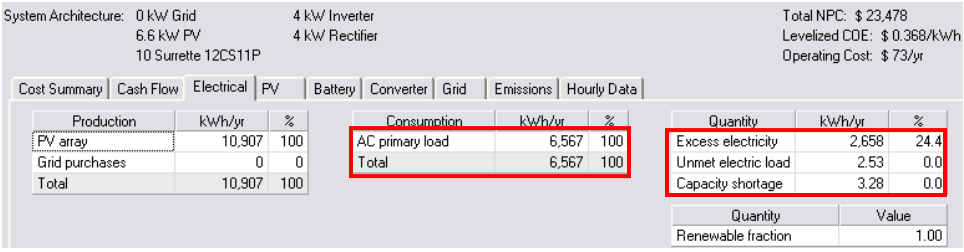
5.2.4 PV power output at 100% and balance Grid Connected

Theoretically measures indicate that the above configuration would account for a standalone renewable energy criteria. But it would be beneficial to identify the above case before we embark onto standalone base so as to verify the potential of the technical assessment compared to the 100% grid connected renewable energy PC potential. Thus for the following basis for the local grid connection was kept to a fraction of 0.001kW to a maximum of 4.2kW with similar increment of 25% every step. Since a minimum 5.4kW PV sizing was considered for the previous case, the current values were put from 5.4kW minimum to a maximum of 7.2kW PV arrays with 0.2kW increment every step. Battery numbers set from 4 numbers to a maximum of 18 numbers along with inverter capacities set to 2kW to a maximum of 6kW considering the current maximum peak power of 4.2kW. Renewable energy fraction now kept as a 100% constraint to allow optimized potential of PV panels.

<u>Electric Power Supply Assessment</u>

Initial optimized results indicate that a 100% renewable PV energy fraction with local grid connection is achieved with 6.6kW PV panels, with 10 numbers of batteries and a 4kW inverter. But ironically the AC primary load is not achieved and falls short to 6,567kWh/yr as compared to the actual 6,570kWh/yr. Also there is unmet load and capacity shortage to a tune of 2.53kWh/yr and 3.28kWh/yr simultaneously as show in Figure 5.15. This unmet load is indicated in Figure 5.16 which indicates that the months in which this occur is March and December. Also there is excess electricity produced to an amount of 24.4% which could be stored in batteries or sold back to the grid in case of sell back capabilities.

The above results do not favor a complete setup for a 100% renewable PV energy power potential and hence further investigation was done to modulate a proper feedback from the simulation with no unmet loads and reduction in excess loads if possible with increment in the number of batteries.



System Architecture: 0 kW Grid, 6.6 kW PV, 10 Surrette 12CS11P, 4 kW Inverter, 4 kW Rectifier

Total NPC: $ 23,478
Levelized COE: $ 0.368/kWh
Operating Cost: $ 73/yr

Cost Summary | Cash Flow | Electrical | PV | Battery | Converter | Grid | Emissions | Hourly Data

Production	kWh/yr	%
PV array	10,907	100
Grid purchases	0	0
Total	10,907	100

Consumption	kWh/yr	%
AC primary load	6,567	100
Total	6,567	100

Quantity	kWh/yr	%
Excess electricity	2,658	24.4
Unmet electric load	2.53	0.0
Capacity shortage	3.28	0.0

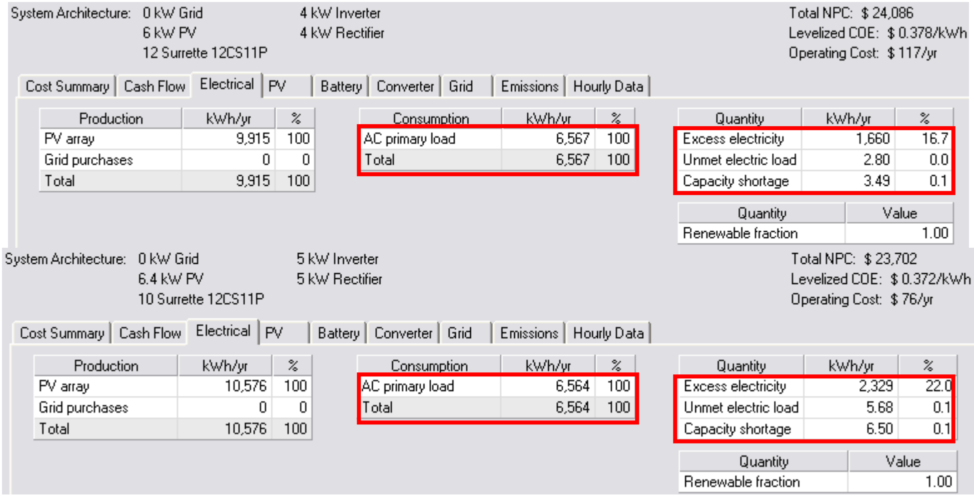
Quantity	Value
Renewable fraction	1.00

Figure 5.15: Yearly electric power production from 0.0kW (0%) grid connection and 6.6kW (100%) PV power output.

Figure 5.16: Unmet Load in March and December with an electric power production from 0kW (0%) grid connection and 6.6kW (100%) PV power output.

In order to evaluate an appropriate model to suit the household the simulation was run at various further values based on 100% renewable energy fraction. Figure 5.17 illustrates reading with these values. Though 6.0kW PV panels reach a 100% requirement they fall short of the total AC primary load with 6,567kWh/yr and an unmet load of 2.80kWh/yr. Though the excess electricity is reduced to 16.7% due to use of 12 numbers of batteries and 4kW inverter they still are not an apt solution to the household. Similarly in spite of increasing the PV panel capacity to 6.4kW the AC primary load is even more reduced to 6,564kWh/yr with a unmet load of 5.68kWh/yr. Now the 10 numbers of batteries are reduced and the excess electricity production is increased to 22.0% as per Figure 5.17.

Finally a balance is achieved as per Figure 5.18 with 7.0kW PV panels along with 10 numbers of batteries and 4kW inverter for a 100% renewable energy requirement of the household. The unmet load are almost 0.0% but sue to the economized battery bank the excess electricity is reached 28.7%.



System Architecture: 0 kW Grid, 6 kW PV, 12 Surrette 12CS11P, 4 kW Inverter, 4 kW Rectifier
Total NPC: $ 24,086
Levelized COE: $ 0.378/kWh
Operating Cost: $ 117/yr

Cost Summary | Cash Flow | Electrical | PV | Battery | Converter | Grid | Emissions | Hourly Data

Production	kWh/yr	%
PV array	9,915	100
Grid purchases	0	0
Total	9,915	100

Consumption	kWh/yr	%
AC primary load	6,567	100
Total	6,567	100

Quantity	kWh/yr	%
Excess electricity	1,660	16.7
Unmet electric load	2.80	0.0
Capacity shortage	3.49	0.1

Quantity	Value
Renewable fraction	1.00

System Architecture: 0 kW Grid, 6.4 kW PV, 10 Surrette 12CS11P, 5 kW Inverter, 5 kW Rectifier
Total NPC: $ 23,702
Levelized COE: $ 0.372/kWh
Operating Cost: $ 76/yr

Cost Summary | Cash Flow | Electrical | PV | Battery | Converter | Grid | Emissions | Hourly Data

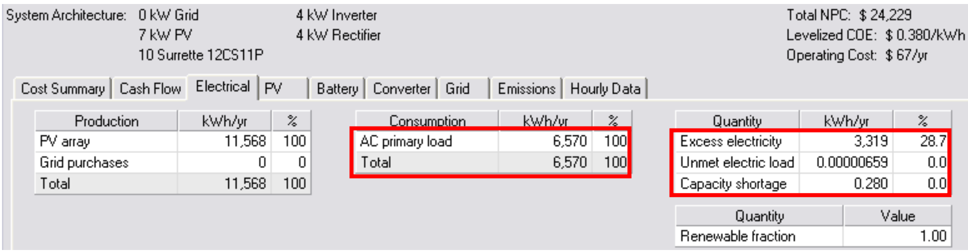
Production	kWh/yr	%
PV array	10,576	100
Grid purchases	0	0
Total	10,576	100

Consumption	kWh/yr	%
AC primary load	6,564	100
Total	6,564	100

Quantity	kWh/yr	%
Excess electricity	2,329	22.0
Unmet electric load	5.68	0.1
Capacity shortage	6.50	0.1

Quantity	Value
Renewable fraction	1.00

Figure 5.17: Yearly electric power production from 0.0kW (0%) grid connection and 6.0kW and 6.4kW (100%) PV power output.



System Architecture: 0 kW Grid, 7 kW PV, 10 Surrette 12CS11P, 4 kW Inverter, 4 kW Rectifier
Total NPC: $ 24,229
Levelized COE: $ 0.380/kWh
Operating Cost: $ 67/yr

Cost Summary | Cash Flow | Electrical | PV | Battery | Converter | Grid | Emissions | Hourly Data

Production	kWh/yr	%
PV array	11,568	100
Grid purchases	0	0
Total	11,568	100

Consumption	kWh/yr	%
AC primary load	6,570	100
Total	6,570	100

Quantity	kWh/yr	%
Excess electricity	3,319	28.7
Unmet electric load	0.00000659	0.0
Capacity shortage	0.280	0.0

Quantity	Value
Renewable fraction	1.00

Figure 5.18: Yearly electric power production from 0.0kW (0%) grid connection and 7.0kW (100%) PV power output.

5.2.5 PV power output at 100% Standalone

In spite of the previous case configuration the following was analyzed to consolidate the standalone model. For the this purpose the simulation was run with slightly higher PV array capacities till 7.4kW as compared to the previous 7.2kW capacity. This was purely to support the standalone criteria as now no local grid connected was setup. Since battery number or the inverter capacity did not amount to higher than 12 numbers or 4kW inverter capacity the same was maintained to follow consistency.

Electric Power Supply Assessment

The evaluation did not give any further modifications or upgrade for the standalone in comparison to the PV 100% grid connected case configuration. All the readings were consistent and the 7.0kW PV panel requirement along with 10 numbers of batteries and 4kW converter was suited best for the standalone case for the entire household model. The 7.4kW additional value of PV capacity only increased the excess electricity to 32.6%.

Further the details of the 7.0kW of PV panels have an overall maximum output is read at 6.15kW with PV penetration ratio of 176% with higher number of operation of hours of 4,390hr/yr. The batteries have also fairly large annual throughput of 4,346kWh/yr with minor losses of 934kWh/yr based on storage depletion of only 14kWh/yr. The battery energy out is 3,887kWh/yr and in capacity is 4,836kWhr/yr with state of charge maximum reaching the battery capacity of almost 88% to a minimum of 76%. The battery does not go below the 60% state of charge throughout the year even during high peak demand months of June, July and August as indicated in Figure 5.19.

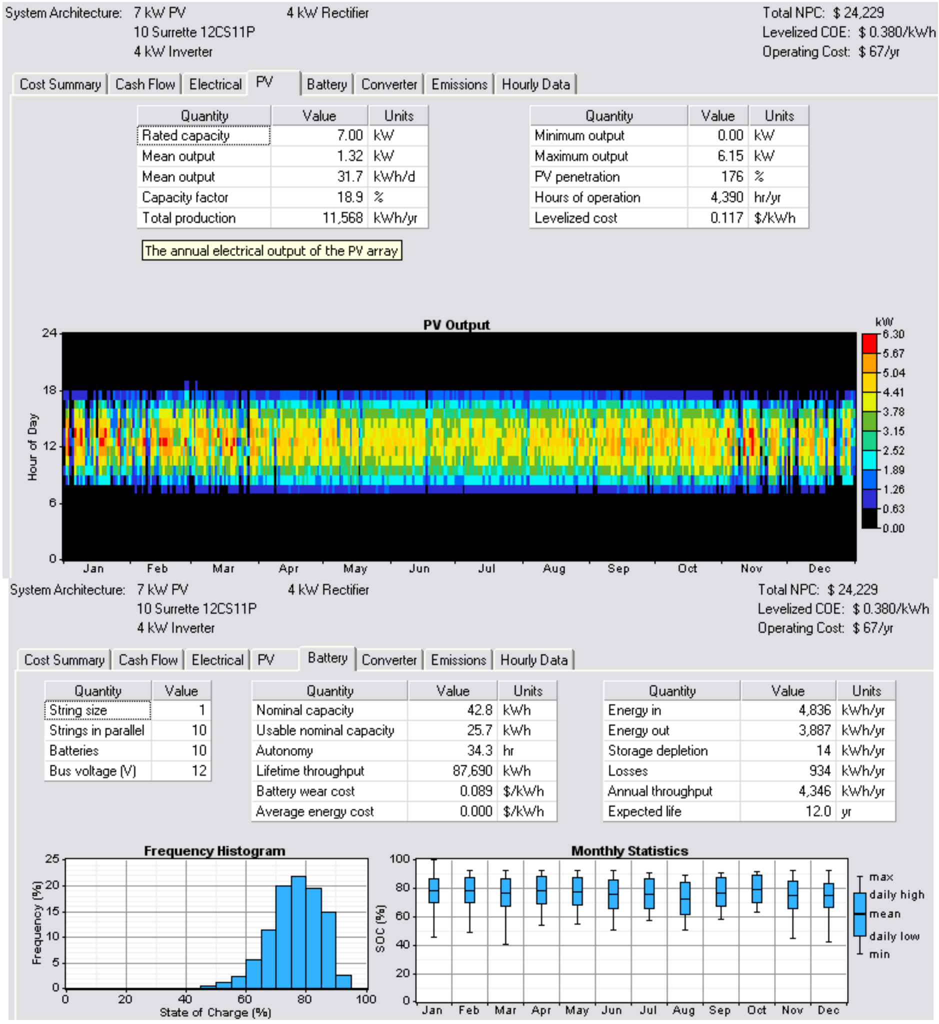


Figure 5.19: 100% Standalone PV case configuration with 7.0kW array capacity properties and Battery properties and overall performance obtained for the model by HOMER.

5.2.6 Summary Table for the PV module Case Configuration

Table 5.4 illustrates the summarized technically optimized system for the PV module case configuration based on complete provision of primary load, negligible unmet loads or capacity shortage, sufficient number of batteries and optimized inverter capacity.

Table 5.4: Technical Optimized Summary Table for PV module Case Configuration

Type of Conf	Grid	PV	Battery	Conv	PV Prod.	Grid Net Purchase	Tot. Elect. Prod.	Primary Load Served	Ren. Frac.	Cap. Shortage Frac.	Unmet Load Frac.	Excess Elect.
	kW	kW	No.	kW	kWh/yr	kWh/yr	kWh/yr	kWh/yr		%	%	kWh/yr
PV-GRID CONNECTED												
25%	3.15	1	1	1	1,856	4,955	6,811	6,570	0.27	0	0	61
50%	1.8	2.4	2	2	3,966	3,939	7,905	6,570	0.5	0	0	998
75%	0.8	5.4	4	3	8,924	2,927	11,851	6,570	0.75	0	0	4,591
100%	0	7	10	4	11,568	0	11,568	6,570	1	0	0	3,319
PV-STANDALONE												
100%	0	7	10	4	11,568	0	11,568	6,570	1	0	0	3,319

5.2.7: Emission Levels for PV module Case Configuration

We have seen earlier the harmful emission by various gases such as CO2, CO, VOC, Sox and NOx simultaneously in section 5.1.2 by the local grid connection. It would be prudent to compare their levels with the current case configuration of PV's in order to derive control parameters in the global warming scenario as per our literature review and chapter 1. Thus for the purpose of consistence we compare on the CO2 levels which is the most sort after topic in the current state of effects to the climate.

Table 5.5 illustrates the reduction in CO2 emission levels in kg/yr depending on the various case configurations modeled for the household ranging from 25% to 100% and standalone. The CO2 emission due to fuel use for the local grid connection is not directly proportionate to the use of renewable energy percentage such as PV's in the study. For 75% of PV renewable energy the maximum reduction obtained is 55.44% due to consistent use of the shortfall of load provision to the house by the local grid. In such a case the PV and its storage capacities has a high level of excess electricity produced but unable to use during required timings of the household load criteria. There is more consistency though in reduction till 50% of PV renewable energy use in the CO2 emission levels accounting for 40.05% and 24.58% as illustrated.

Table 5.5: CO2 Emission due to use of PV module case configuration.

Energy Configuration	CO2 emission kg/yr	Reduction (%)
Local Grid Connection only	5532	0
25% PV-Grid Connection	4172	24.58424
50% PV-Grid Connection	3316	40.05785
75% PV-Grid Connection	2465	55.44107
100% PV-Grid Connection and 100% PV-Standalone	0	100

5.3 WIND TURBINE (WT) MODULE CASE CONFIGURATION

The wind turbine case configuration shall be assessed again as mentioned in chapter 4 Table 4.13 which similar baseline to the PV case configurations to compare the potential of wind energy on the location. Local grid connection fed to the household shall hold the same combinations for the various cases to ranging from 75% to 0% with the balance energy output measured by the wind energy provided by the wind turbine in the same reverse order. Almost all the other balance of components such as batteries and inverter shall be kept to the same values so that the technical and economic evaluation is based on equal grounds. In some case though certain values may be required to be added or subtracted to suit results which feed appropriate power to the household. The main object in this slightly different value additions is to make sure the household is run on complete power/electrical for its successful operation. The variation does not exceed more 5% as compared to the PV case configurations so as to avoid unfair comparatives of the renewable energy resources.

5.3.1 WT power output 25% and balance Grid Connected

As per selection criteria explained in section 4.1.5, the size of the wind turbine is 1kW due to the rotor diameter size constraints on the site and the availability of larger locations. Also smaller manageable diameter could assist the case configuration to see the potential of increasing the number of wind turbines on the located aforesaid site. With 125kWh/month at 4.5m/s characteristics the selection of Whisper 200 suited best for the site and the local wind energy potential which reads an average of 4.695m/s annually. For the current case the local grid values were from the range of 4.2kW (100%), 3.15kW (75%) to the lowest in the case configuration of 1.05kW (25%). The battery numbers ranging from zero to a maximum of 6 numbers due to only 25% renewable energy required, and inverter to a minimum of 1kW o maximum of 4kW respectively. Again maximum renewable energy fraction initially set to 25% from the complete simulation setup.

Electric Power Supply Assessment

Initial evaluation for the 25% renewable energy fraction constraint did not yield any results due to the wind turbine not matching up to the potential of providing required electrical load to the household. This was due to the fact that the 1kW wind turbine potential was lesser than the set up set for 25% renewable energy fraction with only 1 number of wind turbines. Further though additional 2 number of wind turbines values were set up, the potential electricity production increased exponentially and hence it was more advisable to validate it with further reduction in renewable energy fraction to 23%. By this was the at least the capacity of 1 number of 1kW wind turbine could be validated first. As soon as the fraction was reduced to 23% the 1 number 1kW wind turbine simulated results as shown in Figure 5.20 with current local grid connection of 3.15kW (76%) and 1 number 1kW wind turbine (24%) of yearly electrical production of 1,638kWh/yr. Number of batteries required were 1 number and the capacity of inverter identified was 1kW. The primary household load of 6,570kWh/yr was also met with marginal increase in excess electricity production of 1.88kWh/yr. It thus was more technically viable to feed in the 23% renewable energy fraction rather than increase the number of wind turbines for this case of configuration as the results were closer to the 24% renewable energy potential.

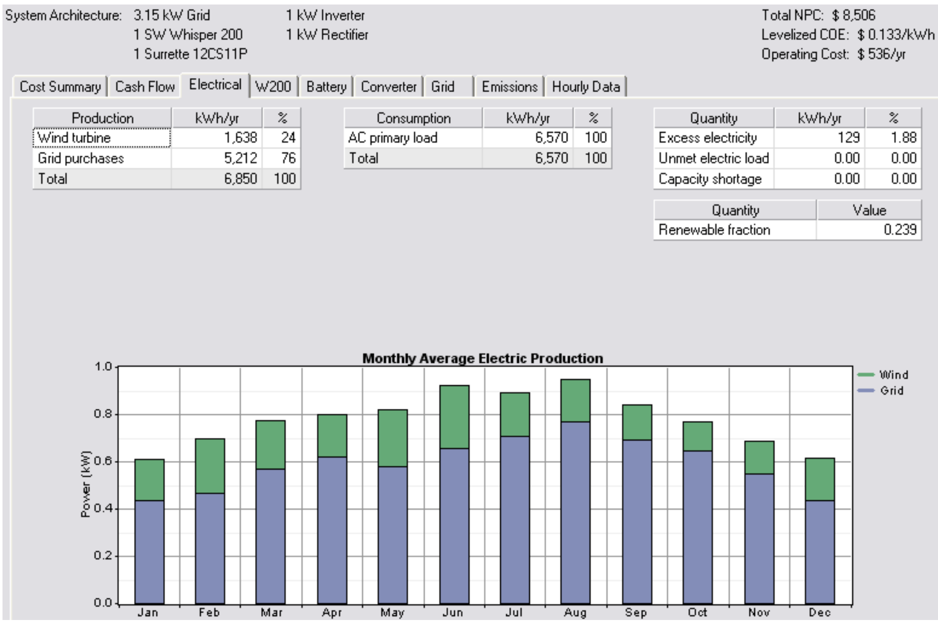
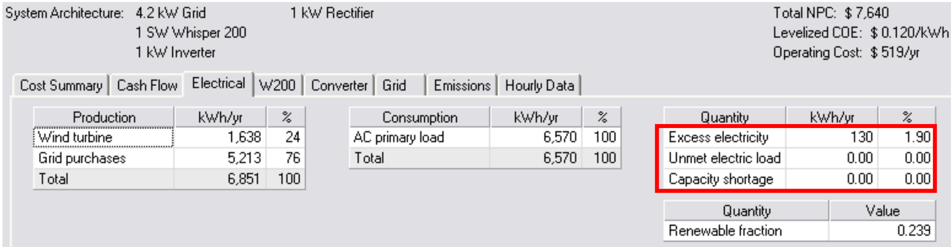


Figure 5.20: Yearly electric power production from 3.15kW (76%) grid connection and 1kW (1 number) (24%) wind turbine power output.

Though the above Figure 5.20 illustrates the use of 76% local grid connection at 3.15kW it would be more appropriate to also run the simulation with the maximum grid connectivity of 4.2kW similar to the PV case configuration. The Figure 5.21 hereby illustrates that a 4.2kW local grid connection also provided a 24% (1,638kWh/yr) 1 number 1 kW wind turbine potential without the need for storage batteries and the inverter capacity is same as earlier to 1kW. Also there is marginal excess electricity production as compared to 3.15kW grid connection with an increment of 1.90% from the 1.88% which is marginal. The difference in the values of grid purchase is seen in the month of July and August peak demand for the 3.15kW local grid connection where as for 4.2kW the reduction in grid purchase is only seen in the month of August.



System Architecture: 4.2 kW Grid, 1 SW Whisper 200, 1 kW Inverter, 1 kW Rectifier

Total NPC: $ 7,640
Levelized COE: $ 0.120/kWh
Operating Cost: $ 519/yr

Cost Summary | Cash Flow | Electrical | W200 | Converter | Grid | Emissions | Hourly Data

Production	kWh/yr	%
Wind turbine	1,638	24
Grid purchases	5,213	76
Total	6,851	100

Consumption	kWh/yr	%
AC primary load	6,570	100
Total	6,570	100

Quantity	kWh/yr	%
Excess electricity	130	1.90
Unmet electric load	0.00	0.00
Capacity shortage	0.00	0.00

Quantity	Value
Renewable fraction	0.239

Figure 5.21: Yearly electric power production from 4.2kW (76%) grid connection and 1kW (1 number) (24%) wind turbine power output.

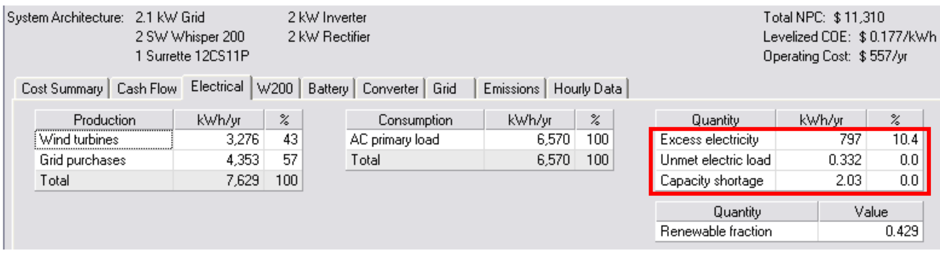
Again similar to the PV case configuration the current WT case also derives electrical power from the local 4.2kW grid in order to avoid the need for more batteries for storage purpose used in the peak month of July, where as storage difference is seen in both month of July and August for a 3.15kW local grid connection.

5.3.2 WT power output 50% and balance Grid Connected

In order to evaluate the above configuration the simulation software set up was done to the following combinations with respect to the readings received from the 23% WT renewable energy potential and the 50% PV potential. The 1kW wind turbines numbers were set ranging from 1 minimum number to a maximum of 4 numbers. The local grid purchase values were 1.05kW, 2.1kW (50%), 3.15kW and 4.2kW respectively. Similar to the PV case configuration the model was added with a 1.8kW local grid purchase to find out if any exceptions were met during the results. Battery numbers ranging from a minimum of 1 numbers to a maximum of 6 numbers and inverter capacities from 1kW-6kW were set respectively again. The renewable energy fraction constraint was run at now 50% as per the case configuration with balance from grid connection.

<u>Electric Power Supply Assessment</u>

Primary assessment for the 2.1kW local grid connection constraint with the balance to be achieved by the renewable energy fraction of 50% was 2 numbers of 1kW wind turbines, 1 number of battery and a 2kW inverter as shown in Figure 5.22. Although the AC primary load of 6,570kWh/yr to the household was met with a 797kWh/yr (10.4%) excess electricity there was again an unmet electrical load read similar to the PV 50% case configuration. Unmet electricity load to the household meant that during certain month and particular timing the house would be without electric power. This was during the month of June only in comparison to the PV 50% case which evaluated June, July and August with higher unmet loads. The current statistics evaluated that the 3,276kWh/yr (43%) electricity produced by the WT would harness an unmet load of 0.332kWh/yr during the month of June as illustrated by Figure 5.22 and Figure 5.23. Thus a further probe into achieving absolute negligible unmet loads was investigated.



System Architecture: 2.1 kW Grid, 2 SW Whisper 200, 1 Surrette 12CS11P, 2 kW Inverter, 2 kW Rectifier

Total NPC: $ 11,310
Levelized COE: $ 0.177/kWh
Operating Cost: $ 557/yr

Cost Summary | Cash Flow | Electrical | W200 | Battery | Converter | Grid | Emissions | Hourly Data

Production	kWh/yr	%
Wind turbines	3,276	43
Grid purchases	4,353	57
Total	7,629	100

Consumption	kWh/yr	%
AC primary load	6,570	100
Total	6,570	100

Quantity	kWh/yr	%
Excess electricity	797	10.4
Unmet electric load	0.332	0.0
Capacity shortage	2.03	0.0

Quantity	Value
Renewable fraction	0.429

Figure 5.22: Yearly electric power production from 2.1kW (57%) grid connection and 1kW (2 number) (43%) wind turbine power output.

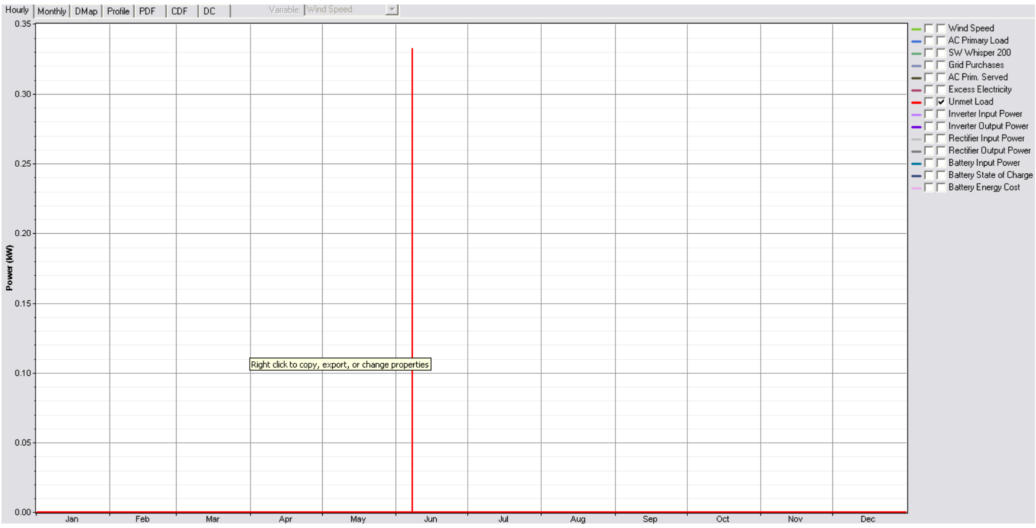


Figure 5.23: Unmet Load in June with an electric power production from 2.1kW (57%) grid connection and 1kW (2 numbers) (43%) WT power output.

Again the 1.8kW local grid connection additional value was probes to evaluate whether the unmet electric load could be nullified. The results were quite similar to the PV 50% case which evaluated the 1.8kW as a better combination reducing the unmet load to minor negligible fraction. Figure 2.24 illustrates the best combination of 1.8kW local grid connection with 2 numbers of 1kW WT along with now 2 numbers of batteries for better storage capacity and a 2kW inverter. The addition of battery now reduced the excess electricity as well to 9.79% on contrary to the previous 10.4%. Though the capacity shortage was 0.01% which is higher than the 2.1kW local grid connection, this does not amount to any problems to the household but is taken care by the addition of the battery herewith. Again it was successfully proven from both the cases of PV and WT for the 50% renewable energy fraction, that exact amount of local grid connection does not amount to the balance being taken by the renewable energy but better combination could be achieved by probing the values with further optimization.

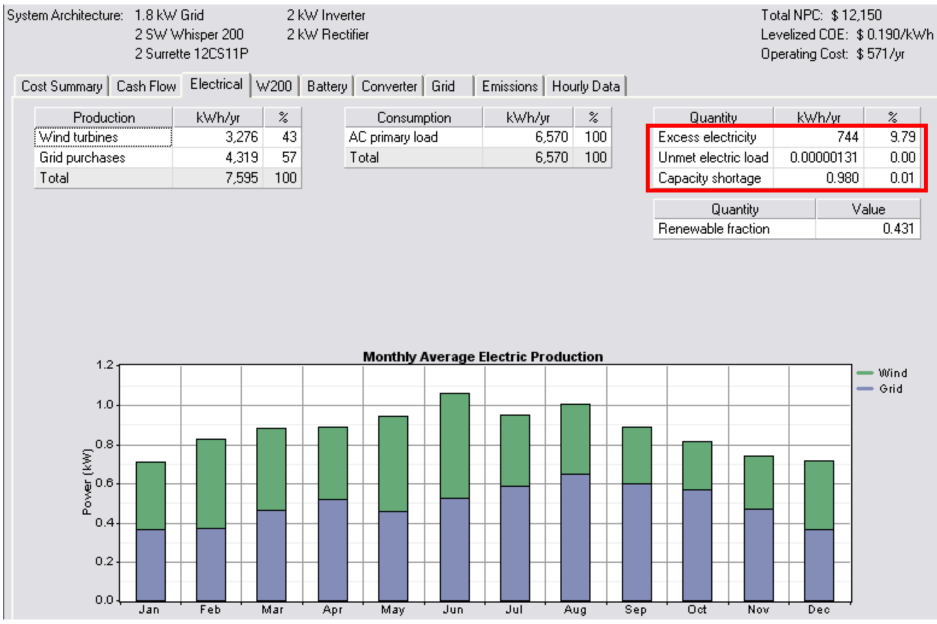


Figure 5.24: Yearly electric power production from 1.8kW (57%) grid connection and 1kW (2 number) (43%) wind turbine power output.

5.3.3 WT power output 75% and balance Grid Connected

Assessment for the above case configuration was set up with local grid connection from 4.2kW to 1.05kW (100% to 25%) and the balance by renewable energy from wind turbines. Again addition of 1.1kW and 0.8kW was added to the grid connection values to read any exception and savings. Since the previous case evaluated 2 numbers of WT, the current case set up for 3 numbers minimum to a maximum of 6 numbers of 1kW WT. Battery numbers from 2 numbers to a maximum of 10 numbers and inverter capacities from 2kW to maximum 6 kW respectively. This is important since the current can be then evaluated on a fair basis with PV and the Hybrid configuration to follow further. Renewable energy fraction set to 75% as per case configuration.

Electric Power Supply Assessment

The simulation of the precise 1.05kW (75%) local grid connection, evaluated the need for 6 numbers of 1kW wind turbines with 5 numbers of batteries and a 3kW inverter as shown in Figure 5.25. The household primary load was met to 6,570kWh/yr with wind turbines producing almost 9,829kWh/yr (78%) and the grid connection electrical production up to 2,852kWh/yr (22%) respectively. There was absolutely marginal unmet load and a capacity shortage percentage amounting to almost zero. But there was excess electricity production of almost 44.2% which could be stored in batteries at a higher number and cost but due to the software validation based on best economized results the minimum number of batteries required showed only 5 numbers to avoid additional cost. It could be further looked upon similar to the PV module case to verify if lowering the grid connection to reduce the excess electricity whereby the percentage of renewable energy fraction could be still amount close to 75%. Hence the 0.8kW local grid connection was probed further.

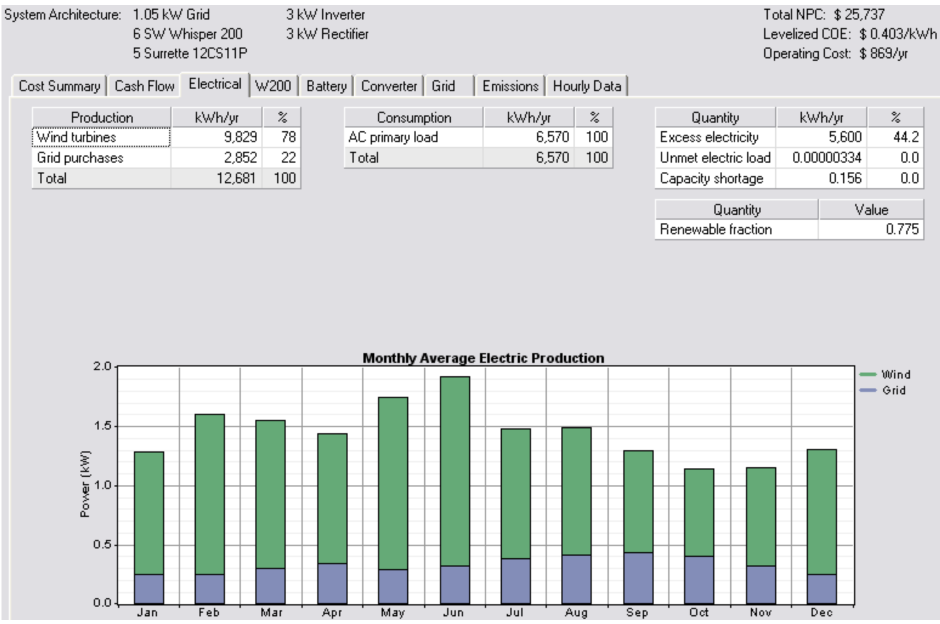


Figure 5.25: Yearly electric power production from 1.05kW (22%) grid connection and 1kW (6 numbers) (78%) wind turbine power output.

After simulating the model to a 0.8kW local grid connectivity it was found that the excess electrical consumption was reduced to 42.7% though no additional battery numbers increased or inverter increment was found. Since the grid connectivity was reduced there was fractional reduction in this yearly electrical purchase to 2,703kWh/yr as compared to the earlier 2,852kWh/yr of 1.05kW grid connection but the household primary electrical load was reduced to 6,569kWh/yr. Also the results showed that there was increment in the unmet electricity load to 0.844kWh/yr which was essentially in the peak month of August. Hence it was not found viable to read the 0.8kW local grid connection in contrast to the PV 75% module case configuration due to the fact that the household primary load was not met along with the unmet electrical load derived by this configuration. Finally it was evaluated that the WT 75% (6 numbers of 1kW WT) renewable energy fraction was more suitable for the local grid connection of 2.1kW which is proven more beneficial to the household with all criteria's met without compromising the successful supply of electricity to the house.

5.3.4 WT power output 100% and balance Grid Connected

Evaluation of the 100% potential from wind turbines with grid connectivity is essential to assess the potential difference in the standalone case and verity technical results with any variation if found. For this purpose the values set up for the validation for the 1kW wind turbine were in a range of 6 numbers to a maximum of 15 numbers considering that the precious case required 6 numbers to satisfy the 75% WT case configuration. The local grid connection was kept "ON" even though the renewable fraction was kept at a 100% constraint to make sure that all the electrical power for the household be achieved by the wind turbines. The numbers of batteries were kept exponentially ranging from a minimum of 8 numbers to a maximum of 42 numbers to assure proper storage and backup for the household. The inverter capacities run with minimum 2kW to maximum 6kW considering the peak power necessity to the household was 4.2kW as assessed earlier. Since wind energy comparatively lower than other countries as noted from the literature review it was necessary that the number of wind turbines and battery storage be kept with maximum variation in combination to achieve better optimization.

Electric Power Supply Assessment

The optimization results from the simulation software run was achieved by the 100% renewable energy with 9 numbers of 1kW wind turbines with a battery storage capacity of 39 numbers as required with a 4kW inverter capacity as shown in Figure 5.26. Since wind energy is not as high compared to the PV 100% module case configuration the current model indicated a large number of batteries accounting for 39 numbers as compared to only 10 numbers in the PV case. Also the wind turbine numbers were also high considering the wind potential in the region but the household was successfully run with electrical power primary load of 6,570kWh/yr with a very high excess electrical production of 6,693kWh/yr (45.4%). This excess electricity indicated that the wind energy does have a substantial contribution in the region but cannot be optimized for our household model. The excess could be ideally stored in the batteries or could be used for other houses around the region. But since the software optimizes results based on cost effectiveness the current model indicate the optimized results suitable to the house run independently.

It is also important to feed in other values such as reduction in the number of batteries, increase in the number of wind turbines etc. to justify the above reading achieved as optimized. Hence the simulation model was run to various other values to verify the potential if any variation or success is met with other combinations. The same simulation thus was run with 10, 11, and 12 numbers of wind turbines and variation in the subsequent number of battery reduction along with the inverter capacity kept to 4.2kW only since the household load did not go beyond these capacities as illustrated in Figure 2.27.

It is also worth mentioning that the excess electricity could be a result of the high wind energy potential in the months which actually do not require peak power such as the month of February and March. Whereas the months of July and August which are the high electricity demand months do not produce the required amount of power by the wind turbines due to lesser wind energy potential in those months. Hence the excess production and need for larger storage number of batteries as seen in Figure 5.26.

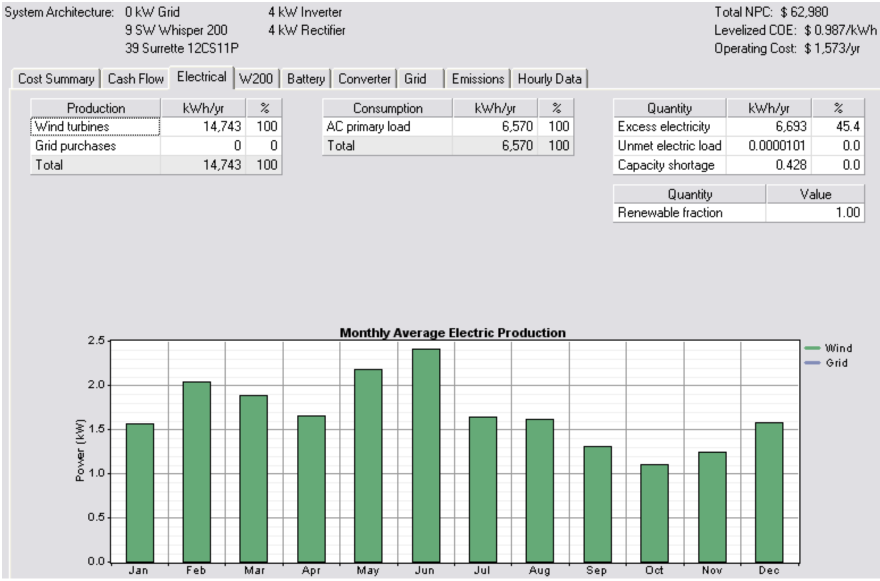


Figure 5.26: Yearly electric power production from 0kW (0%) grid connection and 1kW (9 numbers) (100%) wind turbine power output.

As shown in Figure 5.27 the battery numbers reduced due to the increment in the number of wind turbines since the wind turbines could now provide the required capacity to the household without larger storage. Every 1 number of wind turbine increased reduced the size of the battery numbers by 3. Except the 12 numbers 1kW WT other previous configurations achieved the primary loads to the house of 6,750kWh/yr. Though the increment in excess electricity was seen again exponentially it was worth trying the values to see the difference and if other optimized results were viable as compared to the Figure 5.26.

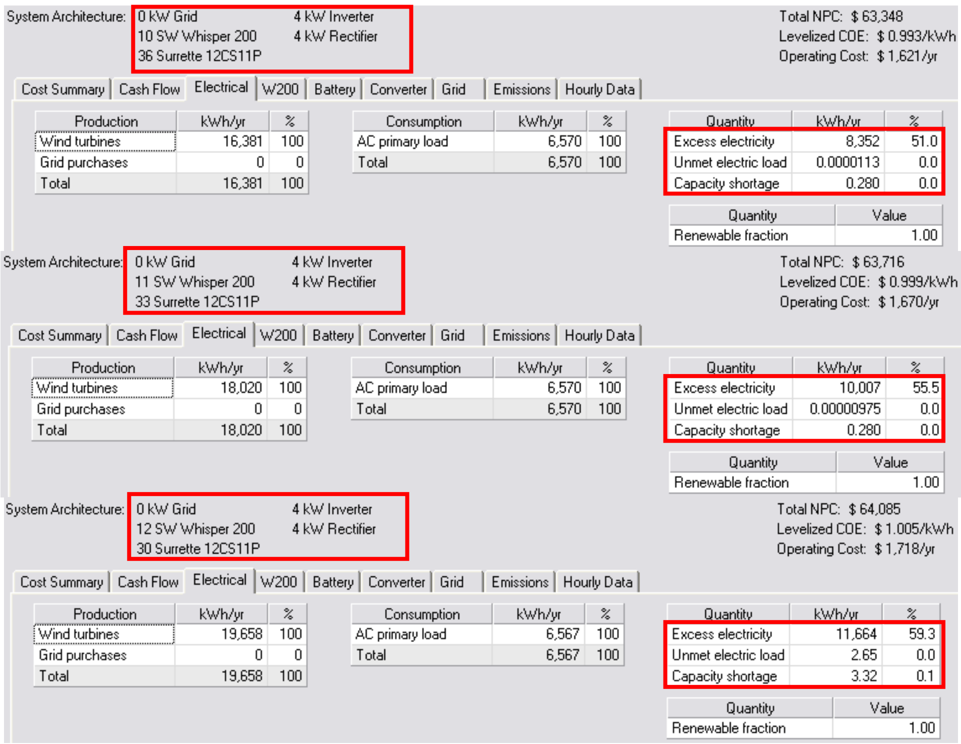


Figure 5.27: Yearly electric power production from 0.0kW (0%) grid connection and 1kW wind turbine (10, 11, and 12 numbers) (100%) WT power output.

5.3.5 WT power output 100% Standalone

For the following case configuration which theoretically measures to the same as the previous case, the values for the number of wind turbines were increased to a maximum of 16 numbers for more possibilities. The number of batteries was also increased to a maximum of 45 numbers for storage purpose, now that system was completely standalone and no other electric supply or storage is possible to the household. The inverter capacity was kept the same values as the previous case to a maximum of 6kW even though the house would not require more than the peak power supply of 4.2kW. No large variation was allowed in comparison to the 100% WT grid connection to avoid unfair readings.

<u>Electric Power Supply Assessment</u>

On contrary to the 100% PV standalone versus grid connected case the current 100% standalone WT case did not match exactly to the 100% WT grid connected optimization. Assessment of the 100% standalone case was difficult as compared to the other whereby the primary energy to the household was not met in most of the case. Readings evaluated brought forward the that the best combination was 9 numbers of 1kW wind turbine along with 40 numbers of battery storage requirement, though the inverter capacity was constant to 4kW for both. The increment in battery capacity was seen by 1 number purely since the precious case the local grid was still connected and though it read 0kW, the spare capacity in case of need was still there for the household. In the current standalone scenario the system had to keep spare electric power supply to the household in case of certain splurge of power requirement and hence the addition of 1 number of battery. Rest all other parameters are quite similar to the 100% WT grid connected case as can be seen from Figure 5.26 and Figure 5.28.

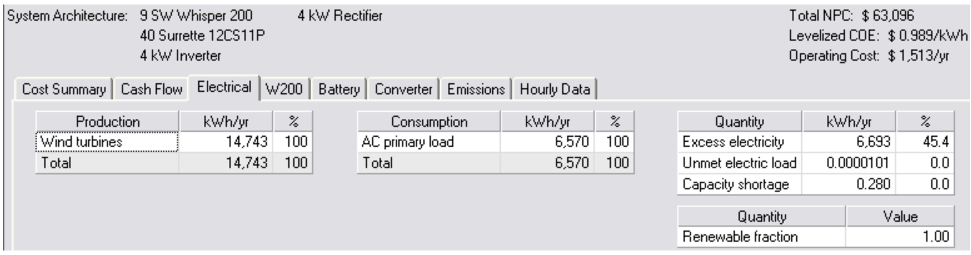


Figure 5.28: Yearly electric power production from a Standalone 1kW wind turbine (9 numbers) (100%) WT power output.

Other values which were rejected due to shortfall of primary load to the household and in many case unmet loads are seen from the Figure 5.29.

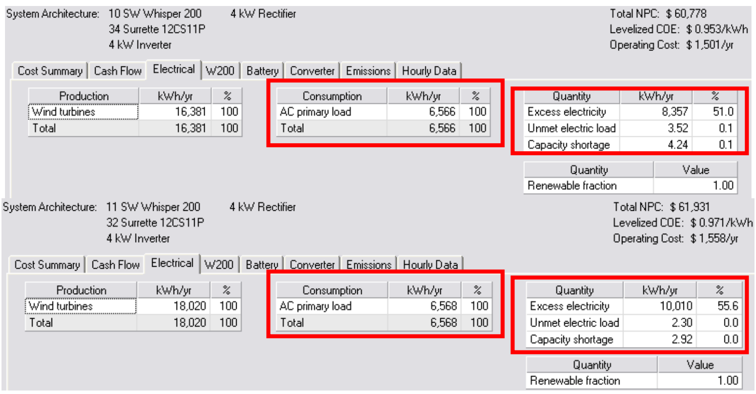


Figure 5.29: Yearly electric power production, Standalone 1kW wind turbine (10 and 11 numbers) (100%) WT power output not meeting primary household load and unmet electric load readings.

Further details of the 9 number 1kW WT standalone case have an overall maximum output of 1.68kW with wind penetration of 224% with almost 6,171hr/yr number of operations throughout the year. It is important to note that the similar 100% PV standalone case, the PV panels work a lot lesser as compared to the wind turbines since the solar energy efficiency is much better than the wind energy efficiency in the region. The battery numbers which is very high to 40 numbers has been explained earlier also has a very high annual throughput of 350,760kWh with losses amounting to 741kWh/yr. The energy out and in is close to about 3,805kWh/yr and 3,055kWh/yr respectively with the state of charge very less as compared to the PV case due to continuous use of power from the batteries amounting to more than 80% in most of the months. It could be summed up by stating that the lack of sufficient wind energy is largely taken care by the state of charge of the battery which gets utilized more often than the PV case except in the months of September and October which has a comparatively lesser state of charge percentage. Also it is important to note that the wind turbine output graph as shown Figure 5.30 is not very consistent as compared to the PV's (Figure 5.19) since wind energy potential is throughout the whole day for 24 hrs where as the PV (solar energy) is available during the timings of 7.00am in the morning to roughly 7.00pm in the evening only.

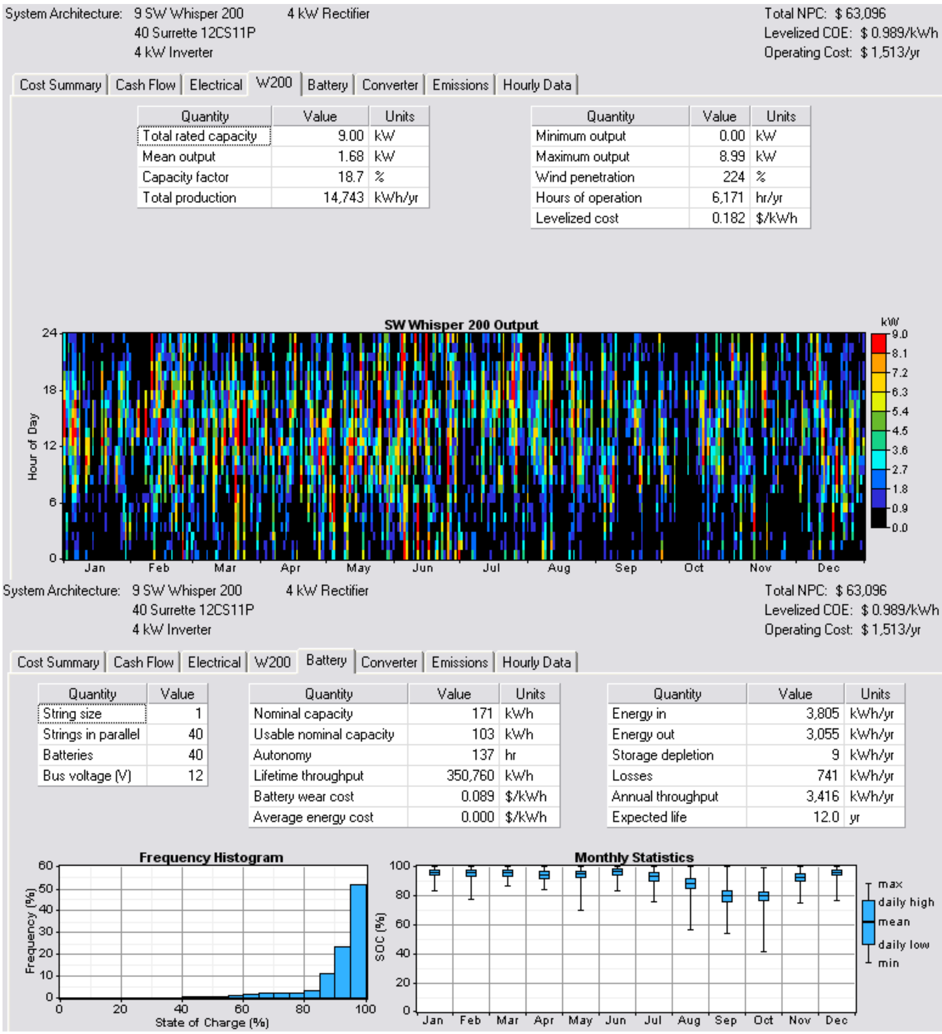


Figure 5.30: 100% Standalone WT case configuration with 1kW (9 numbers) capacity properties and Battery properties obtained from the model

5.3.6 Summary Table for the WT module Case Configuration

Table 5.6 illustrates the summarized technically optimized system for the WT module case configuration based on complete provision of primary load, negligible unmet loads or capacity shortage, sufficient number of batteries and optimized inverter capacity.

Table 5.6: Technical Summary Table for WT module Case Configuration

Type of Conf	Grid	1kW WT	Battery	Conv	WT Prod.	Grid Net Purchase	Tot. Elect. Prod.	Primary Load Served	Ren. Frac.	Cap. Shortage Frac.	Unmet Load Frac.	Excess Elect.
	kW	No	No.	kW	kWh/yr	kWh/yr	kWh/yr	kWh/yr		%	%	kWh/yr
1kW-WT-GRID CONNECTED												
25%	3.15	1	1	1	1,638	5,212	6,850	6,570	0.24	0	0	129
50%	1.8	2	2	2	3,276	4,319	7,595	6,570	0.43	0	0	744
75%	1.05	6	5	3	9,829	2,852	12,681	6,570	0.775	0	0	5,600
100%	0	9	39	4	14,743	0	14,743	6,750	1	0	0	6,693
1kW-WT-STANDALONE												
100%	0	9	40	4	14,743	0	14,743	6,570	1	0	0	6,693

5.2.7: Emission Levels for WT module Case Configuration

Similar to the PV case configuration and the non renewable energy system which was simulated using the software, the current WT module case also evaluates the amount of emissions expelled by the system to the climate. Since we are only identifying on CO2 emission here on, the Table 5.7 illustrates the CO2 emission by the various case configuration of the wind turbine energy system, grid connected and standalone respectively. The reductions in CO2 emission in terms of percentage is fairly less compared to the PV case since the use of grid connection can be clearly seen from the readings obtained earlier. From 25% to 50% renewable use of wind turbines the reduction in CO2 levels as compared to the local (non renewable) grid connection is less with only 20.67% and 34.27% respectively. But for the 75% use of wind turbines the reduction is higher to 56.57% in comparison to the PV case (see Table 5.5). This is in spite of the gird connectivity in PV module for 75% being 0.8kW whereas the WT case grid connectivity being 1.05kW, predominantly due to the fact that the 0.8kW consumption is more regular than the 1.05kW grid connection. In short, it is not necessary that the lesser the grid connectivity, lesser is the CO2 emission levels, but is dependent on the amount and hours of usage by the grid connection working along with the renewable energy system.

Table 5.7: CO2 Emission due to use of WT module case configuration.

Energy Configuration	CO2 emission kg/yr	Reduction (%)
Local Grid Connection only	5532	0
25% WT-Grid Connection	4388	20.67968
50% WT-Grid Connection	3636	34.27332
75% WT-Grid Connection	2402	56.5799
100% WT-Grid Connection and 100% WT-Standalone	0	100

5.4 HYBRIDIZATION OF PHOTOVOLTAIC AND WIND TURBINE (HYPW) MODULE CASE CONFIGURATION

For the HYPW case configuration, the simulation model shall be run similar to the previous cases and based on Table 4.14. The observations and results derived from the individual assessment of the renewable energy system of PV's and WT's shall form the basis of evaluating the current case. Though the method for assessment is the same whereby the local grid connection shall cater to the balance of electrical power supply to the household ranging from 100% to 25% and the renewable energy hybrid system shall be constraint to a minimum of 25% to a maximum of 100% in the reverse order. The balance of components such as batteries and inverter values shall be allocated as combinations to suit the best optimized results for the HYPW case. The main objective of running this research is to technically evaluate the advantages and disadvantage of HYPW case and to assess whether the hybridization proves to be beneficial as a renewable energy system rather than individuals.

5.4.1 HYPW power output 25% and balance Grid Connected

Since the PV 25% module and WT 25% module evaluation resulted in 1kW PV panels and 1 number 1kW WT respectively, the current case of HYPW 25% values were setup with PV's ranging from 0.2kW to maximum 0.8kW incremental and the WT's numbers 1minimum to a maximum of 2 numbers. Balance of components such as battery numbers set up with 1 to 6 numbers maximum and the inverter capacities also 1kW to 4kW similarly. The local grid connection purchase capacity kept to constant ranging 4.2kW (100%), 3.15kW (75%) to minimum 1.05kW with the balance left out to be sourced out by the HYPW renewable energy system. The renewable energy fraction set to a constant 25% to evaluate the results on as all other similar configurations.

<u>Electric Power Supply Assessment</u>

Figure 5.31 illustrates that in order to achieve a 25% renewable energy potential by the HYPW with the balance 3.15kW local grid connection; the requirement for PV's is 0.2kW (331kWh/yr-5%) along with 1 number 1kW wind turbine (1,638kWh/yr-24%). The total amount of electricity generated by the HYPW system with grid connectivity is 6,908kWh/yr with contribution of 28% by the HYPW renewable energy and 72% by the local grid connection. Only 1 number of batteries is required along with 1kW inverter capacity to provide the required case of HYPW 25% renewable energy fraction. Since the 1kW wind turbine selection was already justified in the selection criteria, the flexibility of the same was up to sizing it to the numbers required in the HYPW, whereas for PV's, the panels sizes considered was a minimum of 0.2kW (standard size) with increment every 0.2kW in the model. Hence the WT took precedence to the PV panels since in production of electrical power in order to provide a technically optimized result.

Further investigation into the results also evaluated that the same combination would work without the need for storage batteries when the local grid connection was set up to a maximum of 4.2kW as required for the household as shown in Figure 5.32. The only differences in the two results were increment of the grid purchase from 4,940kWh/yr to 4,941kWh/yr and the unmet electrical load results obtained as an absolute zero. Both the results accounted for the complete electric power supply to the household with the primary load requirement of 6,570kWh/yr respectively. Except due to the assurance of the electrical supply to the household was provided by the 100% 4.2kW grid connection, the requirement for any amount of batteries to store power was nullified in spite of maintained the 28% of HYPW renewable energy provision.

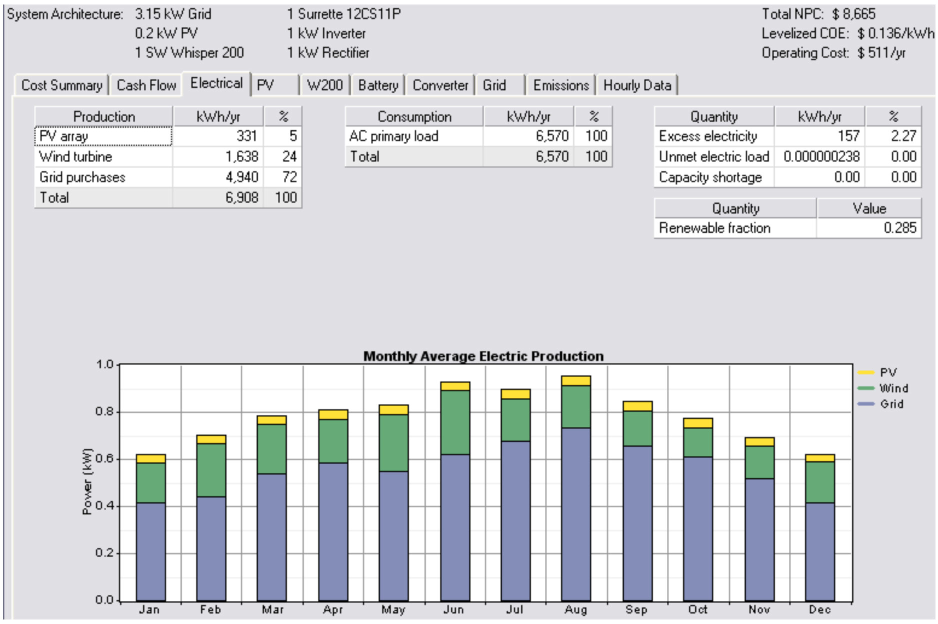


Figure 5.31: Yearly electric power production from 3.15kW (72%) Grid connection and Total HYPW (28%) with 0.2kW PV and 1 number 1kW WT electrical power output.

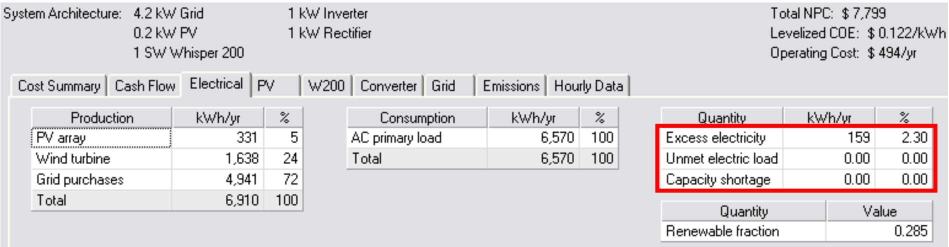


Figure 5.32: Yearly electric power production from 4.2kW (72%) Grid connection and Total HYPW (28%) with 0.2kW PV and 1 number 1kW WT electrical power output.

5.4.2 HYPW power output 50% and balance Grid Connected

The 50% PV and WT case configurations evaluation resulted in 2.4kW PV panels and 2 numbers of 1kW WT. Thus the current 50% HYPW case was evaluated with values for the PV panels set up in the range of 1kW minimum to a maximum of 2.8kW along with the 1kW WT numbers from 1 to 3 maximum with the batteries numbers ranging from 1 number to maximum 6 numbers. The inverter capacity also was set at 1kW to maximum 4kW respectively. Local grid connection values fed in the range of 4.2kW maximum to 21.5kW (50%) minimum of 1.05kW (25%) to set the parameters for grid purchase. Balance of the energy by the HYPW to be sourced was set with now the renewable energy fraction constraint as 50% in accordance with the current case. Also as other previous cases, the exception of lesser local grid connection was kept to compare the overall results on equal grounds with additional 1.8kW local grid purchase simultaneously.

<u>Electric Power Supply Assessment</u>

Figure 5.33 illustrates that the 50% renewable HYPW energy system can be achieved by 1.4kW PV panels (2,314kWh/yr-30%) and 1 number 1kW WT (1,638kWh/yr-22%) along with the local grid connection of 2.1kW (50%). The numbers of batteries required are 2 numbers with an inverter capacity of 2kW respectively. The 2.1kW grid connection produces 48% of the electricity and the balance is taken care by

the HYPW system with 52%. The household primary load is achieved with 6,570kWh/yr but the total electrical production is 7,606kWh/yr with an excess of 699kWhh/yr (9.19%). The unmet load is negligible and hence can be neglected in the view of the zero percentage achieved throughout the whole year. But similar to the previous individual case configuration it would be prudent to investigate whether the 1.8kW local grid connection could bring about any variation or improvement in the same set up.

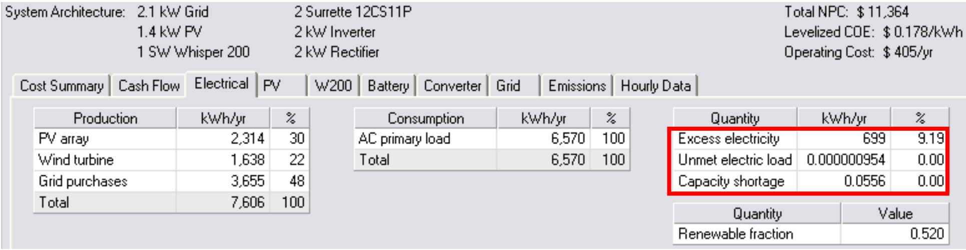


Figure 5.33: Yearly electric power production from 2.1kW (48%) Grid connection and Total HYPW (52%) with 1.4kW PV and 1 number 1kW WT electrical power output.

Investigation in to the 1.8kW local grid connection again resulted in reducing the excess electricity with the reduction in the total electricity produced. The excess electricity production was reduced to 8.54% as compared to the previous 9.19% as shown in Figure 5.34. The essential reduction was in the supply of electrical power from the grid purchase which was now 3,626kWh/yr due to the purchase value reduction with 1.8kW capacity as compared to the previous case. Also since all other results such as batteries and inverter along with renewable energy results remain the same it would be more advisable to main this case as more beneficial to the configuration of 50% HYPW system. With the previous other individual case of PV and WT also working fine wit the 1.8kW local grid connection, it would be fair to compare all the cases of 50% balance with 1.8kW local grid connection to avoid imbalance in the comparison.

Hence the 1.8kW local grid connection with 1.4kW PV panels and 1 number 1kW WT, 2 numbers of batteries and 2kW inverter capacity is found suitable as the best optimized combination for the current case configuration.

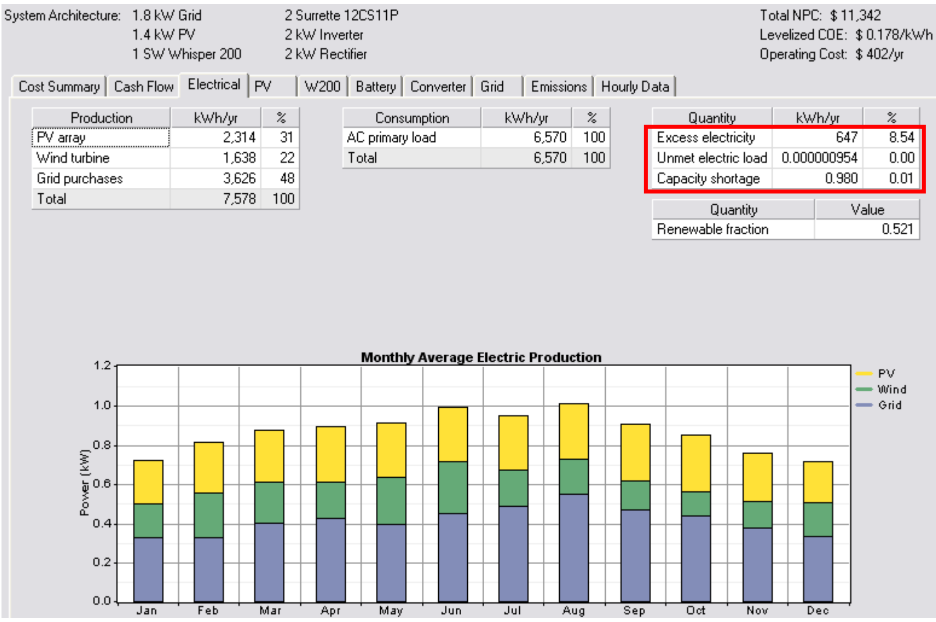


Figure 5.34: Yearly electric power production from 1.8kW (48%) Grid connection and Total HYPW (52%) with 1.4kW PV and 1 number 1kW WT electrical power output.

5.4.3 HYPW power output 75% and balance Grid Connected

The previous case configurations of PV's and WT's individually for 75% renewable energy potential derived results of 5.4kW PV panels and 6 number of 1kW wind turbines. Based on these results the current values for HYPW were set to 4kW PV incremental every 0.2kW to a maximum of 5.8kW PV panels with the 1kW WT ranging from 1 number minimum to maximum 3 numbers respectively. Battery numbers to a maximum 6 numbers to a minimum of 2 numbers, along with inverter capacity 2kW to maximum of 6kW for safe provisions. The local grid connectively set to 1.05kW (25%) to a maximum of 4.2kW (100%). Exceptions such as 0.8kW was added with similar based and criteria previous other case configuration. The renewable energy fraction constraint set to 75% minimum as per the current case configuration.

<u>Electric Power Supply Assessment</u>

Figure 5.35 illustrates that in order to achieve a 75% minimum renewable energy fraction and the balance by the local grid connectivity of 1.05kW (25%), the required PV panels derived are 4KW (6,610kWh/yr-60%) along with 1 number of 1kW (1,638kWh/yr-15%) WT. The numbers of batteries required are 4 numbers with a maximum inverter capacity of 3kW respectively. It is important to note here than in spite of introducing more number of WT the best optimization was achieved as HYPW with only 1 number of 1KW WT which varied in percentage by the balance provision from the PV panels in this case as well as the previous case. Again in spite of the fraction unmet load which could be neglected, the excess electricity production was almost 34.9% with 3,814kWh/yr. Hence another exceptional value for the 0.8kW local grid connection which was explained earlier needs to be assessed to evaluate any improvements or reduction in excess electricity.

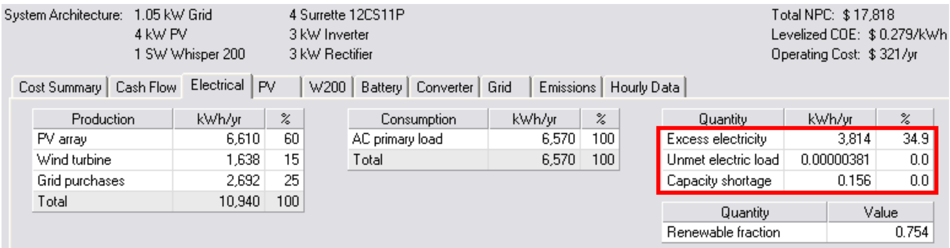


Figure 5.35: Yearly electric power production from 1.05kW (25%) Grid connection and Total HYPW (75%) with 4.0kW PV and 1 number 1kW WT electrical power output.

Figure 5.36 illustrates that for the 0.8kW local grid connection most of the values and balance of components system results are more or less the same to the 1.05kW grid connection. Except there is a reduction the excess electrical load from 34.9% to now 32.8% while meeting the primary load requirement of the household of 6,570kWh/yr. The reduction is primarily in the supply of electrical power from the grid connection which is now 2,514kWh/yr as compared to the 2,692lWh/yr due to the reduction of local grid connectivity constraint of now 0.8kW.

Thus in lieu of the results obtained from 0.8kW local grid connection it was more advisable to utilize these results as more beneficial to the system with 4kW PV panels, 1 number 1kW WT, along with 4 numbers of batteries and 3kW inverter capacity. Since these results produced less excess electricity which would be dumped, with no unmet electrical loads respectively. The renewable energy produced by HYPW system was 75% with the balance provision by the 0.8kW (25%) local grid connection still maintained as per the current case configuration.

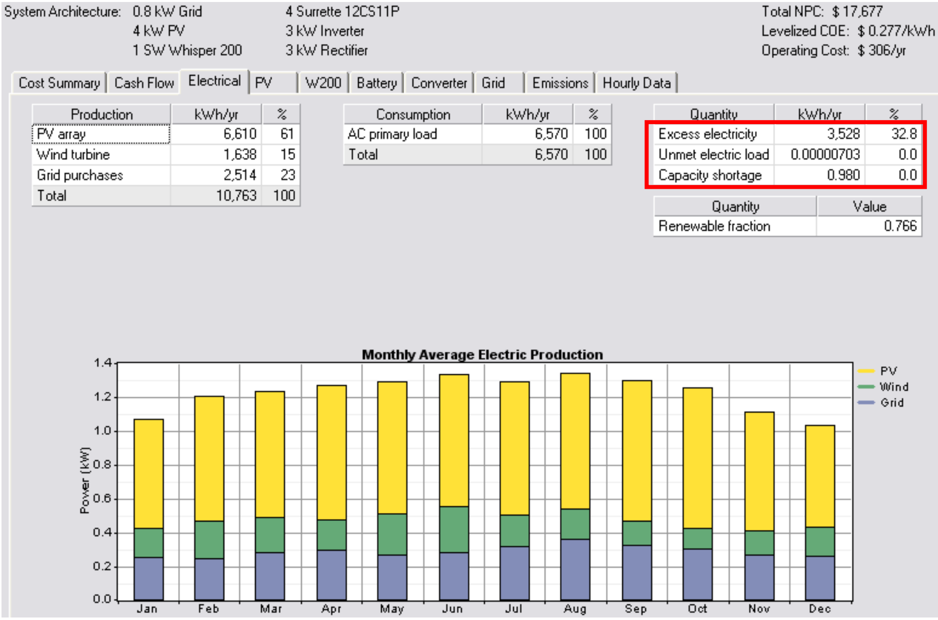


Figure 5.36: Yearly electric power production from 0.8kW (23%) Grid connection and Total HYPW (77%) with 4.0kW PV and 1 number 1kW WT electrical power output.

5.4.4 HYPW power output 100% and balance Grid Connected

Previous case configuration for 100% renewable energy with PV's and WT's derived results with 7.0kW PV panels and 9 numbers of 1kW WT. Thus based on previous results a combination for the HYPW was set up with minimum 4.2kW PV panels to a maximum of 6.8kW along with maximum 4 numbers of 1kW WT and again minimum of 1 numbers respectively. The battery number maximum was 15 numbers which was an average between the result obtained from same configuration of PV's and WT's as individual energy evaluations. The inverter capacity set to maximum of 6kW similarly. The renewable energy fraction constraint set to a maximum of 100% to make sure that the household is supplied with electrical power from the HYPW system only in spite of still grid connected.

<u>Electric Power Supply Assessment</u>

For the 100% HYPW case the results obtained as shown in Figure 5.37 are 5.2kW PV panels (8,593kWh/yr-84%) and 1 number of 1kW WT (1,638kWh/yr-16%). The numbers of batteries required are 10 numbers and the maximum inverter capacity required is 4kW. The HYPW system meets the household primary load requirement of 6,570kWh/yr with an excess electricity production of 20.7% and negligible unmet electrical load of 0%. Consistent with other previous readings the WT producing is limited to 1,638kWh/yr with the balance taken care by the PV panels with increased kW capacity and more number of panels. But it would also be probed to see whether more number of WT could also achieve better results and hence investigated further.

Figure 5.38 illustrates the requirement of 4.2kW and 4.8kW PV panels supported with 2 numbers of 1kW WT respectively. But the results do not yield a complete supply of primary electrical load to the household which read 6,568kWh/yr along with the unmet loads which is seen as 1.68kWh/yr and 1.96kWh/yr respectively. The unmet loads are primarily in the month of February and November for the 4.8kW PV panels and August, September for the 4.2kW PV panels along with 2 numbers of 1kW WT hybrid systems. Other results were also evaluated such as reduction in number of batteries to 8 numbers, but in most cases the primary house load was not served along with substantial unmet electrical loads to the household.

It is observed that the optimized results were at the best combination when the wind turbine were only 1 number 1kW capacity with a yearly output of 1,638kWh/yr. The balance of the electrical supply to the house to be provided by the PV or grid connections in all the above case related to the HYPW case configuration. There are always possibilities of varying the permutation and combination of the renewable energy systems along with the balance of components but the optimization is primarily done based on complete power served to the household and least excess electricity or unmet loads simultaneously for all the case.

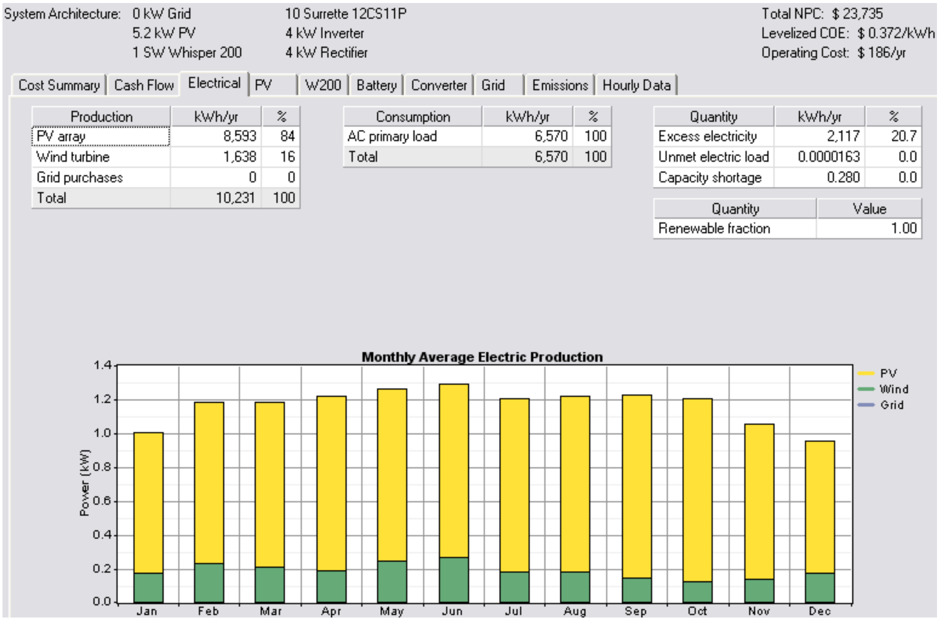


Figure 5.37: Yearly electric power production from 0.0kW (0%) Grid connection and Total HYPW (100%) with 5.2kW PV and 1 number 1kW WT electrical power output.

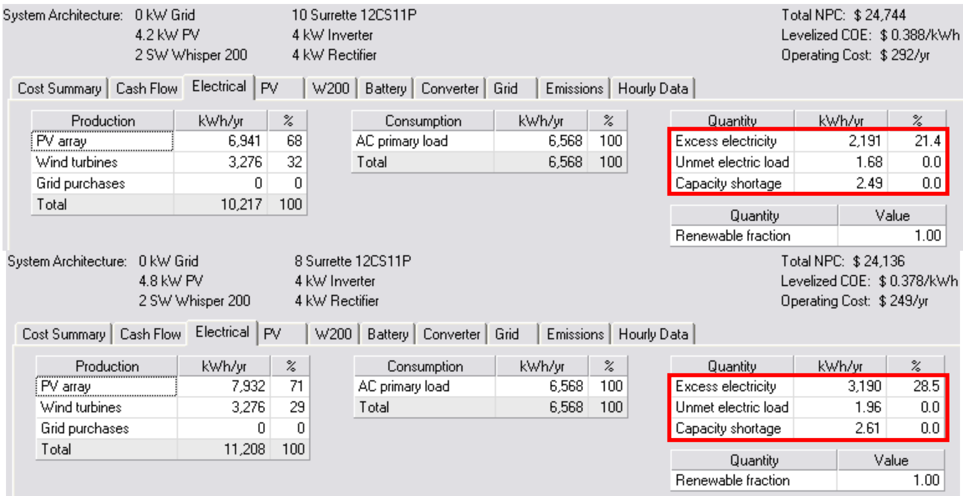


Figure 5.38: Yearly electric power production from 0.0kW (0%) Grid connection and Total HYPW (100%) with 4.2 and 4.8kW PV and 2 number 1kW WT electrical power output.

5.4.5 HYPW power output 100% Standalone

Based on the precious case configuration which is theoretically similar to the current 100% standalone HYPW case configuration is set up in order to find in variation the results in comparative. Hence the earlier set up was assessed with more addition of values to suit 100% standalone criteria with 7.0kW PV panels maximum and addition of 1 more wind turbine accounting for total 3 numbers of 1kW WT. Batteries capacity and the inverter were very much on the higher set up variation values already and hence did not warrant more than earlier. The set up was clearly done without the local grid connection and the renewable fraction was identified since no constraint was required in such a standalone HYPW current case.

<u>Electric Power Supply Assessment</u>

As per Figure 5.39 the standalone 100% HYPW case did not make additions or improvisation to the earlier results in Figure 5.37. The set up derived a 5.2kW PV panels (8,593kWh/yr-84%) and 1 number 1KW WT (1,638kWh/yr). The numbers of batteries required were 10 numbers and 4kW inverter capacity to hold the system and feed the required 6,570kWh/yr electrical load to the household. The excess also matched to about 20.7% with no unmet electric load to the house.

The 100% HYPW standalone case as illustrated in Figure 5.40 with the 5.2kW PV panels showed properties of maximum output capacity of 4.57kW with a PV penetration criteria of almost 131%. The hours of operation were 4,390hr/yr with a capacity average factor of 18.9%. Similarly the 1 number 1kW WT also showed properties with maximum output of 1kW with maximum wind penetration percentage of 24.9% and hours of operation higher than PV accounting to 6,171kWh/yr. The 10 number of batteries with bus voltage of 12V has an annual throughput of 3,756kWh/yr with losses of 798kWh/yr based on the 16kWh/yr storage depletion as shown. The batteries faired true to the selection with its in capacity of 4,173kWh/yr and out capacity of 3,359kWh/yr. The state of charge was excellent throughout the year averaging from minimum of 70% to 80% most of the time throughout the year. Under no circumstances was the batteries state of charge below 60% even during the month of peak electric loads such as July and August.

The 1 number 1kW WT produced electricity standard as other case of 1,638kWh/yr and most of the electricity production was taken care by the PV renewable energy system. Though on 16% production by the WT, its contribution cannot be neglected in the scenario where then excess dumped capacity of the system is almost 2,117kWh/yr. The comparative of the same in terms of economics shall be done in Chapter 6 though technically WT does show a marginal support to the major PV renewable energy system in the 100% HYPW current case configuration.

System Architecture: 5.2 kW PV, 1 SW Whisper 200, 10 Surrette 12CS11P, 4 kW Inverter, 4 kW Rectifier
Total NPC: $ 23,735
Levelized COE: $ 0.372/kWh
Operating Cost: $ 186/yr

Cost Summary | Cash Flow | Electrical | PV | W200 | Battery | Converter | Emissions | Hourly Data

Production	kWh/yr	%
PV array	8,593	84
Wind turbine	1,638	16
Total	10,231	100

Consumption	kWh/yr	%
AC primary load	6,570	100
Total	6,570	100

Quantity	kWh/yr	%
Excess electricity	2,117	20.7
Unmet electric load	0.0000163	0.0
Capacity shortage	0.280	0.0

Quantity	Value
Renewable fraction	1.00

Figure 5.39: Yearly electric power production from Standalone HYPW (100%) with 5.2kW PV and 1 number 1kW WT electrical power output.

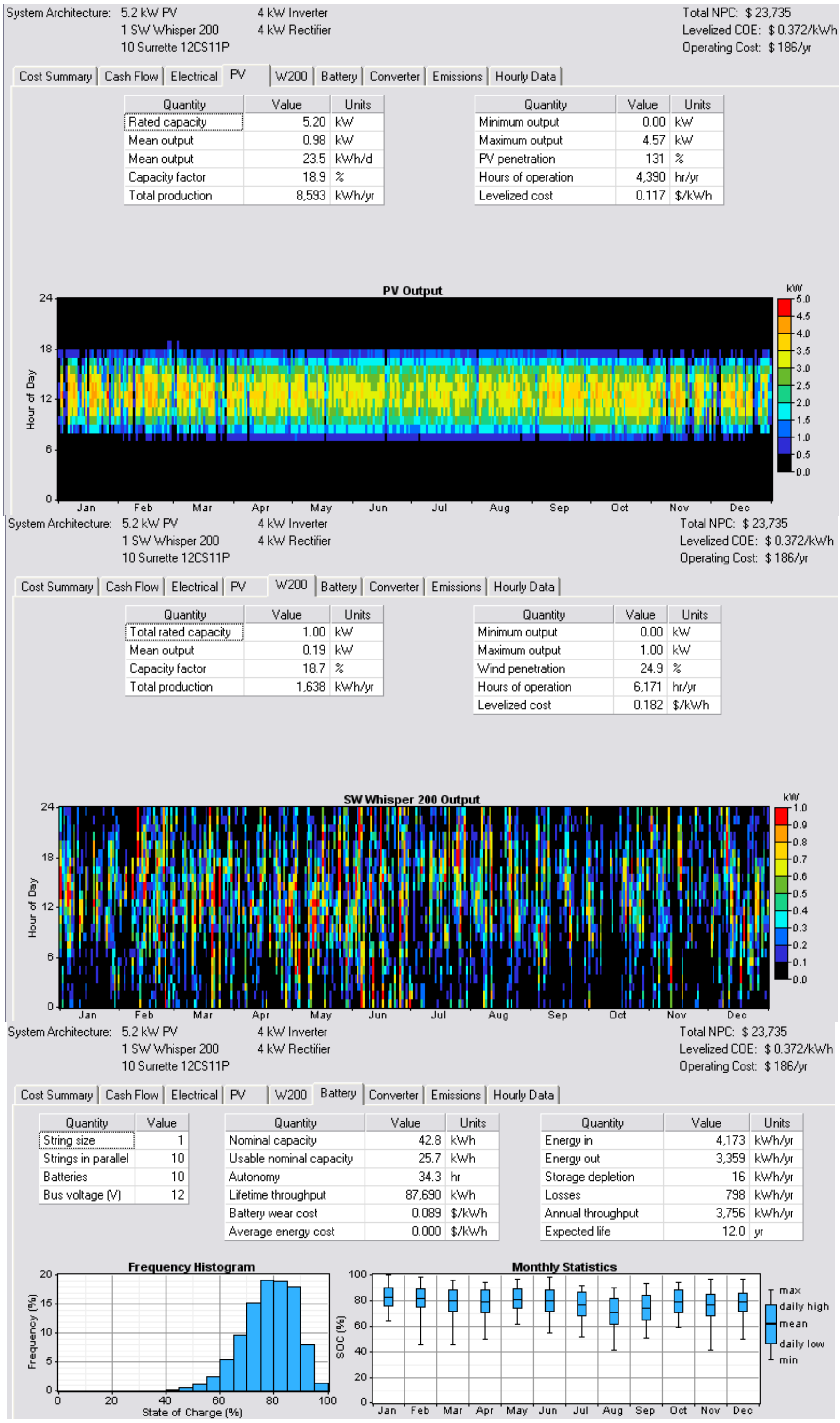


Figure 5.40: 100% Standalone HYPW case configuration with 5.2kW PV panels, 1kW (1 number) WT capacity properties each along with Battery properties obtained from the model

5.4.6 Summary Table for the HYPW module Case Configuration

Table 5.6 illustrates the summarized technically optimized system for the HYPW module case configuration based on complete provision of primary load, negligible unmet loads or capacity shortage, sufficient number of batteries and optimized inverter capacity.

Table 5.8: Technical Summary Table for HYPW module Case Configuration

Type of Conf.	Grid	PV	WT	Battery	Conv	PV Prod.	Wind Prod.	Grid Net Purchases	Tot. Elect. Prod.	Primary Load Served	Ren. Frac.	Cap. Short. Frac.	Unmet Load Frac.	Excess Elect.
	kW	kW	No	No	kW	kWh/yr	kWh/yr	kWh/yr	kWh/yr	kWh/yr		%	%	kWh/yr
HYPW-GRID CONNECTED														
25%	3.15	0.2	1	1	1	331	1,638	4,940	6,908	6,570	0.28	0	0	157
50%	1.8	1.4	1	2	2	2,314	1,638	3,626	7,578	6,570	0.52	0	0	647
75%	0.8	4	1	4	3	6,610	1,638	2,514	10,763	6,570	0.77	0	0	3,528
100%	0	5.2	1	10	4	8,593	1,638	0	10,231	6,570	1	0	0	2,117
HYPW-STANDALONE														
100%	0	5.2	1	10	4	8,593	1,638	0	10,231	6,570	1	0	0	2,117

5.4.7: Emission Levels for HYPW module Case Configuration

The outcome of the CO2 emission levels by the HYPW case configuration was promising with the reduction in the CO2 emission levels much more than the previous case configurations of individual renewable energy systems of PV and WT. From 25% right up to the 75% case configuration of the HYPW there is substantial saving the CO2 emission levels. Though still not matching to the amount of renewable energy resource used, the 25% HYPW showed a reduction by 24.81% where as the 50% HYPW case indicated a reduction close to 44.81%. Also on contrary to the previous cases, the 75% HYPW case indicated a reduction of 61.73% which was the highest as comparative to the only grid connection of 5532kg/yr and other cases. The results obtained in reduction of CO2 emission were much better in case of the hybridization of the PV and WT combined for the function of renewable energy resources.

Table 5.9: CO2 Emission due to use of HYPW module case configuration.

Energy Configuration	CO2 emission kg/yr	Reduction (%)
Local Grid Connection only	5532	0
25% HYPW-Grid Connection	4159	24.81923
50% HYPW -Grid Connection	3053	44.812
75% HYPW -Grid Connection	2117	61.73174
100% HYPW -Grid Connection and 100% HYPW-Standalone	0	100

5.5 OVERALL TECHNICAL SUMMARY AND COMPARISON (ALL CASE CONFIGURATIONS)

It is important that all the case configurations be now compared and summarized to find the optimized results to suit this technical evaluation for the electrical supply to the household. In order to do so all the cases (25%, 50%, 75%, 100% and Standalone) be compared technically with the amount of renewable energy used either grid connected or standalone, evaluate the renewable energy systems as individuals and the benefits hybridization. The following can be done by measuring each renewable energy with its electrical production and compare with the excess electricity produced which would be wasted as dumped electricity not usable to the household due to non availability of extra batteries (to avoid extra cost) or higher production of power output than the house requires during specific hours or months etc. household successfully. Due reductions during the formation of the hybrid system by the individual renewable energy systems shall also form a criteria for a successful comparison.

Table 5.10 shows a complete comparative summary of the all the case configurations based percentages of renewable energy used for every individual and hybrid renewable energy system. For the 25% gird connected case configurations the HYPW case does not prove to be much beneficial especially due to the fact that the individual renewable energy system can provide the necessary electrical power to the household since the requirement is very small with the rest taken care by the 3.15kW local grid connection. The only benefit is the reduction in the size of the PV panels from 1kW to 0.2kW whereas the 1kW 1 number WT also provides the necessary power to the household as per selection criteria. The HYPW also produces unnecessary excess electricity of 159kWh/yr as compared to the other two individuals purely due to the hybridization. Since the requirement of 25% renewable energy is very limited to the household electrical demand it would be more appropriate to use PV panels which serve best as individuals or even the 1kW 1 number WT would suit as optimized. Overall the PV panels are found to be more balance and appropriate for the 25% renewable energy configuration since they require only 1 battery and 1 kW inverter capacity with least excess electricity wastage of 61kWh/yr.

The 50% HYPW case configuration result in reduction in the PV panel's size from 2.4kW to 1.4kW with 1kW WT reduction from 2 numbers to 1 number WT's subsequently. Also there is a fair balance in the production of electrical power from the 1.4kW PV's as 30% and the 1kW 1 number WT's as 22%. Though the total electricity production amounts to 7,606kWh/yr there is comparatively less excess electricity wastage of 699kWh/yr as compared to the individual renewable energy systems of PV and WT. The local grid connection purchase capacity remains constant to 1.8kW for all case configurations. Thus the HYPW 50% case is suited as the more appropriate optimization for such a combination for hybridization considering the individuals since the HYPW system shares almost equal power supply to the household with less wastage of electricity as shown in Table 5.10.

For the 75% all case configurations the excess electricity is much higher as compared to the rest of the case predominantly due to 0.8kW or 1.05kW local grid connection and the sum of the PV's and WT's still producing electricity to its optimum in spite of the household not requiring that much amount of electrical supply. There is definitely imbalance in the overall production of electricity which is accounted by the higher use of renewable energy along with the local grid connection. Since the local grid connection is producing standard supply of electricity by 0.8kW when there is not enough storage or production of electricity by renewable energy, where as the renewable energy is producing surplus electricity during unwanted hours and timings which do not help household power storage long enough and supply them subsequently. Addition of batteries helps in certain cases such as 5 numbers of batteries in case of only WT's but not well enough. Overall Table 5.10 still remarks that the HYPW 75% case is more suitable as it reduced the amount of PV panels form 5.4kW to 4kW and the reduction of 1kW WT from 6 numbers to only 1 number for optimization. Again the excess electricity production is reduced from highest in the case of WT's 5,600kWh/yr to almost half amounting 3,528kWh/yr in the case of 75% HYPW. But most of the power is produced by the PV's accounting for 61% and 15% by the standard production of WT's. Though the ratio distribution is not quite desirable as compared to the 50% case but still accounts for the best among the 75% case configuration, which is the HYPW case in the table.

The case of 100% grid connected and the 100% standalone can be clubbed together here with since almost all the cases show similar results for both the cases except the additions of 40 numbers of batteries from 39 number of batteries in the WT 100% case configuration. It is important to note here that in spite of adding higher numbers of 1kW WT's for these case, the entire configurations cases gave an optimized result for only 1 number of 1kW WT with electricity production of 1,638kWh/yr along with increment in the PV's to take care of the balance renewable energy electricity production to the household. The HYPW 100% case shows an improvisation by the reduction of PV's from 7.0kW to 5.2kW along with the only again 1 number 1kW WT as opposed to 9 numbers in case of only WT's case configuration. The battery sizes are the same as per 10 numbers in the PV only case but significantly from the 40 numbers in the WT's only 100% case respectively. Again the PV's take the higher production electricity production with 84% and the balance by the standard 1kW 1 number WT with 16%. The excess electricity production is reduced significantly in the HYPW 100% to 2,117kWh/yr as compared to the WT's which produced 200% of the electricity required for the household, which is in terms can suit 2 number of houses of the same electricity requirement. Overall the HYPW 100% scores much better in terms of optimization to the household as compared to the individual case configurations.

Though technically the HYPW case is more suitable and found optimized for the electrical production of the household and as renewable energy power generation method out of all case compared in Table 5.10 except 25% case configuration, it remains to be seen whether the same is also economically viable which shall be assessed in further Chapter 6.

Table 5.10: Technical Summary Table for All Case Configurations

Type of REN.	Grid	Grid Output	PV	1KW WT	Battery	Conv.	PV Prod.	PV Output	Wind Prod.	WT Output	Grid Net Purchases	Tot. Elect. Prod.	Excess Elect.
	kW	%	kW	No	No	kW	kWh/yr	%	kWh/yr	%	kWh/yr	kWh/yr	kWh/yr
ALL 25% CASE CONFIGURATIONS-GRID CONNECTED													
PV	3.15	73	1	NA	1	1	1,856	27	NA	NA	4,955	6,811	61
WT	3.15	76	NA	1	1	1	NA	NA	1,638	24	5,212	6,850	129
HYPW	3.15	71	0.2	1	1	1	331	5	1,638	24	4,941	6,910	159
ALL 50% CASE CONFIGURATIONS-GRID CONNECTED													
PV	1.8	50	2.4	NA	2	2	3,966	50	NA	NA	3,939	7,905	998
WT	1.8	57	NA	2	2	2	NA	NA	3,276	43	4,319	7,595	744
HYPW	1.8	48	1.4	1	2	2	2,314	30	1,638	22	3,655	7,606	699
ALL 75% CASE CONFIGURATIONS-GRID CONNECTED													
PV	0.8	25	5.4	NA	4	3	8,924	75	NA	NA	2,927	11,851	4,591
WT	1.05	23	NA	6	5	3	NA	NA	9,829	77	2,852	12,681	5,600
HYPW	0.8	24	4	1	4	3	6,610	61	1,638	15	2,514	10,763	3,528
ALL 100% CASE CONFIGURATIONS-GRID CONNECTED													
PV	0	0	7	NA	10	4	11,568	100	NA	NA	0	11,568	3,319
WT	0	0	NA	9	39	4	NA	NA	14,743	100	0	14,743	6,693
HYPW	0	0	5.2	1	10	4	8,593	84	1,638	16	0	10,231	2,117
ALL 100% CASE CONFIGURATIONS-STANDALONE													
PV	NA	NA	7	NA	10	4	11,568	100	NA	NA	NA	11,568	3,319
WT	NA	NA	NA	9	40	4	NA	NA	14,743	100	NA	14,743	6,693
HYPW	NA	NA	5.2	1	10	4	8,593	84	1,638	16	NA	10,231	2,117
NA- NOT APPLICABLE, **REN**-RENEWABLE ENERGY SOURCE													
PV-PHOTOVOLTAIC, **WT**-WIND TURBINES, **HYPW**-HYBRID PHOTOVOLTAIC AND WIND TURBINE													

Table 5.11 illustrates that not only in terms of technical evaluation but also for higher CO2 level of reduction percentages could be achieved by the HYPW case configuration compared to all the individual cases of PV's and WT's renewable energy resources. The HYPW case configuration ranks highest in the

reduction percentage levels of CO_2 emission. The reason could be predominantly tied up with the technical evaluation whereby the use of fuel based local grid connection is reduced and the effective use of renewable energy is much higher as compared to individual renewable energy resources. No rocket science is required though for the 100% case configuration where the CO_2 emissions are completely nullified by the use of 100% renewable energy resources in any form. But the cases of 25% to 75% shows marked improvements in the reduction of CO_2 emission which are currently proving to be detrimental to the global climatic effects as reviewed and noted from the literature review.

Table 5.11: Technical Summary Table for All Case Configurations CO_2 Emission Reduction %

Case Configuration	**PV's CO2 Reduction (%)**	**WT's CO2 Reduction (%)**	**HYPW's CO2 Reduction (%)**
Local Grid Connection only	0	0	0
25% -Grid Connection	24.58424	20.67968	24.81923
50% -Grid Connection	40.05785	34.27332	44.812
75% -Grid Connection	55.44107	56.5799	61.73174
100% -Grid Connection and 100% -Standalone	100	100	100

Overall the technical basis could be summed up by stating that the HYPW case (hybridization of PV and WT) is technically proven to be more beneficial since the support of the fuel based local grid connection is reduced, and also in terms of reduction CO_2 levels as shown in Table 5.10 and Table 5.11. The economic viability of all the above results in the Chapter 5 shall be further assessed and evaluation in Chapter 6.

CHAPTER 6: ECONOMIC RESULTS AND DISCUSSION

Economics governs most of the factors related to the acceptance of any technology around the world. However advanced the research and methodology, the profits and losses of technology determine the feasibility and practicality of the proposed system. It is comparable to its benefits given the constraints as the most cost effective alternative selected on many instances. The following chapter evaluates the economic assessment of the renewable energy resources as researched in the previous chapter such as PV's, WT's and the Hybrid system of both which has been technically analyzed by way of results obtained for our model household design. The step by step technical assessment shall be now economically weighed to find the most suitable cost effective solution for the household. It may not be necessary that what evolves to the technically best needs to be economically the best as well as seen in our literature review. Thus in order to assess this stance the following criteria shall be evaluated in the economics of the renewable energy system for the model household.

- **Initial Capital Cost**: This is the total installed cost for all the components involved in the use of renewable energy system at the beginning of the project. (HOMER, 2011)

- **Operating Cost**: This is the sum of annual operation and maintenance (O & M) costs, total fuel costs, and annualized replacement cost minus the annual salvage value. It is important to note here that for gird connected system, the operating cost includes the annualized cost of the grid purchased minus the grid sale. But in our case we do not look into grid sale but shall be evaluated as a separate topic post our initial assessment. (HOMER, 2011)

- **Net Present Cost (NPC):** It is the most important factor in our evaluation as it presents the value of all the cost incurred over the lifetime of the project, minus the present value of all the revenue that it earns over its lifetime. (HOMER, 2011)

- **Cost of Energy (COE):** The levelized COE is the average cost per kWh of the used electrical energy produced by the renewable energy system for the household. (HOMER, 2011)

- **Note**: The HOMER software evaluates and optimizes all its results based on the NPC and not the COE simple due to the fact that, the COE derived by the software and it formulation is more arbitrary and disputable which is not the case with NPC. For further clarification a detail explanation has been justified by the software on its "Help Index".

Based on the above definitions the assessment for all the case configuration as mentioned in Chapter 4 shall be carried on for the it economic analysis. The technical results obtained for the use of renewable energy resources i.e. PV's, WT's and HYPW systems shall compared economically after economic results are derived case by case based on their NPC for the electricity production of the household.

6.1 ECONOMIC INPUTS FOR STUDY AND SIMULATION

Since the project is based in Dubai, UAE region it is imperative that the current market rates be derived for the study and calculations for the economic analysis for the model household. The market rates are here by not the same for other locations or regions. In order to do so the market rates as available till 2011 in Dubai, UAE for the local grid connection in kWh along with its fuel cost is mentioned as below. Also the since the economic evaluation involves renewable energy- grid connected and standalone, the market rates for the use of PV panels in kW, the complete cost of the wind turbines (WT) as a system and the balance of component system such as inverter, batteries shall be input to the simulation. The cost of charge controller here is not required as the simulation software does not model the controller though necessary as technical system but in terms of economic can be added to the cost of inverter. The following cost or market rates for the above are mentioned below which shall be justified further in Appendix E for the cost data sheets available from the 2011 market.

Note: HOMER software evaluated cost in US$ currency with the conversion: $1=AED3.673/- (XE-Universal Currency Converter, 2011)

Capital Cost of the System Individuals and Components:

- Cost of Electricity in Dubai, UAE: 30fils/kWh ($0.082/kWh) - Refer Appendix E

The cost of electricity as mentioned above includes 23fils/kWh for local fuel based electricity production plus 7fils/kWh fuel charge

- Cost of PV Suntech polycrystalline panels (200W): $405/-(AED1,487.57/-) per panel - Refer Appendix E

As inputs into HOMER the complete cost of 1kW panel is considered totaling to: $2025/-(AED7, 437.83/-)

- Cost of 1kW WT (Whisper 200): $2000/-(AED7,346.00/-) per WT - Refer Appendix E

- Cost of Battery (Rolls 12V 357Ah Series 5000 Deep Cycle Dual): $700/-(AED2,571.10/-) per battery - Refer Appendix E

- Cost of Inverter (Xantrex 6000W Hybrid Inverter): $3600/-(AED13,222.80/-)- Refer Appendix E

Since the model simulation involves step by step increment in the inverter sizes, the above cost is for 6kW and the same for the 1kW shall be $600/-(AED2,203.80/-) has been calculated.

Replacement and O & M cost of the System Individuals and Components:

As mentioned earlier that the simulation software evaluates the economic viability of the renewable energy system based on the NPC which is the cost of the project over its lifetime, hence it is important that the replacement and O&M cost of the entire individual systems and components be added to achieve a more realistic monetary figure. The following are the assumptions are taken into consideration for the same based on HOMER software analysis literature review.

Table 6.1: Replacement and O & M Cost Input Assumption (HOMER, 2011)

	PV	**WT**	**Battery**	**Inverter**
	$ (AED)	**$ (AED)**	**$ (AED)**	**$ (AED)**
Replacement Cost	1400 (5,142.2)	800 (2,938.4)	700 (2,571.1)	600 (2,203.8)
O & M Cost	0	100 (367.3)	4 (14.7)	0

Note: Economic Conversion factor: $1/-=AED3.673/- (XE-Universal Currency Converter, 2011)

The project lifetime for evaluation is considered for 15 years to avoid higher degradation factor for various components used for the system even though most of manufacturers mention 20 years lifetime (Chaar and Lemont, 2010). Also by retaining the manufacturers lifetime period will also reduce the components salvage values and hence avoided. Hence the replacement cost of PV renewable energy is considered as 70% due to the fact as seen in literature, that the PV's are more susceptible to damages and cells often degrade further as time passes by with accumulation of dust particles and might require replacement of certain panels in due course of time. The O&M is not there as the cost is absorbed in replacement of the panels itself. For the WT the replacement is very minor with certain components inside the WT might require periodic replacement as well as maintenance in the life time of 15 years. Balance of system is critical here with batteries and inverter if damaged might require 100% replacement and comparatively fractional O&M cost as seen from Table 6.1.

6.2 ECONOMIC EVALUATION FOR VARIOUS CASE CONFIGURATIONS

Since the technical assessment and results have been involved with a step by step progression into results oriented summary, it is hereby also evaluated for economic purpose a comparative for all case of non renewable energy system, renewable energy system grid connected and finally the standalone renewable energy solution. For this purpose each individual case for 25% grid connected to 100% grid connected and standalone shall be further analyzed and compared to form the basis of this economic progressive evaluation. But before we proceed with the renewable energy system the main comparative shall also involve the non renewable case configuration of local grid connection as seen in section 5.1.1

6.2.1 Non Renewable Energy Case Configuration Economic Assessment (Local Grid Connection)

Base configuration of non renewable configuration for a local grid connection to the household technical results indicated as electrical power requirement of 4.2kW as per Figure 5.2. The economic evaluation results in the following as shown in Figure 6.1 by the simulation software with the NPC of $5,232/- (AED 19,217.14/-). The NPC includes the capital cost, replacement cost; O&M costs and mainly in this case the costs of buying the power from the grid.

In actual the capital cost of providing the electrical connection to the household from the local grid connection would also involve cost of the payments to DEWA (Dubai Electricity and Water Authority) such as meter rental, installation, connection, commissioning, NOC certificates etc. All these are also true for all grid connections case, but in order to simplify the mode of assessment these cost are not considered for all grid connected cases to avoid complications involving variation in fees from area, location, site etc as governed by DEWA. Hence only the cost of electricity power supply to the household is considered as per the current market rates under the slab rates dictated by DEWA, 2011 as referred from Appendix E.

The operating cost is $539/yr (AED1,979.75/-) which includes only the annualized cost of the grid purchase from DEWA grid connection with the COE $0.082/kWh (30fils/kWh) which is the cost of electricity charged by the local grid connection authority per kWh electricity consumed, DEWA. There is no replacement cost or salvage cost, whereas the fuel cost is already included in the cost of electricity supply by the local authorities.

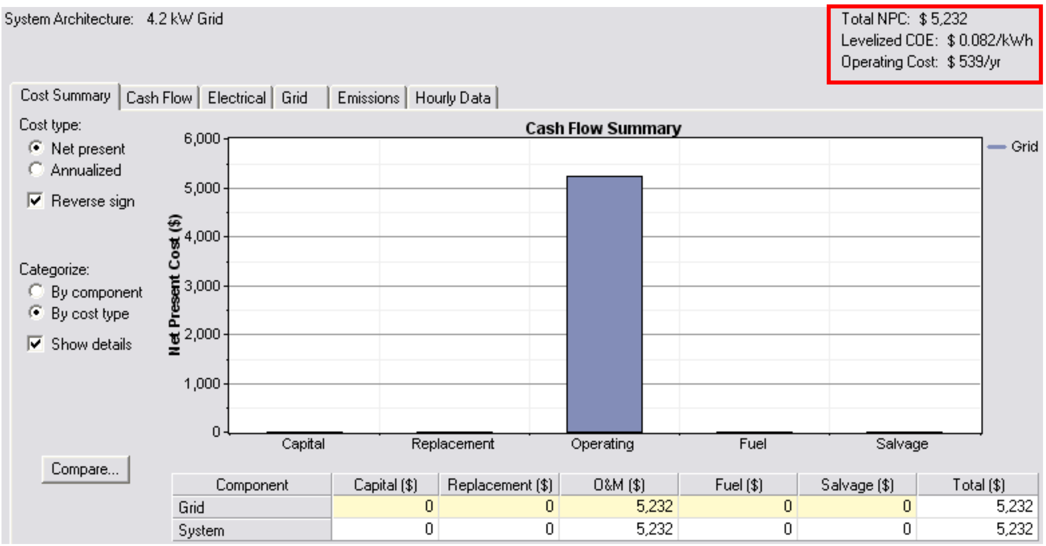


Figure 6.1: Economic results, NPC for non renewable energy (4.2kW Local Grid Connection)

6.2.2 All 25% Renewable Energy Grid Connected Case Configuration Economic Assessment

The technical evaluation results for the 25% renewable energy resources grid connected as illustrated from Table 5.10 is taken as the baseline for economic assessment, in order to simulate the various 25% case configuration. With 3.15kW grid connectivity, supplemented by balance electrical production by 1kW PV panels initially, later by 1kW 1 number WT and finally 0.2kW PV panels and 1kW 1 number WT supported by 1 number of battery and 1kW inverter capacity to the household brought about an economic simulation assessment as shown in Table 6.2. Since a HYPW grid connected system was found to be over designed for the 25% case configuration, it was summarized that the individual renewable energy resources such as PV's and WT's were more than sufficient to meet the household demand technically. Similarly even with the economic results derived the PV's 25% case with its NPC cost at AED 26,787/- and the WT's 25% case NPC cost at AED 31,243/-. The over design of HYPW 25% resulted in higher estimated NOC of AED 31,827/- due to combined increase in the replacement and O&M costs consecutively. Between the individual 25% cases, the PV's termed to be more economical even though the initial investment was very close, but the replacement and O&M cost was comparatively lesser in case of PV's as compared to that of WT's.

Table 6.2: All 25% Renewable Energy-Grid Connected Economic Assessment Results

Type of REN.	Grid	PV	1KW WT	Battery	Conv	Initial Capital Cost	Initial Capital Cost	Operating Cost	Operating Cost	Total NPC	Total NPC	COE	COE
	kW	kW	No	No	kW	$	AED	$	AED	$	AED	$/kWh	AED/kWh
ALL 25% CASE CONFIGURATIONS-GRID CONNECTED													
PV	3.15	1	NA	1	1	3,325	12,213	409	1,502	7,293	26,787	0.114	0.419
WT	3.15	NA	1	1	1	3,300	12,121	536	1,969	8,506	31,243	0.133	0.489
HYPW	3.15	0.2	1	1	1	3,705	13,608	511	1,877	8,665	31,827	0.136	0.500
NA- NOT APPLICABLE, **NPC**-NET PRESENT COST, **COE**-COST OF ENERGY, **CONVERSION**: $1/-=AED3.673/-													
PV-PHOTOVOLTAIC, **WT**-WIND TURBINES, **HYPW**-HYBRID PHOTOVOLTAIC AND WIND TURBINE													

Figure 6.2 illustrates the best combination in terms of economics for the 25% case configuration with only PV's and its balance of component system. The PV replacement cost is practically nullified due to the very minimal requirement of the same with only 1kW panels (only 5 panels of 200W as per selection criteria) where as the batteries do require replacement cost considering the 15 years project lifetime accounting for $348/- (AED 1,278.20/-) and an O&M cost of $39/- (AED 143.24/-). There is an operating cost of the grid connection of 3.15kW which is the balance of the power supply to the household costing $3,946/- (AED 14,493.65/-). The subsequent salvage values can be seen from Figure 6.2 and the inverter identified as an one time investment for the purchase of 1kW inverter capacity costing $600/- (AED2,203.80/-).

Overall for the 25% case configuration the 1kW PV's, 3.15kW grid connection along with 1 number of battery and 1 kW inverter capacity proved to be more cost effective with total NPC of AED 26,787/- with the COE at AED 0.419/kWh.

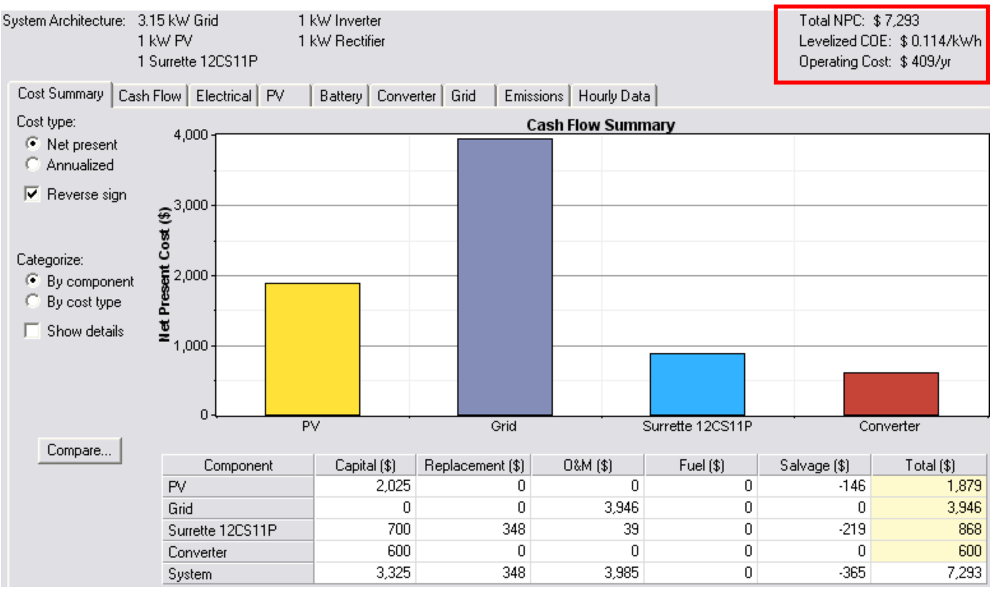


Figure 6.2: Economic results, NPC for 3.15kW (73%) grid connection and 1kW (27%) PV power output.

6.2.3 All 50% Renewable Energy Grid Connected Case Configuration Economic Assessment

The economic assessment for the 50% renewable energy grid connection case evolved results by simulation software as indicated in Table 6.3. As the 50% cases technical evaluation recorded results with 1.8kW local grid connection with 2.4kW PV panels, 2 number of 1kW WT and finally HYPW case of 1.4kW PV hybrid with 1 number 1kW WT supported by batteries and inverter 2kW capacity as illustrated in Table 5.10, the same formed again the baseline for the economic assessment. The 50% WT case was the most costly with the NPC accounting for AED 44,627/- due to high operating cost of AED 2,097/- and subsequent COE resulting at AED 0.190/kWh. But the PV and HYPW cases were very close to fair comparison with HYPW 50% case NPC cost as AED 41,659/- and the PV 50% case NPC cost marginally less at AED 38,868/-. This was primarily due to the considerable reduction in HYPW case renewable energy percentage ratio of PV's from 2.4kW to 1.4kW panels and WT's from 2 numbers reduced to 1 number only 1kW WT. But due to the higher involvement of equipments such as PV's plus WT's the operating cost increased as compared to the PV's only from HYPW operating cost at AED 1,477/- and the PV's 50% only operating cost at AED 1,179/-. The difference in them got the better for 50% PV only case to have a reduction in the NPC as the most cost effective here by reducing the COE to AED 0.610/kWh respectively as shown in Table 6.3.

Table 6.3: All 50% Renewable Energy-Grid Connected Economic Assessment Results

Type of REN.	**Grid**	**PV**	**1KW WT**	**Battery**	**Conv**	**Initial Capital Cost**	**Initial Capital Cost**	**Operating Cost**	**Operating Cost**	**Total NPC**	**Total NPC**	**COE**	**COE**
	kW	kW	No	No	kW	$	AED	$	AED	$	AED	$/kWh	AED/kWh
ALL 50% CASE CONFIGURATIONS-GRID CONNECTED													
PV	1.8	2.4	NA	2	2	7,460	27,401	321	1,179	10,582	38,868	0.166	0.610
WT	1.8	NA	2	2	2	6,600	24,242	571	2,097	12,150	44,627	0.190	0.698
HYPW	1.8	1.4	1	2	2	7,435	27,309	402	1,477	11,342	41,659	0.178	0.654
NA- NOT APPLICABLE, **NPC**-NET PRESENT COST, **COE**-COST OF ENERGY, **CONVERSION**: $1/-=AED3.673/-													
PV-PHOTOVOLTAIC, **WT**-WIND TURBINES, **HYPW**-HYBRID PHOTOVOLTAIC AND WIND TURBINE													

In spite of the technical evaluation resulting in the HYPW 50% case to be better than the rest of the individual 50% cases as per Table 5.10, the economic assessment evaluated the PV's only 50% case to be more cost effective as compared to other cases. Figure 6.3 illustrates the cost distribution of the cost effective PV only 50% grid connected case based on the cost involved by the individual components in the system. Though the 1.8kW local grid connection is cost is as per the balance 50% production of electricity, is still higher due to the extent of excess electricity production as well as mentioned earlier. The PV 50% case with the 2.4kW PV panels, 2 number of batteries and 2kW inverter capacity cost are as per the input parameter of the basic capital cost mentioned in earlier, but there is higher salvage value due to the increment in the size of the renewable energy and the balance of components.

Overall again for the 50% case configuration the 2.4kW PV's, 1.8kW grid connection along with 2 number of battery and 2kW inverter capacity proved to be more cost effective with total NPC of AED 38,868/- with the COE at AED 0.610/kWh. This is similar to the explanation for the earlier case where the cost is reduced due to lesser involvement of renewable energy equipments, with just PV panels used to suffice for the electrical output of the household having lower O&M cost here by reducing the operating cost as compared to the other cases of WT's and HYPW's respectively.

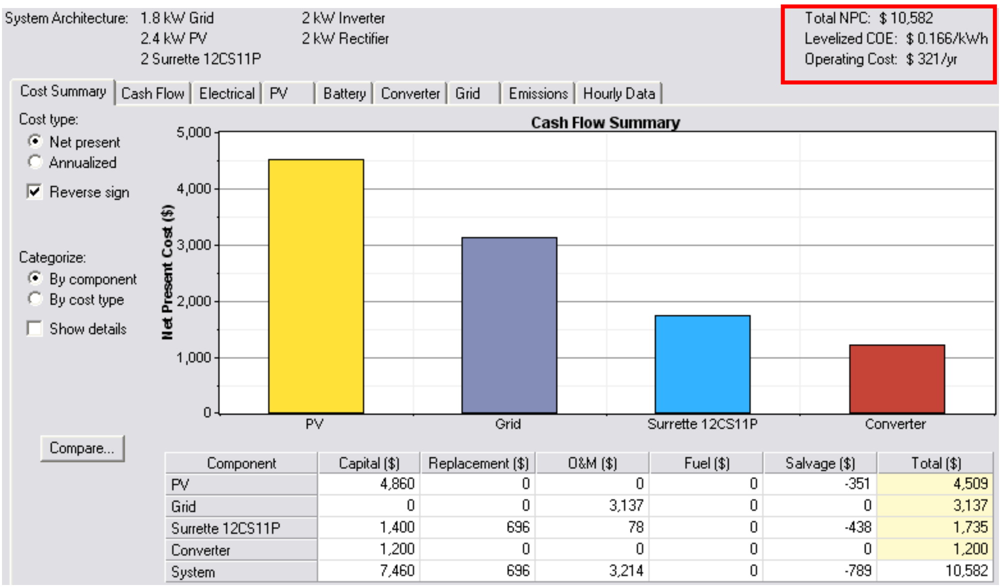


Figure 6.3: Economic results, NPC for 1.8kW (50%) grid connection and 2.4kW (50%) PV power output.

6.2.4 All 75% Renewable Energy Grid Connected Case Configuration Economic Assessment

On contrary to the previous economic assessment of the 25% and 50% case configurations the 75% renewable energy grid connection economics results prove to the better with the HYPW 75% case configuration as shown in Table 6.4. The HYPW 75% case configuration economics resulted in the NPC cost of AED 64,928/- which was lower than its closest competitor, only PV's 75% grid connected with a NPC of AED 65,188/-. The WT 75% case brought about an astonishing figure of NPC of AED 94,532/- predominantly due to the high initial capital cost of AED 63,543/- of the 6 number of 1kW WT along with 5 numbers of batteries and 3kW inverter capacity costs. The operating cost was also respectively increased due to the high number of instrumentation required in the system configuration for a successful household electric load provision. However in the case of only PV's the initial capital cost was also higher as compared to the HYPW with number of PV panels increased with capacity from 5.4kW to reduction of 4kW PV's requirement. Subsequently the operating cost of the HYPW though higher at AED 1,124/- as compared to the PV's, this did not account for NPC for the HYPW case being higher than the PV's 75% grid connected case. In this case, the HYPW due to the lower initial capital cost proved to be more cost effective than the PV's case where by lowering the COE to AED 0.277/kWh which was only fractionally lesser then the PV's COE of AED 0.278/kWh respectively.

Table 6.4: All 75% Renewable Energy-Grid Connected Economic Assessment Results

Type of REN.	**Grid**	**PV**	**1KW WT**	**Battery**	**Conv**	**Initial Capital Cost**	**Initial Capital Cost**	**Operating Cost**	**Operating Cost**	**Total NPC**	**Total NPC**	**COE**	**COE**
	kW	kW	No	No	kW	$	AED	$	AED	$	AED	$/kWh	AED/kWh
ALL 75% CASE CONFIGURATIONS-GRID CONNECTED													
PV	0.8	5.4	NA	4	3	15,535	57,060	228	837	17,748	65,188	0.278	1.021
WT	1.05	NA	6	5	3	17,300	63,543	869	3,192	25,737	94,532	0.403	1.480
HYPW	0.8	4	1	4	3	14,700	53,993	306	1,124	17,677	64,928	0.277	1.017
NA- NOT APPLICABLE, **NPC**-NET PRESENT COST, **COE**-COST OF ENERGY, **CONVERSION**: $1/-=AED3.673/-													
PV-PHOTOVOLTAIC, **WT**-WIND TURBINES, **HYPW**-HYBRID PHOTOVOLTAIC AND WIND TURBINE													

Figure 6.4 illustrates the detailed cost break up for the HYPW 75% grid connected case configuration which proved to be the most cost effective among the other two PV's and WT case configuration. With initial capital cost of AED 53,993/- for the HYPW case involving the 4kW PV panels, 1 number of 1kW WT supported by 4 numbers of batteries and 3kW inverter capacity. The largest contribution in terms of cost was technically and economically by the 4kW PV panels costing $8,100/- (AED 29,751.3/-) followed by the battery cost of $2,800/- (AED 10,284.4/-) and finally 1kW 1 number WT and inverter subsequently costing $ 2000/- and $ 1800/- (AED 7,346/- and AED 6,611.4/-) respectively. The only replacement cost was for batteries over the 15 year project lifetime period with grid O&M cost of $ 2,002/- (AED 7,353.35/-) followed by WT and batteries again respectively. Overall the HYPW 75% grid connected case was the best optimization economically in the configuration with less NPC as seen in Figure 6.4 and Table 6.4.

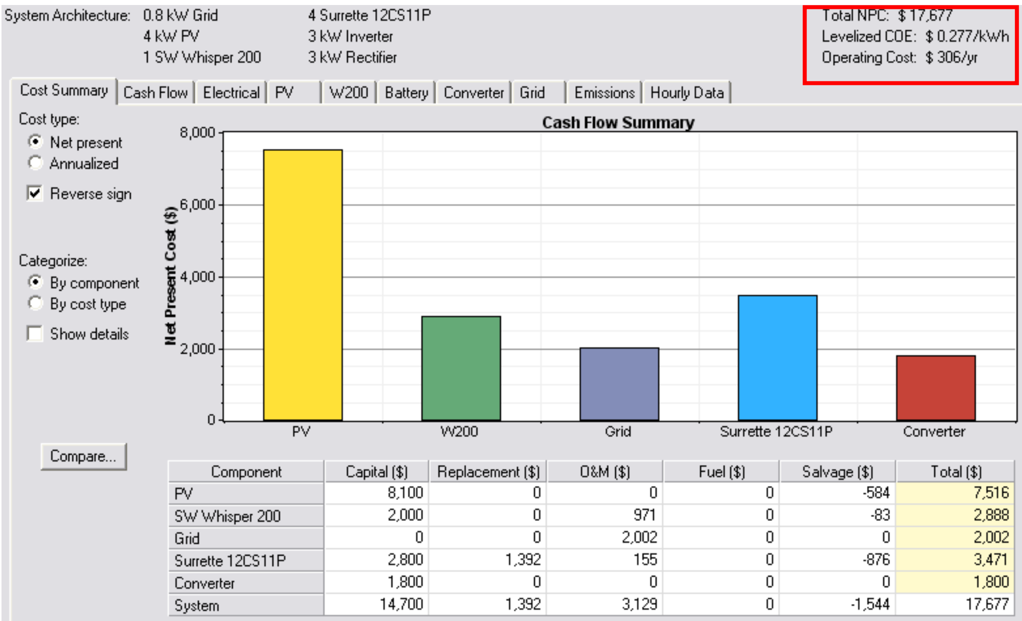


Figure 6.4: Economic results, NPC for 0.8kW (23%) Grid connection and Total HYPW (77%) with 4.0kW PV and 1 number 1kW WT electrical power output.

6.2.5 All 100% Renewable Energy Grid Connected and Standalone Case Configuration Economic Assessment

The economic evaluation for 100% renewable energy grid connected versus standalone derived similar results for PV's 100% and HYPW's 100% due to the technical match as indicated in Table 5.10, except the variation in the number of batteries for the WT 100% grid connected versus standalone case configuration. However as shown in Table 6.5 and Table 6.6 the most economically optimized results for both 100% grid connected and Standalone case were the HYPW economic results showing a NPC of AED 87,179/-. In both case the HYPW showed a remarkable difference as compared to the PV and WT cases due to technical reduction of PV panels from 7kW to 5.2kW and reduction in the number of 1kW WT from 9 numbers to 1 number. Due to this reduction the HYPW initial capital cost was AED 21,930/- which was less as compared to PV's as well as the WT's. Since WT's 100% grid connected and standalone case indicates a higher number of WT increasing the NPC to AED 231,326/- and AED 231,752/- respectively, they were surely not comparable. But the PV's were still matched with a close competition of same NPC of AED 88,993/- for both the case.

Again in spite of the operating cost of HYPW for both case in Table 6.5 and Table 6.6 was higher than PV's with AED 683/- as compared to AED 246/-, the reduction in subsequent initial capital costs due to need of lesser number of PV sizes and numbers and WT numbers in the HYPW case proved beneficial and cost effective. 100% HYPW grid connected and standalone case also evolved a comparatively less COE at AED 0.372/kWh in comparison to fairly closer PV's case configuration COE of AED 0.380/kWh.

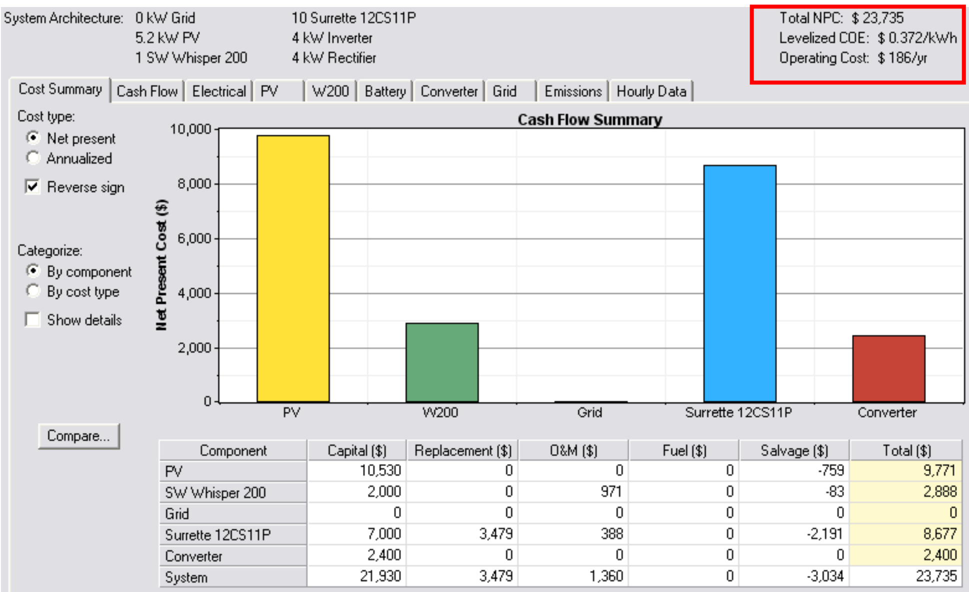
Table 6.5: All 100% Renewable Energy-Grid Connected Economic Assessment Results

Type of REN.	**Grid**	**PV**	**1KW WT**	**Battery**	**Conv**	**Initial Capital Cost**	**Initial Capital Cost**	**Operating Cost**	**Operating Cost**	**Total NPC**	**Total NPC**	**COE**	**COE**
	kW	kW	No	No	kW	$	AED	$	AED	$	AED	$/kWh	AED/kWh
ALL 100% CASE CONFIGURATIONS-GRID CONNECTED													
PV	0	7	NA	10	4	23,575	86,591	67	246	24,229	88,993	0.380	1.396
WT	0	NA	9	39	4	47,700	175,202	1,573	5,778	62,980	231,326	0.987	3.625
HYPW	0	5.2	1	10	4	21,930	80,549	186	683	23,735	87,179	0.372	1.366
NA- NOT APPLICABLE, **NPC**-NET PRESENT COST, **COE**-COST OF ENERGY, **CONVERSION**: $1/-=AED3.673/-													
PV-PHOTOVOLTAIC, **WT**-WIND TURBINES, **HYPW**-HYBRID PHOTOVOLTAIC AND WIND TURBINE													

Table 6.6: All 100% Renewable Energy-Standalone Economic Assessment Results

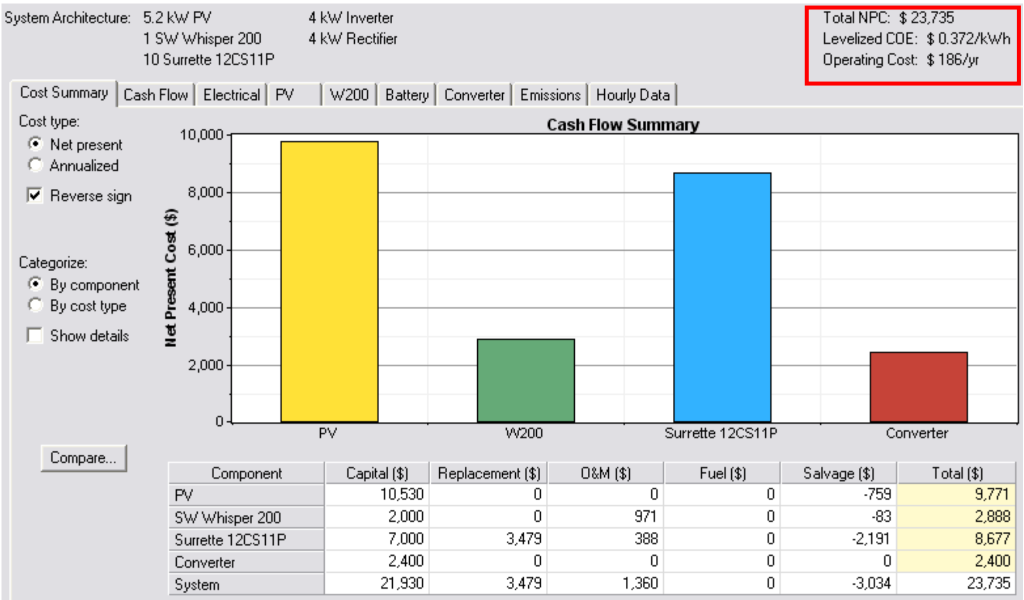
Type of REN.	**Grid**	**PV**	**1KW WT**	**Battery**	**Conv**	**Initial Capital Cost**	**Initial Capital Cost**	**Operating Cost**	**Operating Cost**	**Total NPC**	**Total NPC**	**COE**	**COE**
	kW	kW	No	No	kW	$	AED	$	AED	$	AED	$/kWh	AED/kWh
ALL 100% CASE CONFIGURATIONS-STANDALONE													
PV	NA	7	NA	10	4	23,575	86,591	67	246	24,229	88,993	0.380	1.396
WT	NA	NA	9	40	4	48,400	177,773	1,513	5,557	63,096	231,752	0.989	3.633
HYPW	NA	5.2	1	10	4	21,930	80,549	186	683	23,735	87,179	0.372	1.366
NA- NOT APPLICABLE, **NPC**-NET PRESENT COST, **COE**-COST OF ENERGY, **CONVERSION**: $1/-=AED3.673/-													
PV-PHOTOVOLTAIC, **WT**-WIND TURBINES, **HYPW**-HYBRID PHOTOVOLTAIC AND WIND TURBINE													

Figure 6.5 and Figure 6.6 illustrate a similar breakdown of the costs involved in the optimized cost effective results for the 100% HYPW case and standalone case configuration. Due to higher number of dependability on 5.2kW PV panels the capital cost of the same amounts to be highest to $10,530/- (AED 38,676.7/-) followed by the 10 number of batteries at $ 7000/- (AED 25,711/-) and then the inverter at $2400/- (AED 8,815.2/-) followed finally by the 1 number 1kW WT at $2000/- (AED 7346/-) respectively. There is not grid connection cost in both the case as theoretically, and technically both work in the same system configuration. The only additional cost are the replacement of batteries at $3,479/- (AED 12,778) and the O&M cost of WT and batteries again at $971/- (AED 3,566.5/-) and $388/- (AED 1,425.12/-) respectively. Overall the NPC of HYPW optimization cost is AED 87,179/- which is majorly due to the investment in PV's and batteries in spite of the system being a hybrid of PV's and WT's.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	10,530	0	0	0	-759	9,771
SW Whisper 200	2,000	0	971	0	-83	2,888
Grid	0	0	0	0	0	0
Surrette 12CS11P	7,000	3,479	388	0	-2,191	8,677
Converter	2,400	0	0	0	0	2,400
System	21,930	3,479	1,360	0	-3,034	23,735

Figure 6.5: Economic results, NPC for 0kW (0%) Grid connection and Total HYPW (100%) with 5.2kW PV and 1 number 1kW WT electrical power output.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	10,530	0	0	0	-759	9,771
SW Whisper 200	2,000	0	971	0	-83	2,888
Surrette 12CS11P	7,000	3,479	388	0	-2,191	8,677
Converter	2,400	0	0	0	0	2,400
System	21,930	3,479	1,360	0	-3,034	23,735

Figure 6.6: Economic results, NPC for Standalone HYPW (100%) with 5.2kW PV and 1 number 1kW WT electrical power output.

6.3 EXCESS ELECTRICITY PRODUCTION SALE AND NET METERING

There is excess electricity production by the renewable energy case configuration which can be seen from summary Table 5.10. Technically this excess electricity is surplus electrical energy that must be dumped because it cannot be used to serve a load or charge the battery. Since the simulation software HOMER optimizes results based on "Net Present Cost" the optimized evaluation is derived with minimal investment or overall project cost over the lifetime. Hence the electrical production by the renewable energy resource which is produced in excess and is not required during a specific period served to the household can be stored in batteries in literal terms. But then again batteries have discharge rate, so the unused energy will be discharged from the batteries in due course again, so the software dumps the load in such a situation rather than just increase the number of batteries and finally add more cost. This excess electricity is considered as wastage and could be of good use if sold back to the grid with additional savings and reduction in the NPC cost of the project.

In Dubai, UAE though the sale of electricity is not permitted except by the local electricity and water authorities in the country monitored by the government (DEWA, 2011). But in other countries such as US, Australia, Germany etc. there are schemes and policies available in order to benefit from the production of electricity from renewable energy resources. Once such method known as "Net Metering" with other followed by Green Certificates (REC's), Green Pricing, Feed In Tariff etc (US DOE, 2011). For the purpose of comparison and a model for our case of excess electricity production we look as "Net Metering" which would form the basis of certain savings in the NPC of the household model.

Net Metering: This is a program/incentive for the consumer investors of the renewable energy generation so as to enable their produced renewable energy to be offset by their consumption over a billing period by the electric meter to turn backwards when they generate electricity in excess of their demand. By this method the customers receive retail prices for the excess electricity generated, or in some case when no net meter is available then a second meter is installed to measure electricity that flows backwards to the provider, with the provider purchasing the power at a rate similar to the retail rate. As of November 2010, net metering is offered in 43 states in the USA, (US DOE, 2011) as shown in Table 6.7.

Table 6.7: Example of Net Metering Rates in the US (Wikipedia, 2011)

State	Subscriber limit (% of peak)	Power limit Res/Com(kW)	Monthly rollover	Annual compensation
Alabama	N/A	N/A	N/A	N/A
Alaska	1.5	25	yes, indefinitely	retail rate
Arizona	no limit	125% of load	yes, avoided-cost at end of billing year	retail rate
Arkansas	no limit	25/300	yes, until end of billing year	retail rate
California	5	1,000	yes, can be indefinitely	varies
Colorado	no limit	120% of load or 10/25*	yes, indefinitely	varies*
Connecticut	no limit	2,000	yes, avoided-cost at end of billing year	retail rate
Delaware	5	25/500 or 2,000*	yes, indefinitely	retail rate

Net Purchase and Sale: This is again a different method from Net Metering which does not offer price symmetry with countries such as Germany; Spain etc have adopted a price schedule or Feed In Tariff, in which the customers get paid back for the electricity production generated from renewable energy on their premises. There is a separate meter which counts the actual electricity generation apart from the excess electricity that feeds back to the grid. Particularly in case of Germany specific for solar power, a feed in tariff is more than 2 times the retail rate per kWh for residential customers (Wikipedia, 2011). Table 6.8 illustrates the feed in tariff rates in Germany.

Table 6.8: Example of Feed in Tariff Rates in the Germany (Wikipedia, 2011)

Peak power dependent FiT for solar electricity in €-ct/kWh

type		2004	2005	2006	2007	2008	2009	2010	Jul 2010	Oct 2010	2011
Rooftop mounted	up to 30 kW	57,4	54,53	51,80	49,21	46,75	43,01	39,14	34,05	33,03	28,74
	between 30 kW and 100 kW	54,6	51,87	49,28	46,82	44,48	40,91	37,23	32,39	31,42	27,34
	above 100 kW	54,0	51,30	48,74	46,30	43,99	39,58	35,23	30,65	29,73	25,87
	above 1000 kW	54,0	51,30	48,74	46,30	43,99	33,00	29,37	25,55	24,79	21,57
Ground mounted	contaminated grounds	45,7	43,4	40,6	37,96	35,49	31,94	28,43	26,16	25,37	22,07
	agricultural fields	45,7	43,4	40,6	37,96	35,49	31,94	28,43	-	-	–
	other	45,7	43,4	40,6	37,96	35,49	31,94	28,43	25,02	24,26	21,11

For the purpose of evaluation we use these 2 different methods on our house model as a specific example in the 75% HYPW –Grid connected case which has excess electricity production of 3,528kWh/yr as shown in Table 5.10 in order to derive the technical and economical advantages and benefits if any.

6.3.1 HYPW 75% Renewable Energy Source-Grid Connected with Net Metering program

In order to validate the Net Metering for our case the following inputs are necessary in the simulation software which enables us to derive results with the program. The Grid Sale Back rate needs to be fed in at the same price as the retail rate which is $0.082/kWh (30fils/kWh). Also the grid sale parameter needs to be set in order to enable the software to sell back the excess electrical production was set to maximum of 10kW, which is technically selling all excess electrical production.

Figure 6.7 can be compared in terms of analysis to Figure 5.36 for technical similarity and Figure 6.4 illustrating the economic benefits of Net Metering program for our model household whereby there is reduction in NPC to $ 15,167/-(AED 55,708) which is positive decrement. The reduction is essential due to the sale of excess electricity of 3,151kWh/yr which accounts for 32% sale giving an economic saving of 15% comparable to original NPC of AED 64,928/- without Net Metering.

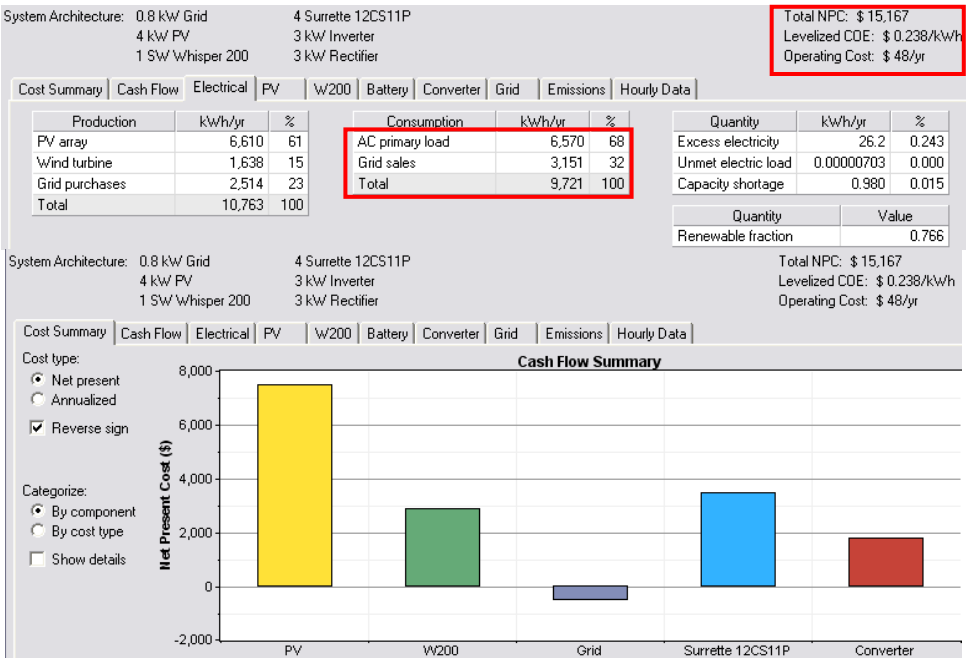


Figure 6.7: Net Metering Economic Results for 75% HYPW- Grid Connected Case Configuration.

Table 6.9 further elaborates the comparison with a break of cost for every component utilized to achieve the HYPW 75% grid connected case configuration with and without net metering. By introducing the net metering the grid sale is seen with the O&M cost in the negative zone reducing the total NPC by 15% with a value of AED 55,708/-. The O&M cost of the grid connection without net metering of AED 11,492.82/- is reduced to AED 2,273.59/- with the program of net metering have a grid sell back rate same as the grid purchase rate.

Table 6.9: Economic Comparison with and without Net Metering (75% HYPW-Grid Connected)

HYPW 75% GRID CONNECTED WITH NET METERING										
Component	**Capital ($)**	**Capital (AED)**	**Replace-ment ($)**	**Replace-ment (AED)**	**O&M ($)**	**O&M (AED)**	**Salvage ($)**	**Salvage (AED)**	**Total ($)**	**Total (AED)**
PV	8,100	29,751	0	0.00	0	0.00	-584	-2145	7,516	27,606
WT	2,000	7,346	0	0.00	971	3,566.48	-83	-304.86	2,888	10,608
Grid	0	0	0	0.00	-507	-1,862.21	0	0	-507	-1,862
Battery	2,800	10,284	1,392	5,112.82	155	569.32	-876	-3217.5	3,471	12,749
Converter	1,800	6,611	0	0.00	0	0.00	0	0	1,800	6,611
System	14,700	53,993	1,392	5,112.82	619	2,273.59	-1,544	-5671.1	15,167	55,708
HYPW 75% GRID CONNECTED WITHOUT NET METERING										
Component	**Capital ($)**	**Capital (AED)**	**Replace-ment ($)**	**Replace-ment (AED)**	**O&M ($)**	**O&M (AED)**	**Salvage ($)**	**Salvage (AED)**	**Total ($)**	**Total (AED)**
PV	8,100	29,751	0	0	0	0.00	-584	-2145	7,516	27,606
WT	2,000	7,346	0	0	971	3,566.48	-83	-304.86	2,888	10,608
Grid	0	0	0	0	2,002	7,353.35	0	0	2,002	7,353
Battery	2,800	10,284	1,392	5112.816	155	569.32	-876	-3217.5	3,471	12,749
Converter	1,800	6,611	0	0	0	0.00	0	0	1,800	6,611
System	14,700	53,993	1,392	5112.816	3,129	11,492.82	-1,544	-5671.1	17,677	64,928
GRID SELL BACK RATE SAME AS PURCHASE=$0.082/kWh (AED 30FILS/kWh)										

6.3.2 HYPW 75% Renewable Energy Source-Grid Connected with Higher Net Sale (Feed In Tariff)

As per section 6.3 second method with net sale feed in tariff 2 times the purchase rate available in Germany, the current case in Dubai, UAE shall be fed with inputs of sell back rate of $0.164/kWh (AED 60fils/kWh). No net metering shall be considered but a simple pay back 2 times of the current rate of purchase shall be analyzed to arrive a possible cost saving. The sale of excess electricity production capacity is maintained at maximum 10kW similar to earlier case of net metering.

For most of configurations run on the simulation software did not yield a technically similar configuration for fair comparison but the results were beyond the bare minimum requirement of 4kW PV panels and 1kW 1 number WT for the HYPW 75% standard case. This was essentially due to the higher sell back rate which instigated to make higher initial investment in order to have a better pay back period over the project lifetime. Thus the technical results illustrated as in Figure 6.8 indicate a 3.15kW grid connection though still balance 25% power output with 4.6kW PV panels, 1 number 1kW WT supported by 3kW inverter capacity. Here the batteries were completely ignored due to the higher grid connection and better renewable energy resources complying with the household electrical demand load. The renewable fraction was still 75%.

The overall economic assessment indicated an upfront initial capital investment of $13,115/- (AED 48,171.13/-) which was still lower than the net metering case due to reduction in the battery costs. But there was higher grid sale of 4,646kWh/yr (41%) saving $ 2,520/- (AED 9,255.96) as seen in Figure 6.8 O&M table. The NPC was considerable reduced to $ 10,811/- (AED 39,708/-) almost 51% less than the original NPC cost of AED 64,928/-. This was also close to the HYPW 25% cost in the original configuration at AED 31,827/-.

Overall the Feed In Tariff introduction with electricity sale rate 2 times than the purchase rate yielded a major reduction accounting for almost 51% as comparable to HYPW 75% original case and almost close to the HYPW 25% grid connected original case configuration with a total NPC of AED 39,708/- and COE at $0.169/kWh (AED 0.620/kWh)

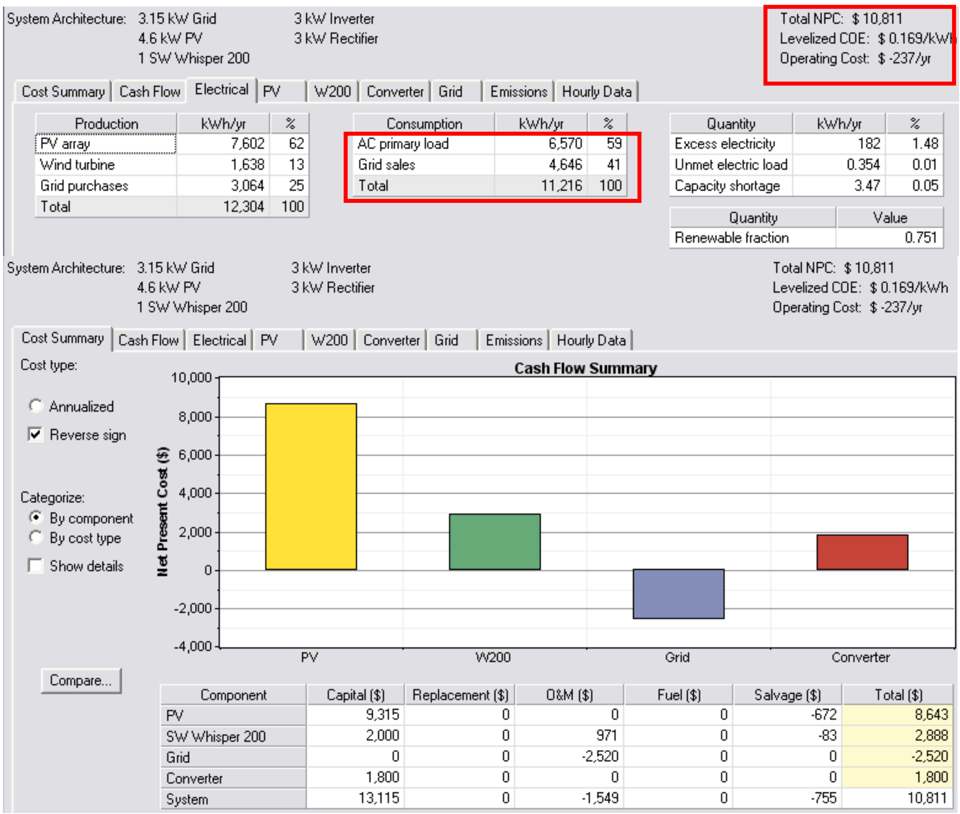


Figure 6.8: Grid Sale 2 times the Grid Purchase Rate Economic Results for 75% HYPW- Grid Connected Case Configuration.

6.4 CARBON EMISSION TAXES

We have already seen from the introduction of Chapter 1, the harmful effects of carbon emission and subsequent CO2 as one of the many heat trapping “Green house Gases” (GHG’s). This being one of the foremost problems faced by many countries with increasing pollution levels from CO2 harmful to human existence many governments have now introduced a system known as “Carbon Tax”. Countries like Canada, Australia, India, China etc have introduced these taxes to curb the CO2 emission levels. It is essentially an environmental tax levied on the carbon contents of the fuel in the form of carbon pricing (Wikipedia, 2011). Also a Cap-and-Trade is a market based approach providing economic incentives to control CO2 emissions or pollution by their respective reductions. These systems are currently preferred by the Canadian Federal Government along with United States as reflected in Act of American Clean Energy and Security in 2010 (Davidson, 2010).

The cost of electricity from the fuel based conventional source can thus be raised to $30/tonne of carbon emitted as an example for carbon taxes according to Davidson, 2010 and Houston 2010. This is in conjunction to MacCracken 2010 which mentions the CO2 marginal cost could be $26/tonne of carbon emitted in 2010 if a proposal as carbon emission mitigation has to be achieved on faster basis. This could also be true to our case considering Dubai; UAE is one of the foremost runners on CO2 emission levels as seen in literature review, with the cost of electricity very cheap in the region leading to misuse of conventional based fuel electricity production. This would advertently increase the use of renewable energy with the careful use of grid connection avoiding increasing levels of CO2 emission in the country.

With the above proposed assumption of introducing $30/tonne (AED 110.19/tonne) as carbon emission tax, we could come to a figure which would reduce the cost, NPC of renewable energy and could an added incentive to the Net Metering or Feed In tariff cases which have been analyzed earlier. Since the CO2 emission levels have been measured by our simulation results leading to the total CO2 emission of 5,532kg/yr from the local grid connection conventional fuel based electricity production. The below following could be reduction to the NPC by the use of renewable energy resources in our 100% and Standalone HYPW case configuration.

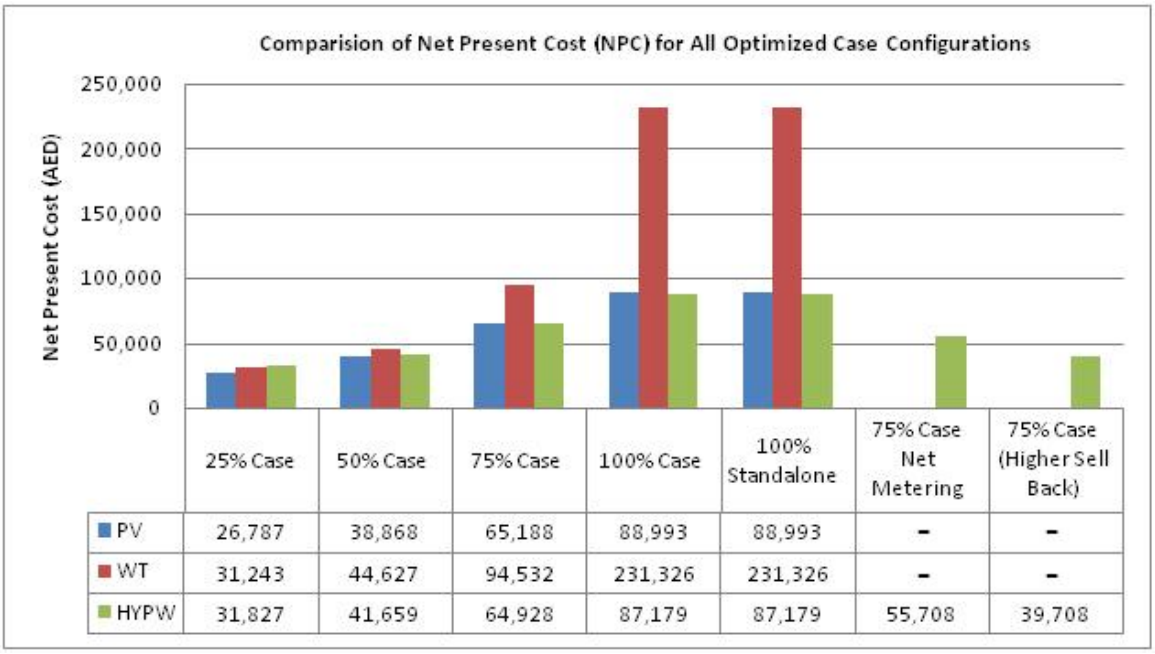
Reduction in NPC= AED 110.19/tonne x 5.532tonne/yr = AED 609.57/- per year

The above is just a proposed example for the 100% HYPW-grid connected and HYPW Standalone case and subsequent reduction could add value to the other cases where the CO2 emissions kg/yr have been analyzed as per Table 5.11 in Chapter 5.

6.5 OVERALL ECONOMIC SUMMARY AND COMPARISON (ALL CASE CONFIGURATIONS)

The above economic assessment done using the same simulation software did not match the technical evaluation results 100% but led to new dimensions in the most cost effective system configuration for electrical demand criteria of our household model. Various factors evaluated in the economic assessment of the various case configurations from 25% to 100% and finally standalone renewable energy systems such as initial capital cost, replacement cost, O&M cost, net present cost (NPC) and cost of energy (COE) were scrutinized to bring about the most cost effective economic optimization. Finally as criteria to zero upon the cost effective system, the net present cost (NPC) and cost of energy (COE) were set as a benchmark to evaluate and analyze results in favor of economics to the investor of the household model. The simulation software also optimizes results primarily based on the net present cost as explained earlier due to basic formation for the economic assessment as a whole complete system. Since the project lifetime is considered as 15 years the results obtained for NPC are more of a governing factor, as the NPC gives a complete value of the cost incurred over the project lifetime by subtracting the present value of all the revenues that its earns over its lifetime.

Figure 6.9 summarizes a graph indicated the economic comparison of the various case configuration ranging from 25%, 50%, 75%, 100% grid connected and standalone renewable energy resources along with suggestive programs and methods to enhance the monetary aspects for the investor of the renewable energy use in the household model. The 25% renewable energy grid connected all case configuration economic results indicate that the only PV would be more cost effective due to the shear reduction in the amount number of components involved as compared to the HYPW 25% case. Though the WT 25% case is also comparatively cost effective calculative it accounts for higher operating cost and hence a little expensive than the PV's 25% case. A similar analytical explanation is also true for all 50% case configurations, whereby the PV's are again most cost effective and optimized economically due to its reduction in number of components and lesser operating cost leading to overall reduction in the NPC value of the system. Thus for both 25% and 50% all case configurations the PV system proves to be clear winner with the NPC values being AED 26,787/- and AED 38,868/- respectively. This was not similar to the technical evaluation results whereby the HYPW case was found to be a better optimized solution as compared to the economic analysis during the 50% case configuration as illustrated in Table 5.10.



	25% Case	50% Case	75% Case	100% Case	100% Standalone	75% Case Net Metering	75% Case (Higher Sell Back)
PV	26,787	38,868	65,188	88,993	88,993	-	-
WT	31,243	44,627	94,532	231,326	231,326	-	-
HYPW	31,827	41,659	64,928	87,179	87,179	55,708	39,708

Figure 6.9: Economic Summary for all Case Configuration

However as the percentage of renewable energy increases with reduction in dependence on local grid connection, the HYPW case system proves to be more dominant in the comparison as illustrates from Figure 6.9. With the case configuration leading to 75%, 100% and Standalone case configurations, the HYPW system was more economical as compared to its individual cases of PV's and WT's. The effective reason being the reduction in initial investment due to lesser number of components such as reduction in PV capacities in kW and reduction in the number of 1kW WT's. Also the operating cost was reduced considerable due to the reduction in the number of components, resulting in the overall reduction the NPC value and the COE subsequently. Though the reduction in NPC for HYPW case was AED 64,929/- marginally less as compared to the closest match of PV;s case with NPC value of AED 65,188/-, finally the less NPC value of HYPW was a clear winner. Also in the case of 100% grid connected and Standalone case the HYPW was marginally less as compared to the PV's case with NPC value of AED 87,179/- . In spite of the fact that the reduction was not substantial in the economic market every marginal decrement counts and could to be beneficial to the investor in the longer run. With programs and methods such as Net Metering and Feed In Tariff the reduction could add more value to the HYPW case where by the reduction being substantial amounting to 15% and more so 51% as comparable to the original NPC value case configuration of HYPW.

Finally it could be summarized that HYPW case configuration proves to be more economically with increased/higher power production capacity from the renewable energy resource. This could further add value and incentive to investors with methods such as Net Metering, Feed In Tariffs and Carbon Taxes which reduce the NPC along with return of investments faster and lesser in order to promote renewable energy resources and less dependence on fossil fuel based conventional methods of electricity production and curb CO_2 emission levels.

CHAPTER 7: CONCLUSION AND FURTHER WORK

The aim of the research was to bring forth the potential advantages and disadvantages of harnessing renewable energy resources such as (solar energy) photovoltaic's and (wind energy) with wind turbines as compared to the conventional method of power production from fossil fuels, in Dubai, UAE. With the current set of problems faced by the world as regards to global warming mainly contributed to the harmful emissions of gases such as CO2, the reduction of these levels was seen to be instrumental in the hands of renewable energy resources from natural production of power especially from the large contribution of the building industry. The literature review set the tone for the research parameters and helped in forming the objective of this dissertation using solar energy and wind energy as of the foremost and freely natural available abundant resources. The simulation methodology proved to be more instrumental in the design and modeling of the household to be set as an example to research the use of photovoltaic's (PV's) and wind turbines (WT's) with their common balance of system components. With simulation methodology analyzed in two parts, such as technical viability and economic feasibility to bridge the gap between possibilities and realities were emphasized, This was in order to bring forth a complete set of value which is practical and achievable to the current situation around the world and the current state of power production industry. A step by step progression was selected to assess the potentials of this dissertation in order to relate to all possible gaps technically and economically for the PV's, WT's and the hybridization of both (HYPW's) so as to find the benefits of merging systems to the consumer, investor and the bring forth solutions to fill the gaps.

7.1 CONCLUSION

The very first step of equating the electrical load schedule led to the local grid formation to evaluate a maximum requirement of 4.2kW peak power with the primary load requirement of 6,570kWh/yr as derived for the household from the simulation software. With this benchmark to supply the electrical demand load to the household with the use of polycrystalline PV's as best selection criteria due to the very close proximity of mono-crystalline PV's in terms of it efficiency output and more so economically half the cost of the later proved instrumental. Similarly since the wind energy potential was comparatively lesser in comparison to the solar energy as assessed from the literature review, a more conservative selection of 1kW wind turbine (WT) was found more suitable and manageable as the requirement of the household for the UAE, Dubai region. Associated balance of the system components selected with due consideration to the required power demand and their adaptability to the various case configurations. The step by step progression of the various identified case configuration with a use of PV's first, WT's second and finally their hybridization HYPW's from 25%, 50%, 75%, 100% grid connected and standalone renewable energy resources, laid the foundation of the results evolved as technically and economically optimized via the simulation methodology.

The technical results obtained from the simulation software evaluated the first small step towards use of renewable energy systems with 25% grid connected. The 25% all case configurations optimized the PV's only case as the dominant technical solution with 1kW PV panels, 1 number of battery with 1kW inverter capacity with a ratio of 27% electrical output from PV panels and 73% from the balance 3.15kW local grid connection. The effective reason being the low electrical demand from the renewable energy with high solar potential in the region, apart from even the WT's proving to be an effective solution for such low demand electrical requirement but higher excess electrical overall production which would be wastage of power technically along with higher grid net purchased compared to PV's. But beyond the 25% all case configuration the HYPW system of renewable energy proved as a better solution in comparison to the individuals of PV's and WT's due to its higher electrical load demand and potential. The optimized results were a good combination of hybridization of HYPW with their respective contribution of solar and wind energy efficiencies by the PV's contributing higher and the WT's maintaining a constant supportive contribution with the electrical production of 1,638kWh/yr respectively.

The HYPW 50%, 75%, 100% grid connections and standalone all case configuration were more successful in the optimization of power provision to the household due to the following technical reasons:

- Reduction in the requirement of PV panels in the case of HYPW configuration from 2kW to 1.4kW PV panels (50% case), 5.4kW reduced to 4kW PV's (75% case), 7kW reduced to 5.2kW PV's (100% and Standalone case) hybridized with 1kW 1 number WT's along with a subsequent support from an aptly evaluated size of the batteries and inverters.

- HYPW systems had lesser dependence on the local grid connection with minimum net grid purchase at every stage of the all case configurations compared to the isolated PV's and WT's cases.

- The WT's case beyond the 25% case configuration were not technically sound due to the lesser wind potential in the region leading to higher number of wind turbines not feasible to house on the proposed site with 1kW WT evaluating 2 numbers (50% case), 6 numbers (75% case) and finally 9 numbers (100% and Standalone case). Not only the 1kW WT numbers were very high but the requirement of battery storage numbers was also astonishingly higher as compared to the HYPW or PV system.

- The HYPW system excess electricity production from the 50% all case configuration onwards was also lower as compared to other systems which would prove to be wastage of electricity in the region with no possibilities of sell back schemes in the UAE.

- Although the PV's all case configuration was the closest technical match to the all case configuration of HYPW system, the later was optimized as the best solution considering the economic and technical reduction and balance in the grid connection case and standalone criteria.

The economics of renewable energy based on the net present cost (NPC) and the cost of energy (COE) over the projects 15 years lifetime, evaluated results in conjunction to the technical optimization. Though not entirely equal to the technical result except till the case of 50% case, the HYPW system was more cost effective as compared to the other two PV's and WT's system. Again however for the minimal 25% and 50% renewable energy grid connected all case configurations proved more economical with only PV's system. This was essentially due to the lesser operating cost with minimal necessity use of number of components involved in provision of the electrical demand to the household. The PV being a singular renewable energy component was more cost effective than the HYPW system.

However the following reasons formed the basis of the HYPW system being more economically optimized for 75%, 100% grid connected and standalone case configurations:

- Considerable reduction in the number of PV panels in the HYPW system leading to lesser initial capital cost, with the balance electrical production taken care by the 1 number 1kW WT comparatively cheaper than the number of 1kW PV's required otherwise.

- Number of components reduced leading to lowering of the operating cost of the replacements and O&M costs in the HYPW system.

- Again the WT isolated case could not be economically viable due to the high investment in the number of WT's required to meet the demand and subsequent high cost for the storage of batteries.

- Once again PV's only isolated case was the closest match to the HYPW system in terms of the NPC and the COE but due to the high replacement cost involved in the degradation of the PV's only case, the HYPW proved to be beneficial and cost effective as hybridization with 1kW 1 number WT rather than increase the kW's or number of PV panels respectively.

Further it is important to note that the in spite of the HYPW system being better technically and economically with increased power demand as a renewable energy system rather than individual resources, they cannot still match up to the low cost of energy in the region with the only grid connected case NPC for the projects 15 years life time value at $5,232/- (AED 19,217/-). This is no way comparable to the 100% grid connected or standalone case where the HYPW's NPC value is AED 87,179/- and almost 4.5 times more expensive than the current conventional fuel based method of power production for the building industry.

However in order to promote renewable energy systems, only scientific facts alone are not sufficient to bring about a change. The right public policies are required to ensure that the system and awareness towards renewable energy resources reaches its full potential. Governments can adopt policies and programs to mandate the environmental optimal use of alternative technologies. As illustrated with examples in section 6.3 the following suggestions reflect means of reducing the cost of renewable energy's NPC and cutting the CO2 emission levels associated with the building industry:

- Introduction of sale of excess electricity production by way of "Net Metering" programs could reduce the NPC of renewable energy project lifetime by 15% as illustrated from the 75% grid connected case.

- Feed in Tariff allowing the higher sale (2 times the retail rate) could further reduce the burden on the renewable energies NPC value by almost 51% and additional schemes by ways of carbon taxes to cap the emission levels of CO2 harmful to the environment.

- Support investors or developer to retrofit existing buildings with energy efficient and cleaner means of power production by giving incentives.

- More public awareness and government funding.

Finally to summarize and answer the questions formulated during the aim and objective of the dissertation the above conclusion could prove to bring investors, developers, architects, engineers, mainly the government a step towards a revolutionary energy saving and sustainable technologies for future projects and better environment.

7.2 FURTHER WORK

The current research for the hybridization (HYPW) of renewable energy resources of photovoltaic's (PV's) and wind turbines (WT's) has many facets as seen from the literature review. These facets are seen through a single mode of dissertation with selection criteria, methodology, region and its associated components. Technical evaluation and economics related to the HYPW were also specific to the location and current market conditions. It should here by hence be noted that the same research could be repeated every two years for the following reasons:

- Increase in the efficiency and change in economics of PV panels and wind turbines with the advancement in technologies due to market demand making it more acceptable.
- Power cost increasing every year as fossil fuels becoming costlier due to increase in population, reduction and depletion in resources which could be benefitted by such renewable energy resource.

- Different climatic conditions, other areas of building technologies improvising, new materials in market, more research etc
- The aim of this research was finally to make the building industry self sufficient and less depended on harmful gases either emitted or in production to avoid the change in climatic conditions globally.

Furthermore the research could be continued to examine the several different conditions and criteria's discussed here on. Since the main emphasis was the electrical energy consumption in buildings, the current dissertation was held for residential isolated housing loads. But with the change in different types of electrical loads for various buildings as illustrated in Table 7.1 the effective evaluation of PV's, WT's, and the HYPW's system could vary drastically. This is primarily due to the fact that different buildings have different peak loads, timings, and sizes etc. which have their respective effects on the HYPW system whereby the PV's and WT's might operate on the specific suitable energy output potential technically as well as economically. Since the research is oriented towards the demand and supply basis like most times, changing the various demands will alter results related to the supply of power from the renewable energy resources.

Table 7.1: Load Characteristics of Various Building Types (Ruan et al, 2009)

Type	Item	Cooling	Heating	Hot water	Total thermal demand	Electricity
Hotel	Peak (kW)	835	1233	1733	2558	1458
	Average (kW)	173	315	824	1285	864
	Load factors	0.21	0.26	0.48	0.52	0.59
	Annual (GJ/a)	9914	5426	25,916	41,257	27,164
Hospital	Peak (kW)	1619	2433	2203	4346	1380
	Average (kW)	125	303	641	1048	601
	Load factors	0.08	0.12	0.29	0.24	0.44
	Annual (GJ/a)	9521	3927	20,155	33,603	18,894
Store	Peak (kW)	1300	958	367	1198	3216
	Average (kW)	194	92	69	323	1324
	Load factors	0.15	0.10	0.19	0.27	0.41
	Annual (GJ/a)	2903	6096	2160	11,160	41,608
Office	Peak (kW)	1315	1635	85	1635	1062
	Average (kW)	166	150	23	311	487
	Load factors	0.13	0.09	0.27	0.19	0.46
	Annual (GJ/a)	4719	5226	710	10,656	15,310

Secondly the selection criteria of the renewable energy components for the research was also based on the demand of the house with the type of PV's and sizing for the WT's with lead to HYPW systems. Changing the type of components might yield different results, such as consideration of mono-crystalline PV's with higher output efficiencies and WT's to be smaller capacities with better power output curves and larger numbers due to its feasibility of different specific location and availability of space site or building integrations. Again due to the vast research done on types, sizes and economics etc of PV's and WT's worldwide a better combination might evolve for the HYPW system suiting a specific building type or even for that matter the current set of dissertation. Also due to the constant advances technologically in the balance of components system such as battery storage and inverter type, capacity, cost etc. could be a fine determining factor technically and economically as noted in the literature review.

Finally it is important to note that the current research was also specific to the region UAE, Dubai, and the available freely natural abundant resources such as solar and wind energy has specific characteristics and percentages related. The same might not be true to different regions with different climatic conditions leading to values harnessing solar and wind energy subsequently. Since the solar energy and wind energy potential various with location and region on the world map based on their respective latitude and longitude, the same would have different results in the evaluation of the HYPW system, with different balance mechanism adopted by PV's contribution as hybridized with the WT's consequently. With PV's being more dominant in the middle eastern region with abundant solar power, the same might be reversed with the WT's taking more charge of the HYPW system with its high wind potential giving a totally different technical and economic evaluation in region such as United Kingdom having better wind resources as shown in Figure 5.23

The simulation methodology adopted for the dissertation may enhance the benefits from each technology and resources available from different locations as per Table 7.2. Due to the flexibility and interdependency of the building energy sector with its design parameter the simulation methodology based on computer software's proves to be multifaceted to derive results with varied combinations and permutations faster with more details in certain ways. Although it cannot be neglected that in many stances the computer software could be oriented to suit the researcher desired results, but the same is also true for laboratory test or field measurements. But finally the economics, time factor and sincerity of the researcher could prove to be useful hand to the simulation methodology. However if the budget and time factor would allow, it would add value to run a laboratory test or field monitoring of the actual case in parallel to the simulation method.

Table 7.2 Selected cities based on location and climatic conditions (NASA SSE Database, 2011)

City	Country	Latitude (Degrees)	Longitude (Degrees)	Solar Radiation (KWh/m2/day)	Wind Speed @10m height (m/s)
Sydney	Australia	-33.8	151.2	4.86	4.50
Hong Kong	China	22.2	114.2	3.12	4.56
New York	USA	40.7	-73.9	4.56	5.0
London	UK	51.4	0.0	2.63	5.36
Moscow	Russia	55.7	37.6	3.03	3.01

With the involvement of field measurement and surveying of the existing buildings harnessing solar and wind energy potential in the region, may yield a satisfactory supportive technical and economical realistic evaluation. Unfortunately due to the limited use of these two resources in the building sector installation, let aside the hybridization of the same, the same cannot be achieved successfully.

At the core of all research and findings, it is important to note that no revolution can be achieved in isolation. The countries contribution and the willingness of the subsequent government to adopt these scientific findings by means of regulation, policies or programs decide the acceptance of any technological spectrum. With the every country now more so aware than before due to the constant forums set to form goals to achieve cleaner and harmful emission free energy the time will surely be bridged when dependence on renewable energy resources will be the front runner worldwide. The current awareness and advances in the field of sustainable development in the Middle East, there are far more opportunities for researchers, economists, professionals in the environment and energy sector. One of the most important steps towards sustainable development in the UAE is set by Abu Dhabi with its Masdar project, formation of the Estidama regulatory compliances which shall harness better and cleaner technologies with faster advances towards renewable energy sector. Slowly but surely more policies and incentives introduction by the region shall pull the investors and companies, professional towards the benefits of this technology and opportunities. Through the hereby dissertation researched in the field of renewable energy power sector, the long term benefits with the support of subsidization and privatization could lead to enhanced standards of sustainable built environment worldwide.

REFERENCES

3Tier Inc., (2008). www.3tier.com (assessed April 12, 2011)

Al Fin: (2008) *OTEC: Ocean Thermal Energy Conversion*. http://alfin2100.blogspot.com/2008/01/otec-ocean-thermal-energy-conversion.html. (assessed May 9, 2011).

Azhar, S., Brown, J. & Farooqui, R., (2009). *BIM-based Sustainability Analysis: An Evaluation of Building Performance Analysis Software*. October 2009, Pages 1-9. http://ascpro.ascweb.org/chair/paper/ (assessed May 9, 2011)

Bekele, G. & Palm, B., (2010). *Feasibility study for a standalone solar–wind-based hybrid energy system for application in Ethiopia*. Applied Energy, Volume 87, Issue 2, February 2010, Pages 487-49. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 30, 2011)

Bekele, G., (2009). *Study into the potential and feasibility of a standalone solar wind hybrid electric energy supply system*. School of Industrial Engineering and Management Royal Institute of Technology, KTH Stockholm, December 2009, Pages 1-148. http://www.diva-portal.org/smash/get/ (assessed May 15, 2011)

Bhadra S N, K. D. (2010). *Wind Electrical Systems*. Oxford University Press. (assessed March 6, 2011)

Chaar, L.E., Lamont, L.A., (2010). *Global solar radiation: Multiple on-site assessments in Abu Dhabi, UA*E. Renewable Energy, Volume 35, Issue 7, July 2010, Pages 1596-1601. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 15, 2011)

Chaar, L.E., Lamont, L.A., (2011). *Enhancement of a stand-alone photovoltaic system's performance: Reduction of soft and hard shading*. Renewable Energy, Volume 36, Issue 4, April 2011, Pages 1306-1310. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 24, 2011)

Currie, M.J., Mapel, J.K, Heidel, T.D., Goffri, S. and Baldo, M.A., (2008) "*High-efficiency organic solar concentrators for photovoltaics,*" Science, Vol. 321, No. 5886, 226-228 (2008). http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 15, 2011)

Dali, M., Belhadj, J. & Roboam, X., (2010). *Hybrid solar–wind system with battery storage operating in grid-connected and standalone mode: Control and energy management – Experimental investigation.* Energy, Volume 35, Issue 6, June 2010, Pages 2587-2595. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 12, 2011)

Davidson, D, (2009). *Nuclear Energy in Alberta*: What you need to know. Alberta: University of Alberta. (Assessed May 9, 2011)

Dr. Chinchilla, R., Dr. Guccione, S. & Tillman, J. (2011). *Wind Power Technologies: A need for research and development in improving VAWT's airfoil characteristics*. Journal of Industrial Technology, Volume 27, Number 1, January 2011, Pages 1-6. http://www.atmae.org/ (assessed June 13, 2011)

Dubai Meteorological Department, (2011). http://www.dia.ae/DubaiMet/MET/Climate.aspx (assessed June 15, 2011)

Gadkari, S.A., (2009). *A Hybrid Reconfigurable Solar and Wind Energy System*. Cleveland State University, May 2009 http://etd.ohiolink.edu/send-pdf.cgi/ (assessed May 15, 2011)

Global Wind Energy Council, (2010). GLOBAL WIND REPORT - Annual market update 2010. http://www.gwec.net/fileadmin/documents/Publications/ (assessed June 15, 2011)

Google Maps, (2011). http://www.googlemaps.com (assessed April 30, 2011).

Haq, Z., (2010). *Energy Information Administration / Biomass for Electricity Generation*. http://www.eia.org (assessed May 21, 2011)

Harvey, L.D.D., (2010). *Energy and the New Reality 2. Carbon Free Energy Supply*. Earthscan Publication. http://www.earthscan.co.uk. (assessed May 9, 2011)

Henemann, A. (2008). *BIPV: Built-in solar energy*. Renewable Energy Focus, Volume 9, Issue 6, Supplement, November-December 2008, Pages 14,16-19. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 13, 2011)

Herzog, A.V., Lipman, T.E. & Kammen, D. M. (2009). *Renewable Energy Resources*. Pages 1-63. http://www-fa.upc.es/personals/fluids/oriol/ale/eolss.pdf. (assessed May 21, 2011)

Hoicka, C.E., & Rowlands, I.H., (2011). *Solar and wind resource complementarity: Advancing options for renewable electricity integration in Ontario, Canada*. Renewable Energy, Volume 36, Issue 1, January 2011, Pages 97-107. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 15, 2011)

Hongxing, Y., Wei, Z. & Chengzhi, L., (2009). *Optimal Design and techno-economic analysis of a hybrid solar-wind power generation system*. Applied Energy, Volume 86, Issue 2, February 2009, Pages 163-169. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 15, 2011)

Hoogwijk, M., Broek, R. & Berndes, G. (2003). *The contribution of biomass in the future global energy supply: a review of 17 studies. Biomass and Bioenergy*. Pages 1-28. http://nws.chem.uu.nl/publica/Publicaties2003/E2003-40.pdf (assessed March 30, 2011)

Houston, (2010). *Researches calculate the cost of CO2 emissions, call for carbon tax*. Rice University. http://rice.edu/nationalmedia/news2010-07-07-natgas.html (assessed June 24, 2011)

Hua, S., Zhou, Q., Kong, D. & Ma, J. (2006). *Application of valve-regulated lead-acid batteries for storage of solar electricity in stand-alone photovoltaic systems in the northwest areas of China* . Journal of Power Sources, Volume 158, Issue 2, 25 August 2006, Pages 1178-1185. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 13, 2011)

Intergovernmental Panel on Climate Change, (2011). The IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, UN Climate Change Conference June 2011. www.ipcc.ch/docs/srren/presentations/bonn/Edenhofer.pdf (assessed April 10, 2011)

International Energy Agency, (2009). 35 Key Energy Trends in 35 Years. www.iea.org/journalists/ministerial2009/fs_scoreboard.pdf (assessed May 12, 2011)

International Energy Agency, (2010). CO2 Emission from Fuel Combustion Highlights, 2010 Edition. www.iea.org/co2highlights/co2highlights.pdf (assessed June 10, 2011)

International Energy Agency, (2010). Key World Energy Statistics. www.iea.org/textbase/nppdf/free/2010/key_stats_2010.pdf (assessed May 18, 2011)

International Energy Agency, (2010). The Economics of Transition in the Power Sector, January 2010. www.iea.org/Textbase/npsum/economics_of_transitionSUM.pdf (assessed April 12, 2011)

International Energy Agency, (2011). Monthly Electricity Statistics, March 2011. www.iea.org/stats/surveys/mes.pdf (assessed April 24, 2011)

International Energy Agency, (2011). Technology Roadmap, Energy Efficient Buildings: Heating and Cooling Equipments. http://www.iea.org/papers/2011/buildings_roadmap.pdf (assessed May 15, 2011)

James, P.A.B., Sissons, M.F., Bradford, J., Myers, L.E., Bahaj, A.S., Anwar, A. & Green, S. (2011). *Implications of the UK field trial of building mounted horizontal axis micro-wind turbines*. Energy Policy, Volume 38, Issue 10, October 2010, Pages 6130-6144. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 13, 2011).

Kaldellis, J.K., Zafirakis, D. (2011). *The wind energy (r)evolution: A short review of a long history.* Renewable Energy, Volume 36, Issue 7, July 2011, Pages 1887-1901. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 12, 2011)

Kazim, A.M., (2007). *Assessments of primary energy consumption and its environmental consequences in the United Arab Emirates*. Renewable and Sustainable Energy Reviews, Volume 11, Issue 3, April 2007, Pages 426-446. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 9, 2011)

Kazmi, A., (2009). *Abu Dhabi perfect for wind farming. Gulf news Newspaper*, Published: 23:00 July 6, 2009. http://gulfnews.com/news/gulf/uae/environment/ (assessed May 9, 2011)

Kurtz, S. (2010). *Practical Issues when selecting PV Technologies*. GE 2010 Electronics Packaging Symposium. NREL/PR-540-49386. September 2010. http://www.nrel.gov/docs/fy10osti/ (assessed April 12, 2011)

Ledo, L., Kosasih, P.B., Cooper, P., (2011). *Roof mounting site analysis for micro-wind turbines*. Renewable Energy, Volume 36, Issue 5, May 2011, Pages 1379-1391. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 24, 2011)

Lombard, L.P., Ortiz, J. & Pout C., (2008). *A review on buildings energy consumption information*. Energy and Buildings, Volume 40, Issue 3, 2008, Pages 394-398. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 21, 2011)

Lund, J.W., Freeston, D.H. & Boyd, T.L. (2011). *Direct utilization of geothermal energy 2010 worldwide review*. Geothermics, Volume 40, Issue 3, September 2011, Pages 159-180. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 24, 2011)

M. Kalantar, S.M. Mousavi G., (2010). *Dynamic behavior of a stand-alone hybrid power generation system of wind turbine, microturbine, solar array and battery storage*. Applied Energy, Volume 87, Issue 10, October 2010, Pages 3051-3064. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 15, 2011)

Maerefat, M. & Ebrahimpour. A. (2010). *A method for generation of typical meteorological year*. Energy Conversion and Management, Volume 51, Issue 3, March 2010, Pages 410-417. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 15, 2011)

Masdar, (2011). http://www.masdar.ae (assessed June 10, 2011)

Montoro, D.F. (2010). *PV Diffusion into the Building Sector*. European Photovoltaic Industry Association. October 2010, Pages 1-43. http://www.bre.co.uk/filelibrary/events/BIPV/Daniele_Fraile_Montoro.pdf (assessed May 12, 2011)

Müller, G., Jentsch, M.F., Stoddart, E., (2009). *Vertical axis resistance type wind turbines for use in buildings*. Renewable Energy, Volume 34, Issue 5, May 2009, Pages 1407-1412. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 9, 2011)

Muneer T., Asif M. and Munawars (2005): *Sustainable Production of Solar Electricity with Particular Reference to the India Economy*. Renewable Sustainable Energy Review. Vol 9 444-473. http://www.eurojournals.com/ejsr_35_2_02.pdf (assessed May 15, 2011)

Muyeen, S.M., Al-Durra, A. & Tamura, J., (2011). *Variable speed wind turbine generator system with current controlled voltage source inverter*. Energy Conversion and Management, Volume 52, Issue 7, July 2011, Pages 2688-2694. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 24, 2011)

Nandi, S.K. & Ghosh, H.R., (2010). *Prospect of wind–PV-battery hybrid power system as an alternative to grid extension in Bangladesh*. Energy, Volume 35, Issue 7, July 2010, Pages 3040-3047. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed March 15, 2011)

NASA, Surface Meteorology and Solar Energy, (2011). http://eosweb.larc.nasa.gov/sse/ (assessed April 24, 2011)

Nema, P., Nema, R.K., Rangnekar, S., (2009). *A current and future state of art development of hybrid energy system using wind and PV-solar: A review*. Renewable and Sustainable Energy Reviews, Volume 13, Issue 8, October 2009, Pages 2096-2103. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 6, 2011)

Norton, B., Eames, P.C., Mallick, T.K., Huang, M.J., McCormack, S.J., Mondol, J.D., Yohanis, Y.G., (2011). *Enhancing the performance of building integrated photovoltaics*. Solar Energy, Volume 85, Issue 8, August 2011, Pages 1629-1664. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 9, 2011)

Okeil, A., (2010). *A holistic approach to energy efficient building forms. Energy and Buildings*, Volume 42, Issue 9, September 2010, Pages 1437-1444. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 24, 2011)

Omer, S. A., Wilson, R. & Riffat, S. B., (2003). *Monitoring results of two examples of building integrated PV (BIPV) systems in the UK*. Renewable Energy, Volume 28, Issue 9, July 2003, Pages 1387-1399. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 6, 2011)

Orr, L., Edwards, C. & Sassoon, R., (2010). *Global Climate and Energy Project, Stanford University*. http://gcep.stanford.edu/pdfs/gcep_brochure.pdf (assessed May 16, 2011)

Paatero, J.V., & Lund, P.D., (2006). *A model for generating household electricity load profiles*. International Journal of Energy Research, volume 30, number 5, pages 273290. http://lib.tkk.fi/Diss/2009/isbn9789522481252/article1.pdf (assessed June 5, 2011)

Parida, B., Iniyan, S. & Goic, R. (2011). *A review of solar photovoltaic technologies*. Renewable and Sustainable Energy Reviews, Volume 15, Issue 3, April 2011, Pages 1625-1636. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 12, 2011)

Patnaik, I., (2009). *Wind as a Renewable Energy Source*. National Institute of Technology Rourkela, Rourkela-769008, Orissa, May 2009, Pages 1-44, http://ethesis.nitrkl.ac.in/ (assessed June 6, 2011)

Prasad GVT, Srinivas S, Sriram V, (2010). *Hybrid Solar and Wind off Grid System Design and Control*. International Journal of Engineering and Technology, Volume 2(24), 2010, Pages 548-552. http://www.ijest.info/docs/ (assessed April 12, 2011)

Quaschning, V. (2004). *Technical and economical system comparison of photovoltaic and concentrating solar thermal power systems depending on annual global irradiation*. Solar Energy, Volume 77, Issue 2, 2004, Pages 171-178. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 15, 2011)

Radhi, H. (2010). *Energy analysis of façade-integrated photovoltaic systems applied to UAE commercial buildings. Solar Energy*, Volume 84, Issue 12, December 2010, Pages 2009-2021. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 12, 2011)

Radhi, H. (2010). *Technical and Energy Assessment of Building Integrated Photovoltaic Systems applied to the UAE Office Buildings*. Proceedings of the Tenth International Conference for Enhanced Building Operations, Kuwait, October 2010, Pages 26-28. http://repository.tamu.edu/ (assessed June 24, 2011)

Reichling, J.P. & Kulacki, F.A. (2008). *Utility scale hybrid wind–solar thermal electrical generation: A case study for Minnesota*. Energy, Volume 33, Issue 4, April 2008, Pages 626-638. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed March 20, 2011)

Renewable Energy Policy Network for the 21st Century, (2010). Renewable 2010 Global Status Report. http://www.ren21.net/Portals/97/documents/GSR/REN21_GSR_2010_full_revised%20Sept2010.pdf (assessed April 24, 2011)

Rosa, A.V., (2009). *Chapter 15 - Wind Energy*. Fundamentals of Renewable Energy Processes (Second Edition), 2009, Pages 723-797. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 13, 2011)

Rourke, S. (2009). *Solar Photovoltaic Industry*. Institute for analysis of solar energy, 24th April 2009. Pages 1-26. http://www.slideshare.net/gwsolar/pv-status-and-pathways-stephen-orourke (assessed April 10, 2011).

Ruan, Y., Liu, Q., Zhou, W., Firestone, R., Gao, W. & Watanabe, T., (2009). *Optimal option of distributed generation technologies for various commercial buildings.* Applied Energy, Volume 86, Issue 4, Pages 1641-1653. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed March 30, 2011)

Sharpe, T., & Proven, G. (2010). *Crossflex: Concept and early development of a true building integrated wind turbine*. Energy and Buildings, Volume 42, Issue 12, December 2010, Pages 2365-2375. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 9, 2011)

Soysal, O. A. & Soysal, H. S. (2007). *A Residential Example of Hybrid Wind-Solar Energy System: WISE*. Maryland Energy Administration under Contracts 2007-02-B043J and #2007-01-B0310, November 2007. http://faculty.frostburg.edu/ (assessed June 6, 2011)

Standalone Wind Energy Buyers Guide, (2004). www.nrcan.gc.ca/redi (assessed March 24, 2011)

The Arup Journal. BedZED, (2003). http://www.arup.com/_assets/_download/download68.pdf (assessed April 24, 2011).

Toledo, O.M., Filho, D.O., Diniz, A.S.A.C., (2010). *Distributed photovoltaic generation and energy storage systems: A review.* Renewable and Sustainable Energy Reviews, Volume 14, Issue 1, January 2010, Pages 506-511. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 24, 2011)

U.S. Energy Information Administration / International Energy Outlook, 2010. World Energy Demand and Economic Outlook Chapter 2. http://205.254.135.24/oiaf/ieo/pdf/world.pdf (assessed May 15, 2011)

US Department of Energy, (2011). United Arab Emirates Energy Data, Statistics and Analysis - Oil, Gas, Electricity etc. January 2011. http://www.eia.gov/cabs/uae/ (assessed June 6, 2011)

US Energy and Information Administration, (2011). Annual Energy Outlook 2011 with Projections till 2035. http://www.eia.gov/forecasts/aeo/pdf/0383%282011%29.pdf (assessed April 12, 2011)

Van Wijk, Coelingh, A. J. M. J.P., (1993). *Wind power potential in the OECD countries, Energy Research Center*, Report number 93091, Utrecht University, Netherlands. http://www.interacademycouncil.net/Object.File/Master/10/361/Wind%20Energy.pdf (assessed May 15, 2011)

Vijay R. & Sethi, A.K., (2011). *Pitch Control of Horizontal Axis Wind Turbine*. National Institute of Technology Rourkela, Rourkela-769008, Orissa, January 2011, Pages 1-33, http://ethesis.nitrkl.ac.in/ (assessed June 12, 2011)

Walker, S.L., (2011). *Building mounted wind turbines and their suitability for the urban scale—A review of methods of estimating urban wind resource*. Energy and Buildings, Volume 43, Issue 8, August 2011, Pages 1852-1862. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 15, 2011)

Wikipedia, (2011). http://en.wikipedia.org/ (assessed March 6, 2011)

World Bank, (2011). http://www.google.com/publicdata/overview/ (assessed June 15, 2011)

Yao, F., Bansal, R.C., Dong, Z., Saket, R.K. & Shakya, J.S., (2010). *Wind Energy Resources: Theory, Design and Applications*. HANDBOOK OF RENEWABLE ENERGY TECHNOLOGY, Chapter 1, January 2010, Pages 3-20. http://www.worldscibooks.com/environsci/ (assessed May 15, 2011)

Yoon, J.H., Song, J. & Lee, S.J. (2011). *Practical application of building integrated photovoltaic (BIPV) system using transparent amorphous silicon thin-film PV module*. Solar Energy, Volume 85, Issue 5, May 2011, Pages 723-733. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 6, 2011)

Zahedi, A., (2006). *Solar photovoltaic (PV) energy; latest developments in the building integrated and hybrid PV systems*. Renewable Energy, Volume 31, Issue 5, April 2006, Pages 711-718. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 6, 2011)

Zghal, W., Kantchev, G. & Kchaou, H., (2011). *Optimization and management of the energy produced by a wind energizing system*. Renewable and Sustainable Energy Reviews, Volume 15, Issue 2, February 2011, Pages 1080-1088. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 12, 2011)

BIBLIOGRAPHY

AboulNaga, M.M. & Elsheshtawy, Y.H., (2001). *Environmental sustainability assessment of buildings in hot climates: the case of the UAE*. Renewable Energy, Volume 24, Issues 3-4, November 2001, Pages 553-563. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 6, 2011)

Ai, B., Yang, H., Shen, H. & Liao, X., (2003). *Computer-aided design of PV/wind hybrid system*. Renewable Energy, Volume 28, Issue 10, August 2003, Pages 1491-1512. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 13, 2011)

Al-Badi, A.H., Albadi, M.H., Al-Lawati, A.M. & Malik, A.S., (2011). *Economic perspective of PV electricity in Oman*. Energy, Volume 36, Issue 1, January 2011, Pages 226-232. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 13, 2011)

Al-Bahadly, I., (2009). *Building a wind turbine for rural home*. Energy for Sustainable Development, Volume 13, Issue 3, September 2009, Pages 159-165. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 21, 2011)

Albrecht, J., (2007). *The future role of photovoltaics: A learning curve versus portfolio perspective*. Energy Policy, Volume 35, Issue 4, April 2007, Pages 2296-2304. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 15, 2011)

Alnaser, W.E., Alnaser, N.W., (2011). *The status of renewable energy in the GCC countries*. Renewable and Sustainable Energy Reviews, Volume 15, Issue 6, August 2011, Pages 3074-3098. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 15, 2011)

Arakawa, C., Ariga, S. & Iida, M., (2002). *Proposal of vernacular design for wind turbine. Journal of Wind* Engineering and Industrial Aerodynamics, Volume 90, Issues 12-15, December 2002, Pages 1731-1741. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 9, 2011)

Benemann, J., Chehab, O. & Gabriel, E.S., (2001). *Building-integrated PV modules*. Solar Energy Materials and Solar Cells, Volume 67, Issues 1-4, March 2001, Pages 345-354. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 10, 2011)

Blanco, M.I., (2009). *The economics of wind energy*. Renewable and Sustainable Energy Reviews, Volume 13, Issues 6-7, August-September 2009, Pages 1372-1382. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 15, 2011)

Braun, P. & Rüther, R., (2010). *The role of grid-connected, building-integrated photovoltaic generation in commercial building energy and power loads in a warm and sunny climate*. Energy Conversion and Management, Volume 51, Issue 12, December 2010, Pages 2457-2466. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 15, 2011)

Carr, A.J., (2005). *A Detailed Performance Comparison of PV modules of Different Technologies and the Implications for PV System Design Methods*. University of Murdoch, Western Australia, July 2005, Pages 1-251. http://researchrepository.murdoch.edu.au/ (assessed April 12, 2011)

Castro, C., Mediavilla, M., Miguel, L.J. & Frechoso, F., (2011). *Global wind power potential: Physical and technological limits*. Energy Policy, In Press, Corrected Proof, Available online 29 June 2011. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 6, 2011)

Chan, H., Mao, Y., Ghahremanian, S., Janbakhsh, S., (2006). *Wind Energy*. Renewable Energy, Volume 2, September 2006, Pages 1- 80. http://exergy.se/goran/hig/ses/ (assessed June 20, 2011)

Chemisana, D., (2011). *Building Integrated Concentrating Photovoltaics: A review*. Renewable and Sustainable Energy Reviews, Volume 15, Issue 1, January 2011, Pages 603-611. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 12, 2011)

Chen, H.H., Kang, H.Y. & Lee, A.H.I., (2010). *Strategic selection of suitable projects for hybrid solar-wind power generation systems*. Renewable and Sustainable Energy Reviews, Volume 14, Issue 1, January 2010, Pages 413-421. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 20, 2011)

Cheng, C.L., Chan, C.Y. & Chen, C.L. ., (2005). *Empirical approach to BIPV evaluation of solar irradiation for building applications*. Renewable Energy, Volume 30, Issue 7, June 2005, Pages 1055-1074. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 24, 2011)

Diakaki, C., Grigoroudis, E. & Kolokotsa, D., (2008). *Towards a multi-objective optimization approach for improving energy efficiency in buildings*. Energy and Buildings, Volume 40, Issue 9, 2008, Pages 1747-1754. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 13, 2011)

Dr. Pecen, R., Dr. Salim, M.D. & Dr. Timmerman, M., (2000). *A Hybrid Solar-Wind Power Generation System as an Instructional Resource for Industrial Technology Students*. Journal of Industrial Technology, Volume 16, Number 3 - May 2000 to July 2000. http://atmae.org/jit/Articles/ (assessed March 30, 2011)

Eltawil, M.A. & Zhao, Z., (2010). *Grid-connected photovoltaic power systems: Technical and potential problems—A review*. Renewable and Sustainable Energy Reviews, Volume 14, Issue 1, January 2010, Pages 112-129. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 9, 2011)

Field, C.B., Campbell, J.E. & Lobell, D.B., (2008). *Biomass energy: the scale of the potential resource.* Trends in Ecology & Evolution, Volume 23, Issue 2, February 2008, Pages 65-72. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 24, 2011)

Grant, A., Johnstone, C. & Kelly, N., (2008). *Urban wind energy conversion: The potential of ducted turbines*. Renewable Energy, Volume 33, Issue 6, June 2008, Pages 1157-1163. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 12, 2011)

Hocaoglu, F.O., Gerek, O.N. & Kurban, M., (2009). *The effect of model generated solar radiation data usage in hybrid (wind–PV) sizing studies.* Energy Conversion and Management, Volume 50, Issue 12, December 2009, Pages 2956-2963. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 24, 2011)

Ibrahim, A., Othman, M.Y., Ruslan, M.H., Mat, S. & Sopian, K., (2011). *Recent advances in flat plate photovoltaic/thermal (PV/T) solar collectors*. Renewable and Sustainable Energy Reviews, Volume 15, Issue 1, January 2011, Pages 352-365. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 15, 2011)

Lam, J.C., Wan, K.K.W., Wong, S.L. & Lam, T.N.T., (2010). *Principal component analysis and long-term building energy simulation correlation*. Energy Conversion and Management, Volume 51, Issue 1, January 2010, Pages 135-139. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 12, 2011)

Liu, L. & Wang, Z., (2009). *The development and application practice of wind–solar energy hybrid generation systems in China*. Renewable and Sustainable Energy Reviews, Volume 13, Issues 6-7, August-September 2009, Pages 1504-1512. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 12, 2011)

Lu, X., McElroy, M.B. & Kiviluoma, J., (2009). *Global potential for wind-generated electricity*. Harvard University, Cambridge, MA, April 29, 2009. http://www.pnas.org/content/ (assessed April 10, 2011)

Muralikrishna, M. & Lakshminarayana, V., (2008). *Hybrid (Solar-Wind) Energy System for Rural Electrification*. ARPN Journal of Engineering and Applied Science, Volume 3, No. 5, October 2008, Pages 50-58. http://www.arpnjournals.com/ (assessed May 15, 2011)

Ortlepp, A., (2007). *The Design and Performance of a standalone solar and wind powered RTM house*. Department of Electrical Engineering, University of Saskatchewan, March 2007. http://library2.usask.ca/theses/available/ (assessed June 13, 2011)

Ozgener, L., Hepbasli, A. & Dincer, I., (2006). *Performance investigation of two geothermal district heating systems for building applications: Energy analysis*. Energy and Buildings, Volume 38, Issue 4, April 2006, Pages 286-292. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 9, 2011)

Pagliaro, M., Ciriminna, R. & Palmisano, G., (2010). *BIPV: merging the photovoltaic with the construction industry*. Istituto per lo Studio dei Materiali Nanostrutturati, CNR, via U. La Malfa 153, 90146 Palermo, Italy, 2010; 18:61–72. http://www.interscience.wiley.com (assessed May 9, 2011)

Rehman, S. & Al-Hadhrami, L.M., (2010). *Study of a solar PV–diesel–battery hybrid power system for a remotely located population near Rafha, Saudi Arabia*. Energy, Volume 35, Issue 12, December 2010, Pages 4986-4995. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 24, 2011)

Reich, N.H., Van Sark, W.G.J.H.M., Turkenburg, W.C. & Sinke, W.C., (2010). *Using CAD software to simulate PV energy yield – The case of product integrated photovoltaic operated under indoor solar irradiation.* Solar Energy, Volume 84, Issue 8, August 2010, Pages 1526-1537. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 10, 2011)

Rockett, A.A., (2010). *The future of energy – Photovoltaics*. Current Opinion in Solid State and Materials Science, Volume 14, Issue 6, December 2010, Pages 143-148. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed May 9, 2011)

Shun, S. & Ahmed, N.A., (2008). *Utilizing wind and solar energy as power sources for a hybrid building ventilation device.* Renewable Energy, Volume 33, Issue 6, June 2008, Pages 1392-1397. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 13, 2011)

Sims, R.E.H., Mabee, W., Saddler, J.N. & Taylor, M., (2010). *An overview of second generation biofuel technologies*. Bioresource Technology, Volume 101, Issue 6, March 2010, Pages 1570-1580. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed June 12, 2011)

Wan, K.K.W., Li, D.H.W., Yang, L. & Lam, J.C., (2010). *Climate classifications and building energy use implications in China*. Energy and Buildings, Volume 42, Issue 9, September 2010, Pages 1463-1471. http://www.sciencedirect.com.ezproxy.aus.edu/ (assessed April 12, 2011)

APPENDIX A: SIMULATION RESULTS

System Architecture: 4.2 kW Grid

Total NPC: $ 5,232
Levelized COE: $ 0.082/kWh
Operating Cost: $ 539/yr

Cost Summary | Cash Flow | Electrical | Grid | Emissions | Hourly Data

Production	kWh/yr	%
Grid purchases	6,570	100
Total	6,570	100

Consumption	kWh/yr	%
AC primary load	6,570	100
Total	6,570	100

Quantity	kWh/yr	%
Excess electricity	0.00	0.00
Unmet electric load	0.00	0.00
Capacity shortage	0.00	0.00

Quantity	Value
Renewable fraction	0.00

Figure A.1: Yearly Electric Power Production from Local Grid Connection at 4.2kW peak power requirement.

Table A.1: Monthly Energy purchased from the Local Electric Grid Connection.

System Architecture: 4.2 kW Grid

Cost Summary | Cash Flow | Electrical | Grid | Emissions | Hourly Data

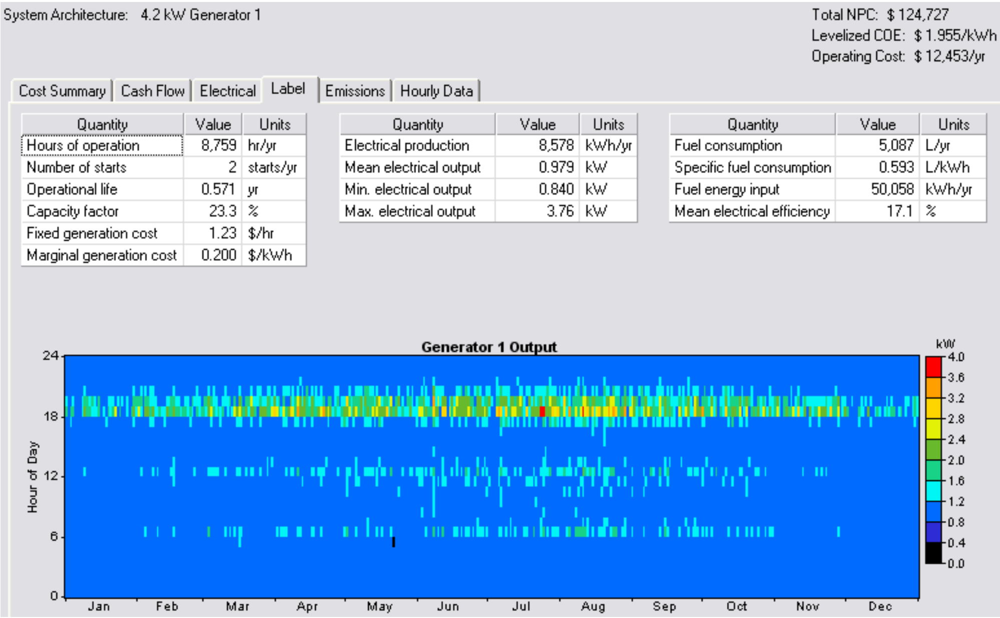
Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
Jan	430	0	430	2	35	0
Feb	437	0	437	2	36	0
Mar	551	0	551	3	45	0
Apr	556	0	556	3	46	0
May	582	0	582	3	48	0
Jun	621	0	621	3	51	0
Jul	647	0	647	4	53	0
Aug	687	0	687	4	56	0
Sep	591	0	591	3	48	0
Oct	561	0	561	3	46	0
Nov	477	0	477	3	39	0
Dec	431	0	431	2	35	0
Annual	6,570	0	6,570	4	539	0

System Architecture: 4.2 kW Grid

Cost Summary | Cash Flow | Electrical | Grid | Emissions | Hourly Data

Pollutant	Emissions (kg/yr)
Carbon dioxide	5,532
Carbon monoxide	1.25
Unburned hydrocarbons	0
Particulate matter	0.328
Sulfur dioxide	33.5
Nitrogen oxides	9.85

Figure A.2: Harmful Emission to the environment due to the power supply from local grid connection to the household model.

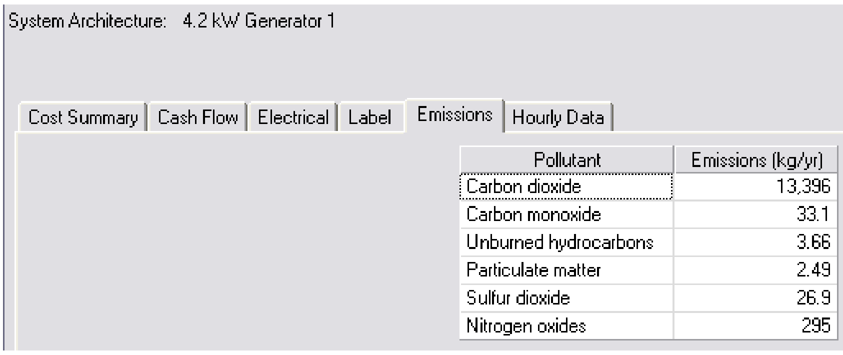


Quantity	Value	Units
Hours of operation	8,759	hr/yr
Number of starts	2	starts/yr
Operational life	0.571	yr
Capacity factor	23.3	%
Fixed generation cost	1.23	$/hr
Marginal generation cost	0.200	$/kWh

Quantity	Value	Units
Electrical production	8,578	kWh/yr
Mean electrical output	0.979	kW
Min. electrical output	0.840	kW
Max. electrical output	3.76	kW

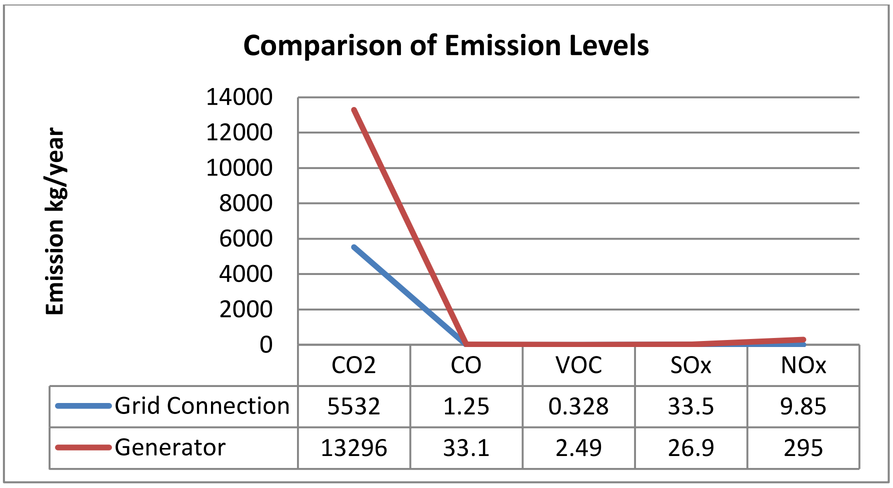
Quantity	Value	Units
Fuel consumption	5,087	L/yr
Specific fuel consumption	0.593	L/kWh
Fuel energy input	50,058	kWh/yr
Mean electrical efficiency	17.1	%

Figure A.3: 4.2kW peak power generator output values hourly, monthly and yearly respectively.



Pollutant	Emissions (kg/yr)
Carbon dioxide	13,396
Carbon monoxide	33.1
Unburned hydrocarbons	3.66
Particulate matter	2.49
Sulfur dioxide	26.9
Nitrogen oxides	295

Figure A.4: Harmful Emission to the environment due to the power supply from independent diesel generator to the household model.



	CO2	CO	VOC	SOx	NOx
Grid Connection	5532	1.25	0.328	33.5	9.85
Generator	13296	33.1	2.49	26.9	295

Figure A.5: Comparison of Emission (kg/yr) between local grid connection and generator with 4.2kW peak power supply to the model house.

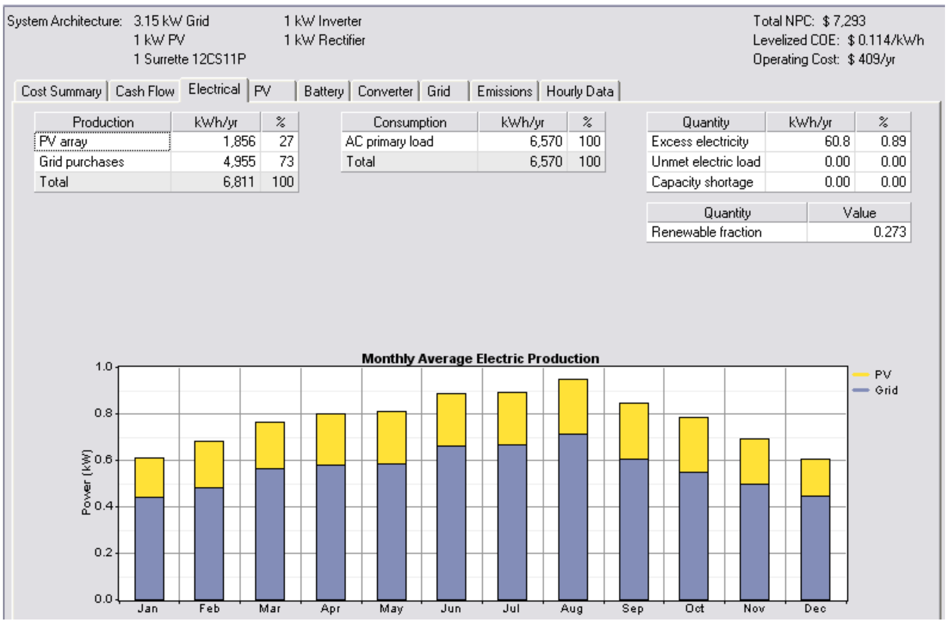


Figure A.6: Yearly electric power production from 3.15kW (73%) grid connection and 1kW (27%) PV power output.

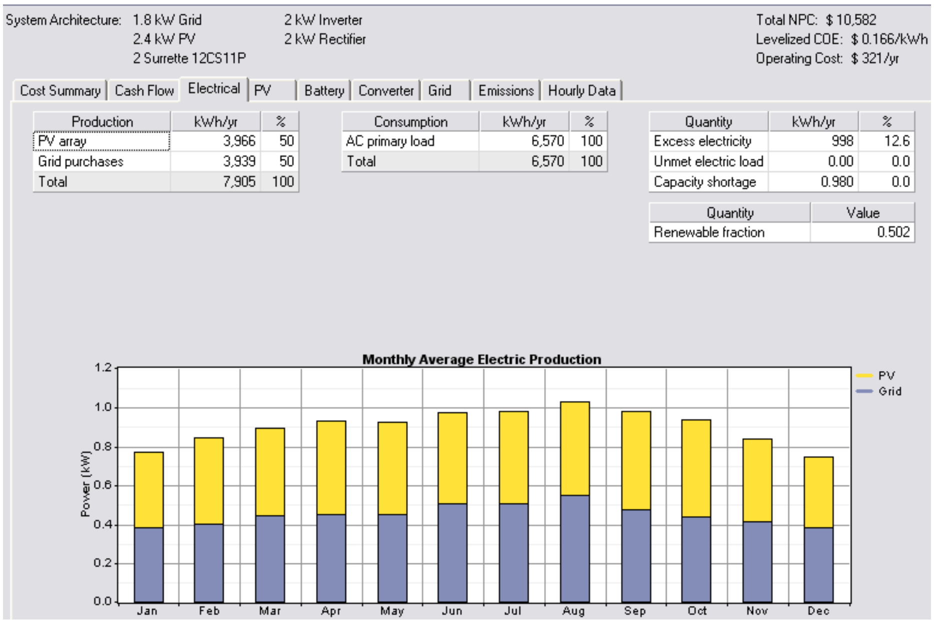
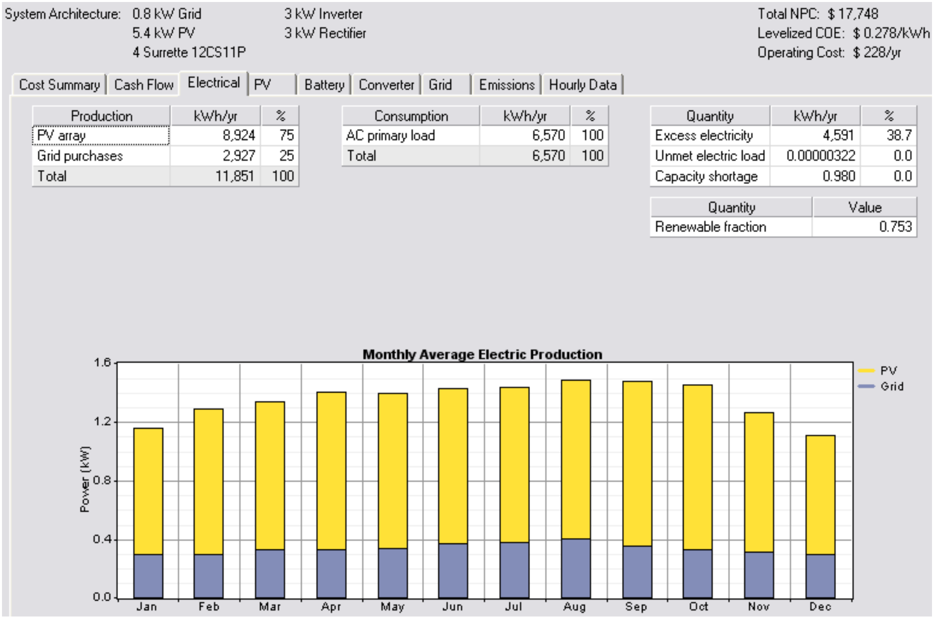


Figure A.7: Yearly electric power production from 1.8kW (50%) grid connection and 2.4kW (50%) PV power output.



System Architecture: 0.8 kW Grid, 5.4 kW PV, 4 Surrette 12CS11P, 3 kW Inverter, 3 kW Rectifier

Total NPC: $ 17,748
Levelized COE: $ 0.278/kWh
Operating Cost: $ 228/yr

Cost Summary | Cash Flow | Electrical | PV | Battery | Converter | Grid | Emissions | Hourly Data

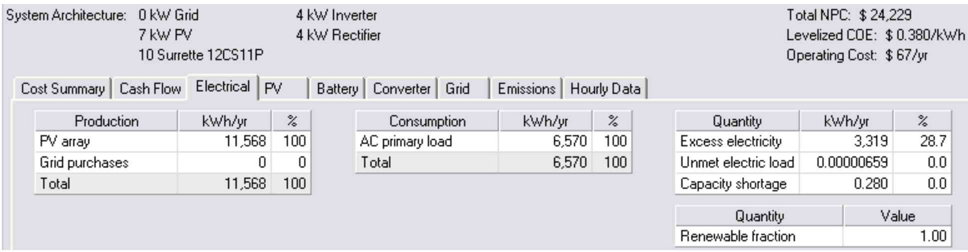
Production	kWh/yr	%
PV array	8,924	75
Grid purchases	2,927	25
Total	11,851	100

Consumption	kWh/yr	%
AC primary load	6,570	100
Total	6,570	100

Quantity	kWh/yr	%
Excess electricity	4,591	38.7
Unmet electric load	0.00000322	0.0
Capacity shortage	0.980	0.0

Quantity	Value
Renewable fraction	0.753

Figure A.8: Yearly electric power production from 0.8kW (75%) grid connection and 5.4kW (25%) PV power output.



System Architecture: 0 kW Grid, 7 kW PV, 10 Surrette 12CS11P, 4 kW Inverter, 4 kW Rectifier

Total NPC: $ 24,229
Levelized COE: $ 0.380/kWh
Operating Cost: $ 67/yr

Cost Summary | Cash Flow | Electrical | PV | Battery | Converter | Grid | Emissions | Hourly Data

Production	kWh/yr	%
PV array	11,568	100
Grid purchases	0	0
Total	11,568	100

Consumption	kWh/yr	%
AC primary load	6,570	100
Total	6,570	100

Quantity	kWh/yr	%
Excess electricity	3,319	28.7
Unmet electric load	0.00000659	0.0
Capacity shortage	0.280	0.0

Quantity	Value
Renewable fraction	1.00

Figure A.9: Yearly electric power production from 0.0kW (0%) grid connection and 7.0kW (100%) PV power output.

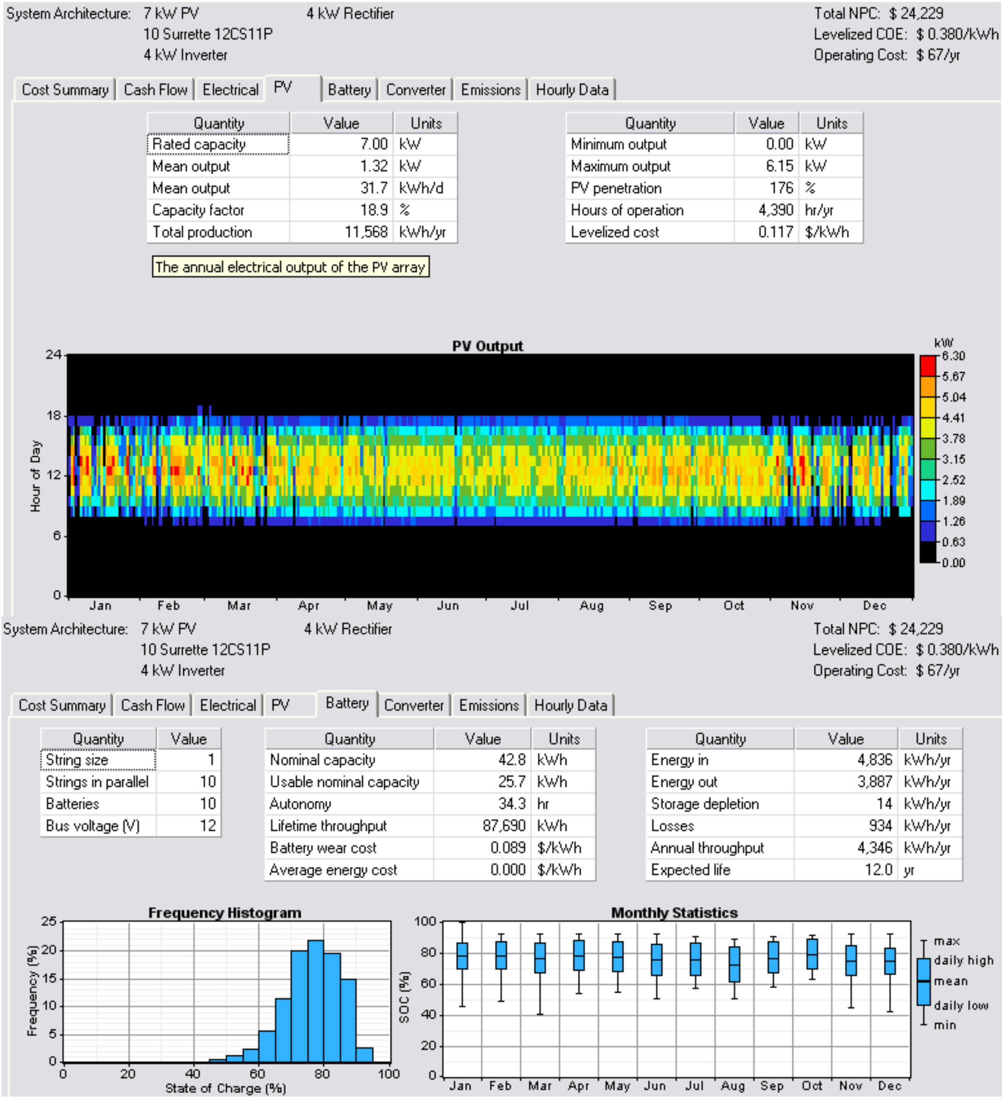


Figure A.10: 100% Standalone PV case configuration with 7.0kW array capacity properties and Battery properties obtained from the model.

Table A.2: Technical Summary Table for PV module Case Configuration

Type of Conf	Grid	PV	Battery	Conv	PV Prod.	Grid Net Purchase	Tot. Elect. Prod.	Primary Load Served	Ren. Frac.	Cap. Shortage Frac.	Unmet Load Frac.	Excess Elect.
	kW	kW	No.	kW	kWh/yr	kWh/yr	kWh/yr	kWh/yr		%	%	kWh/yr
PV-GRID CONNECTED												
25%	3.15	1	1	1	1,856	4,955	6,811	6,570	0.27	0	0	61
50%	1.8	2.4	2	2	3,966	3,939	7,905	6,570	0.5	0	0	998
75%	0.8	5.4	4	3	8,924	2,927	11,851	6,570	0.75	0	0	4,591
100%	0	7	10	4	11,568	0	11,568	6,570	1	0	0	3,319
PV-STANDALONE												
100%	0	7	10	4	11,568	0	11,568	6,570	1	0	0	3,319

Table A.3: CO2 Emission due to use of PV module case configuration.

Energy Configuration	CO2 emission kg/yr	Reduction (%)
Local Grid Connection only	5532	0
25% PV-Grid Connection	4172	24.58424
50% PV-Grid Connection	3316	40.05785
75% PV-Grid Connection	2465	55.44107
100% PV-Grid Connection and 100% PV-Standalone	0	100

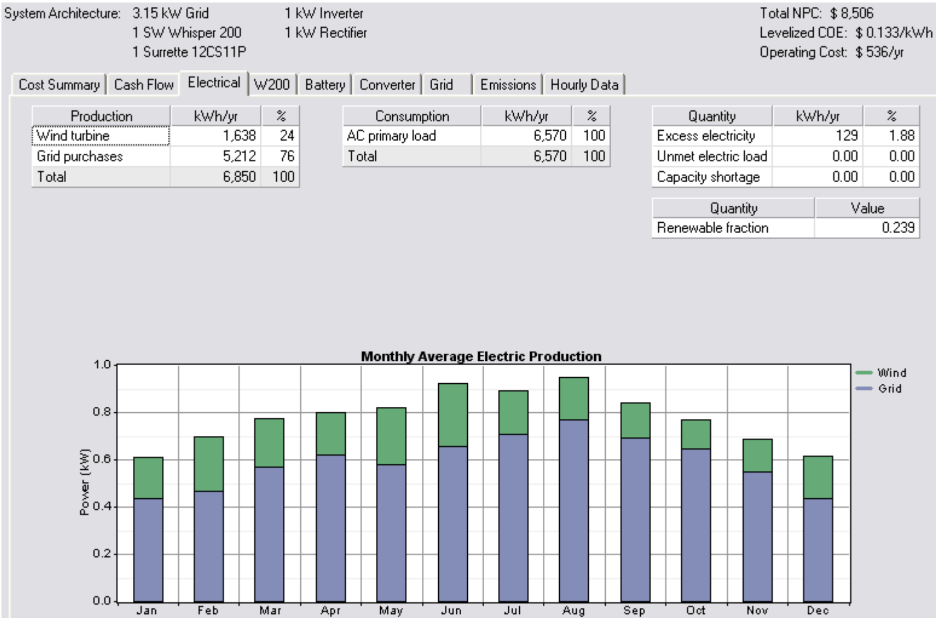


Figure A.11: Yearly electric power production from 3.15kW (76%) grid connection and 1kW (1 number) (24%) wind turbine power output.

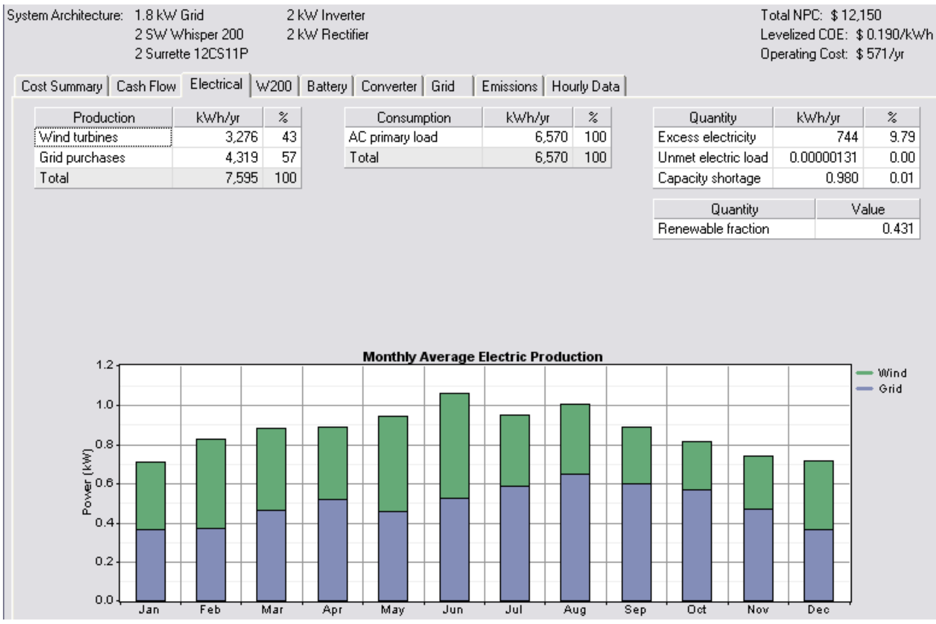


Figure A.12: Yearly electric power production from 1.8kW (57%) grid connection and 1kW (2 number) (43%) wind turbine power output.

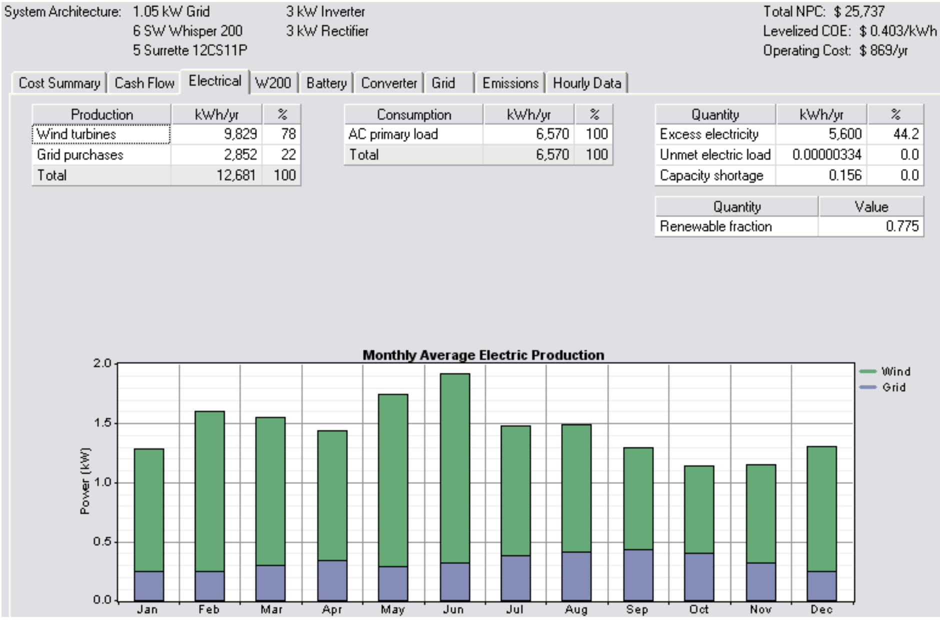


Figure A.13: Yearly electric power production from 1.05kW (22%) grid connection and 1kW (6 numbers) (78%) wind turbine power output.

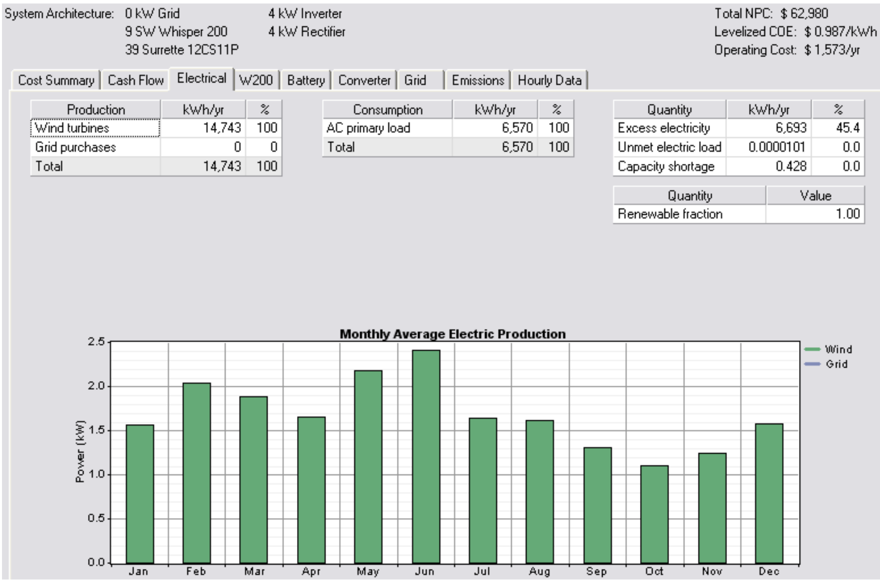


Figure A.14: Yearly electric power production from 0kW (0%) grid connection and 1kW (9 numbers) (100%) wind turbine power output.

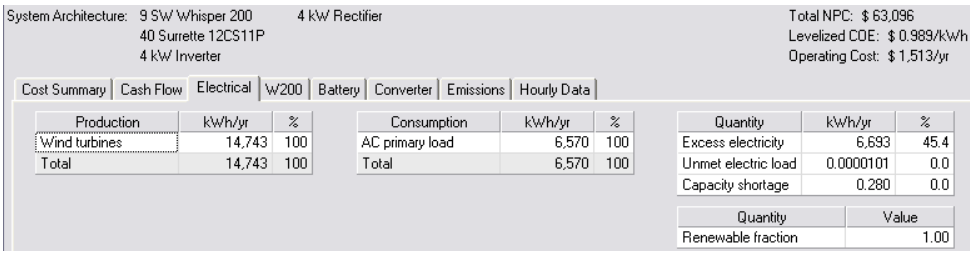


Figure A.15: Yearly electric power production from a Standalone 1kW wind turbine (9 numbers) (100%) WT power output.

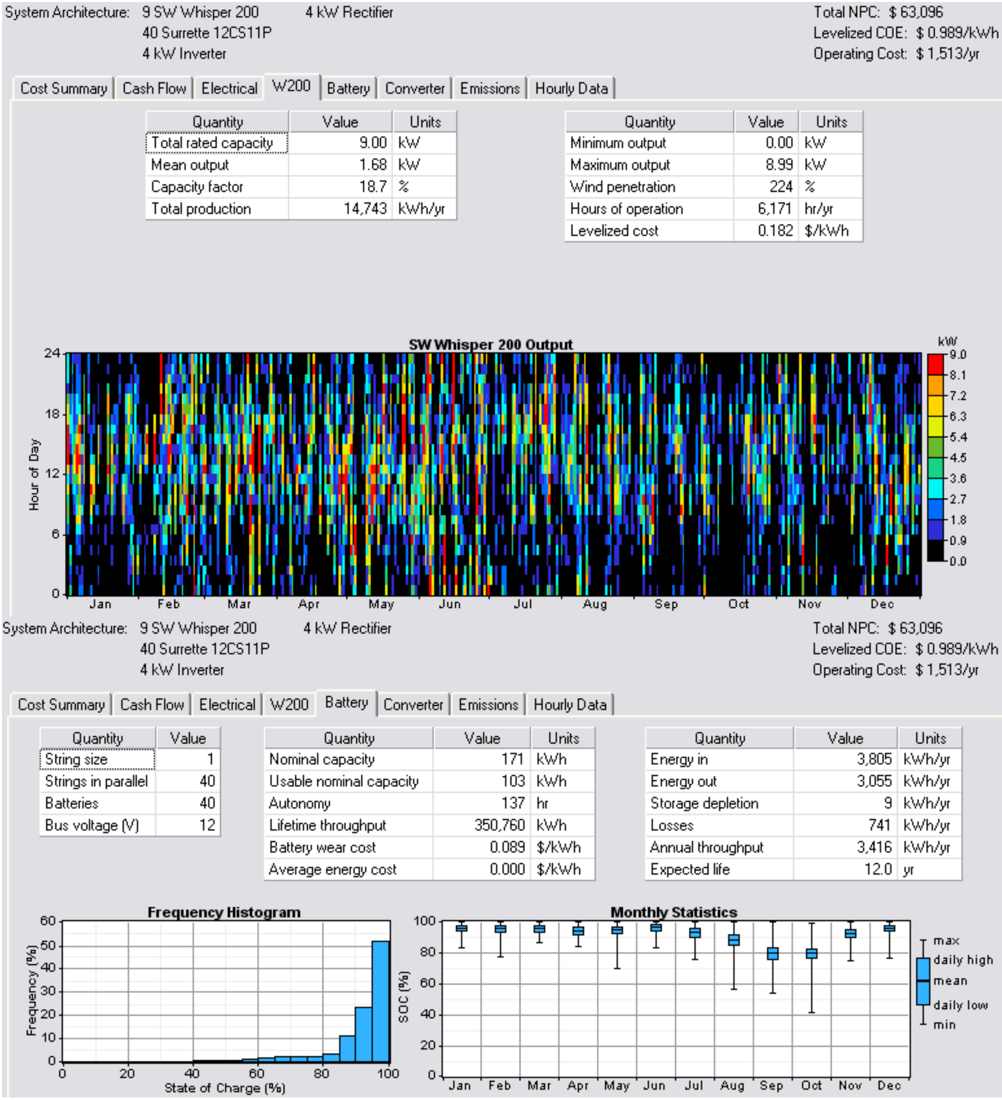


Figure A.16: 100% Standalone WT case configuration with 1kW (9 numbers) capacity properties and Battery properties obtained from the model

Table A.4: Technical Summary Table for WT module Case Configuration

Type of Conf	Grid	1kW WT	Battery	Conv	WT Prod.	Grid Net Purchase	Tot. Elect. Prod.	Primary Load Served	Ren. Frac.	Cap. Shortage Frac.	Unmet Load Frac.	Excess Elect.
	kW	No	No.	kW	kWh/yr	kWh/yr	kWh/yr	kWh/yr		%	%	kWh/yr
1kW-WT-GRID CONNECTED												
25%	3.15	1	1	1	1,638	5,212	6,850	6,570	0.24	0	0	129
50%	1.8	2	2	2	3,276	4,319	7,595	6,570	0.43	0	0	744
75%	1.05	6	5	3	9,829	2,852	12,681	6,570	0.775	0	0	5,600
100%	0	9	39	4	14,743	0	14,743	6,750	1	0	0	6,693
1kW-WT-STANDALONE												
100%	0	9	40	4	14,743	0	14,743	6,570	1	0	0	6,693

Table A.5: CO2 Emission due to use of WT module case configuration.

Energy Configuration	CO2 emission kg/yr	Reduction (%)
Local Grid Connection only	5532	0
25% WT-Grid Connection	4388	20.67968
50% WT-Grid Connection	3636	34.27332
75% WT-Grid Connection	2402	56.5799
100% WT-Grid Connection and 100% WT-Standalone	0	100

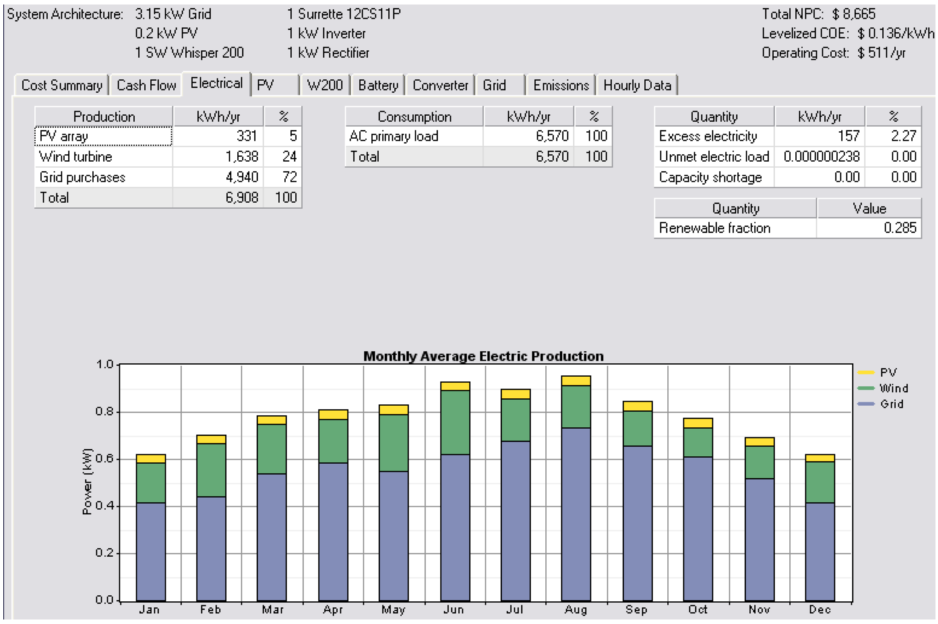


Figure A.17: Yearly electric power production from 3.15kW (72%) Grid connection and Total HYPW (28%) with 0.2kW PV and 1 number 1kW WT electrical power output.

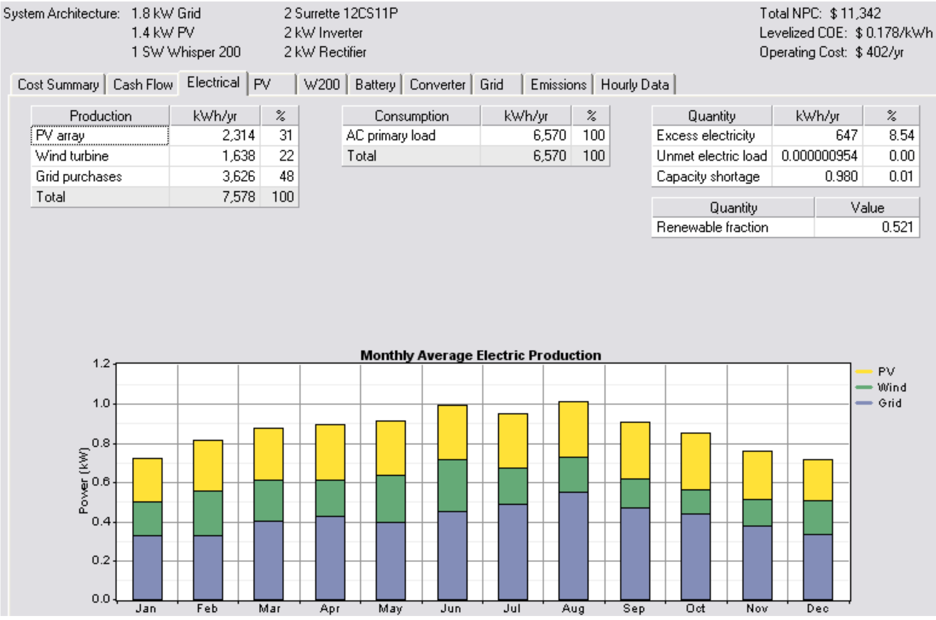


Figure A.18: Yearly electric power production from 1.8kW (48%) Grid connection and Total HYPW (52%) with 1.4kW PV and 1 number 1kW WT electrical power output.

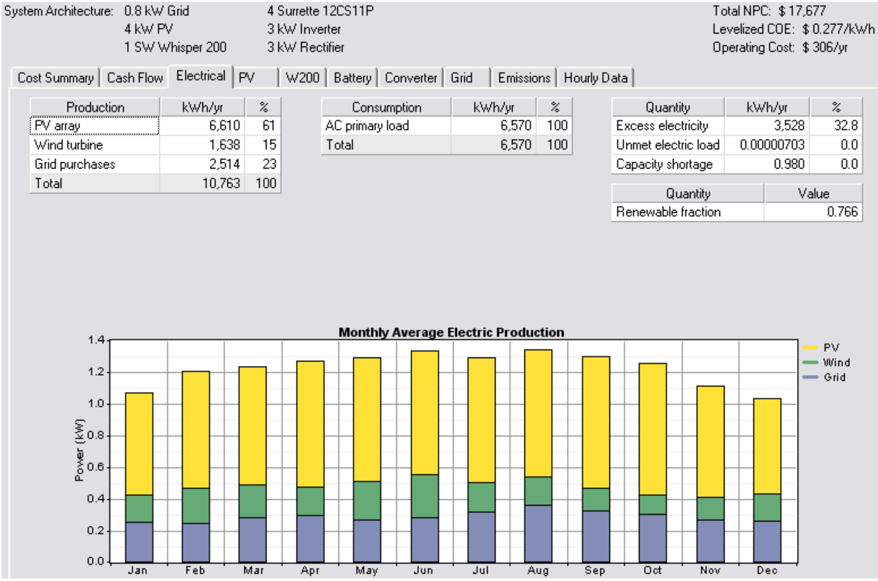


Figure A.19: Yearly electric power production from 0.8kW (23%) Grid connection and Total HYPW (77%) with 4.0kW PV and 1 number 1kW WT electrical power output.

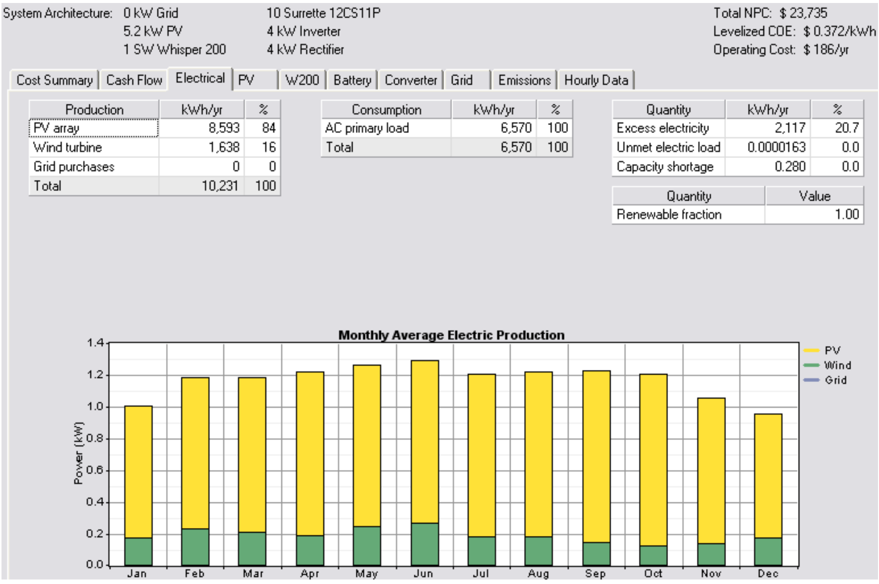


Figure A.20: Yearly electric power production from 0.0kW (0%) Grid connection and Total HYPW (100%) with 5.2kW PV and 1 number 1kW WT electrical power output.

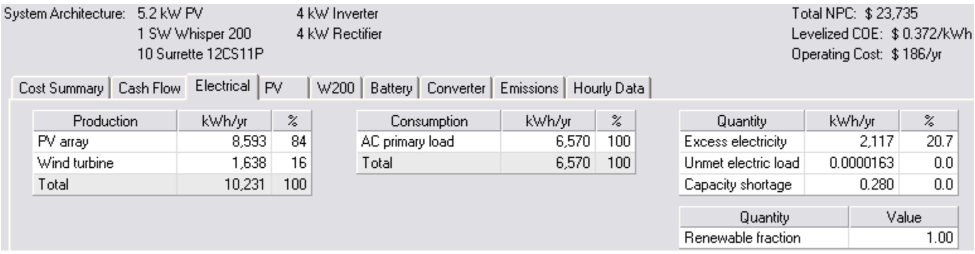


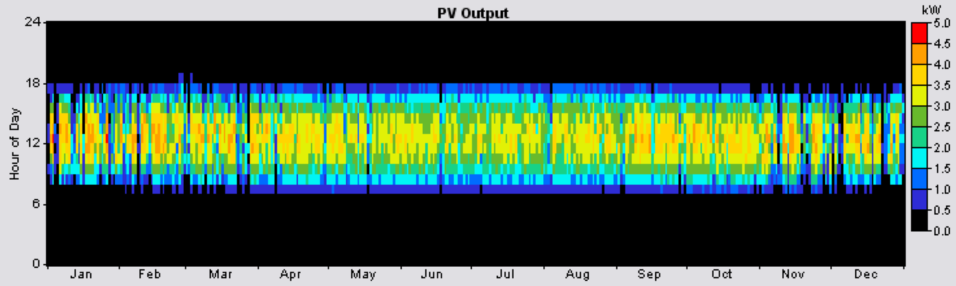
Figure A.21: Yearly electric power production from Standalone HYPW (100%) with 5.2kW PV and 1 number 1kW WT electrical power output.

System Architecture: 5.2 kW PV | 4 kW Inverter | Total NPC: $ 23,735
1 SW Whisper 200 | 4 kW Rectifier | Levelized COE: $ 0.372/kWh
10 Surrette 12CS11P | Operating Cost: $ 186/yr

Cost Summary | Cash Flow | Electrical | PV | W200 | Battery | Converter | Emissions | Hourly Data

Quantity	Value	Units
Rated capacity	5.20	kW
Mean output	0.98	kW
Mean output	23.5	kWh/d
Capacity factor	18.9	%
Total production	8,593	kWh/yr

Quantity	Value	Units
Minimum output	0.00	kW
Maximum output	4.57	kW
PV penetration	131	%
Hours of operation	4,390	hr/yr
Levelized cost	0.117	$/kWh

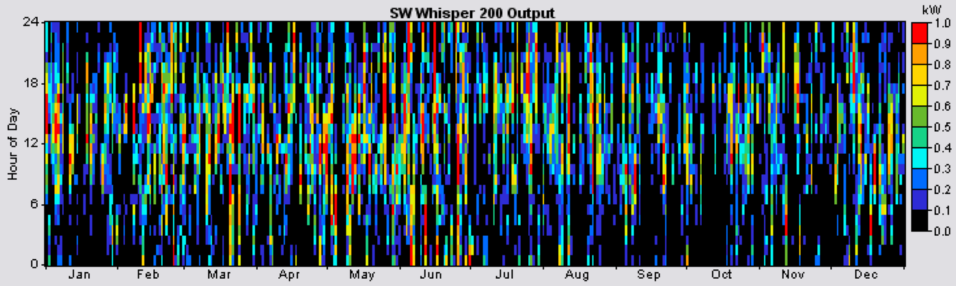


System Architecture: 5.2 kW PV | 4 kW Inverter | Total NPC: $ 23,735
1 SW Whisper 200 | 4 kW Rectifier | Levelized COE: $ 0.372/kWh
10 Surrette 12CS11P | Operating Cost: $ 186/yr

Cost Summary | Cash Flow | Electrical | PV | W200 | Battery | Converter | Emissions | Hourly Data

Quantity	Value	Units
Total rated capacity	1.00	kW
Mean output	0.19	kW
Capacity factor	18.7	%
Total production	1,638	kWh/yr

Quantity	Value	Units
Minimum output	0.00	kW
Maximum output	1.00	kW
Wind penetration	24.9	%
Hours of operation	6,171	hr/yr
Levelized cost	0.182	$/kWh



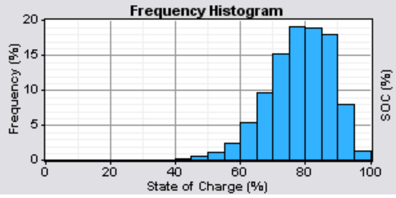
System Architecture: 5.2 kW PV | 4 kW Inverter | Total NPC: $ 23,735
1 SW Whisper 200 | 4 kW Rectifier | Levelized COE: $ 0.372/kWh
10 Surrette 12CS11P | Operating Cost: $ 186/yr

Cost Summary | Cash Flow | Electrical | PV | W200 | Battery | Converter | Emissions | Hourly Data

Quantity	Value
String size	1
Strings in parallel	10
Batteries	10
Bus voltage (V)	12

Quantity	Value	Units
Nominal capacity	42.8	kWh
Usable nominal capacity	25.7	kWh
Autonomy	34.3	hr
Lifetime throughput	87,690	kWh
Battery wear cost	0.089	$/kWh
Average energy cost	0.000	$/kWh

Quantity	Value	Units
Energy in	4,173	kWh/yr
Energy out	3,359	kWh/yr
Storage depletion	16	kWh/yr
Losses	798	kWh/yr
Annual throughput	3,756	kWh/yr
Expected life	12.0	yr



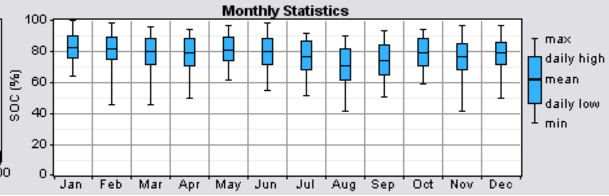


Figure A.22: 100% Standalone HYPW case configuration with 5.2kW PV panels, 1kW (1 number) WT capacity properties each along with Battery properties obtained from the model

Table A.6: Technical Summary Table for HYPW module Case Configuration

Type of Conf.	Grid	PV	WT	Battery	Conv	PV Prod.	Wind Prod.	Grid Net Purchases	Tot. Elect. Prod.	Primary Load Served	Ren. Frac.	Cap. Short. Frac.	Unmet Load Frac.	Excess Elect.
	kW	kW	No	No	kW	kWh/yr	kWh/yr	kWh/yr	kWh/yr	kWh/yr		%	%	kWh/yr
HYPW-GRID CONNECTED														
25%	3.15	0.2	1	1	1	331	1,638	4,940	6,908	6,570	0.28	0	0	157
50%	1.8	1.4	1	2	2	2,314	1,638	3,626	7,578	6,570	0.52	0	0	647
75%	0.8	4	1	4	3	6,610	1,638	2,514	10,763	6,570	0.77	0	0	3,528
100%	0	5.2	1	10	4	8,593	1,638	0	10,231	6,570	1	0	0	2,117
HYPW-STANDALONE														
100%	0	5.2	1	10	4	8,593	1,638	0	10,231	6,570	1	0	0	2,117

Table A.7: CO2 Emission due to use of HYPW module case configuration.

Energy Configuration	CO2 emission kg/yr	Reduction (%)
Local Grid Connection only	5532	0
25% HYPW-Grid Connection	4159	24.81923
50% HYPW -Grid Connection	3053	44.812
75% HYPW -Grid Connection	2117	61.73174
100% HYPW -Grid Connection and 100% HYPW-Standalone	0	100

Table A.8: Technical Summary Table for HYPW module Case Configuration

Type of Conf.	Grid	PV	WT	Battery	Conv	PV Prod.	Wind Prod.	Grid Net Purchases	Tot. Elect. Prod.	Primary Load Served	Ren. Frac.	Cap. Short. Frac.	Unmet Load Frac.	Excess Elect.
	kW	kW	No	No	kW	kWh/yr	kWh/yr	kWh/yr	kWh/yr	kWh/yr		%	%	kWh/yr
HYPW-GRID CONNECTED														
25%	3.15	0.2	1	1	1	331	1,638	4,940	6,908	6,570	0.28	0	0	157
50%	1.8	1.4	1	2	2	2,314	1,638	3,626	7,578	6,570	0.52	0	0	647
75%	0.8	4	1	4	3	6,610	1,638	2,514	10,763	6,570	0.77	0	0	3,528
100%	0	5.2	1	10	4	8,593	1,638	0	10,231	6,570	1	0	0	2,117
HYPW-STANDALONE														
100%	0	5.2	1	10	4	8,593	1,638	0	10,231	6,570	1	0	0	2,117

Table A.9: CO2 Emission due to use of HYPW module case configuration.

Energy Configuration	CO2 emission kg/yr	Reduction (%)
Local Grid Connection only	5532	0
25% HYPW-Grid Connection	4159	24.81923
50% HYPW -Grid Connection	3053	44.812
75% HYPW -Grid Connection	2117	61.73174
100% HYPW -Grid Connection and 100% HYPW-Standalone	0	100

Table A.10: Technical Summary Table for All Case Configurations

Type of REN.	Grid	Grid Output	PV	1KW WT	Battery	Conv.	PV Prod.	PV Output	Wind Prod.	WT Output	Grid Net Purchases	Tot. Elect. Prod.	Excess Elect.
	kW	%	kW	No	No	kW	kWh/yr	%	kWh/yr	%	kWh/yr	kWh/yr	kWh/yr
ALL 25% CASE CONFIGURATIONS-GRID CONNECTED													
PV	3.15	73	1	NA	1	1	1,856	27	NA	NA	4,955	6,811	61
WT	3.15	76	NA	1	1	1	NA	NA	1,638	24	5,212	6,850	129
HYPW	3.15	71	0.2	1	1	1	331	5	1,638	24	4,941	6,910	159
ALL 50% CASE CONFIGURATIONS-GRID CONNECTED													
PV	1.8	50	2.4	NA	2	2	3,966	50	NA	NA	3,939	7,905	998
WT	1.8	57	NA	2	2	2	NA	NA	3,276	43	4,319	7,595	744
HYPW	1.8	48	1.4	1	2	2	2,314	30	1,638	22	3,655	7,606	699
ALL 75% CASE CONFIGURATIONS-GRID CONNECTED													
PV	0.8	25	5.4	NA	4	3	8,924	75	NA	NA	2,927	11,851	4,591
WT	1.05	23	NA	6	5	3	NA	NA	9,829	77	2,852	12,681	5,600
HYPW	0.8	24	4	1	4	3	6,610	61	1,638	15	2,514	10,763	3,528
ALL 100% CASE CONFIGURATIONS-GRID CONNECTED													
PV	0	0	7	NA	10	4	11,568	100	NA	NA	0	11,568	3,319
WT	0	0	NA	9	39	4	NA	NA	14,743	100	0	14,743	6,693
HYPW	0	0	5.2	1	10	4	8,593	84	1,638	16	0	10,231	2,117
ALL 100% CASE CONFIGURATIONS-STANDALONE													
PV	NA	NA	7	NA	10	4	11,568	100	NA	NA	NA	11,568	3,319
WT	NA	NA	NA	9	40	4	NA	NA	14,743	100	NA	14,743	6,693
HYPW	NA	NA	5.2	1	10	4	8,593	84	1,638	16	NA	10,231	2,117
NA- NOT APPLICABLE, **REN**-RENEWABLE ENERGY SOURCE													
PV-PHOTOVOLTAIC, **WT**-WIND TURBINES, **HYPW**-HYBRID PHOTOVOLTAIC AND WIND TURBINE													

Table A.11: Technical Summary Table for All Case Configurations CO2 Emission Reduction %

Case Configuration	PV's CO2 Reduction (%)	WT's CO2 Reduction (%)	HYPW's CO2 Reduction (%)
Local Grid Connection only	0	0	0
25% -Grid Connection	24.58424	20.67968	24.81923
50% -Grid Connection	40.05785	34.27332	44.812
75% -Grid Connection	55.44107	56.5799	61.73174
100% -Grid Connection and 100% -Standalone	100	100	100

APPENDIX B: PRODUCT SUPPLIERS

The following is the list of PV (Photovoltaic's) and WT (Wind Turbine) along with their balance of components products and suppliers in UAE and Worldwide.

PV

Suntech Power: http://ap.suntech-power.com/en/about.html

Suntech develops, manufactures, and delivers the worlds most reliable and cost-effective solar energy solutions. They are the world's largest producer of silicon solar modules. They offer clean power for every application and market, from off-grid systems, to homes, to the world's largest solar power plants. Their solar modules are installed in over 80 countries.

WT

Southwest Wind power: http://www.windenergy.com/

In 1987, Southwest Windpower was created with a goal: to create a small, reliable, battery-charging wind generator to complement solar energy systems powering rural areas of the world. They modified a Ford alternator to create their first wind generator, the Windseeker®. The company introduced its AIR series turbines, which were produced and shipped to more than 100 countries and became the best-selling battery-charging wind turbine in history.

Battery

Rolls Surrette Battery Company Ltd: http://www.surrette.com/

Surrette Battery Company is one of North America's leading lead-acid battery manufacturers. Established in 1935, with a production facility in Salem, Massachusetts, Surrette relocated to Canada in 1959 and is the Nation's only remaining independent battery manufacturer.

Inverter and Charge Controller

Xantrex: http://www.xantrex.com/

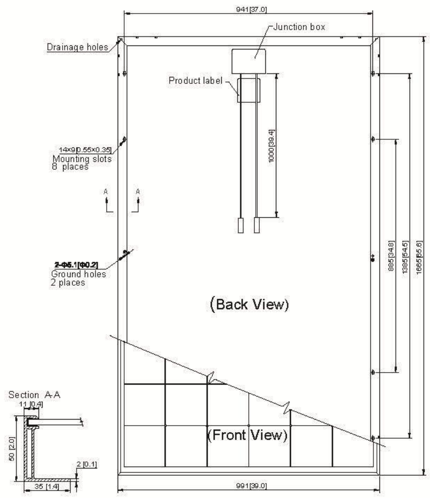
A subsidiary of Schneider Electric, is a world leader in the development, manufacturing and marketing of advanced power electronic products and systems for the mobile power markets. The company's products convert and control raw electrical power from any central, distributed, renewable, or backup power source into high-quality power required by electronic equipment and the electricity grid.

APPENDIX C: DATASHEETS

The following are the data sheets for products used in the simulation:

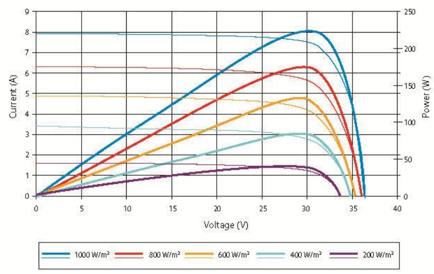
A.C.1. PV Panels

STP230 - 20/Wd
STP225 - 20/Wd



Note: mm [inch]

Current-Voltage & Power-Voltage Curve (225-20)



Exellent performance under weak light conditions: at an irradiation intensity of 200 W/m² (AM 1.5, 25 °C), 95.5% or higher of the STC efficiency (1000 W/m²) is achieved

Electrical Characteristics

STC	STP230-20/Wd	STP225-20/Wd
Optimum Operating Voltage (Vmp)	29.8 V	29.6 V
Optimum Operating Current (Imp)	7.72 A	7.61 A
Open Circuit Voltage (Voc)	36.8 V	36.7 V
Short Circuit Current (Isc)	8.25 A	8.15 A
Maximum Power at STC (Pmax)	230 W	225 W
Module Efficiency	13.9%	13.6%
Operating Module Temperature	-40 °C to +85 °C	
Maximum System Voltage	1000 V DC (IEC) / 600 V DC (UL)	
Maximum Series Fuse Rating	20 A	
Power Tolerance	0 /+5 %	

STC: Irradiance 1000 W/m², module temperature 25 °C, AM=1.5
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

NOCT	STP230-20/Wd	STP225-20/Wd
Maximum Power at NOCT (Pmax)	168 W	165 W
Optimum Operating Voltage (Vmp)	27.1 V	26.9 V
Optimum Operating Current (Imp)	6.20 A	6.12 A
Open Circuit Voltage (Voc)	33.9 V	33.8 V
Short Circuit Current (Isc)	6.68 A	6.65 A

NOCT: Irradiance 800 W/m², ambient temperature 20 °C, AM=1.5, wind speed 1 m/s
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

Mechanical Characteristics

Solar Cell	Polycrystalline 156 × 156 mm (6 inches)
No. of Cells	60 (6 × 10)
Dimensions	1665 × 991 × 50mm (65.6 × 39.0 × 2.0 inches)
Weight	19.8 kgs (43.7 lbs.)
Front Glass	3.2 mm (0.13 inches) tempered glass
Frame	Anodized aluminium alloy
Junction Box	IP67 rated
Output Cables	TUV (2Pfg1169:2007), UL 4703, UL 44 4.0 mm² (0.006 inches²), symmetrical lengths (-) 1000 mm (39.4 inches) and (+) 1000 mm (39.4 inches)
Connectors	RADOX® SOLAR integrated twist locking connectors

Temperature Characteristics

Nominal Operating Cell Temperature (**NOCT**)	45±2°C
Temperature Coefficient of Pmax	-0.44 %/°C
Temperature Coefficient of Voc	-0.33 %/°C
Temperature Coefficient of Isc	0.055 %/°C

Packing Configuration

Container	20'GP	40'HC
Pieces per pallet	21	21
Pallets per container	6	28
Pieces per container	126	588

Dealer information

Specifications are subject to change without further notification

www.suntech-power.com | E-mail: sales@suntech-power.com **EN-STD-Wd-NO2.01-Rev 2011**

Figure C.1: Specification for PV used in the simulation (Suntech Power, 2011)

A.C.2: Wind Turbine

Technical Specifications

WHISPER 100

Rotor Diameter	7 ft (2.1 m)
Weight	47 lb (21 kg) box: 74 lb (22.56 kg)
Shipping Dimensions	51 x 20 x 13 in (1295 x 508 x 330 mm)
Mount	2.5 in schedule 40 (6.35 cm) pipe
Start-Up Wind Speed	7.5 mph (3.4 m/s)
Voltage	12, 24, 36, 48 VDC
Rated Power	900 watts at 28 mph (12.5 m/s)
Turbine Controller	Whisper controller
Body	Cast aluminum/marine option
Blades	3-Carbon reinforced fiberglass
Overspeed Protection	Patented side-furling
Kilowatt Hours Per Month	100 KWh/mo at 12 mph (5.4 m/s)
Survival Wind Speed	120 mph (55 m/s)
Warranty	5 year limited warranty

WHISPER 200

Rotor Diameter	9 feet (2.7 m)
Weight	65 lb (30 kg) box: 87 lb (39.46 kg)
Shipping Dimensions	51 x 20 x 13 in (1295 x 508 x 330 mm)
Mount	2.5 in schedule 40 (6.35 cm) pipe
Start-Up Wind Speed	7 mph (3.1 m/s)
Voltage	24, 36, 48 VDC (HV available)
Rated Power	1000 watts at 26 mph (11.6 m/s)
Turbine Controller	Whisper controller
Body	Cast aluminum/marine option
Blades	3-Carbon reinforced fiberglass
Overspeed Protection	Patented side-furling
Kilowatt Hours Per Month	200 KWh/mo at 12 mph (5.4 m/s)
Survival Wind Speed	120 mph (55 m/s)
Warranty	5 year limited warranty

WHISPER

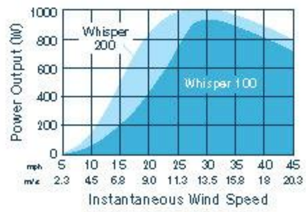
Whisper 100/200

Reliable Remote Power

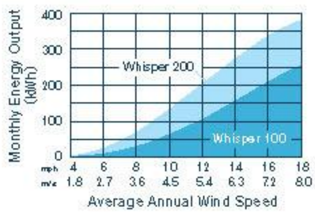
Whisper 100 provides dependable energy for remote homes, telecommunication sites and rural applications in moderate to extreme environments. Reliable operation by thousands of customers makes Whisper 100 the top selling small wind turbine in its class. Assuming a 12 mph (5.4 m/s) average wind, a Whisper 100 will produce 100 kWh per month. Best for moderate to high wind – 9 mph (4 m/s) and above.

The versatile Whisper 200 powers applications from remote homes to water pumping. The Whisper 200's 9-foot (2.7 m) blade has almost twice the swept area of the Whisper 100, yielding twice the energy. A high voltage model is available for transmission over long distances. Best for low to moderate wind – 7 mph (3 m/s) and above.

POWER



MONTHLY ENERGY



FIVE YEAR WARRANTY

Southwest Windpower
1801 W. Route 66
Flagstaff, AZ 86001 USA
928.779.9463
www.windenergy.com

Makers of Skystream 3.7®/ AIR / Whisper

Printed on recycled paper using vegetable inks.

Figure C.2: Specification for WT used in the simulation (Southwest Wind Power, 2011)

A.C.3: Battery

Rolls

BATTERY ENGINEERING

WWW.ROLLSBATTERY.COM MADE IN CANADA

DEEP CYCLE

SERIES: 5000

MODEL: 12 CS 11P

BATTERY TYPE: 12 VOLTS

DIMENSIONS:

LENGTH	559	MM	22	INCHES
WIDTH	286	MM	11 1/4	INCHES
HEIGHT	464	MM	18 1/4	INCHES

WEIGHTS:

WEIGHT DRY	100	KG	220	LBS.
WEIGHT WET	123	KG	272	LBS.

CONTAINER CONSTRUCTION:

CONTAINER: (INNER)	POLYPROPYLENE
COVER: (INNER)	POLYPROPYLENE - HEAT SEALED TO INNER CONTAINER
CONTAINER: (OUTER)	HIGH DENSITY POLYETHYLENE
COVER: (OUTER)	HIGH DENSITY POLYETHYLENE SNAP FIT TO OUTER CONTAINER

TERMINALS: FLAG WITH STAINLESS STEEL NUTS AND BOLTS

HANDLES: MOLDED

PLATES:

POSITIVE PLATE DIMENSION:

HEIGHT	273	MM	10.750	INCHES
WIDTH	143	MM	5.625	INCHES
THICKNESS	6.73	MM	0.265	INCHES

NEGATIVE PLATE DIMENSION:

HEIGHT	273	MM	10.750	INCHES
WIDTH	143	MM	5.625	INCHES
THICKNESS	4.70	MM	0.185	INCHES

CELLS: 6 **PLATES/CELL:** 11

POSITVE PLATE ENVELOPED BY VERTICAL SLYVER GLASS MAT

SEPARATOR:

THICKNESS	3	MM	0.105	INCHES

INSULATION:

GLASS MAT	1	MM	0.020	INCHES

CAPACITY:

CRANK AMPS:

COLD (CCA)	0°F / -17.8°C	845
MARINE (MCA)	32°F / 0°C	1056

ELECTROLYTE RESERVE:

ABOVE PLATES 95 MM 3.75 INCHES

RESERVE CAPACITY:

RC @ 25A 768 MINUTES

20 HR RATE: 357

	HOUR RATE	SPECIFIC GRAVITY	CAP / AH	CURRENT / AMPS
CAPACITY @	100 HOUR RATE	1.280 SP. GR.	503	5.03
CAPACITY @	72 HOUR RATE	1.280 SP. GR.	475	6.59
CAPACITY @	50 HOUR RATE	1.280 SP. GR.	439	8.78
CAPACITY @	24 HOUR RATE	1.280 SP. GR.	371	15.5
CAPACITY @	**20 HOUR RATE**	**1.280 SP. GR.**	**357**	**17.9**
CAPACITY @	15 HOUR RATE	1.280 SP. GR.	332	22.1
CAPACITY @	12 HOUR RATE	1.280 SP. GR.	311	25.9
CAPACITY @	10 HOUR RATE	1.280 SP. GR.	296	29.6
CAPACITY @	8 HOUR RATE	1.280 SP. GR.	278	34.8
CAPACITY @	6 HOUR RATE	1.280 SP. GR.	253	42.2
CAPACITY @	5 HOUR RATE	1.280 SP. GR.	239	48
CAPACITY @	4 HOUR RATE	1.280 SP. GR.	221	55
CAPACITY @	3 HOUR RATE	1.280 SP. GR.	200	67
CAPACITY @	2 HOUR RATE	1.280 SP. GR.	171	86
CAPACITY @	1 HOUR RATE	1.280 SP. GR.	121	121

Surrette

BATTERY COMPANY LIMITED

1 STATION RD SPRINGHILL, NOVA SCOTIA CANADA B0M 1X0 1.800.681.9914

REV.2

Jan-10

12 CS 11P

Figure C.3: Specification for Battery used in the simulation (Rolls Surrette Battery Company, 2011)

A.C.4: Inverter

Smart choice for power™

xantrex™

Xantrex™ XW Series Hybrid Inverter/Charger

Electrical Specifications			
Model	XW6048-120/240-60	XW4548-120/240-60	XW4024-120/240-60
Continuous output power	6,000 W	4500 W	4000 W
Surge rating (10 seconds)	12,000 W	9000 W	8000 W
Surge current	L-N: 105 Arms (7 sec) L-L: 40 Arms (20 sec)	L-L: 52.5 Arms (7 sec) L-N: 70 Arms (20 sec)	L-N: 75 Arms (20 sec) L-L: 35 Arms (20 sec)
Waveform	True sine wave	True sine wave	True sine wave
Low-load efficiency	95%	95%	95%
Idle consumption - search mode	< 8 W	< 8 W	< 8 W
AC connections	AC1 (Grid), AC2 (Generator)	AC1 (Grid), AC2 (Generator)	AC1 (Grid), AC2 (Generator)
AC voltage	120/240 Vac split-phase	120/240 Vac split-phase	120/240 Vac split-phase
AC input breaker	60 A two-pole	60 A two-pole	60 A two-pole
Utility interactive	Yes	Yes	Yes
CEC weighted efficiency	92.5%	93%	91%
CEC power rating	5752 W	4500W	4000 W
AC input voltage range (bypass/charge mode)	L-N: 80 - 150 Vac (120 V nominal); L-L: 160 - 270 Vac (240 V nominal)		
AC input frequency range (bypass/charge mode)	55 - 65 Hz (default); 44 - 70 Hz (allowable)		
AC1 voltage range – Sell mode (automatically adjusts when entering Sell mode)*	L-N: 108 - 130 +/- 1.5 Vac; L-L: 214 - 260 +/- 3.0 Vac		
AC1 frequency range – Sell mode (automatically adjusts when entering Sell mode)*	59.4 - 60.4 +/- 0.05 Hz		
AC output voltage	L-N: 120 Vac +/- 3%; L-L: 240 Vac +/- 3%		
AC output frequency	60.0 +/-0.1 Hz		
DC current at rated power	130 A	96 A	178 A
Total harmonic distortion	< 5%		
Automatic transfer relay	60 A		
Typical transfer time	8 ms		
DC input voltage (nominal)	50.4 Vdc	50.4 Vdc	25.2 Vdc
DC input voltage range	44 - 64 Vdc	44 - 64 Vdc	22 - 32 Vdc
Maximum continuous charge rate	100 A	85 A	150 A
Efficiency at maximum charge rate	89.4%	90.2%	85.8%
Power factor corrected charging	0.98	0.98	0.98
Emissions	FCC Class B	FCC Class B	FCC Class B
Multiple-unit configurations	Up to three parallel units in 120/240-volt split-phase configuration		
Auxiliary relay output	0-12 Vdc, maximum 250 mA DC		
Non-volatile memory	Yes	Yes	Yes
System network	Xanbus™ (publish-subscribe network, no need for hubs or special cards)		
Mechanical Specifications			
Mounting	Wall mount, backplate included		
Inverter dimensions (H x W x D)	23 x 16 x 9" (580 x 410 x 230 mm)		
Inverter weight	125 lb (57 kg)	115 lb (52 kg)	115 lb (52 kg)
Shipping dimensions	28 x 22 ¼ x 10 ½" (711 x 565 x 267 mm)		
Shipping weight	132 lb (60 kg)	122 lb (55 kg)	122 lb (55 kg)
Display panel	Status LEDs indicate AC In status, faults/warnings, equalize mode, battery level. Three-character display indicates output power or charge current, fault/warning codes. On/Off and equalize buttons		
Battery temperature sensor	Included	Included	Included
Standard warranty	Five years (10 years optional)	Five years (10 years optional)	Five years (10 years optional)
Part number	865-1000	865-1005	865-1010
Environmental Specifications			
Enclosure type	NEMA Type 1 – Indoor (sensitive electronic components sealed inside enclosure)		
Operational temperature range	-13 to 158 °F (-25 to 70 °C)		
Accessories			
Remote display	Optional XW System Control Panel monitors and configures all devices connected to Xanbus™ Network		
Generator support	Optional XW Automatic Generator Start module connects to Xanbus™ Network. Automatically activates generator to recharge depleted battery bank or assist inverter with heavy loads		
Power distribution & panel conduit boxes	Optional balance-of-systems components for NEC compliant installations, includes pre-wired AC and DC circuit breakers, bus bars and multiple knockouts for conduit and additional breakers		
Regulatory Approvals			
UL 1741 1st Edition: 2005 Version CSA 107.1-01			

Specifications subject to change without notice

Figure C.4: Specification for Inverter used in the simulation (Xantrex, 2011)

حكومة دبي
GOVERNMENT OF DUBAI

هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

CHAITANYA BIPIN KULKARNI
MOHD & OBAID AL MULLA CO.PVT.LTD.
FLAT-206(W SUB METER)
313 SH KHALIFA BIN ZAYED RD
POST BOX : 49561 ,Dubai

B14 B1423 192.00 Residential Exp

		Aug-11	
الفاتورة عن شهر Invoice for the Month of		06.07.2011	05.08.2011
		Electricity الكهرباء	**Water المياه**
رقم العداد	Meter No	329995T	90044146
القراءة السابقة	Previous Reading	64540	419565
القراءة الحالية	Current Reading	64766	422297
الاستهلاك	Consumption	226	2732

Previous Month's Summary بيانات الشهر السابق

الخدمة Service	المبلغ المستحق بالفاتورة Previous Invoice Balance	الدفعات المستلمة Payment Accounted Upto 11.07.2011	التعديلات Adjustments	المتأخرات Arrears
Electricity الكهرباء	80.80	80.80	0.00	0.00
Water المياه	149.89	149.89	0.00	0.00
Sewerage الصرف الصحي	18.96	18.96	0.00	0.00
Cooling التبريد	0.00	0.00	0.00	0.00
Housing Fee رسوم السكن	205.00	205.00	0.00	0.00
Advance Payments المدفوعات المقدمة				0.00
Total المجموع	**454.65**	**454.65**	**0.00**	**0.00**

رقم الحساب **Contract Account No:**	2015133658
رقم العميل Business Partner No:	10263677
رقم العقار Premise No:	313056447
رقم الفاتورة Invoice No.:	100151253094
تاريخ الفاتورة Invoice Date:	10-Aug-11
تاريخ الاستحقاق Pay By:	24-Aug-11

Current Month Charges رسوم الشهر الحالي

الخدمة Service	شريحة الاستهلاك Slab	الاستهلاك Consumption	التعرفة Rate	المبلغ AED
Electricity الكهرباء	G	226	23	51.98
	Y	0	0	0.00
	O	0	0	0.00
	R	0	0	0.00
				67.80
Fuel Surcharge أسعار الوقود		226	7	15.82
Meter Charges رسوم العداد				4.00
Other Charges رسوم أخرى				0.04
Total المجموع		**226**		**71.84**
Water المياه	G	2732	3.5	95.62
	Y	0	0	0.00
	O	0	0	0.00
Fuel Surcharge أسعار الوقود		2732	0.4	10.93
Meter Charges رسوم العداد				2.00
Other Charges رسوم أخرى				0.00
Total المجموع		2732		108.55
Sewerage الصرف الصحي				13.66
Housing Fee رسوم السكن				205.00
Cooling التبريد				0.00
Total المجموع				218.66
Total Current Month Charges اجمالي رسوم الشهر الحالي				399.05
Total Amount Due اجمالي المبلغ لمستحق				399.05

Figure C.5: Reference DEWA electricity bill for household electric load consumption (DEWA, 2011)

APPENDIX D: SIMULATION DATA

The following is the data used in order to sun the simulation based on the solar and wind data along with the primary demand load.

Table D.1: Load Analysis for the House Model (US, DOE, 2011)

Equipment and Appliances	Total Nos.	Generic Rated Power as per US.DOE (W)	Total Rated Power (W)	Average Hours/day	kWh/day
Mechanical					
Water Pump	1	1100	1100	0.5	0.55
AC (5-Tons)	1	2200	2200	4.5	9.9
Kitchen					
Refrigerator	1	500	500	4.5	2.25
Coffee Maker	1	900	900	0.15	0.135
Toaster	1	800	800	0.15	0.12
Micro Oven	1	500	500	0.5	0.25
Dishwasher	1	1200	1200	0.5	0.6
Slow Cooker	1	110	110	0.5	0.055
Mixer Grinder	1	300	300	0.15	0.045
Lighting					
GF LED lights	18	15	270	4	1.08
FF LED lights	18	15	270	4	1.08
Exhaust Fans	3	100	300	2	0.6
Outdoor Lights	8	5	40	8	0.32
Office and Entertainment					
TV 32"	4	120	480	2	0.96
DVD Player	2	20	40	3	0.12
Music System	2	25	50	1	0.05
Laptop	2	50	100	8	0.8
Printer	1	20	20	0.15	0.003
Modem, Router etc	1	20	20	3	0.06
Laundry					
Washing Dyer Machine	1	500	500	1	0.5
Iron	1	1000	1000	0.5	0.5
Small Power Points	2	6	12	2	0.024
				Total AC Load (kWh/day)	20.002

Parameters for Sizing and Pointing of Solar Panels and for Solar Thermal Applications:

Monthly Averaged Insolation Incident On A Horizontal Surface ($kWh/m^2/day$)													
Lat 27.76 Lon 50.32	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	3.67	4.65	5.41	6.65	7.43	7.87	7.76	7.32	6.68	5.68	4.20	3.35	5.89

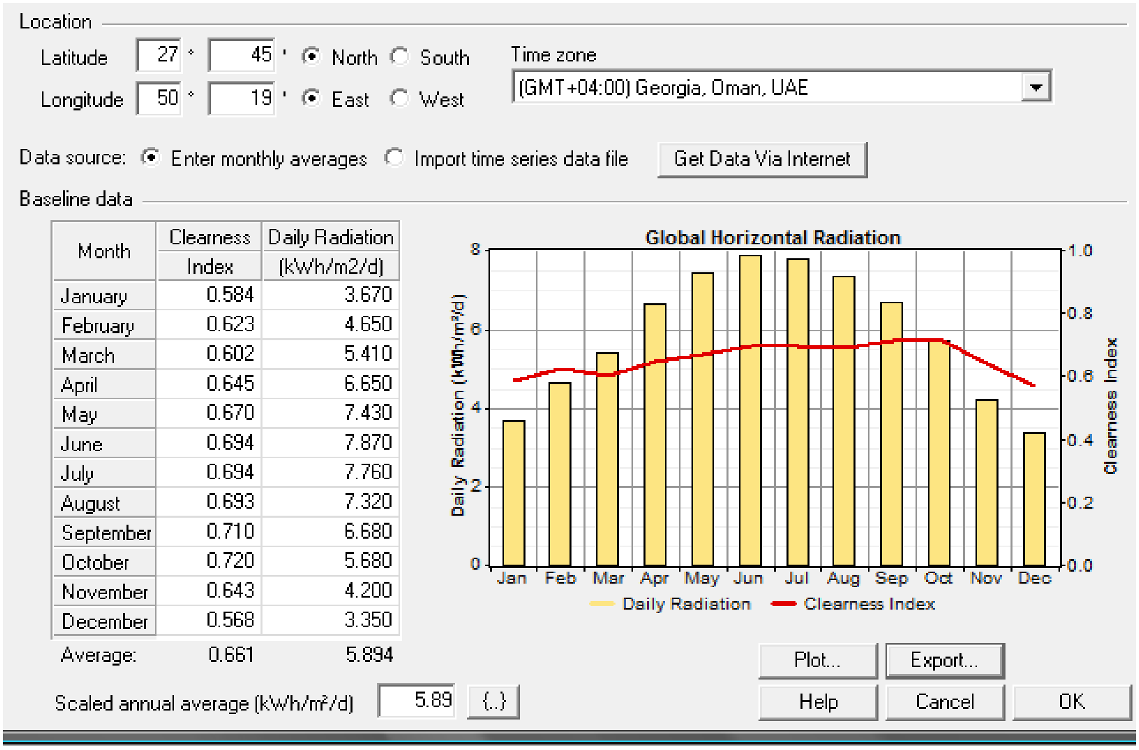


Figure D.1: Site Specific Solar Radiation Data (NASA SSE Database, 2011 as solar resource input parameters in HOMER software)

Table D.2: Wind Speed Statistics Specific to Site (NASA SSE Database)

Monthly Averaged Wind Speed At 10 m Above The Surface Of The Earth For Terrain Similar To Airports (m/s)													
Lat 27.76 Lon 50.32	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	4.57	5.09	4.92	4.67	5.24	5.48	4.66	4.63	4.28	4.04	4.20	4.59	4.69

It is recommended that users of these wind data review the SSE [Methodology](). The user may wish to correct for biases as well as local effects within the selected grid region.	*All height measurements are from the soil, water, or ice/snow surface instead of "effective" surface, which is usually taken to be near the tops of vegetated canopies.*

Meteorology (Wind):

Monthly Averaged Wind Speed At 50 m Above The Surface Of The Earth (m/s)													
Lat 27.76 Lon 50.32	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	5.34	5.95	5.75	5.46	6.13	6.41	5.45	5.43	5.01	4.72	4.91	5.37	5.49

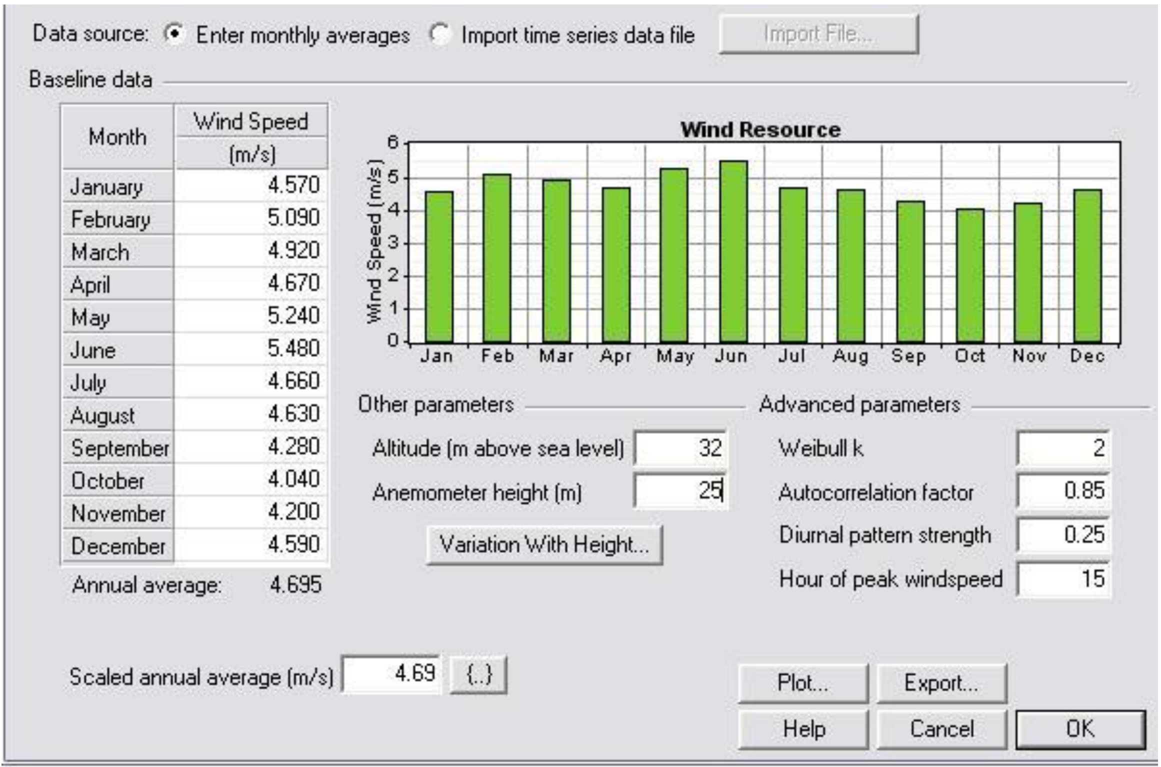


Figure D.2: HOMER wind speed resource input parameters (HOMER, 2011)

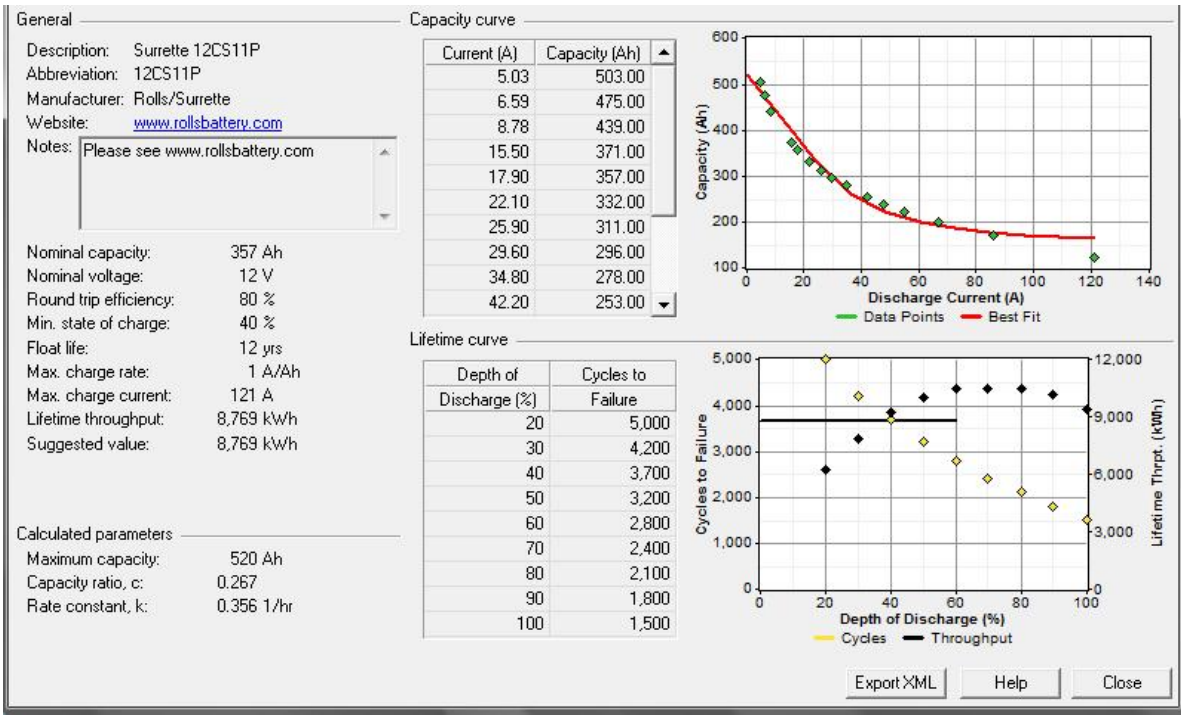


Figure D.3: Battery Input for HOMER simulation software (Rolls Battery, 2011)

Table D.3: Typical Hourly Electric Load Profile Assumption for House Model (Paatero and Lund, 2006)

No.	Hours Per Day	Hourly Load (kW)	3 Hour (%)	3hr Interval Total (kW)
1	00:00 - 01:00	0.21255	3.744493392	0.82875
2	01:00 - 02:00	0.18525		
3	02:00 - 03:00	0.43095		
4	03:00 - 04:00	0.4095	8.370044053	1.8525
5	04:00 - 05:00	0.63765		
6	05:00 - 06:00	0.80535		
7	06:00 - 07:00	1.22655	13.48898678	2.98545
8	07:00 - 08:00	0.9399		
9	08:00 - 09:00	0.819		
10	09:00 - 10:00	0.8385	12.84581498	2.8431
11	10:00 - 11:00	0.96525		
12	11:00 - 12:00	1.03935		
13	12:00 - 13:00	1.34745	14.34361233	3.1746
14	13:00 - 14:00	1.01205		
15	14:00 - 15:00	0.8151		
16	15:00 - 16:00	0.77415	12.89867841	2.8548
17	16:00 - 17:00	0.79755		
18	17:00 - 18:00	1.2831		
19	18:00 - 19:00	2.40045	25.63876652	5.6745
20	19:00 - 20:00	1.95585		
21	20:00 - 21:00	1.3182		
22	21:00 - 22:00	0.936	8.669603524	1.9188
23	22:00 - 23:00	0.585		
24	23:00 - 00:00	0.3978		
	Total AC Load (kWh/day)	**22.1325**	**100**	**22.1325**

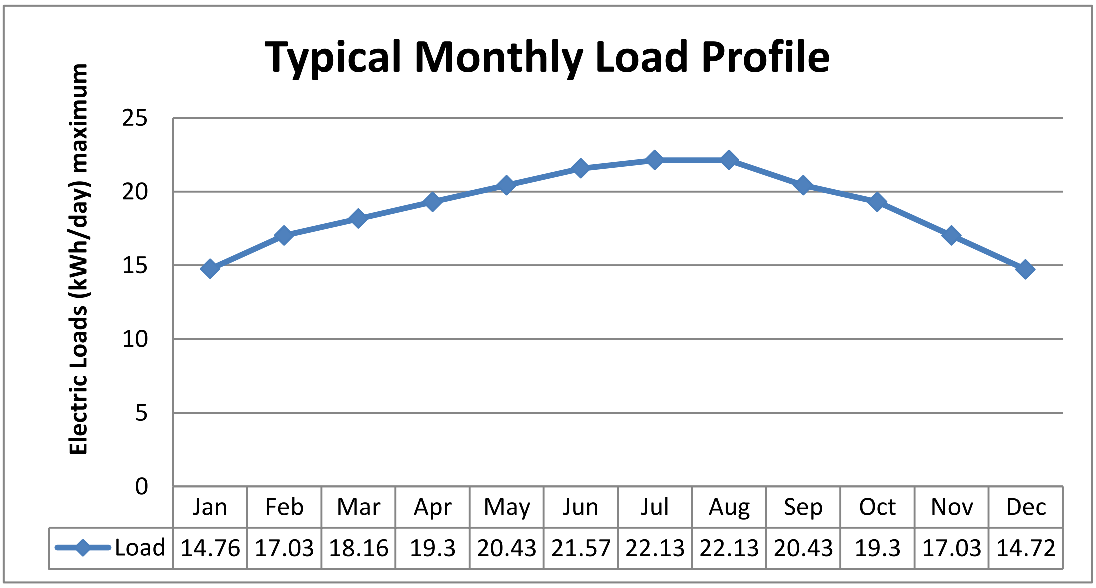


Figure D.4: Typical Monthly Load Profile Graph Manual Assumption.

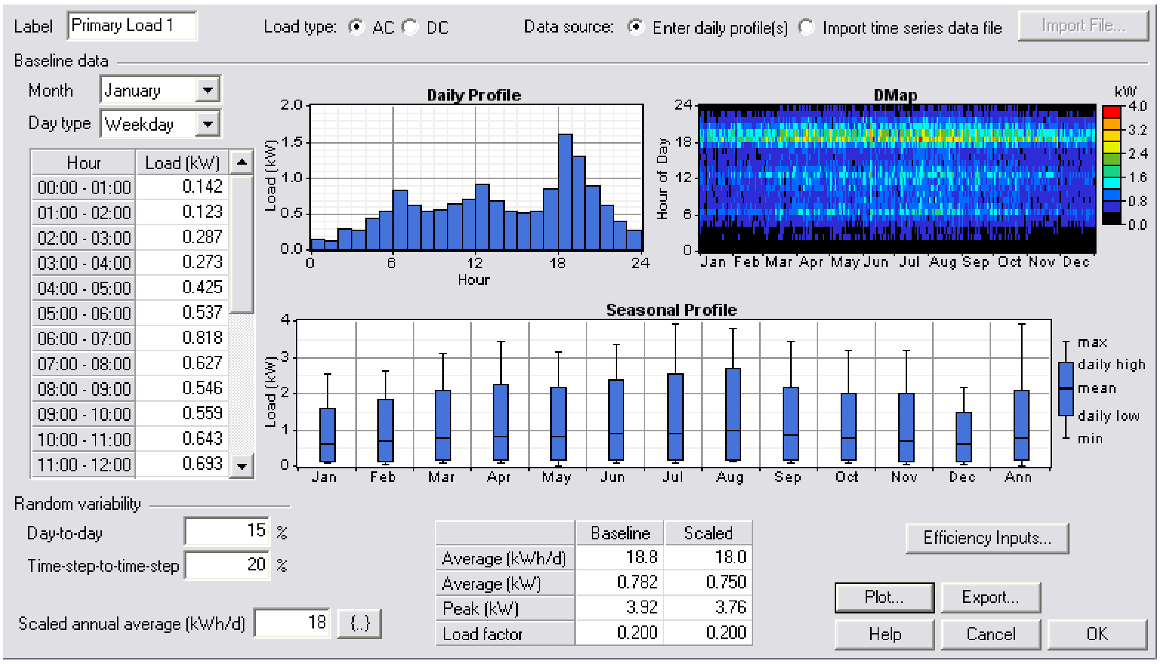


Figure D.5: Monthly Load Profile (HOMER, 2011).

APPENDIX E: ECONOMIC RESULTS AND DATASHEETS

The following are the results that are derived from the economic analysis based on the datasheets as per current market rates in UAE and Worldwide:

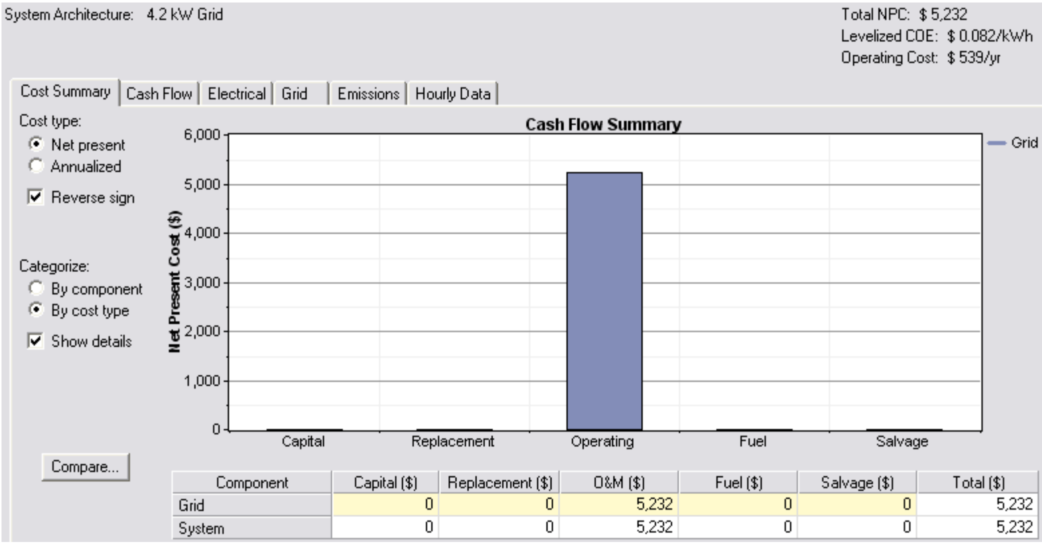


Figure E.1: Economic results, NPC for non renewable energy (4.2kW Local Grid Connection)

Table E.1: All 25% Renewable Energy-Grid Connected Economic Assessment Results

Type of REN.	Grid	PV	1KW WT	Battery	Conv	Initial Capital Cost	Initial Capital Cost	Operating Cost	Operating Cost	Total NPC	Total NPC	COE	COE
	kW	kW	No	No	kW	$	AED	$	AED	$	AED	$/kWh	AED/kWh
ALL 25% CASE CONFIGURATIONS-GRID CONNECTED													
PV	3.15	1	NA	1	1	3,325	12,213	409	1,502	7,293	26,787	0.114	0.419
WT	3.15	NA	1	1	1	3,300	12,121	536	1,969	8,506	31,243	0.133	0.489
HYPW	3.15	0.2	1	1	1	3,705	13,608	511	1,877	8,665	31,827	0.136	0.500
NA- NOT APPLICABLE, **NPC**-NET PRESENT COST, **COE**-COST OF ENERGY, **CONVERSION**: $1/-=AED3.673/-													
PV-PHOTOVOLTAIC, **WT**-WIND TURBINES, **HYPW**-HYBRID PHOTOVOLTAIC AND WIND TURBINE													

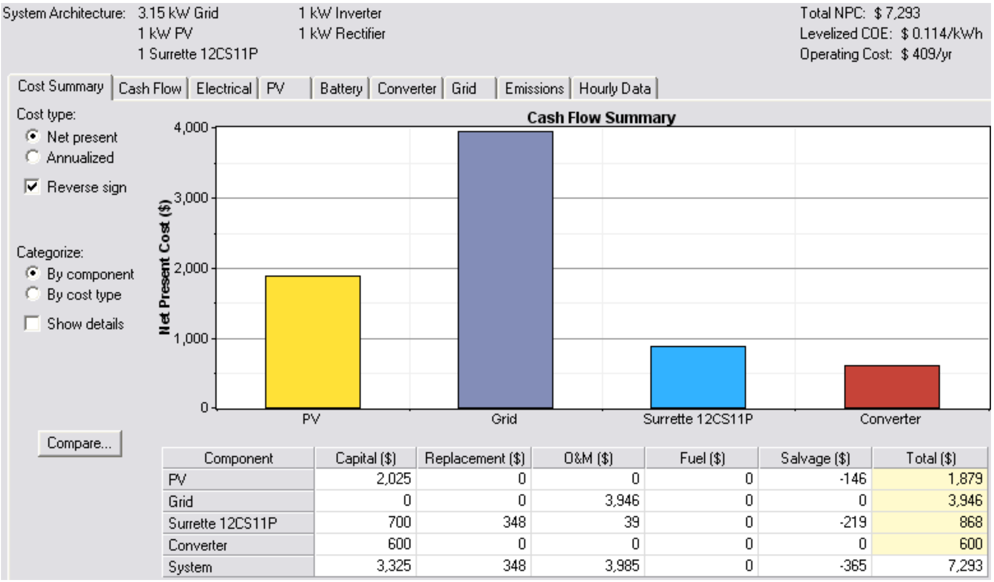


Figure E.2: Economic results, NPC for 3.15kW (73%) grid connection and 1kW (27%) PV power output.

Table E.2: All 50% Renewable Energy-Grid Connected Economic Assessment Results

Type of REN.	Grid	PV	1KW WT	Battery	Conv	Initial Capital Cost	Initial Capital Cost	Operating Cost	Operating Cost	Total NPC	Total NPC	COE	COE
	kW	kW	No	No	kW	$	AED	$	AED	$	AED	$/kWh	AED/kWh
ALL 50% CASE CONFIGURATIONS-GRID CONNECTED													
PV	1.8	2.4	NA	2	2	7,460	27,401	321	1,179	10,582	38,868	0.166	0.610
WT	1.8	NA	2	2	2	6,600	24,242	571	2,097	12,150	44,627	0.190	0.698
HYPW	1.8	1.4	1	2	2	7,435	27,309	402	1,477	11,342	41,659	0.178	0.654
NA- NOT APPLICABLE, **NPC**-NET PRESENT COST, **COE**-COST OF ENERGY, **CONVERSION**: $1/-=AED3.673/-													
PV-PHOTOVOLTAIC, **WT**-WIND TURBINES, **HYPW**-HYBRID PHOTOVOLTAIC AND WIND TURBINE													

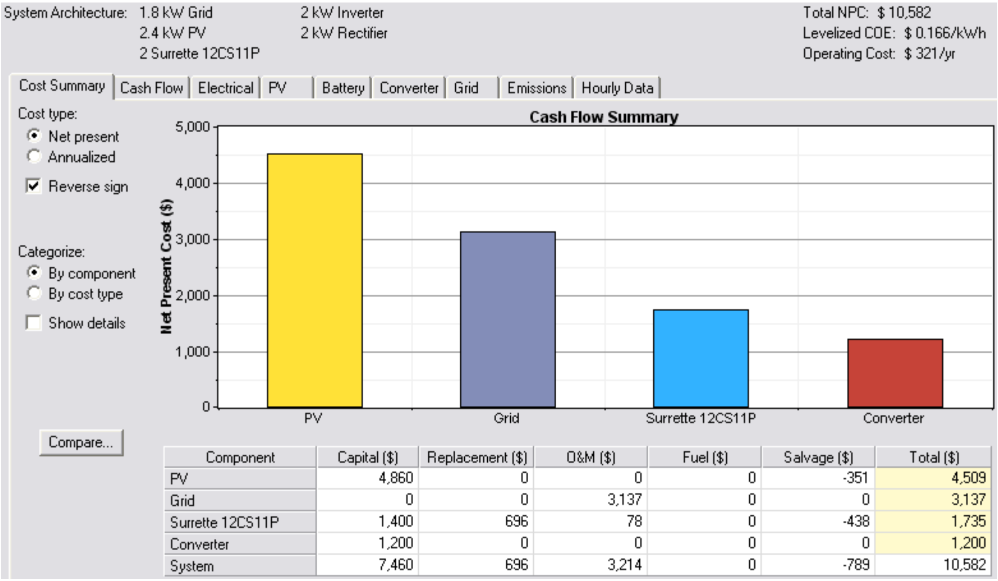


Figure E.3: Economic results, NPC for 1.8kW (50%) grid connection and 2.4kW (50%) PV power output.

Table E.3: All 75% Renewable Energy-Grid Connected Economic Assessment Results

Type of REN.	**Grid**	**PV**	**1KW WT**	**Battery**	**Conv**	**Initial Capital Cost**	**Initial Capital Cost**	**Operating Cost**	**Operating Cost**	**Total NPC**	**Total NPC**	**COE**	**COE**
	kW	kW	No	No	kW	$	AED	$	AED	$	AED	$/kWh	AED/kWh
ALL 75% CASE CONFIGURATIONS-GRID CONNECTED													
PV	0.8	5.4	NA	4	3	15,535	57,060	228	837	17,748	65,188	0.278	1.021
WT	1.05	NA	6	5	3	17,300	63,543	869	3,192	25,737	94,532	0.403	1.480
HYPW	0.8	4	1	4	3	14,700	53,993	306	1,124	17,677	64,928	0.277	1.017
NA- NOT APPLICABLE, **NPC**-NET PRESENT COST, **COE**-COST OF ENERGY, **CONVERSION**: $1/-=AED3.673/-													
PV-PHOTOVOLTAIC, **WT**-WIND TURBINES, **HYPW**-HYBRID PHOTOVOLTAIC AND WIND TURBINE													

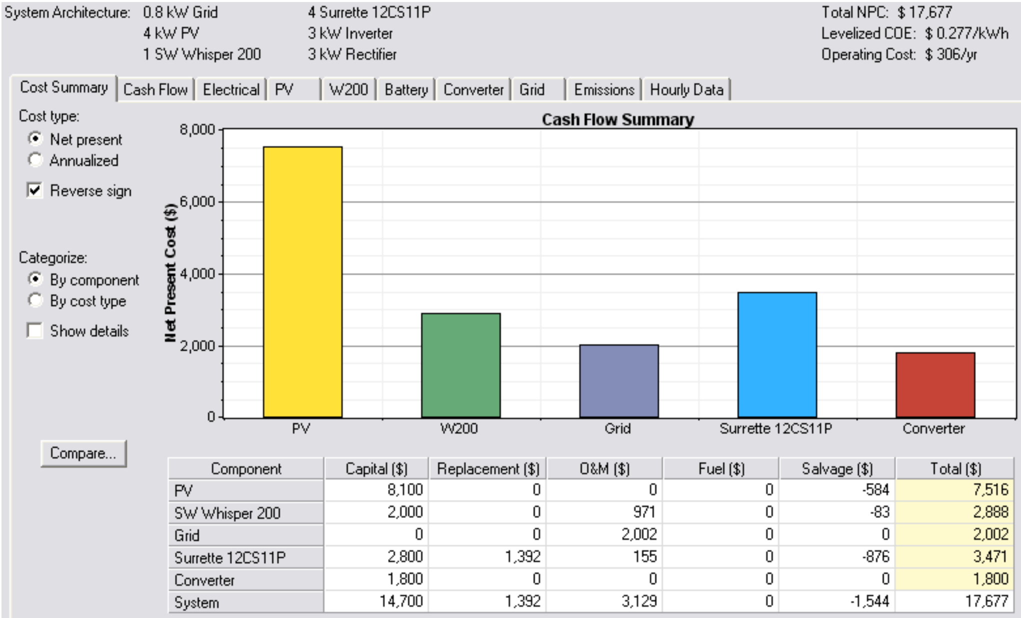


Figure E.4: Economic results, NPC for 0.8kW (23%) Grid connection and Total HYPW (77%) with 4.0kW PV and 1 number 1kW WT electrical power output.

Table E.4: All 100% Renewable Energy-Grid Connected Economic Assessment Results

Type of REN.	Grid	PV	1KW WT	Battery	Conv	Initial Capital Cost	Initial Capital Cost	Operating Cost	Operating Cost	Total NPC	Total NPC	COE	COE
	kW	kW	No	No	kW	$	AED	$	AED	$	AED	$/kWh	AED/kWh
ALL 100% CASE CONFIGURATIONS-GRID CONNECTED													
PV	0	7	NA	10	4	23,575	86,591	67	246	24,229	88,993	0.380	1.396
WT	0	NA	9	39	4	47,700	175,202	1,573	5,778	62,980	231,326	0.987	3.625
HYPW	0	5.2	1	10	4	21,930	80,549	186	683	23,735	87,179	0.372	1.366
NA- NOT APPLICABLE, **NPC**-NET PRESENT COST, **COE**-COST OF ENERGY, **CONVERSION**: $1/-=AED3.673/-													
PV-PHOTOVOLTAIC, **WT**-WIND TURBINES, **HYPW**-HYBRID PHOTOVOLTAIC AND WIND TURBINE													

Table E.5: All 100% Renewable Energy-Standalone Economic Assessment Results

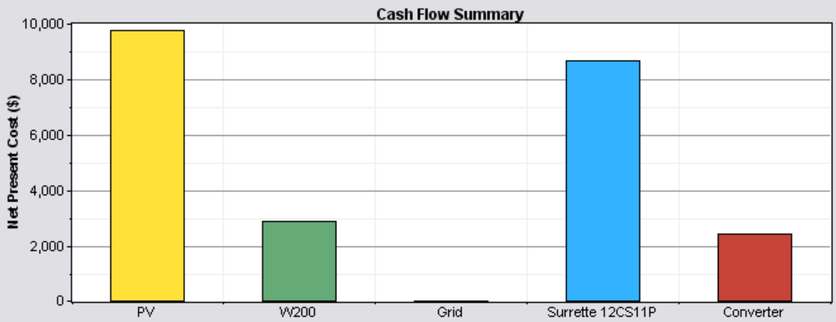
Type of REN.	Grid	PV	1KW WT	Battery	Conv	Initial Capital Cost	Initial Capital Cost	Operating Cost	Operating Cost	Total NPC	Total NPC	COE	COE
	kW	kW	No	No	kW	$	AED	$	AED	$	AED	$/kWh	AED/kWh
ALL 100% CASE CONFIGURATIONS-STANDALONE													
PV	NA	7	NA	10	4	23,575	86,591	67	246	24,229	88,993	0.380	1.396
WT	NA	NA	9	40	4	48,400	177,773	1,513	5,557	63,096	231,752	0.989	3.633
HYPW	NA	5.2	1	10	4	21,930	80,549	186	683	23,735	87,179	0.372	1.366
NA- NOT APPLICABLE, **NPC**-NET PRESENT COST, **COE**-COST OF ENERGY, **CONVERSION**: $1/-=AED3.673/-													
PV-PHOTOVOLTAIC, **WT**-WIND TURBINES, **HYPW**-HYBRID PHOTOVOLTAIC AND WIND TURBINE													

System Architecture: 0 kW Grid, 5.2 kW PV, 1 SW Whisper 200, 10 Surrette 12CS11P, 4 kW Inverter, 4 kW Rectifier

Total NPC: $ 23,735
Levelized COE: $ 0.372/kWh
Operating Cost: $ 186/yr

Cost Summary | Cash Flow | Electrical | PV | W200 | Battery | Converter | Grid | Emissions | Hourly Data

Cost type: Net present / Annualized; Reverse sign
Categorize: By component / By cost type; Show details
Compare...



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	10,530	0	0	0	-759	9,771
SW Whisper 200	2,000	0	971	0	-83	2,888
Grid	0	0	0	0	0	0
Surrette 12CS11P	7,000	3,479	388	0	-2,191	8,677
Converter	2,400	0	0	0	0	2,400
System	21,930	3,479	1,360	0	-3,034	23,735

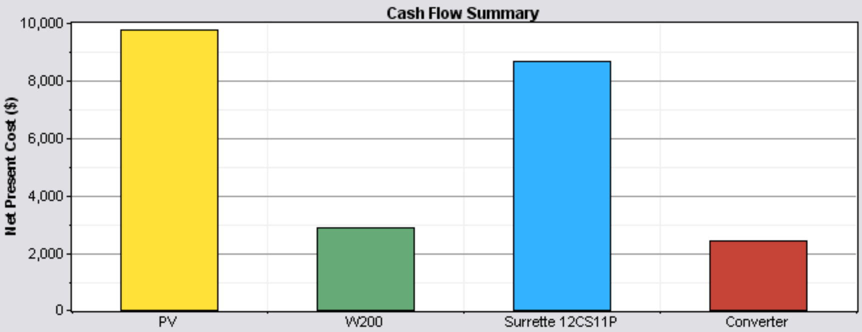
Figure E.5: Economic results, NPC for 0kW (0%) Grid connection and Total HYPW (100%) with 5.2kW PV and 1 number 1kW WT electrical power output.

System Architecture: 5.2 kW PV, 1 SW Whisper 200, 10 Surrette 12CS11P, 4 kW Inverter, 4 kW Rectifier

Total NPC: $ 23,735
Levelized COE: $ 0.372/kWh
Operating Cost: $ 186/yr

Cost Summary | Cash Flow | Electrical | PV | W200 | Battery | Converter | Emissions | Hourly Data

Cost type: Net present / Annualized; Reverse sign
Categorize: By component / By cost type; Show details
Compare...



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	10,530	0	0	0	-759	9,771
SW Whisper 200	2,000	0	971	0	-83	2,888
Surrette 12CS11P	7,000	3,479	388	0	-2,191	8,677
Converter	2,400	0	0	0	0	2,400
System	21,930	3,479	1,360	0	-3,034	23,735

Figure E.6: Economic results, NPC for Standalone HYPW (100%) with 5.2kW PV and 1 number 1kW WT electrical power output.

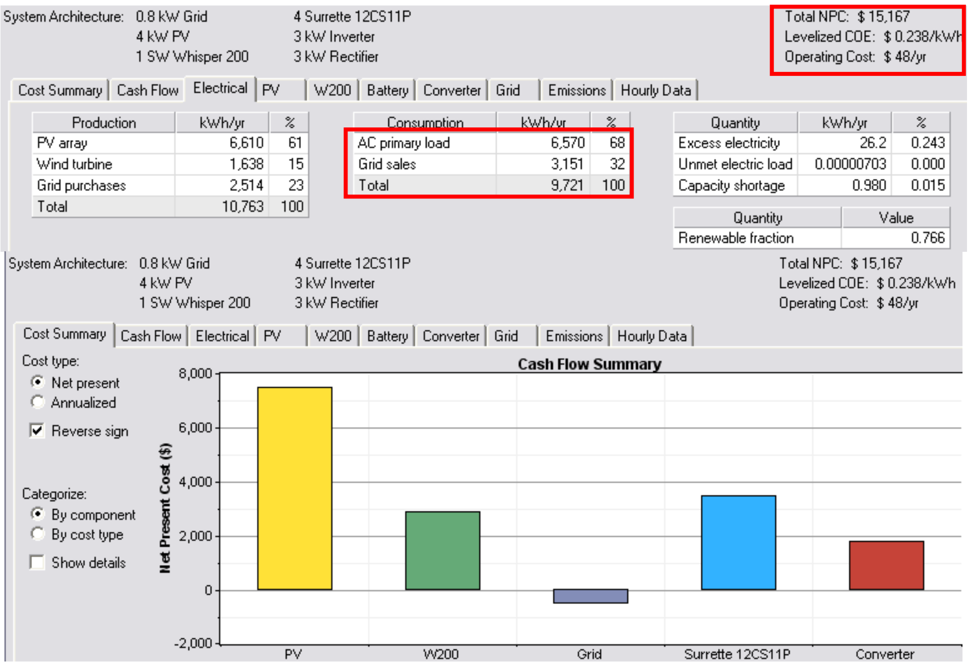


Figure E.7: Net Metering Economic Results for 75% HYPW- Grid Connected Case Configuration.

Table E.6: Economic Comparison with and without Net Metering (75% HYPW-Grid Connected)

HYPW 75% GRID CONNECTED WITH NET METERING										
Component	Capital ($)	Capital (AED)	Replace-ment ($)	Replace-ment (AED)	O&M ($)	O&M (AED)	Salvage ($)	Salvage (AED)	Total ($)	Total (AED)
PV	8,100	29,751	0	0.00	0	0.00	-584	-2145	7,516	27,606
WT	2,000	7,346	0	0.00	971	3,566.48	-83	-304.86	2,888	10,608
Grid	0	0	0	0.00	-507	-1,862.21	0	0	-507	-1,862
Battery	2,800	10,284	1,392	5,112.82	155	569.32	-876	-3217.5	3,471	12,749
Converter	1,800	6,611	0	0.00	0	0.00	0	0	1,800	6,611
System	14,700	53,993	1,392	5,112.82	619	2,273.59	-1,544	-5671.1	15,167	55,708
HYPW 75% GRID CONNECTED WITHOUT NET METERING										
Component	Capital ($)	Capital (AED)	Replace-ment ($)	Replace-ment (AED)	O&M ($)	O&M (AED)	Salvage ($)	Salvage (AED)	Total ($)	Total (AED)
PV	8,100	29,751	0	0	0	0.00	-584	-2145	7,516	27,606
WT	2,000	7,346	0	0	971	3,566.48	-83	-304.86	2,888	10,608
Grid	0	0	0	0	2,002	7,353.35	0	0	2,002	7,353
Battery	2,800	10,284	1,392	5112.816	155	569.32	-876	-3217.5	3,471	12,749
Converter	1,800	6,611	0	0	0	0.00	0	0	1,800	6,611
System	14,700	53,993	1,392	5112.816	3,129	11,492.82	-1,544	-5671.1	17,677	64,928
GRID SELL BACK RATE SAME AS PURCHASE=$0.082/kWh (AED 30FILS/kWh)										

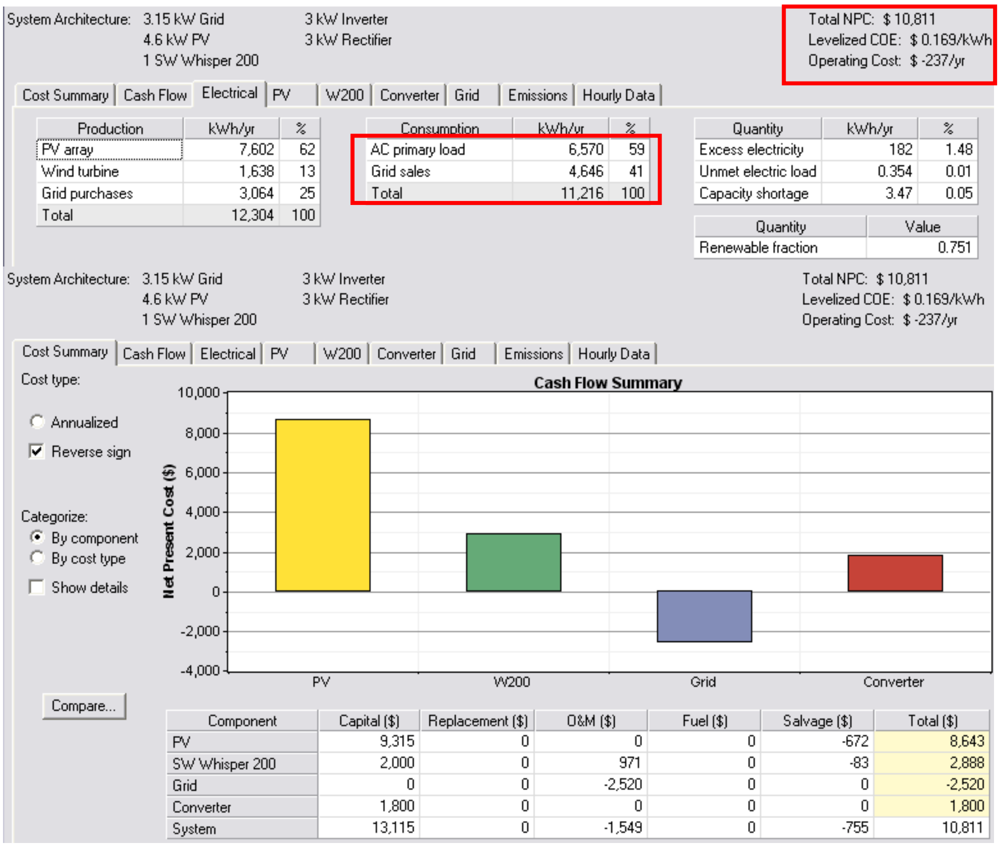


Figure E.8: Grid Sale 2 times the Grid Purchase Rate Economic Results for 75% HYPW- Grid Connected Case Configuration

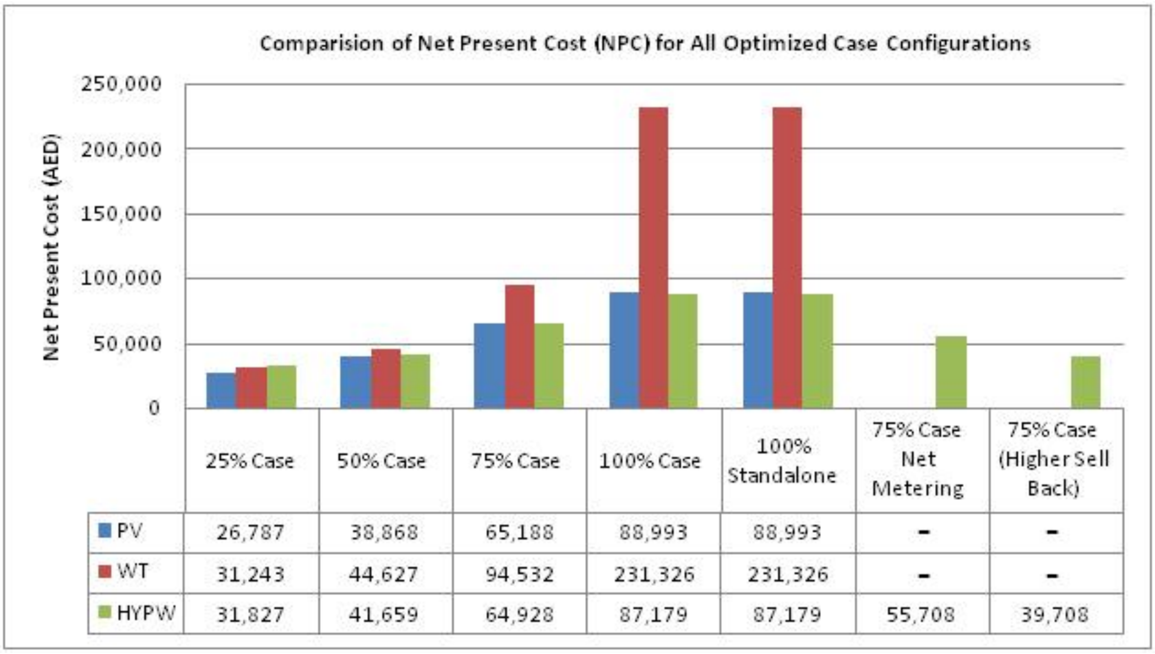


Figure E.9: Economic Summary for all Case Configuration

altE store
making renewable do-able

Friendly. Knowledgeable. Helpful.

Reason #4: More than a business,
Renewable Energy is our passion. »

MY ACCOUNT | LOG IN
877-878-4060

BUY | LEARN | INSTALL | SHARE

Search Products

0

SHOP PRODUCTS ALL Store / Solar Panels

SUNTECH STP225-20/WD 225W 20V SOLAR PANEL

$459.00 List price $713.00

1 +ADD

Currently In Stock: 8
Estimate Shipping

DETAILS | DOCUMENTS | REVIEWS

Item code	Model number	Volts	Watts	Cell Tech	Connector Type
SUC225-STP225CH	STP225-20/WD	20.00V	225.00W	Polycrystalline	Solarline 2 Locking

SunTech
Polycrystalline Silicon Solar Cells
STP225-20/Wd 225Watt

SUNTECH

Suntech's STP225-20/Wd solar panels are designed and built to deliver highest efficiency and reliable power for on-grid residential and commercial systems worldwide. Relying on Suntech's well-known stringent manufacturing standards and latest PV technology, these solar modules provide the highest possible energy output per Watt. Superior conversion rate and exceptional low-light performance enable it to deal with the most challenging conditions of military, utility, residential and commercial installations. This module is the perfect choice for those who demand outstanding performance and exceptional uniform appearance.

See the Product Documentation section above for more information.

Features

- High efficiency
- Nominal 20V DC for standard output
- Outstanding low-light performance
- High transparent low-iron, tempered glass
- Unique techniques give the panel following features: esthetic appearance, with stands high wind-pressure and snow load, and easy installation
- Unique technology ensure that problems of water freezing and warping do not occur
- 25 year transferable power output warranty
- Certifications: UL1703, IEC 61215, IEC 61730, conformity to CE
- ISO 9001: 2008 and ISO 14001: 2004 certified facilities

Built for long service life

- Cells embedded in EVA (ethylene vinyl acetate)
- Transmissive low-iron, tempered glass on the front
- Weather and waterproof film back
- High strength frame

Electrical Characteristics

Model	STP225 -20/Wd
Optimum Operating Voltage (Vmp)	29.6 V

Figure E.10: Quotation for Suntech Power PV Panels (AltE Store, 2011)

Whisper H80	WT 2500	AWP 3.6	Jake, Short Case
Southwest Windpower	Proven Engineering	African Windpower	Abundant Renewable Energy
78.5	96.7	109.0	154.0
10.0	11.1	11.8	14.0
7.0	6.0	6.0	6.0
26.0	26.0	25.0	18.0
1,000	2,500	1,000	2,400
1,000	2,900	950@24 V; 1,050@48 V	2,400 @ 48 V
120	145	100 Experienced	80 Operating; 100 furled
900	300	350	225
Injection molded plastic	Polypropylene	Fiberglass	Sitka spruce
13.4	4.6	5.5	5.0
PM 3 AC	PM 3 AC	PM 3 AC	DC
Angle governor	Hinged blades	Side facing	Blade pitch governor
26.0	26.0	25.0	23.5
Dynamic brake	Disc brake	Dynamic brake	Folding tail
65	440	250	500
250	1,124	250	750
12 to 48, or 220	24, 48, 120, or 240	12, 24, 48, or 220	24 to 48
Controller & dump load	Battery controller	Battery controller	
With batteries	With batteries	With batteries	With batteries
60	167*	75	240*
90	206*	105	300*
125	292*	130	340*
160	333*	168	410*
190	417*	192	460*
215	465*	226	500*
265	542* *Estimated by author	246	550* *Estimated by author
$1,995.00	$6,900.00	$2,214.00	$8,700.00
$25.41	$71.35	$20.31	$56.49
$30.69	$15.68	$8.86	$17.40
0.83	4.55	2.29	3.25
5	96	45	100
3	9	3	20
2	2	2	2
Annual inspection	Annual inspect & grease	Annual inspect & grease	Annual inspect & grease
HVLV available	Downwind	HVLV available	Includes stub tower

Figure E.11: Quotation for Wind Turbine, Whisper 200 alternatively known as Whisper H80 (Home Power, 2011)

Rolls 12V 357Ah Series 5000 Deep Cycle Dual Container Battery

Voltage: 12V
Capacity (c20): 357Ah
Dimensions (mm): 559 long x 286 wide x 464 high
Weight: 123.0 kgs
Terminal: 19

Part No: RB-12CS11P

Our Price: £697.00
VAT: £139.40
Total: £836.40

Qty: 1 Buy It
Seen it cheaper?

Technical Spec | Rolls | Ask About | QUICKCODE 606

Rolls Battery Recombination Caps £14.00
Rolls Battery Maintenance Kit £123.00

Additional Information
Specification
12 Volt
Series 5000
Flag Terminal Standard
New Generation
Dual Container
Non Breakable
Bolt-on Cells - Individual Cell Removal
Ten (10) Year Warranty

Figure E.12: Quotation for Rolls Surrette Battery (The Power Store, 2011)

Grid-Tie Systems
Off-Grid Systems

See Reviews

ONLY: $3,651.40

In Stock, Call 866.274.0642 for Availability

Item Number: XW6048

Efficiency: 0.894
Min Temp: -25
Pout: 6000
Pmax: 6000
Imax: 130
Vmin_mppt: 44
Vmax_mppt: 64
Vmax: 64
Freight Shipping Required

Quantity: 1 ADD TO CART

Find PVPower.com:
Solar Community
SolarMail Sign-Up
Connect on Twitter
On Facebook
YouTube Channel

Xantrex XW6048 Inverter, 6000W, Grid Tied, Battery Back-Up, 120V/240V

Xantrex brings the next generation of inverter/charger to market, with the XW Hybrid Inverter/Charger, the heart of the XW System. The XW Hybrid Inverter/Charger (XW) is a true sine wave, 120/240-volt AC, split-phase, inverter/charger that incorporates a DC to AC inverter, a battery charger, and an AC auto-transfer switch. It is the foundation for battery-based residential and commercial solar applications up to 18 kilowatts (kW). Capable of being grid-interactive or grid-independent, the XW can operate with generators and renewable energy sources to provide full-time or backup power.

Designed with consultation and input from industry experts, dealers, and installers, the XW sets a new standard for battery-based inverter/chargers. Integrating the best features available in the market, innovative new features by Xantrex and balance-of-systems components, the XW Hybrid Inverter/Chargers design makes installation quicker and easier. The XW offers high efficiency and unprecedented surge capacity to maximize the owners return on investment. No other inverter/charger looks or performs like the XW.

*This item may be shipped freight - please call 1-866.274.0642 for shipping quote, or place order and you will be contacted shortly with a shipping quote before you are charged.

Product Features:
Pure sine wave output
120/240 volt AC spilt-phase operation
Dual AC inputs

Live Help: Offline

Figure E.13: Quotation for Xantrex Inverter (PV Power, 2011)

GOVERNMENT OF DUBAI

هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

Customers Business Community eServices DEWA

Sunday, 14 August 2011 | 14 Ramadhan 1432

Search

Home ▸ Customers ▸ Tariff Details

- Login -
New User? Enroll Now
Forgot Your Password?

Quick Links
FAQ
Customer Guide
Online Bill Payment
Methods of Payment
Careers
Customer Service Location
Tariff Calculator
Tenders
Conservation Tips
Site Map
Featured Links
eComplain Procedure
Media Corner
Contact Us

WebMail EMPLOYEES ONLY

WEBSITE SURVEY

50 years of Excellence

Electricity and Water Tariff

In line with the decision of the Supreme Energy Council in Dubai to adjust the electricity and water tariff for all DEWA customers which is applied from 1st January 2011, a fuel surcharge is added for electricity & water consumption from this date.

Fuel surcharge in your monthly electricity & water bill will vary based on the rate of increase or decrease of the actual fuel cost supplied to DEWA generation plants.

Fuel Surcharge will be shown separately in your monthly bill and will be charged by Fils/kWh for electricity and Fils/IG for water.

The new tariff intended to promote efficient consumption of electricity and water at a time it is increasingly needed, equally in the conservation and preservation of our precious resources. To know more on our conservation programs, initiatives and related conservation tips, please visit our conservation Tips.

Electricity Tariff

Residential / Commercial

Consumption/ month		Slab tariff
G	0-2000 kWh	23 fils / kWh
Y	2001-4000 kWh	28 fils / kWh
O	4001-6000 kWh	32 fils / kWh
R	6001 kWh & Above	38 fils / kWh

Industrial

Consumption/ month		Slab tariff
G	0-10000 kWh	23 fils / kWh
Y	10001 kWh & Above	38 fils / kWh

Water Tariff

Residential

Consumption/ month		Slab tariff
G	0-6000 IG*	3.5 fils / IG*
Y	6001-12000 IG*	4.0 fils / IG*
O	12001 IG* & above	4.6 fils / IG*

Industrial & Commercial

Consumption/ month		Slab tariff
G	0-10000 IG*	3.5 fils / IG*
Y	10001-20000 IG*	4.0 fils / IG*
O	20001 IG* & above	4.6 fils / IG*

Fuel Surcharge - August 2011

	Tariff
Electricity	7.0 fils / kWh
Water	0.4 fils / IG*

*IG = Imperial Gallon

Tariff Calculator

Figure E.14: Electricity Tariff in Dubai, UAE (DEWA, 2011)