TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

PEER HAMOOD UR RAHMAN

ENERGY MANAGEMENT OF HIGH RISE BUILDING AS MICRO GRID

Master of Science Thesis

Examiner: prof. Pertti Järventausta
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ABSTRACT

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Increase of power demand and greenhouse gas emission from nonrenewable energy resources change the direction to use of renewable energy resources as micro grids. The solar and wind energy is free, infinite, and environment friendly. Due to the uncertain nature of renewable energy resources i.e. solar energy and wind energy, a system cannot depend entirely on single renewable energy resource. Therefore, a hybrid power system, with two or more renewable resources of energies is a better choice for isolated loads.

In this thesis, feasibility of hybrid power system consisted of solar panel and wind turbine energy storages and biogas generator is studied for a virtual high-rise building. Two cases were studied in this thesis work i.e. case Tampere, Finland and case Colorado, United States of America. Solar irradiance and wind speed measurements are collected for year 2016 from these two places and then energy generation is calculated and compared with electrical load required by a virtual high-rise building. Each case is divided into three subcases and one year is divided into three quarters (i.e. January to April, May to August and September to December). Hybrid power systems based on renewable energy sources can be effective option to provide continuous energy supply to electrical loads in a high-rise building. In addition, an application is developed to calculate the payback time of the hybrid power system.

Hybrid power system is based on renewable energy resources and so its CO_2 generation is also less than nonrenewable energy resources. As the duration of daytime and wind speed is different around the globe, there is difference in the behavior of hybrid power system in both case studies. The hybrid power system provides a very feasible solution for energy demands of high-rise building. Solar and wind energy has become the least expensive renewable energy technologies and requires one-time investment and need less maintenance cost in existence and has attract the interest of scientists and educators the world over. Based on the results of case study, hybrid system is more feasible when compared to the installation of single renewable energy resource in case Colorado and in case Tampere, hybrid system is more effective in second quarter of the year (i.e. May to August).

PREFACE

I have done my thesis to complete my Master's Degree in Electrical Engineering in Tampere university of Technology in year 2017.

I most venerably acknowledge the invaluable guidance of my respected supervisor Professor Pertti Järventausta. His help and guidance has flourished my knowledge and give me guidance to reach the goals of my thesis.

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I am also heartily obliged and thankful to my most beloved mother for bestowing spiritual and moral heed on me imbued with kindness. Her selfless, loving and painstaking personality is really source of inspiration for me. Last but not the least, I would like to thank my family ,siblings and friends for their brilliant moral support that served as an energizer to achieve my goal.

Tampere, 17.10.2017

Peer Hamood Ur Rahman

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

A	Area
B(t)	Battery state of charge at time ‘t’
B_{min}	Minimum battery charge
B_{max}	Maximum battery charge
CO_2	Carbon dioxide
D	De-rating factor
I_{rrec}	Irradiance received
I_{stc}	Irradiance at standard conditions
L(t)	Electrical load at time ‘t’
m/s	Meter per second
n	Number of turbines
$P(t)_{S.gen}$	Power generated from solar panels at time ‘t’
$P(t)_{W.gen}$	Power generated from wind turbines at time ‘t’
P_{cap}	Capacity of solar panels
$P(t)_{req}$	Total power required at time ‘t’
ρ	Air density
V(t)	Speed of wind at time ‘t’
€	Euro
$	Dollar

AC	Alternate current
DC	Direct current
DMS	Distribution management system
GHG	Greenhouse gas emissions
GUI	Graphical user interface
HAWT	Horizontal axis wind turbine
kWh	Kilo watt-hour
MWh	Mega watt-hour
MDMS	Meter data management system
PV	Photovoltaic
QMS	Quality monitoring system
SCADA	Supervisory control data acquisition system
VAWT	Vertical axis wind turbine
TUT	Tampere University of Technology

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1. INTRODUCTION

World is changing its approach from large power generation plants to micro power generation units. Buildings are the integral part of energy infrastructure and they consume 40 % of the total energy (Economidou *et al.*, 2011). In order to achieve the targets of Paris agreement (Economist, 2015) and to reduce the carbon emission, integration of renewable energy resources in high-rise buildings for self-generation is one of the initial steps. The journey towards self-powered high-rise buildings is in its initial stage and it need more research on its feasibility. The most feasible energy resources that can be installed in high-rise building are solar power, wind power and biogas. However, the issue is that renewable energy resources like solar and wind power are uncertain and cannot provide energy for every hour in a day. Weather conditions are different all over the world and one cannot rely on single source for power generation for whole year.

This thesis discusses the feasibility of renewable energy resources that includes solar, wind, and biogas energy and batteries. Focus is on energy generation depending on real time weather condition and calculations and three different seasons are discussed. The amount of revenue that could be saved by installing renewable energy resources is also calculated for three cases.

Basic theory of solar panels, wind turbines energy storages and gas turbines is important to discuss to get initial idea. In chapter 2, an introduction to smart grid and renewable energy resources used in this thesis are discussed. In chapter 3, previous case studies and an overview of the work that been already done about the integration of renewable energy resources in high-rise buildings are discussed. In chapter 4, feasibility of installation of renewable energy resources is discussed in two cases, i.e. case Tampere in Finland and case Colorado in United States of America. These cases are discussed for each renewable energy resource. For both case countries, three different subcases are discussed, i.e. January, June and October and possible energy output from solar panels and wind turbines on case days are calculated and discussed. Statistical analysis for each case is discussed. In chapter 5, a self-switching hybrid power system is proposed that will switch between resources based on their availability. Chapter 6 is the conclusion of this thesis in which general overview of the focused topics and future of hybrid system is given. Future research topics are also discussed.

2. SMART GRID

Smart grid is a new and intelligent technology that is capable to manage the power generation, transmission, distribution and demand, and capable of information exchange using smart metering and other intelligent devices. Smart grid increases the reliability, efficiency and makes it easier for the small generators to be part of the whole power system. It uses a comprehensive computer based systems that monitors and operate the whole power system from the generation to the end customer. In conventional power grid system in the past, it was difficult to integrate renewable power generation resources and it required more investments. Smart grid makes it easier to integrate the renewables with low cost and minimize effects of the network fault and errors. It gives more secure and safe power network system and it can deal with the challenges of increasing demand of electricity. Demand response can be accomplished with smart grid. Demand response is the sifting of load from peak hours to the hours that have low power demand. Data management with smart grid is easier for example to check the balance between production and consumption at any time. Smart metering provides a two-way highly advance communication with smart grid and provides information about the power consumption, demand, power quality and power outages. Faults in power network is easier to detect while using smart grid. These faults can be detected and seen on supervisory control data acquisition system (SCADA) or by other graphical user interference systems (GUI) which also provide instant trouble shooting and security to the network by continuous monitoring. With smart grid distribution management system (DMS), meter data management system (MDMS), Quality Monitoring system (QMS), measurement database and network data base can be connected to give more reliable monitoring system including the generation data of renewable energy resources integrated with power grid system (Knuuti, 2013; Pasonen and Hoang, 2014; Momeneh *et al.*, 2016).

2.1 Micro grid

A micro grid is a part of smart grid and can be defined as a technology system that can integrate distributed generators, energy storages and controllable load, capable to operate with main power grid in normal conditions, and operate in island mode if needed. Islanding can be defined as in case of fault in supplying network, when the micro grid start operating by its own and block the network where fault occurs. Micro grid defers from the traditional grid in terms of reliability, self-adequacy and self-healing. Micro grid is a low or medium voltage power system and it helps to decrease the outage time during the fault in network. Energy storage devices are integrated with micro grid to provide power when needed. Micro grid can utilize many power sources individually or simultaneously. Mostly renewable energy resources are used to integrate in micro grids like solar and wind. Gas power generators or diesel generators can also be used with micro grids. While in islanding mode, a micro grid is utilizing many sources in the same time to give more efficient power system and to give high power quality. Micro grid also reduces electricity cost of the building or any place where it is installed by getting low or zero supply from the main grid and producing its own power (Knuuti, 2013; Pasonen and Hoang, 2014; Momeneh *et al.*, 2016).

2.2 Renewable energy resources

The demand of renewable energy resources is growing with time and many countries are moving forward with installation of renewable energy resources. The growing price of nonrenewable energy resources like oil and fossil fuels and the continuous emission of carbon dioxide CO_2 are the reason behind the adoption of renewable energy resources. These resources include solar, wind, hydro, and geothermal energy. These energy resources have very low or completely zero greenhouse gas emissions (GHG) and they are available freely in nature. These resources need only installation cost, and then weekly or monthly maintenance cost is needed (Knuuti, 2013; Pasonen and Hoang, 2014; Momeneh *et al.*, 2016).

2.3 Solar power

Sun is a huge and powerful source of energy in all energy sources. Sun has a radiation power of 300 million terawatt (Kuronen, 2008). One square meter of earth surface receives 14,368 watts of power. Sun gives so much of energy in one hour to earth that is equal to the amount of energy used in whole year in the whole world. This solar energy can be used for example for houses and high-rise buildings for power.

Solar radiations are converted into electricity using photovoltaic cell. Power from solar energy can be used for all kinds of electricity loads. A solar power generating building can also act as a micro grid by generating its own power for the building. Solar panels can be installed in a building more easily than any other energy generating system. One can install them on roof, on windows or on side outer wall.

In Finland, although there is dark time for almost 6 months, we can utilize solar energy in summer time when we have sun for almost 18 hours. In other countries like United Kingdom and United states, we can use solar energy almost for 8 to 9 months. In Africa, it can be used for whole year with great efficiency and reliability. In addition, Middle East is same case as Africa.

Today, there are many different types of PVs available in market having different efficiencies. The most efficient PVs has the efficiency of 35-40% (Kuronen, 2008). For residential use, PV with 20% efficiency is worthy and it is more suitable for cost return.

Solar technologies are either active or passive. Active techniques use typical technical installation of components that includes solar panels, pumps and fans to convert solar energy into electrical energy. This scenario is more productive and effective for places with low shadow effects and hence for high-rise buildings it is more productive. Output production from active technique depends on the efficiency of the panels i.e. more efficiency means less number of PV panels in array and vice versa (Ali and Armstrong.J, 2007). Passive technologies include selecting materials with favorable thermal properties and referencing the position of a building to the sun. The main idea is to use the solar energy directly and to trap and store solar energy within the building by considering the whole architecture and design of the building according to sun direction and path (El, 2010; Pasonen and Hoang, 2014).

2.3.1 Solar panel

A solar panel consists of large number of solar cells interconnected with each other. The solar panel can be used to generate enough large voltage, which can be used for commercial purposes and for use in residential. With the fluctuating nature of solar irradiance, solar cells produce a fluctuating direct current (DC) output which are further converted to alternating current (AC) using inverters (Markvart, 2000). Substantial number of solar cells are interconnected inside the modules. Arrays are formed when modules are wired together, and then connected to inverter to produces power with the desired voltage and frequency. At midday, when solar panel receive maximum irradiance, output is at maximum point. There are many problems related to solar energy, e.g., smoothing, uncertainty, fluctuation and different ways are used to overcome these problems.

Figure 2-1 *Typical solar panel tilted towards sun*

2.4 Wind energy

Wind is also a renewable energy source. Wind energy convert kinetic energy into mechanical energy by rotating the wind turbine and then this mechanical energy is converted to electrical energy. At the suitable position where there is sufficient amount of wind, we can get sufficient amount of energy. We can drive maximum of 59% of power from wind on theoretically (Ragheb and M.Ragheb, 2011). While in practice, a wind turbine can convert 30-35% of wind energy into electrical energy (Lofthouse, Simmons and Yonk, 2014). In the generation of electricity from wind, we need to take care of the position of direction of wind, speed of wind, and the geographical position where we can get maximum speed of wind most of the time (Smith and Killa, 2007). Generally, large wind farms are developed at coast side and on hills to get maximum power. Some houses that are on hills can also use single wind turbine for power generation (Smith and Killa, 2007; Osama Helmy and Abu Hijleh, 2009; El, 2010).

2.4.1 Wind turbines

A wind turbine is a rotating machine which converts the wind kinetic energy into mechanical energy. If the mechanical energy is then converted to electricity, the machine is called a wind generator, wind turbine.

Wind turbines can be separated into two types based by the axis in which the turbine rotates as Horizontal Axis Wind Turbines and Vertical Axis Wind Turbines . Wind energy is converted into mechanical energy using rotors, nacelle, generator, gear shaft etc. To get higher wind speed, height of the tower is increased to get maximum output from the wind turbines.

2.4.2 Horizontal axis wind turbine (HAWT)

The axis of rotation of horizontal-axis wind turbines (HAWT) is horizantal as indicated by their name. In HAWT, electrical generartor and main rotor shaf are at the top of the tower. A gear system is connected in HAWT to control the variable wind speed which is connected with the rotor and generator. To get constant frequency, the gear system enables the wind turbine to rotat with desire speed. Downwind machines have also been built, as they no longer require a yaw mechanism to keep them facing the wind, and also because in high winds the blades can turn out of the wind thereby increasing drag and coming to a stop. As downwind systems may cause regular turbulence most of the HAWTs' are upwind to avoid fatigue. Typical construction of a wind turbine is given below in the figure 2-1 in which different parts of the wind turbines are mentioned (Mahagaonkar, Chavan and M.Tamboli, 2014; Meshram *et al.*, 2015).

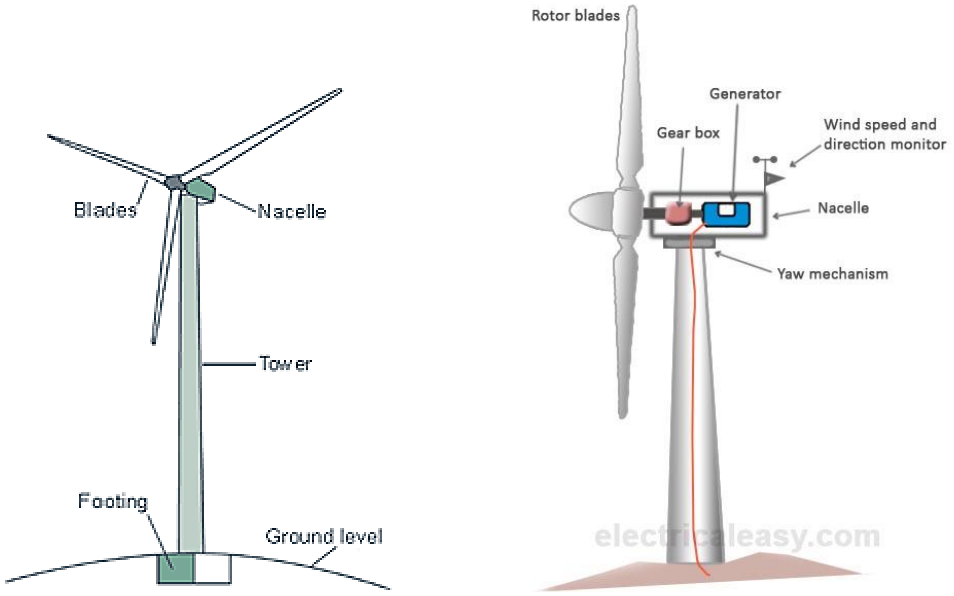

Figure 2-1 *Horizantal axis wind turbine and its components*

2.4.3 Vertical axis wind turbines (VAWT)

Vertical axis wind turbine (VAWT) are more practical in high-rise buildings in urban areas. They occupy less space than horizontal axis wind turbines (HAWT) and can be installed near the floor or ground. Georges Jean Darrieus designed first VAWT in 1931. VAWT has the ability to utilize wind energy coming from any direction. It is not necessary for VAWT to face the direction of flow of wind. VAWTs need average wind speed from 2 to 3 m/s for starting generation. They do not require any yaw mechanism and have low shaft, which makes their maintenance more easy then HAWT. There are two types of VAWT, Savonius and Darrieus wind turbines. Savonious is a self-start wind turbine with high torque and low efficiency while Darrieus need external power to get started and have high efficiency. VAWT can be installed in buildings with four different scenarios,

1. close to the building
2. on the roof
3. between the buildings or
4. inserted in air conducts through buildings

Different types of VAWT are given in following figure 2-2 (Mahagaonkar, Chavan and M.Tamboli, 2014; Meshram *et al.*, 2015; Casini, 2016).

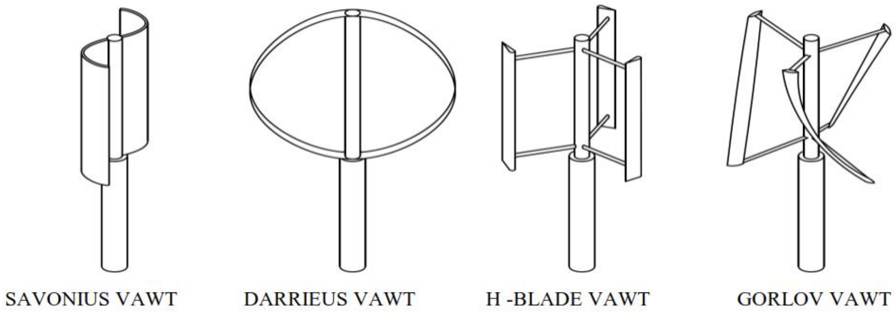

Figure 2-2 *Different types of vertical axis wind turbine (VAWT)*

2.5 Bio Gas Based Power Generation System

Biogas is a renewable energy resource and it is produced from waste materials that includes agriculture waste, food, municipal waste, plastic bags and other organic waste materials. The use of biogas also allow us to rely less on nonrenewable resources. On one hand, the production of biogas need waste materials from society and municipality and hence it helps in maintaining a clean environment and a sustainable waste management. Amount of GHG emission is also reduced by producing biogas from waste materials. Biogas can be produced by decomposition of organic waste materials in absence of oxygen and by burning the waste materials (Teodorita Al Seadi, Dominik Rutz, Heinz Prassl, Michael Köttner, Tobias Finsterwalder, Silke Volk, 2008).

A gas generator is used to produce electric energy from biogas. There are many types of gas generators depending on their sizes, which varies from 1 kW to 300 MW. Gas turbines can be used in industrial and residential sectors as they provide handsome amount of energy with relative low CO_2 emission. It is also possible to use the high temperature exhaust for heating purposes in winter season. Gas turbines has high reliability and efficiency when used with full load. Main components of simple cycle gas turbine is given in figure 2-4 below (States Department of Energy, 2016). Two main products can be generated from the gas turbines as shown in the figure 2-3, heat from exhaust and electricity from the generator. They can be easily controlled and can be used for daily use in a building or in any industry. These generators are also called combine heat and power generators as they produce both in same time.

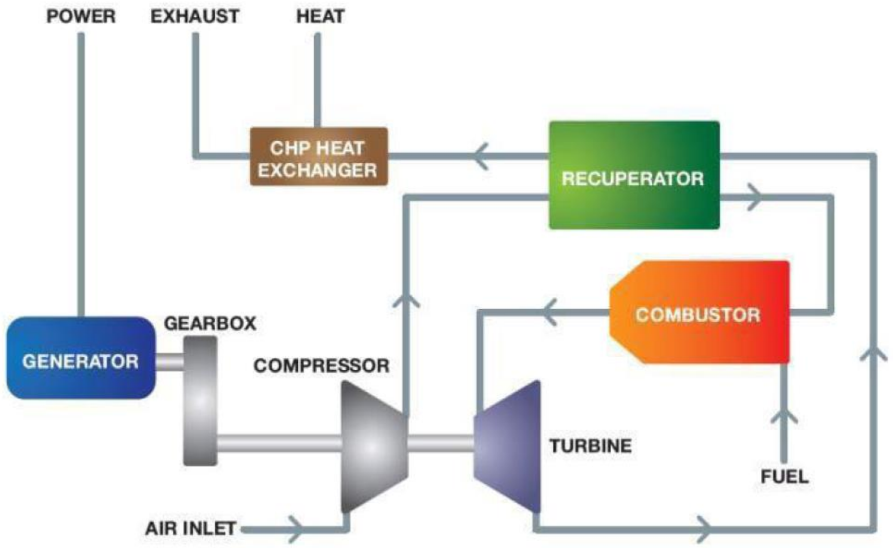

Figure 2-3 *Gas generator flow diagram*

2.6 Energy Storages

Energy storages are used to store energy for later use, e.g. to use it at maximum load time. For the integration of renewable energy resources, energy storage is very important to get a smooth output as renewable energy resources like solar and wind energy gives variable outputs depending on availability of solar radiation and wind. Energy can be stored using batteries, flywheels, compressed air storages, thermal storages. In buildings, the more practical approach will be batteries. Batteries can be divided into following categories that are different from each other based on technology (Battke *et al.*, 2013; Leinonen, 2016).

- Lead acid batteries
- Super capacitor batteries
- Lithium-ion batteries
- Nickel-cadmium batteries
- Sodium sulfur batteries
- Flow batteries

A centralized energy storage system can be used for back up and to provide power in different faults and peak hours. A centralized storage system is connected to grid system. Energy storages has the ability to provide backup from some seconds to many hours. They also control the frequency and maintain voltage quality. They also have the ability to fill the gaps in power generation from renewable energy resources as wind power and solar power when there is low wind or less solar radiation. In case of fault and islanding energy storages are the one that can help in black start in which all the generators are first shut down and then started while using battery powers. In Finnish grid system, if the frequency is less than 49.9 Hz, the energy storages will start discharging if they are used for frequency control. It means that production is less then consumption and so storage system will provide rest of power needed at that time. On the other hand, if the frequency is higher than 50.1 Hz, which means that production is higher than consumption, the energy storages will start charging. This scenario can be easily applied while using renewables energy resources like wind and solar. Storage system also save transmission costs and costs during blackouts. While providing uninterrupted power to the important places for example hospitals and servers during outages, energy storages attracts importance and attention from grid designers (Battke *et al.*, 2013; Leinonen, 2016). A practical application of energy storage integrated with wind power system installed in Sweden is shown in figure 2-4.

Figure 2-4 *Energy storages (batteries) installed with wind turbines in Sweden*

3. EXAMPLES ON INTEGRATION OF RENEWABLES TO HIGH RISE BUILDING

There are many high-rise buildings where renewable energy resources are installed. Mostly only one energy source is installed, either wind or solar panels. In new buildings, constructors have now started installing solar panels along with wind turbines. Few cases are discussed below to give an overview about the integration of renewable energy resources in high-rise buildings.

3.1 Feasibility study of PV installed in New York

A case was studied in New York (Kayal, 2009) about the feasibility of PV panels in the building of 20 floors in 2009. Area of the building was 900 m^2 and located in New York. Project lifetime was calculated to be 25 years with inverter life time of 15 years. PV panels were installed on every available facade of the building and on the roof. Two types of PV panels were used, single crystalline PV panel with efficiency 12 % and energy capacity of 40 W per module and Thin film PV panels with efficiency 8 % with capacity of 130 W per module. PV panels on façade area were installed vertically while on roof they were tilted for an angle of 41 degrees. The angle of tilt was decided on the basis of maximum radiation value of PV panel throughout the day. Distance between adjacent buildings were assumed to be 10 m, 30 m and 40 m. Price of electricity in New York for off peak time was 0.09 dollars per kWh and for on peak time 0.12 dollars per kWh. Connectivity cost and demand charges were 75 dollars and 10 dollars per kW per month. Energy consumption without PV panels was 15.1 MWh in one day. Observation and calculations were made for both summer and winter season. On typical clear summer day, crystalline PV panels generated about 2267 kWh and thin film PV panels generated about 669 kWh of energy annually. With combination of both generations, energy cost was reduced by 82615 dollars per year, which was 17 % of the total electricity cost per year. Similarly on a typical cloudy day of winter the combine generation from both type of PV panels was 1228 kWh, which reduced the cost of energy by 3110 dollars (Kayal, 2009).

3.2 Crystal Palace Slovenia

Crystal palace in Slovenia is an example of standalone high-rise building. Solar panels were installed on every available façade of the 90 m high building. In this building both passive and active techniques of solar energy is used to lower the power consumption of the building and make solar panels sufficient to fulfil the demand of the building. Solar panels produce averagely 100 kWh/h of power at mid day. The actual picture of the building with installed solar panel on every available façade is given below in figure 3-1. Solar panels are also installed on the roof of the building.

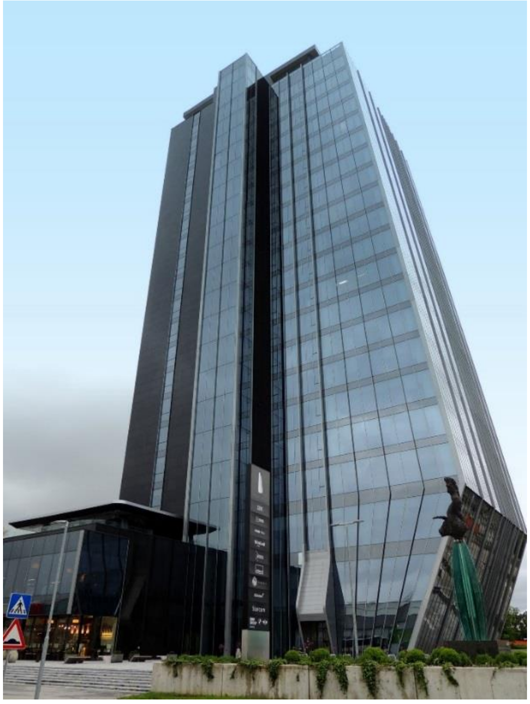

Figure 3-1 *PV panels installed in Crystal palace located in Slovenia*

3.3 Bahrain world trade center

Bahrain world trade center located in Bahrain was the first high rise building that use horizontal axis wind turbine at the height of maximum 136 m from ground surface. This building is 240 m high. Total number of floors in this building is 50 and the whole project was completed in 2008. Three wind turbines were installed at height of 60 m, 98 m and 136 m respectively. Wind turbine faces north against the direction of wind and get maximum wind stream due to the special S structure of the building, which stream every wind towards the turbine which strikes the building at an angle of 40 degrees. Three turbines produces energy of 340-400 MWh, 360-430 MWh and 400-470 MWh per year respectively. The combination of energy yield from each turbine contribute 11-15 % of the total power consumption of the building. The actual picture of the building with three installed horizontal axis wind turbines is given in figure 3-2. The structure of the building is designed as according to sustainable principles to utilize more wind energy for the production of power (Smith and Killa, 2007; Osama Helmy and Abu Hijleh, 2009; El, 2010).

Figure 3-2 *Horizontal axis wind turbines installed between two buildings of world trade center located in Bahrain*

3.4 The Pearl River tower

The Pearl River tower is located in Guangdong Sheng, China. This building is 309.7 m high with total 71 floors. This building is said to be the net zero energy building. The building uses wind energy, solar energy and fuel cells for its energy use. The shape of the building is completely based on aerodynamic principles and there are small openings on different points of the building where vertical axis wind turbines were installed. Active and passive approach of solar energy makes it possible for this building to use solar energy more efficiently. The annual reduction from main supply is 58% as shown in figure 3-3.

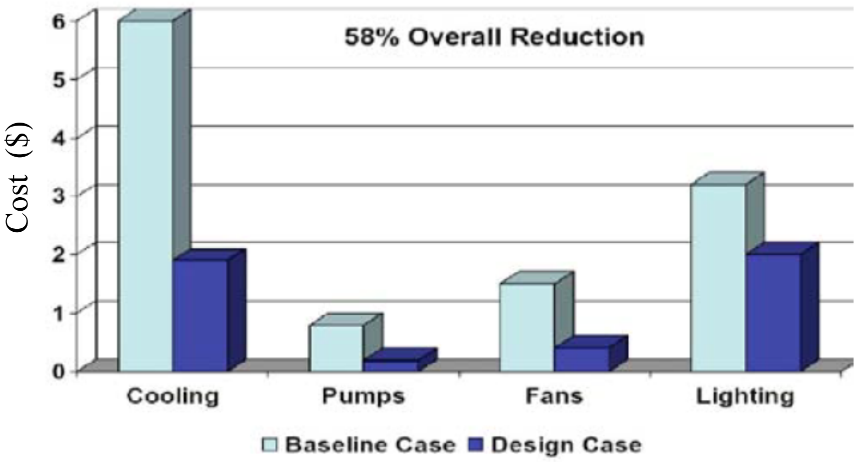

Figure 3-3 *Graphical representation of reduction in energy consumption with installation of renewable energy resources*

The actual design of the building with installed solar panels and wind turbines is given below. Fuel cells were installed in the basement of the building. The movement of wind through the building can also be seen from the figure 3-4 (Frechette *et al.*, 2008; El, 2010).

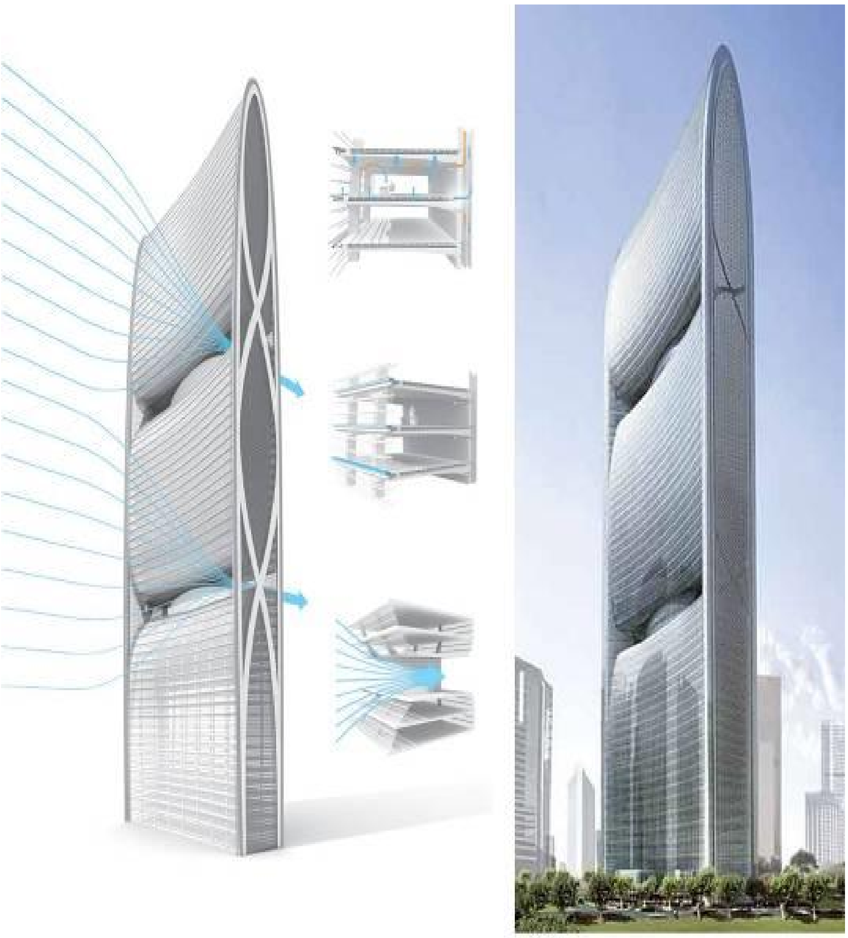

Figure 3-4 *Wind turbine location and flow of wind through turbines*

4. INSTALLATION OF RENEWABLES AND ENERGY MANAGEMENT OF HIGH-RISE BUILDING

In this thesis, the feasibility of installation of renewable energy resources is studied by two cases, i.e. case Tampere in Finland and case Colorado in United States of America using actual real time measurements. For case Tampere, measurements have been collected from sensors installed in Tampere University of Technology (TUT) in Tampere, Finland. In TUT's solar power research plant, 69 polycrystalline PV modules were installed on roof top facing south with a titled angle of 30 degree. Peak power of PV plant is 13.1 kWp. In this solar power research plant, different sensors were installed to measure the weather parameters, i.e. CMP22 pyrometer measure global irradiance on the horizontal plane, CMP21 pyrometer measure diffused radiation on horizontal plane, HMP155 measures ambient temperature and humidity, and WS425 sensor measures wind speed and direction. This plant is used for research work e.g. for thermal behavior of solar panels, smoothing of PV output and other research topics (Mäki and Valkealahti, 2011; Torres Lobera *et al.*, 2013; Lappalainen and Valkealahti, 2016).

For case Colorado, measurements were collected by Solar Radiation Research laboratory (SSRL) located in Colorado, working under National Renewable Energy laboratory (NERL). SSRL is a government owned laboratory used for research and development in renewable energy resources.

A virtual high-rise building of 100 meters high, i.e. equal to 328.084 ft. is considered for this thesis. Total floor area was calculated as 40 * 40 m and façade area is 4480 m^2. For this thesis, electrical load consumption of a virtual high-rise building is calculated by using real electrical consumption data of a Finnish block of flats having 20 apartments as a reference. Electrical load consumption is measured for one complete year and based on that real measured data, estimated electrical load consumption is calculated for virtual high-rise building. Load of the building is calculated for each hour and curves for January, June and October is given in figure 4-1.

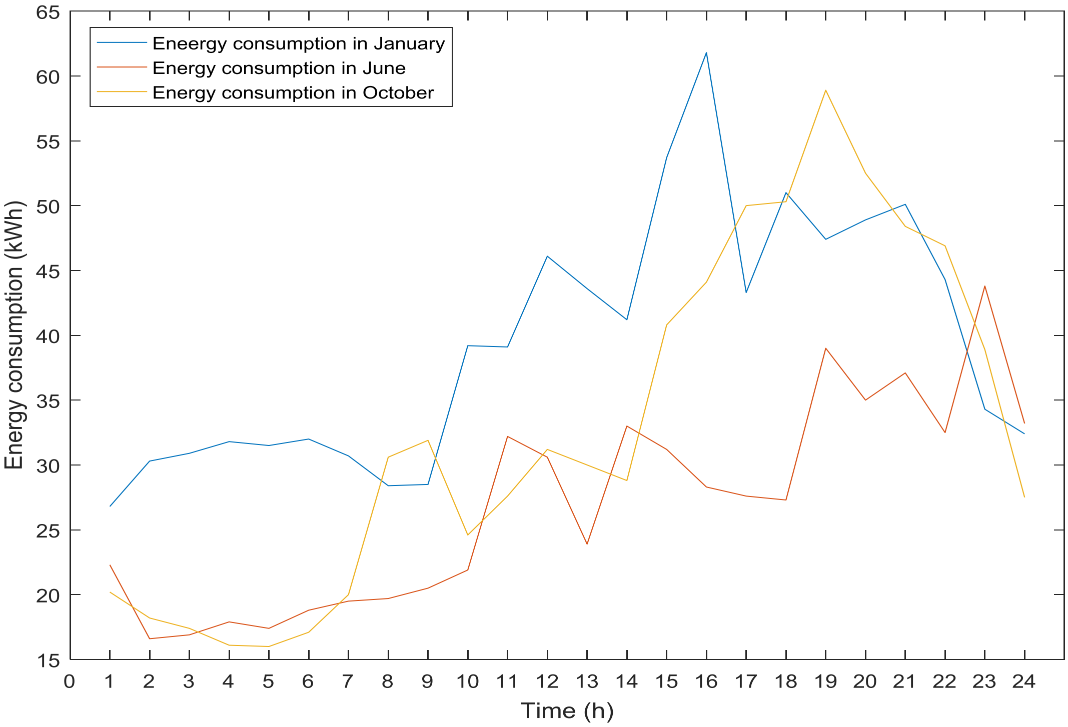

Figure 4-1 *Hourly energy consumption of virtual high-rise building*

4.1 Installation of Solar Panels

Solar panels can be installed in a building in many ways. They can be installed on the rooftops and on the façade areas. Mostly on façade area, solar panels were installed above certain point from where there is low possibility of shadow. On rooftops, PV panels are installed with a specific tilt angle, or tracking system can be installed with solar panels that allow solar panel to change their direction with the changing direction of sun. In this case study it is suggested to install solar panels on façade area as there may be shadow effect on rooftop due to installation of vertical axis wind turbines. For the maximum efficiency, solar panels are installed facing south. It is necessary to leave some space between solar panels for future maintenance operations. It is also possible to give a certain tilt angle to solar panels but it will need more support from building. It is very important to measure and analyze the strength of the building, or façade area that will support the solar panels because in winters snow adds more weight. The maximum number of PV panels installed on a building is calculated by using equation (1).

$$\text{PV panel required } = \frac{\text{available façade area}}{\text{PV panel dimensions (area)}} \tag{1}$$

SP3S PV panel is selected for installation having efficiency of 12.1 % with maximum power 235 W. Maximum voltage at maximum power is 64.5 V. Area of one SP3S PV panel is 2.16 $m^{2.}$.

Total number of PV panels used are 1000. Output power is calculated using real time irradiance measured by sensors installed in TUT. Production from PV panels is calculated using equation (2)

$$P(t)_{S.gen} = D \times P_{cap} \sum_{t=1}^{N} \frac{I(t)_{rrec}}{I_{stc}} \tag{2}$$

Where $P(t)_{s.gen}$ is the generation from PV panels at time 't', D represents de-rating factor due to losses, P_{cap} represents PV panel capacity, $I(t)_{rrec}$ represents available irradiance at time 't'and I_{stc} represents irradiance in standard test conditions (1000 W/m^2).

The connection of solar panels is given in following figure 4-2 in which each solar panel represents a group of solar panels, and for each group of solar panels, one inverter is installed that will convert direct current to alternate current. It must be taken into account that from economic and efficacy perspective, it is more economical and efficient to install separate inverter for each group instead of installing one big inverter for all solar panels. There is distribution board and one measurement and control unit that will measure the output and control the whole process.

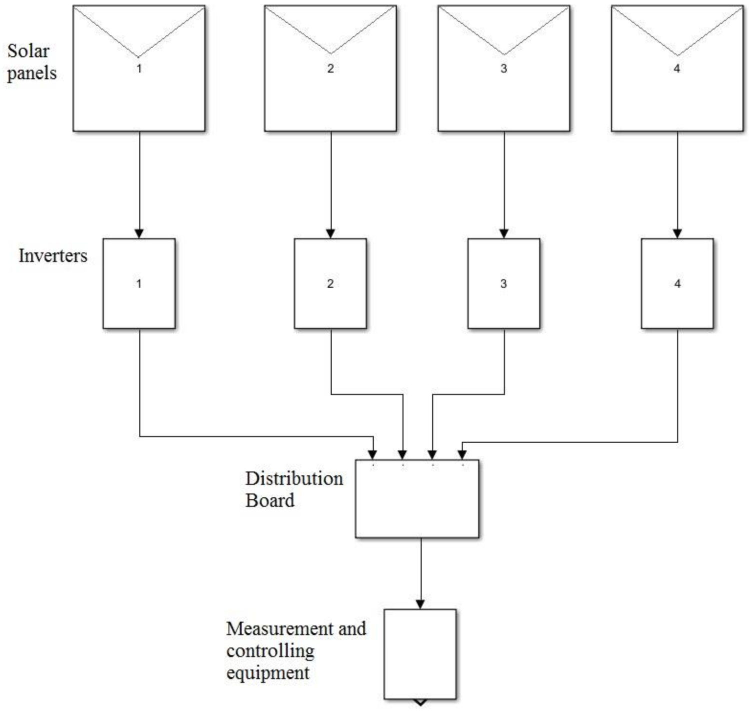

Figure 4-2 *Representation of solar energy system generation system*

4.1.1 Case Tampere

Solar irradiance is measured in Tampere. It is observed that sensors receive maximum irradiance in mid-year while in January and December there is very low irradiance. The annual irradiance curve measured is given below in figure 4-3.

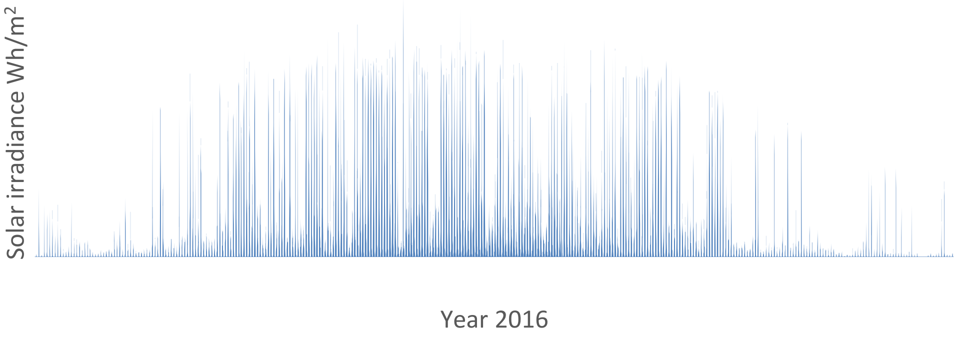

Figure 4-3 Yearly measured solar irradiance in Tampere, Finland

According to above irradiance, three cases are studied for different seasons, January, June and October. Hourly irradiance received by PV panels were measured for 1st day of January, June and October using sensor installed in TUT shown in figure 4-4.

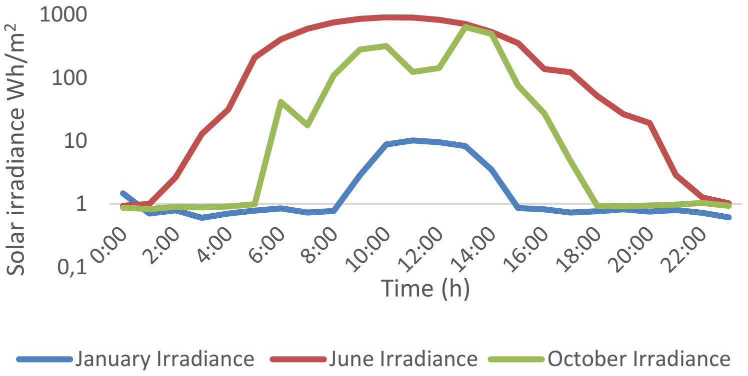

Figure 4-4 Measured irradiance on the first days of January, June and October

For month of January, value of irradiance is very low and there is low output from PV panels. As in January, PV panels receive maximum solar irradiance between 10:00 to 14:00 hour which is almost 21 % of the whole day and for the rest of the day there are very low values of irradiance. On other hand, in June the value of irradiance is very high as compared to the January. The duration of day is also very long in June and it can be seen clearly from the curve that solar irradiance increases from 02:00 and reaches to its peak at 11:00 hour. PV panels receive more irradiance between 05:00 to 18:00. It is almost 59 % of the day. While for the first day of October, the value of irradiance is different. Here a day with shadow is considered for October to get a different scenario than other two days which are completely sunny days. The sudden decline or change in the curve is due to shadow caused by clouds. It is seen from the curve that maximum irradiance received is between 06:00 to 15:00 hours, which is 42 % of the whole day. The amplitude of the peak curve decreases in October.

Solar irradiance measured with the help of sensors installed at TUT are than used to get the possible energy output from PV panels installed on virtual high rise building. Power generation from PV panels installed on virtual high-rise building using measured irradiance by sensors installed at TUT on first day of January, June and October is given in the figure 4-5. The generation unit is kWh.

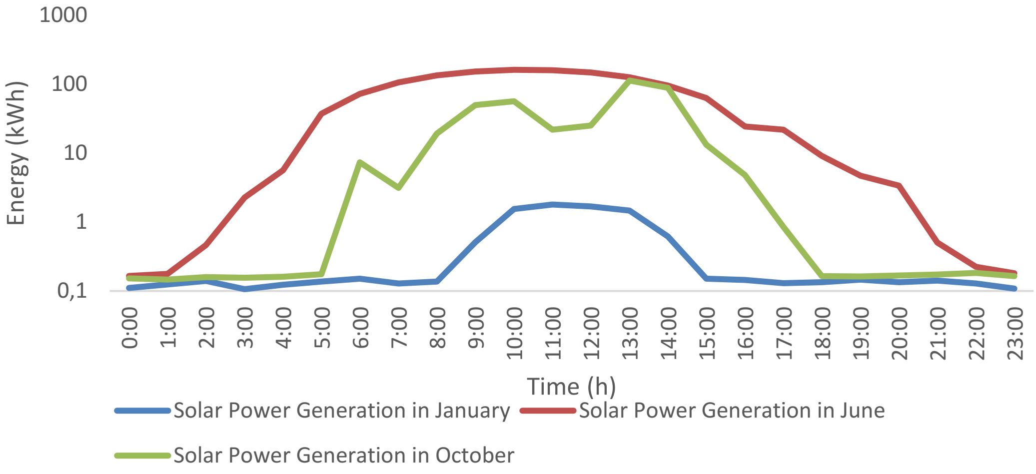

Figure 4-5 *Energy generation from PV panels on first day of January, June and October*

It can be observed from the curves that with the change in received irradiance, output of solar panels changes. PV panels give maximum output in month of June and total output for a complete day is 1319 kWh. For January, we get minimum output as we are receiving less amount of irradiance and the total output for one day in January is 10 kWh. In October, we get different irradiance values as here a day with shadow is considered and total production from PV panels is 402 kWh.

Comparison of the generation for each hour indicates that area of curve increases with maximum peaks during summer season in Finland when there is more irradiance available. Comparison of solar generation with available hourly load measurements given in start of chapter is represented in figure 4-6.

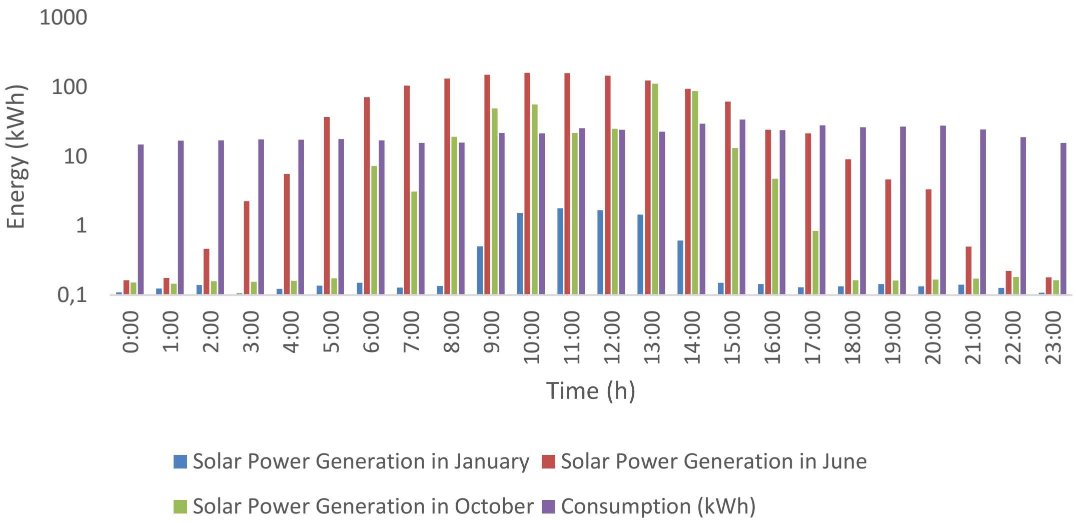

Figure 4-6 *Comparison of energy generation in January, June, October and consumption per hour.*

According to the figure 4-7 given above, the difference between the generation and consumption is greater in January and it is not sufficient to meet the requirements of all loads. In this case, there is need of alternate energy resources such as wind turbines and gas generators. In June, the generation is more than consumption and it is possible to save extra generation in batteries or other energy storage devices like electric vehicles. The extra energy saved in energy storages can be used in low generation hours. In October, the generation is equal to consumption after 06:00 until 15:00. Still there are some hours where the generation from PV panels is low. In these hours, alternate energy source is needed.

For statistical analysis (i.e. presented in appendix A) of one year is divided into three quarters i.e. from January to April is considered as first quarter, from May to August is the second quarter and third quarter is from September to December. From January to April, the mean value of energy generation from solar panels is 13 kWh/h and its standard deviation including negative values is 31.6 kWh. Most of the values for power generation of solar panels lies between 0 to 25 kWh/h and very few values are greater than 30 kWh/h.

In second quarter of the year, i.e. from May to August, in Finland, the duration of day is longer than other two quarter of the year and there is more solar energy available in these months. The mean value of the energy generated from solar panels is 31.3 kWh/h which is almost the double of mean value in first quarter. Standard deviation including negative values is 45.5 kWh. Most of the values for power generation of solar panels lies between 0 to 50 kWh/h and there are some values that lies in higher range, i.e. greater than 50 until 180 kWh/h.

In the third quarter of the year, i.e. from September to December, the length of daytime reduces gradually. It means that there will be less solar irradiance in third quarter of the year. The mean value of solar energy generation is 9.27 kWh/h, standard deviation including negative values is 26.51 kWh, and most of the values for power generation of solar panels lies between 0 to 20 kWh/h. Very few values are greater than 20 kWh/h.

4.1.2 Case Colorado

Colorado is 21st most populated state of United States of America and its capital is Denver. Colorado is famous for its landscapes, mountains and rivers. For Colorado, yearly solar irradiance is calculated and plotted by solar radiation research laboratory and represented in figure 4-8 below.

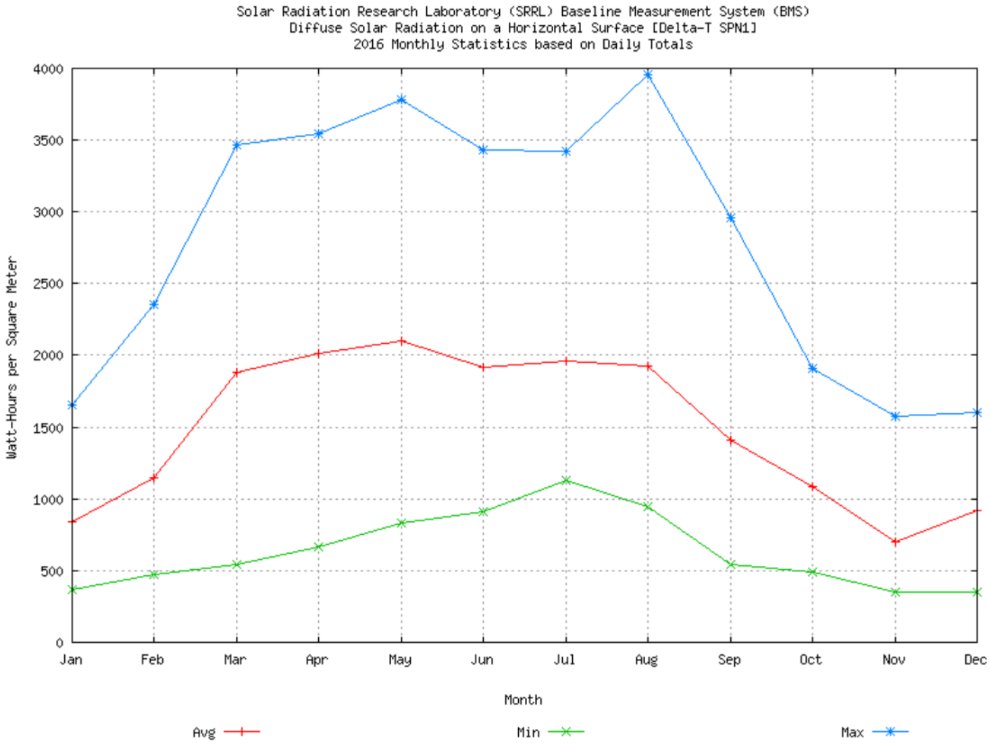

Figure 4-7 *Yearly measured solar irradiance in Colorado, United States of America*

Solar irradiance is calculated for first day of January, June and October by NERL. Hourly irradiance is shown in figure 4-8.

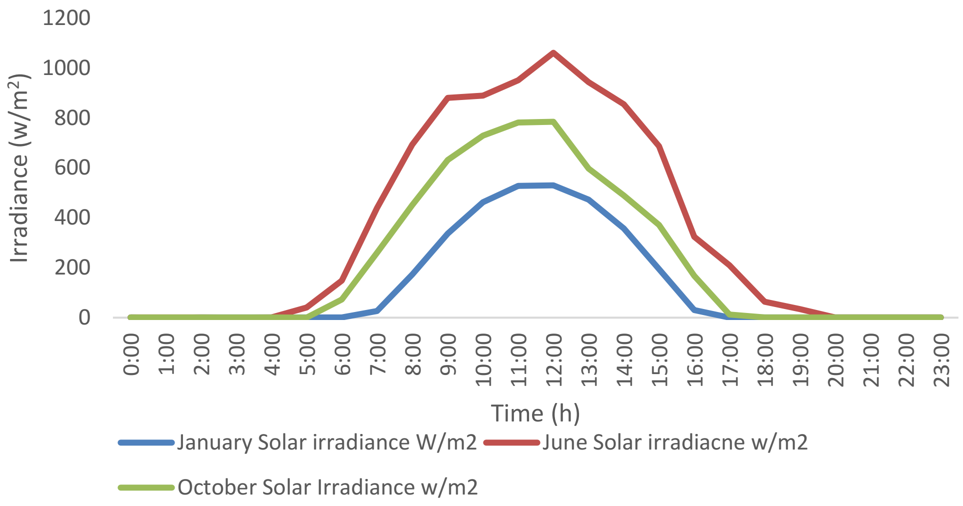

Figure 4-8 *Solar irradiance measured by Solar Radiation Research Laboratory (SRRL) in Colorado, USA*

In January, solar irradiance starts increasing from 07:00 and it ends on 16:00. Energy generation is greater in these hours. It is almost 41.1 % of the whole day in which significant amount of energy is generated. In June, as the duration of day is much greater than the duration of days in other months, there is more irradiance from 05:00 hour to 18:00 hour. It is almost 58.3 % of the entire day. In case of October, there is more irradiance from 06:00 hour to 16:30 hour. It is almost 45.83 % of the whole day. As if there is more irradiance, there will be more energy generation and hence in June there will be more energy generation than other two months.

The possible energy generation and comparison of energy generation from PV panels and load consumption of building shown in figure 4-1 is given in following figure 4-9.

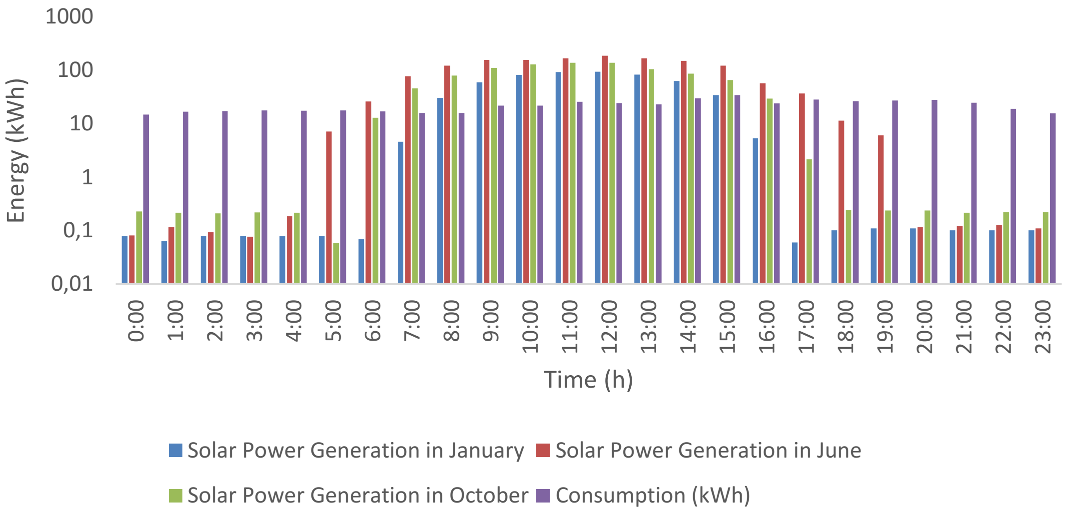

Figure 4-9 *Comparison of solar power generation and load from a virtual building at Colorado, USA*

In January from 18:00 hour to 5:00 hour, generation from solar panels is low and hence there is need of alternate energy resource in these hours. The extra energy generated from 08:00 to 16:00 can be stored in storage devices and can be used later. In June, there is extra generation from 06:00 hour to 17:00 hour and that can be used in later hours from 19:00 hour to 04:00. In addition, an alternate energy resource can be used in these hours like wind turbines or gas generators. In October, extra generation is from 07:00 to 15:00 and that extra energy can be stored in storage devices and can be used in low generation hours from 16:00 to 06:00 with alternate energy resources.

From the perceptive of statistical analysis (i.e. presented in appendix B) where one year is divided in three quarter, the measurements in USA are different from solar energy generation in Finland. In all three quarters of the year, there are very reasonable values calculated in statistical analysis for the virtual building in Colorado. From January to April, the mean value of energy generation from solar panels is 30.34 kWh/h and its standard deviation including negative values is 44.59 kWh. Most of the values for power generation of solar panels lies between 0 kWh to 30 kWh/h. There are some values in the range of 30 kWh/h to 120 kWh/h and few are greater than 120 kWh/h.

In second quarter of the year (i.e. from May to August), in Colorado, the duration of day is longer than other two quarter of the year and there is more solar energy available in these months. The mean value of the energy generated from solar panels is 47.51 kWh/h that is almost the double of mean value in first quarter and standard deviation including negative values is 59.4 kWh. Most of the values for power generation of solar panels lies between 0 to 50 kWh/h and there are some significant values that lies in higher range (i.e. great than 50 until 180 kWh/h).

In third quarter of the year (i.e. from September to December), the length of daytime reduces slowly in Colorado and average day light time is 7 to 8 hours. It means that there will be less solar irradiance in third quarter of the year. The mean value of solar energy generation is 27.4 kWh/h, standard deviation including negative values is 40.95 kWh, and most of the values for power generation of solar panels lies between 0 to 30 kWh/h. Between 30 to 100 kWh/h there are some significant values but few values are greater than 20 kWh/h.

4.2 Installation of Vertical axis Wind Turbine (VAWT)

Vertical axis wind turbine gives more energy production when installed on the rooftops of the building. As they have the ability to catch wind from any direction, they can produce energy with any wind condition. Other reasons for installing a wind turbine are already discussed in section 2.

For a virtual building of height 100 m, installation of four wind turbines on the rooftop were selected as UGE 4K GTDarrieus Turbine. Cost of one UGE 4K GTDarrieus wind turbine is 20 k€ and maximum capacity is 4 kW.

Wind speed is variable throughout the year and hence the generation is also variable. Production from wind turbine can be calculated by using following equation (3).

$$P(t)_{W.gen} = 0.5 \times \rho \times A \times n \sum_{t=1}^{N} V(t)^3 \tag{3}$$

Where ρ means air density, A means swept area of wind turbine, which is equal to πr^2 in this case, Cp means power coefficient and V means wind speed. For the installation of VAWT, the strength of roof must be consider to support wind turbines and other instruments connected to wind turbines. Weather conditions must also be examined to know the estimate production of the wind turbines.

4.2.1 Case Tampere

Wind speed is measured by using sensors at TUT and actual wind speed calculated for one year is shown in the figure 4-10.

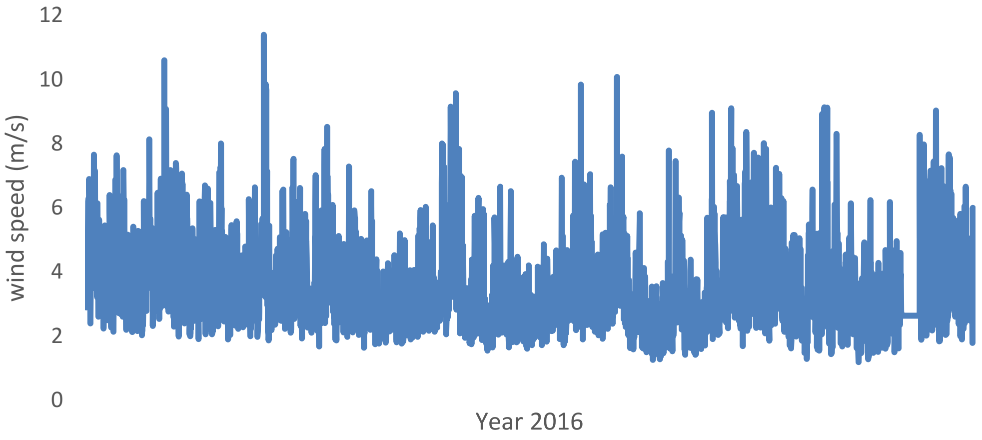

Figure 4-10 *Average hourly wind speed in year 2016 in Tampere, Finland*

The curve in the figure 4-12 shows the variable behavior of wind. In addition, due to variable wind speed there will be variable power generation. Wind speed for the first days of January, June and October is calculated using measurement data from the sensors installed in TUT and the resultant curves are given below in figure 4-11.

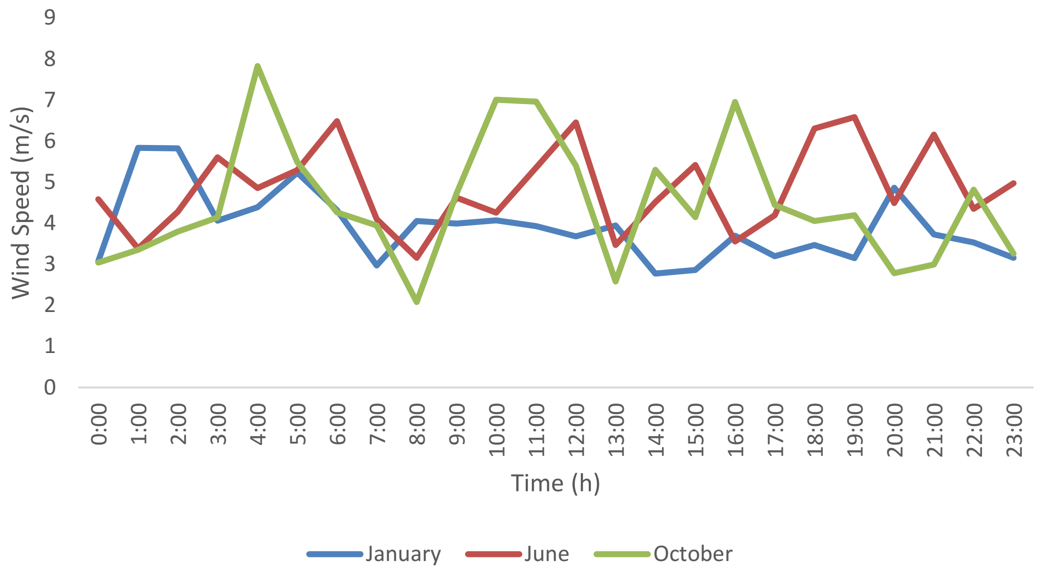

Figure 4-11 *Hourly wind speed on first day of January, June and October measured by sensors installed in TUT Tampere, Finland*

The curves show that there are some high values of wind speed in October and low values in January. However, the difference is small between all three curves. This result cannot be valid for every year like solar irradiance where PV panel receive maximum irradiance in June and minimum irradiance in January. Wind speed also varies with temperature, but there are other factors that affect wind speed. Wind speed also changes with every instant of time, and because of that average hourly value of wind speed is selected. As the maximum wind speed is not exceeding 8 m/s, hence wind turbine can be operated with this speed safely. Power generation from wind turbines using hourly average values of wind speed is represented in figure 4-12.

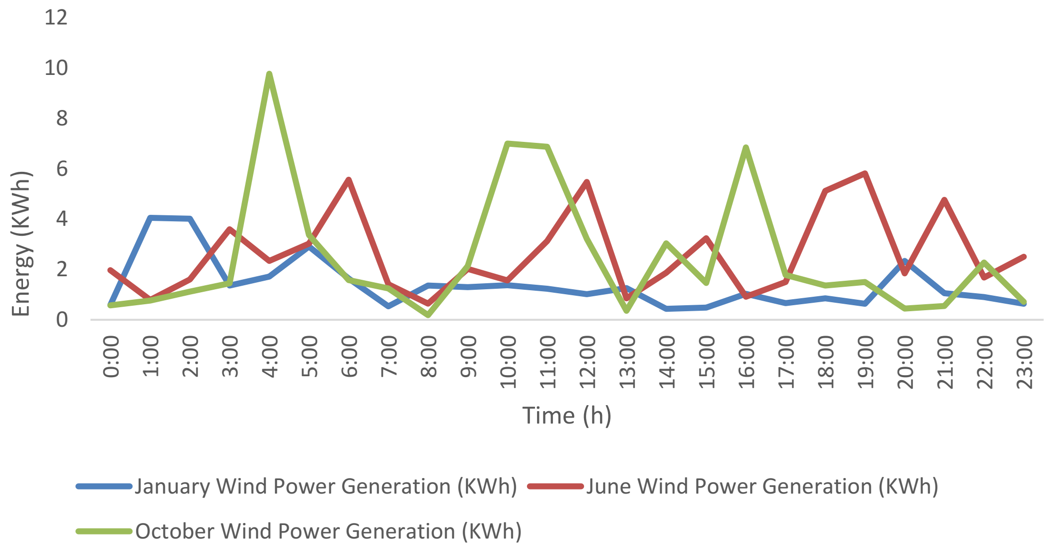

Figure 4-12 *Hourly energy generation in first day of January, June and October by wind turbines*

The maximum energy generation in the case study is in October as wind speed sensor measured more wind in the example day of this month. For the maximum speed of 7.83 m/s, the energy generated is 7.33 kWh. Total generated energy during the first days of January, June and October is given in table 4-1.

Table 4-4-1 *Energy generation in case days in Tampere, Finland*

Month (1st day)	Energy Generation (kWh/day)
January	25.04
June	47.4
October	44.6

When wind turbines are installed on the rooftop a comparison bar graph is produced to look how much wind turbines can meet the consumption needs of the building. The comparison of energy generation and consumption is given below in figure 4-13.

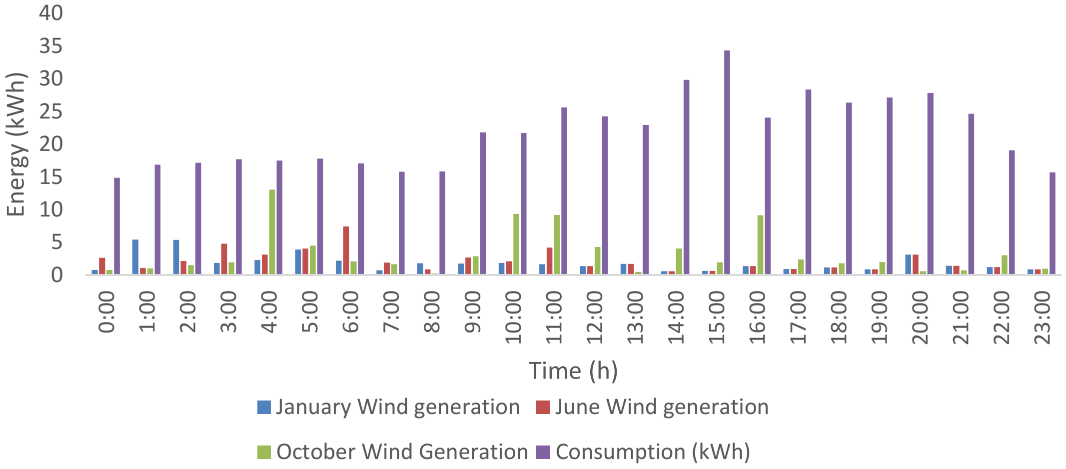

Figure 4-13 *Comparison of hourly energy consumption with wind energy generation from three wind turbines*

Energy consumption of the building is greater than generation from wind turbines in all three months. Energy generation from wind turbines is not sufficient for the load and there is need of alternate energy resource to fill the gap between generation and load. Wind generation can be sum up with solar power generation to meet the requirements of load. In off peak hours if there is more wind energy than it can be stored in energy storages. If there is more wind energy, for example, when wind speed is greater than 6 m/s, the energy generation from wind turbines increases and support the consumption needs of the building but it of course depends on weather conditions.

Statistical analysis (i.e. presented in Appendix. A) provide information that in the first quarter of the year (i.e. from January to April), the wind generation from vertical axis wind turbines in the first quarter of the year have mean value 1.6 kWh/h and standard deviation is 2.2 kWh. Most of the output generation values lies between 0 to 3 kWh/h, and very few greater than 4 kWh/h. In the second quarter of the year (i.e. from May to August), the mean value of wind energy is 1.67 kWh/h and standard deviation is 2.3 kWh. The range for the maximum values for wind energy remains same as it was in the first quarter of the year. It can be noticed that wind speed also reduces slightly in third quarter of the year. The mean value of the wind energy generation is 1.4 kWh/h, standard deviation is 2.09 kWh. The range for maximum values almost remains the same as it was for the first quarter.

4.2.2 Case Colorado

Colorado is a hilly area and there are mountains and river. Wind speed in Colorado is much greater than wind speed in Tampere, Finland, and hence there will be more energy generation from wind turbines. Wind speed is calculated by SRRL for year 2016. The curves of maximum, minimum and average wind speed are given in the figure 4-14.

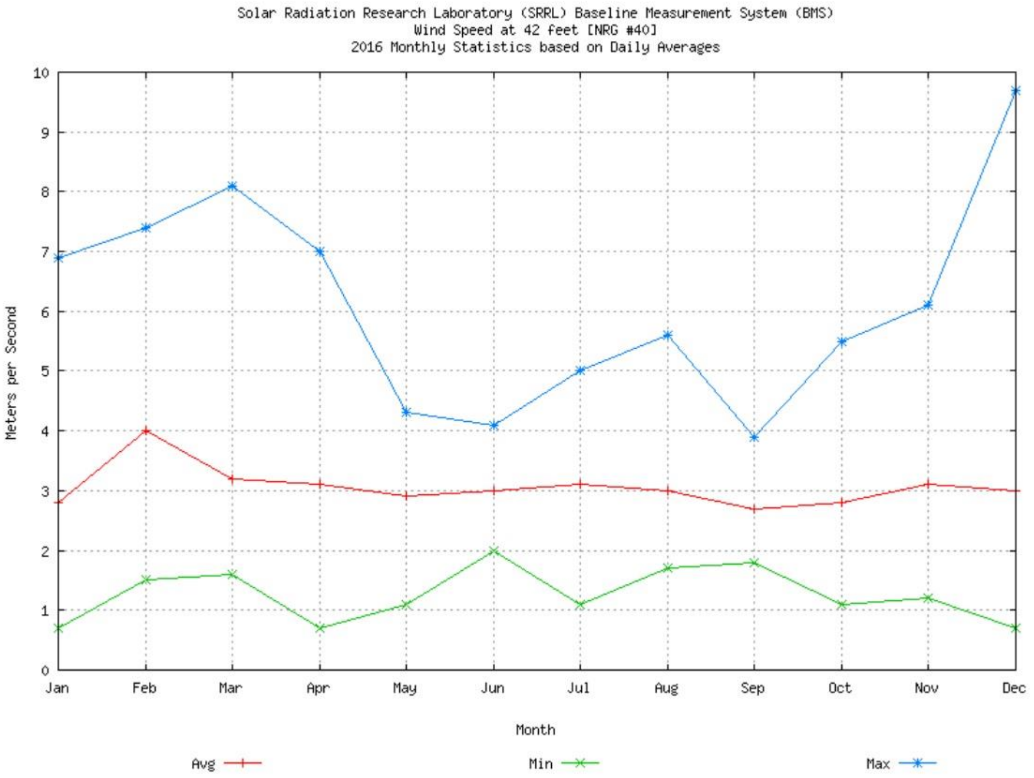

Figure 4-14 *Measured yearly wind speed in Colorado, United States of America*

Wind speed in Colorado is calculated by SRRL and wind speed on first day of January, June and October is given in figure 4-15.

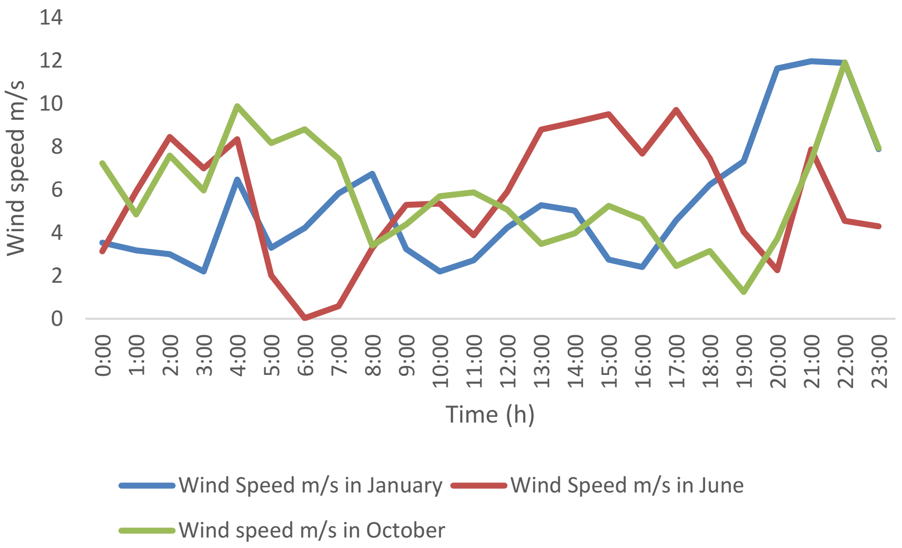

Figure 4-15 *Wind speed on first day of January, June and October measured by sensors installed at SSRL in Colorado*

Nature of wind speed is variable and it cannot be same for every day or for every year. It can be noticed that in June there is more wind in mid-day time. Using the above measurements of wind speed on virtual high-rise building as mentioned in section 4-1 with load curve given in figure 4-1, the output energy generation from four vertical axis wind turbines with load is given in figure 4-16.

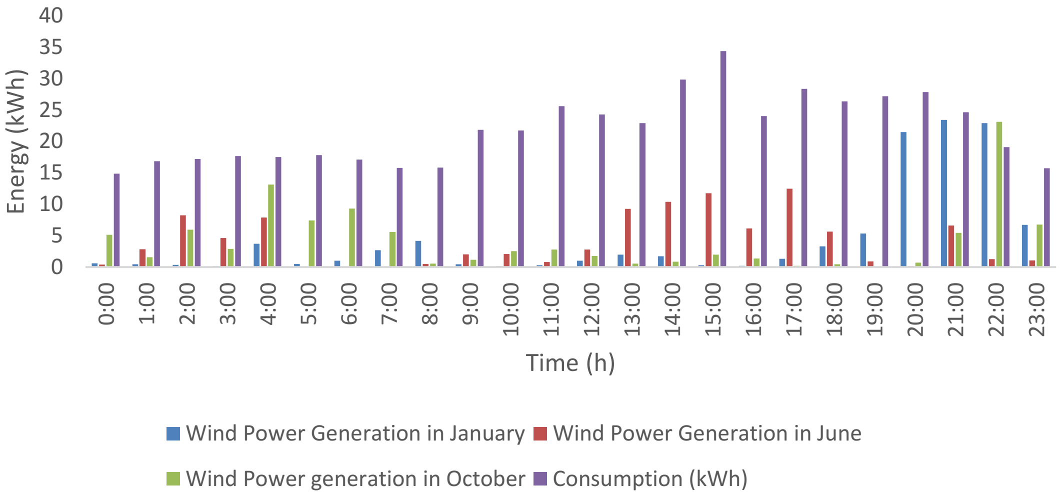

Figure 4-16 *Comparison of energy generation from four wind turbines installed on virtual building located at Colorado, USA*

Energy generation from wind turbines in virtual building does not sufficiently fulfil the requirements of load. There are very few hours where energy generation is greater than consumption and for remaining hours, there is less generation as shown in figure 4-16.

Statistical analysis (i.e. presented in Appendix. B) shows that the wind generation from vertical axis wind turbines in first quarter of the year have mean value 1.6 kWh/h and standard deviation is 4.4 kWh. The most of the output generation values lies between 0 to 5 kWh/h and reduces the yield significantly, few values reaches 7 kWh/h. The wind speed data extracted from NERL database shows different behavior in the second quarter of the year. It shows that the average wind speed reduces in the second quarter of the year. The mean value of wind energy is 0.67 kWh/h and standard deviation is 1.10 kWh. The range for the maximum values for wind energy remains same as it was in the first quarter of the year. Wind speed also reduces slightly, the mean value of the wind energy generation is 1.16 kWh/h, standard deviation is 6.15 kWh. The range for maximum values almost remains the same as it was for the first quarter.

4.3 Installation of energy storages

From above two cases, it can be observed that at some time the available energy generated from renewable energy resources are much greater than required energy for the load. This extra energy can be stored and can be used later when there is not much available generation from renewables. There are several ways to store energy. The most convenient and feasible solutions for high-rise buildings is to store extra energy in batteries and in electrical vehicles. A battery system of 300 kWh capacity is proposed for this model. Energy stored in energy storages can be calculated using (4).

$$B(t) = P(t)_{S.gen} + P(t)_{W.gen} - L(t) \tag{4}$$

where B(t) represents state of charge at time ‘t’, $P(t)_{S.gen}$ represents power generated from solar panels at time ‘t’, $P(t)_{W.gen}$ represents power generated from wind turbines at time ‘t’ and L(t) represents electric load at time ‘t’. Stored energy in energy storage can be summed up with the previous value of energy storage as given in (5).

$$B(t)_{total} = B(t-1) + B(t) \tag{5}$$

Where B(t) is the state of charge of energy storages at time ‘t’ and B(t-1) is the previous value of energy storages. The total charge in energy storage must be less than the maximum value and greater than minimum value for normal and efficient use i.e.

$$B_{min} < B(t)_{total} < B_{max} \tag{6}$$

The extra generation from solar energy can be seen from the comparison bar graph of load and solar generation in figure. This extra solar energy bar graph is given in figure 4-17.

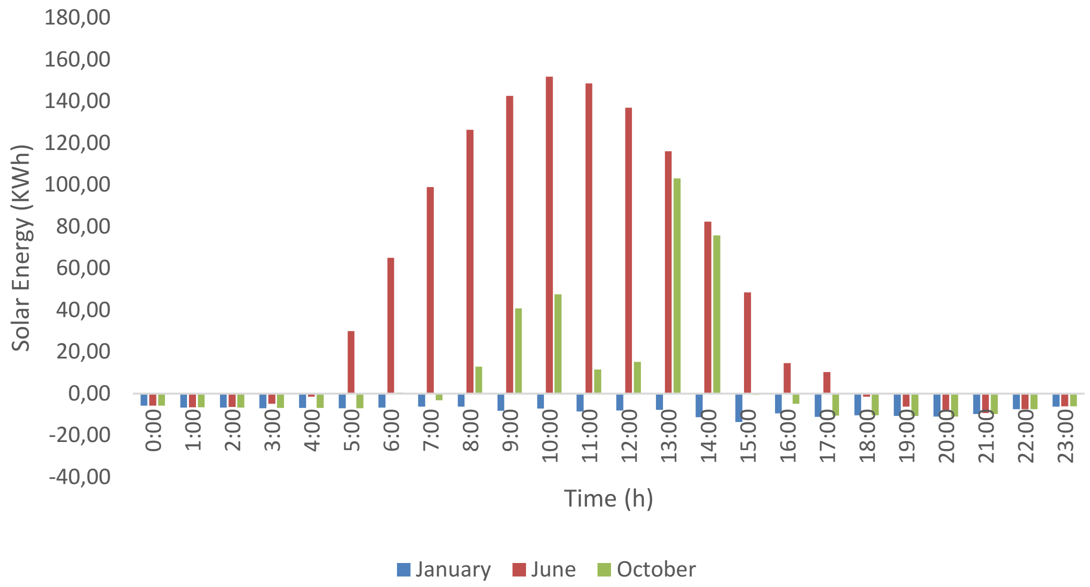

Figure 4-17 *Difference of hourly energy generated and consumption for case Tampere, Finland*

In above figure positive values indicates the availability of extra energy while negative values indicate that there is no extra energy and there is need of more energy to meet the needs of load. In January due to cloudy and less day hours the amount of irradiance is less and hence the energy generation too. While for June, there are more high values for extra energy generation during 05:00 to 17:00. This extra energy can be stored in energy storage devices. On first day of October, the value of extra generation varies and there is extra energy generation from 8:00 to 14:00.

For case Colorado, USA, the bar graph for extra energy or required energy to handle load requirements is given in figure 4-18.

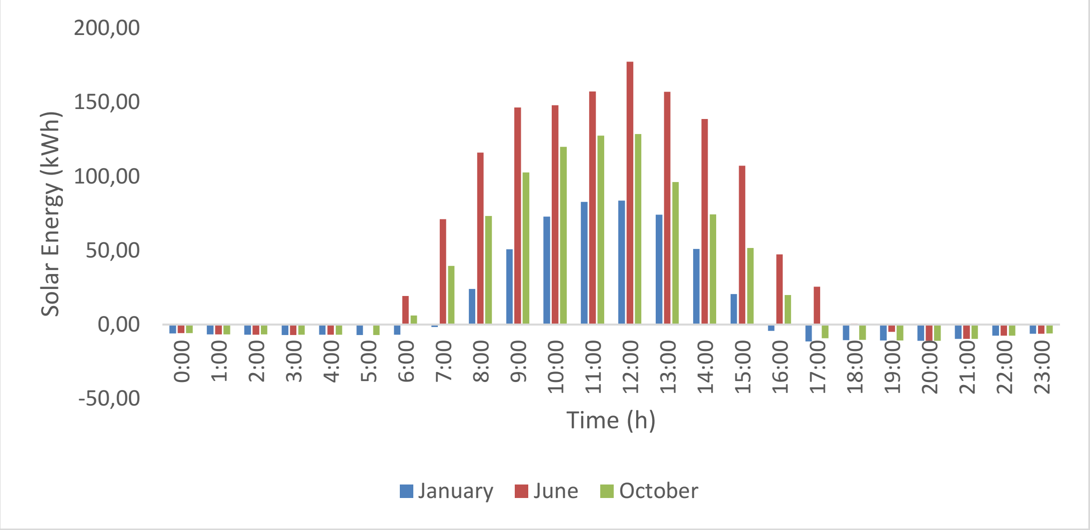

Figure 4-18 *Difference of hourly energy generated and consumption for case Colorado, USA*

Same scenario can be used for wind energy. The extra energy can be stored or required energy can be provided using batteries. For wind energy AC to DC and then DC to AC inverters are used and for solar energy DC to AC inverters are used.

5. HYBRID POWER GENERATION SYSTEM

To get more sustainable, reliable and cost efficient system, the need of renewable energy resources grows everyday which provide cheap energy from solar, wind and gas. However, as solar and wind are variable, they cannot meet the need of load all the time. It is necessary to use alternate energy resources for some hours when there is not enough production from weather dependent renewables. Solution is to design a system, which provide energy from all these resources whenever needed, and can be switched from one resource to other according to the need of load. The system is also capable to use two or more resources at the same time. In this thesis, a hybrid system is proposed and hourly energy management is considered. This hybrid system consists of solar and wind power production, gas generators and storage devices. A block diagram of the main idea is given in figure 5-1.

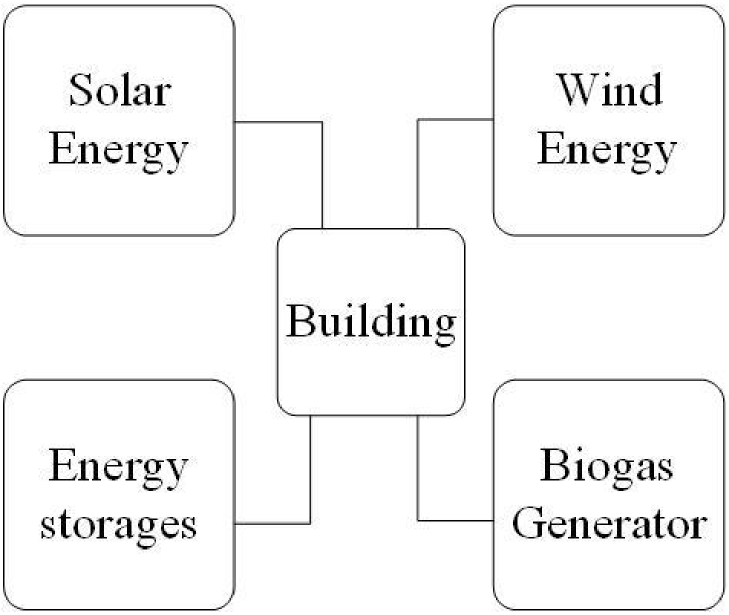

Figure 5-1 *Block diagram of hybrid power generation system*

Sum of energy generated from PV panels and wind turbines by the hybrid power production system of figure 5-1 on the first days of January, June and October in Tampere is given in figure 5-2.

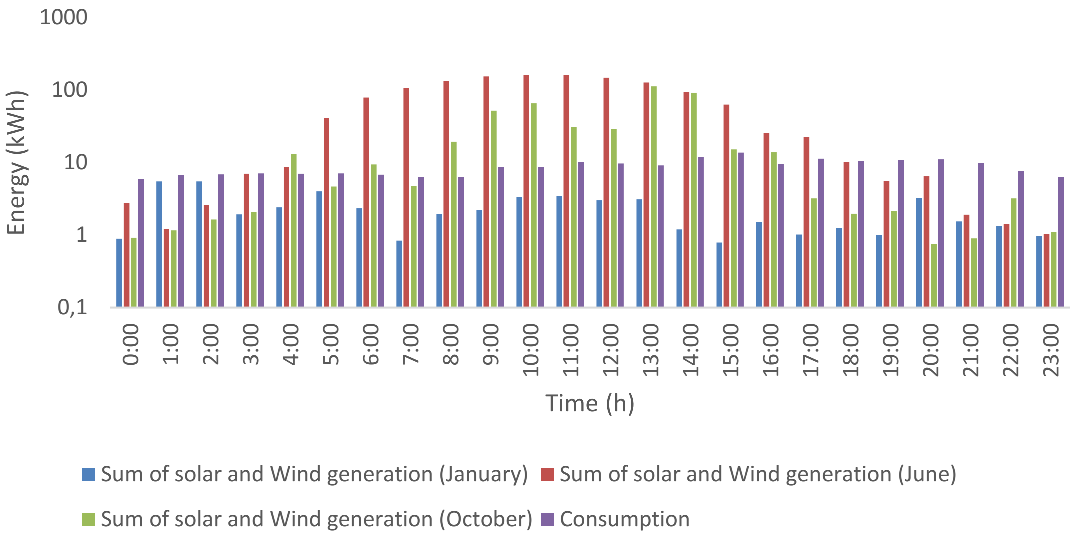

Figure 5-2 *Comparison of generation with consumption for each day in January, June and October in Tampere, Finland*

From above all measurements and calculations, total energy generation for constant load (i.e. 209.61 kWh per day) for both cases (i.e. case Tampere and Colorado) are given in following table 5-1.

Table 5-1 *Energy available in case Tampere and Colorado on case days*

	January	June	October
Available energy from PV plant and wind turbine (kWh/day) (Tampere)	54.49	1371.05	482.40
Available energy from PV plant and wind turbine (kWh/day) (Colorado)	654.1	1548.1	1046.9

For the first day of January, generation from solar panels and wind turbines is 54.49 kWh while the required energy for building is 209.61 kWh. There is need of alternate energy resource and in this case, biogas generator is used. In figure 5-3 hourly load is represented along with possible energy production resource. In first hours energy storages are used and if there is some generation from solar and wind, it will be stored in batteries. Similarly, when gas generators are used the energy generation form solar and wind power will be stored in batteries. Hourly energy management for case Tampere is shown in figure 5-3.

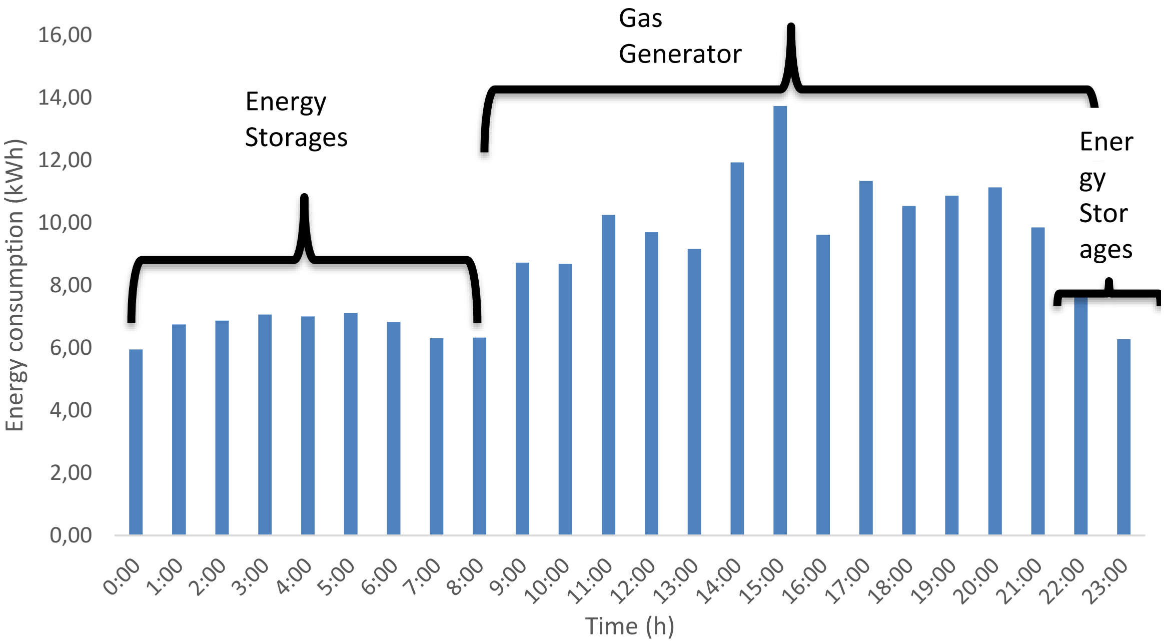

Figure 5-3 *Hourly energy management for first day of January*

In first seven hours (i.e. from 00:00 to 07:00), it is more feasible to use energy storages (batteries). For the peak hours, energy will be provided from gas generation and it will also provide heating for the building. In addition, in off peak hours energy stored in batteries will be utilized. Percentage of each source used for providing energy to the load is presented in figure 5-4.

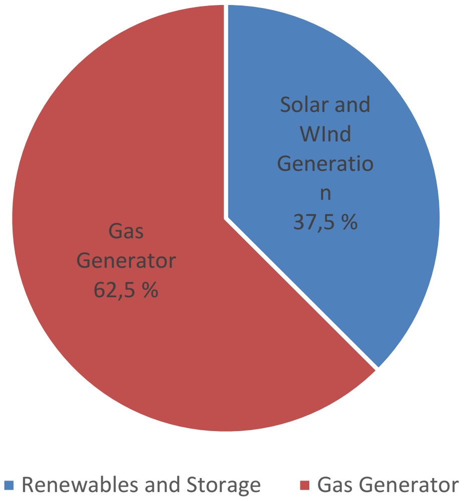

Figure 5-4 *Percentage energy usage of energy resources in January*

In June as the length of day is long and there is more energy generation from solar panels and wind energy, there is no need for gas generator. The total energy generation from solar panels and wind turbines is 1371.05 kWh and total consumption for one day is 209.61 kWh. The load can be easily handled by energy generated from wind turbines and solar panels. Ideally, in evening times when there is more need of energy in loads, gas generator can be used. The percentage for combine wind and solar and gas generator for month of June is given below in figure 5-5.

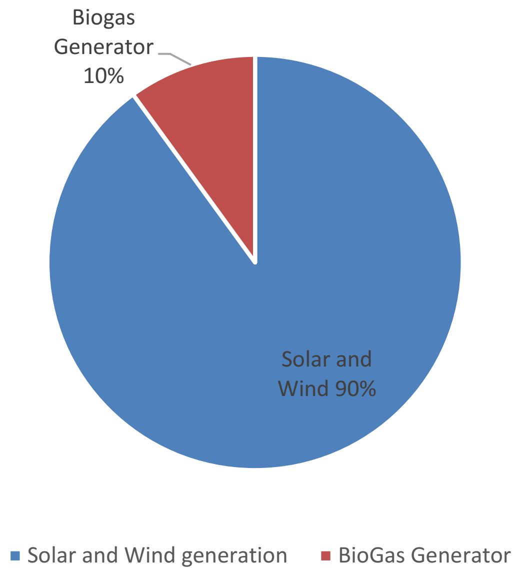

Figure 5-5 *Percentage energy usage of energy resource in June*

For October, the combined generation from solar and wind is 482.40 kWh. The case of October is different as a day with cloudy weather is considered having low energy generation from solar panels. The proposed hourly energy management from 0:00 to 5:00 is based on energy storages and from 6:00 to 9:00 gas generator is used. As there is more solar and wind energy from 10:00 to 18:00, solar and wind energy is used in those hours and again after 18:00. Gas generator is turned on till 22:00. In addition, after that energy storages are utilized. Percentage use of each resource is given in figure 5-6.

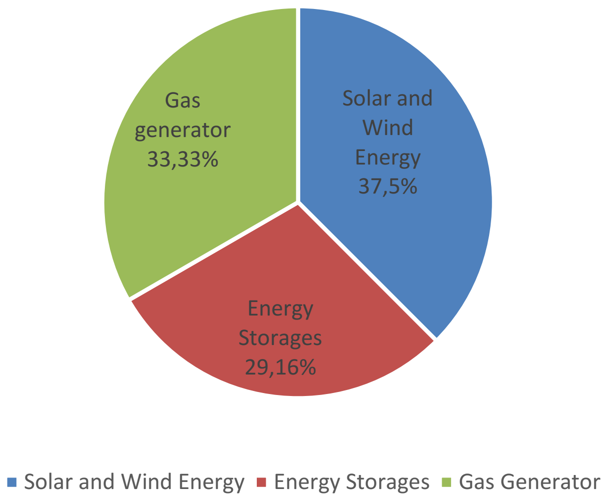

Figure 5-6 *Percentage energy usage of energy source in October*

5.1 Generic model

A simple generic model of hybrid power system has been designed in Simulink. Simulink model of solar generation is designed using equation (2) and for wind generation, equation (3) is used. Solar and wind models are given in figure 5-7. Solar irradiance and wind speed are variables and changed with time while other parameters are constants.

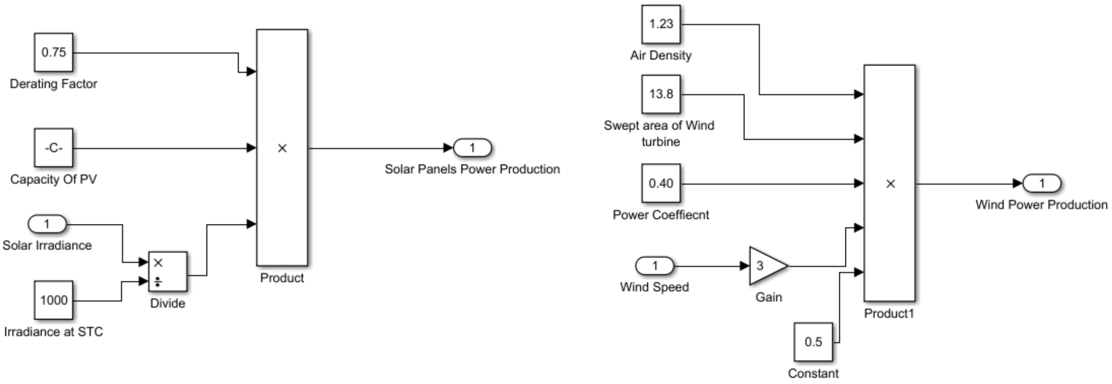

Figure 5-7 *Simulink model of solar generation and wind generation with variable solar irradiance and wind speed respectively*

The sum of solar and wind generation is then compared with load for each hour. If the load is greater than the generation then the system will automatically switch the gas generator on or in other case, the system will continue with solar and wind generating system. For this model energy generation from gas generator is calculated using equation (7).

$$P(t)_{req} = L(t) - \{P(t)_{S.gen} + P(t)_{W.gen}\} \tag{7}$$

Where $P(t)_{req}$ is the amount of energy required from biogas to meet the needs of electrical load. The combined model of solar and wind power production, energy storages and gas generator and the flow chart is given in figure 5-8 and 5-9 respectively.

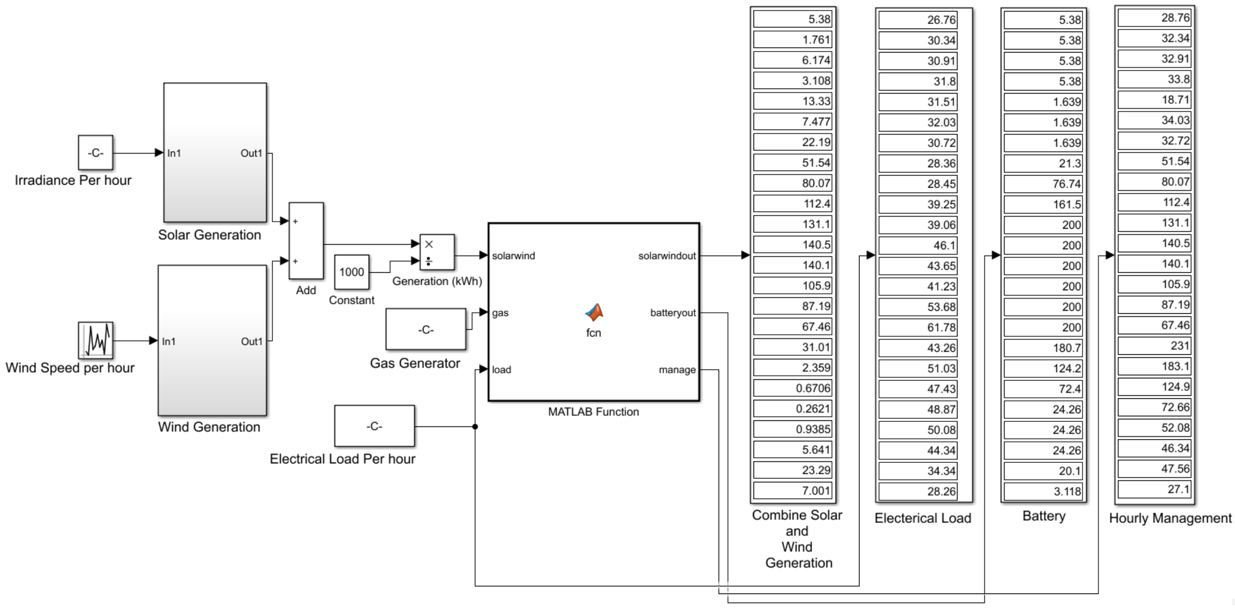

Figure 5-8 *Generic model of hybrid power generation system with self-switching system*

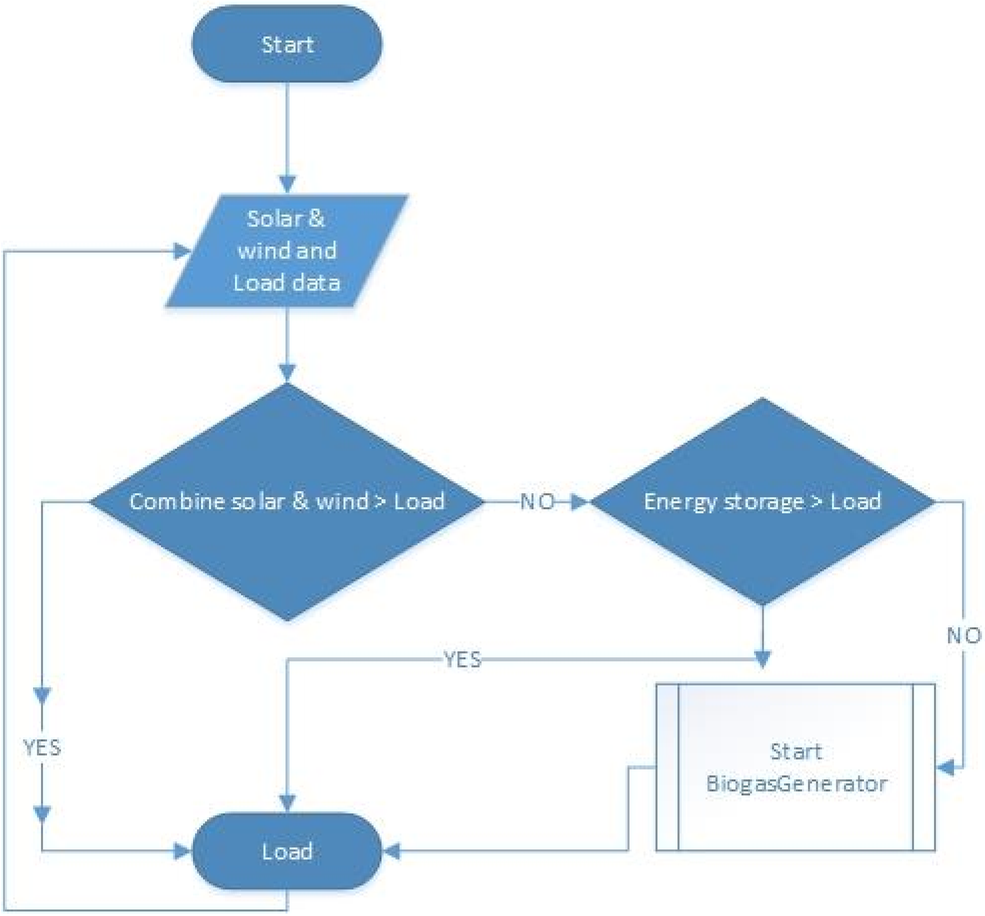

Figure 5-9 *Flow chart of hybrid power system*

For example, if an hourly load is 9 kWh and generation from combined solar and wind is together 5 kWh. Both values will be compared and switch will decide based on output from the comparison logic. If the value is negative, it will switch to gas generator (10 kWh generation) and if the value is positive it will continue with solar and wind generations. Curves of generation from wind and solar and load is given in figure 5-10.

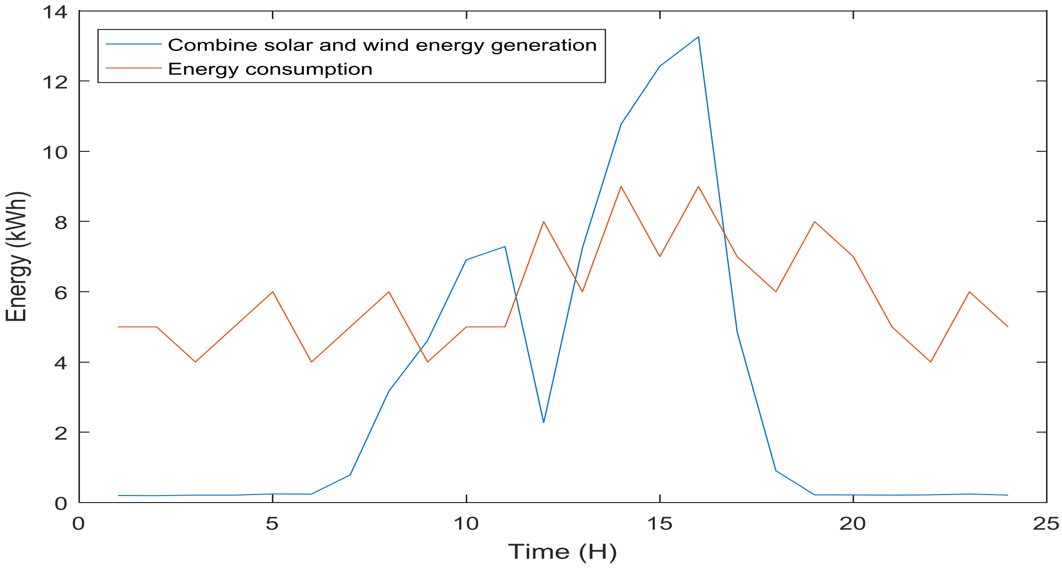

Figure 5-10 *Curves of combined generation from solar and wind, and load*

In figure 4-9 blue curve represents hourly load per hours and black curve represents generation from solar and wind. Generation in some points is not sufficient for load and for those points alternate energy resource is needed. When gas generator is added, the switch selects the source to provide energy to the load and the curves are given in figure 5-11.

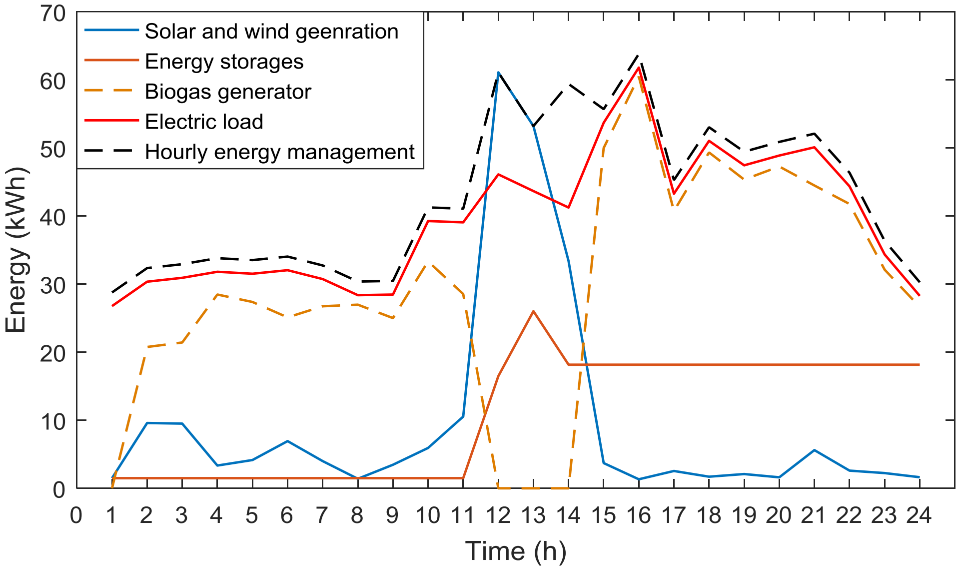

Figure 5-11 *Curves of energy generation from solar and wind, energy consumption, energy storage in batteries and energy management with hybrid system in January*

In figure 5-11, blue curve represents the combined solar and wind energy generation, brown curve represent the energy storages, orange doted curve represents the energy from biogas generator, red curve represents electrical load and black curve represents energy management from hybrid energy system. In first eleven hours energy management is covered by gas generator and combined solar and wind generation, which gives supply to the building as the combined solar and wind energy generation is not enough to feed building needs. After eleventh hour the value of combined solar and wind power generation becomes greater than consumption requirement and hence the system switched from gas generator to combined solar and wind power generation. It continues on working until the energy generation from solar panels and wind turbines become less than energy consumption. The system switches from combined solar and wind power generation to energy storages. From 14:00 to 24:00, energy is supplied from the combination of gas generator and combined solar and wind power generation system. This scenario does not remain the same for all days as the value of energy storage keep on changing and in some days, there is more production from combined solar and wind energy generation system. There is probability that use of gas generator is reduced after some period and use of energy storages, and combined solar and wind generation is increased. Hourly energy management in June and October is presented in figure 5-12 and 5-13 respectively.

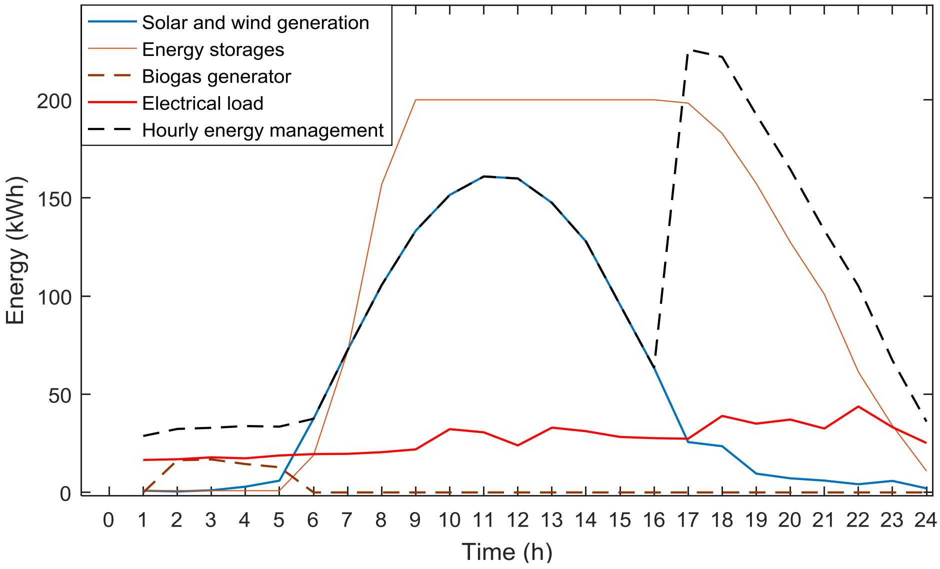

Figure 5-12 *Curves of energy generation from solar and wind, energy consumption, energy storage in batteries and energy management with hybrid system in June*

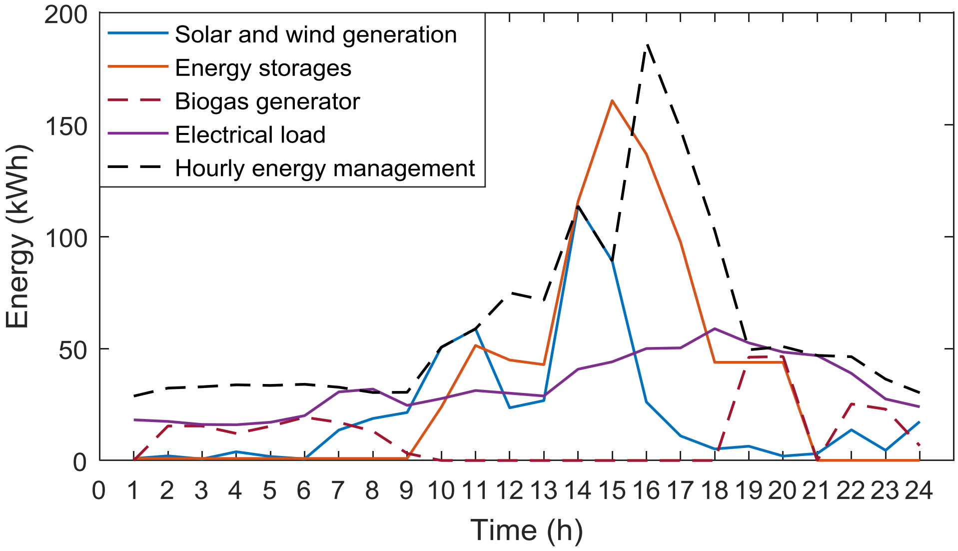

Figure 5-13 *Curves of energy generation from solar and wind, energy consumption, energy storage in batteries and energy management with hybrid system in October*

The percentage of each integrated resource used independently in three quarters (i.e. January to April, May to August and September to December) in case Tampere are given in table 5-2.

Table 5-2 *Percentage of each resources used in three quarters in case Tampere*

Resource (%)	PV and wind turbine	Energy storages	Gas generator
First quarter	15.08 %	31.68 %	53.23 %
Second quarter	32.7 %	66.73 %	0.47 %
Third quarter	3.825 %	13.9 %	82.3 %

For case Colorado, hourly energy management in January, June and October is represented in figure 5-14, 5-15 and 5-16 respectively. It can be noticed that use of biogas generator is less than in case Tampere.

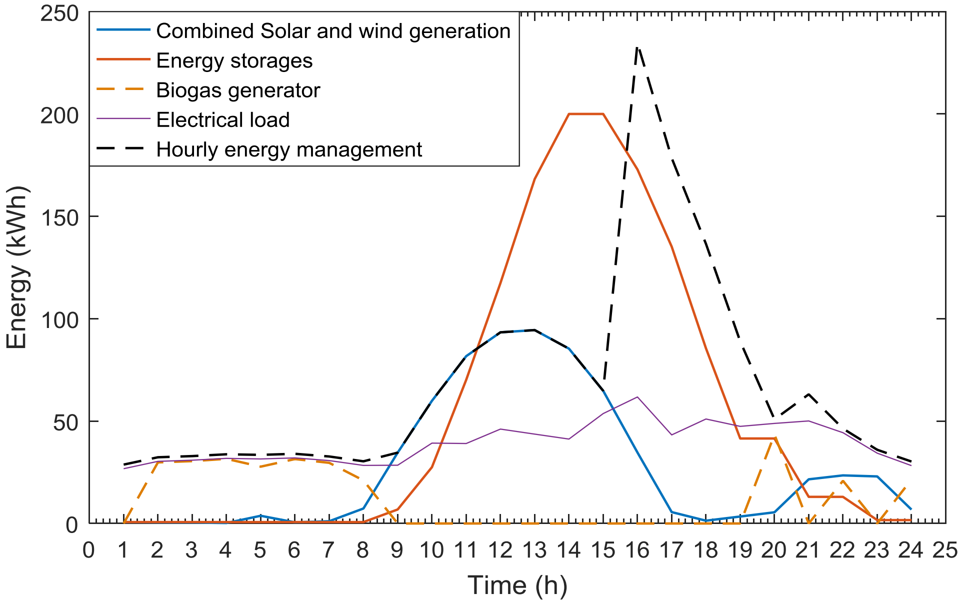

Figure 5-14 *Curves of energy generation from solar and wind, energy consumption, energy storage in batteries and energy management with hybrid system in January*

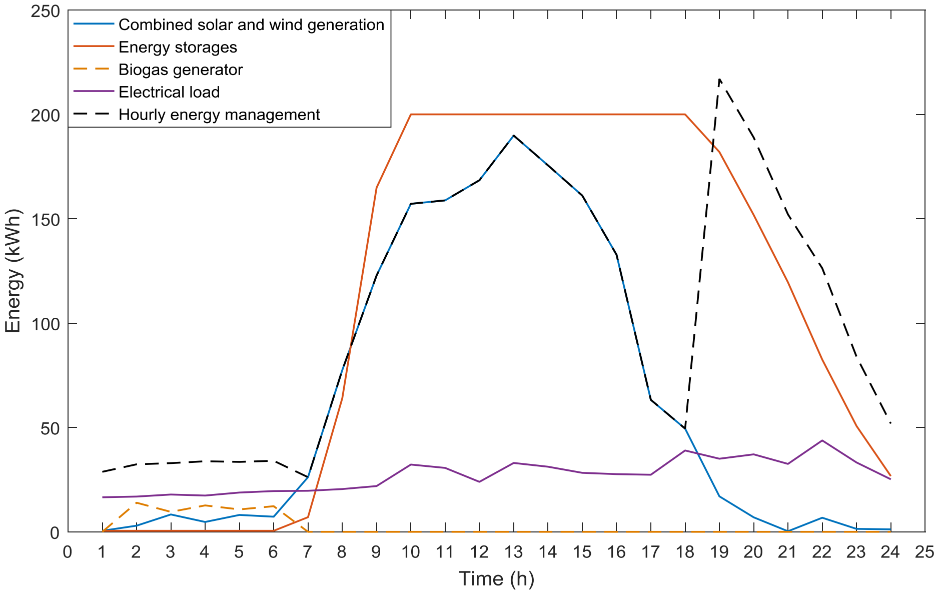

Figure 5-15 *Curves of energy generation from solar and wind, energy consumption, energy storage in batteries and energy management with hybrid system in June*

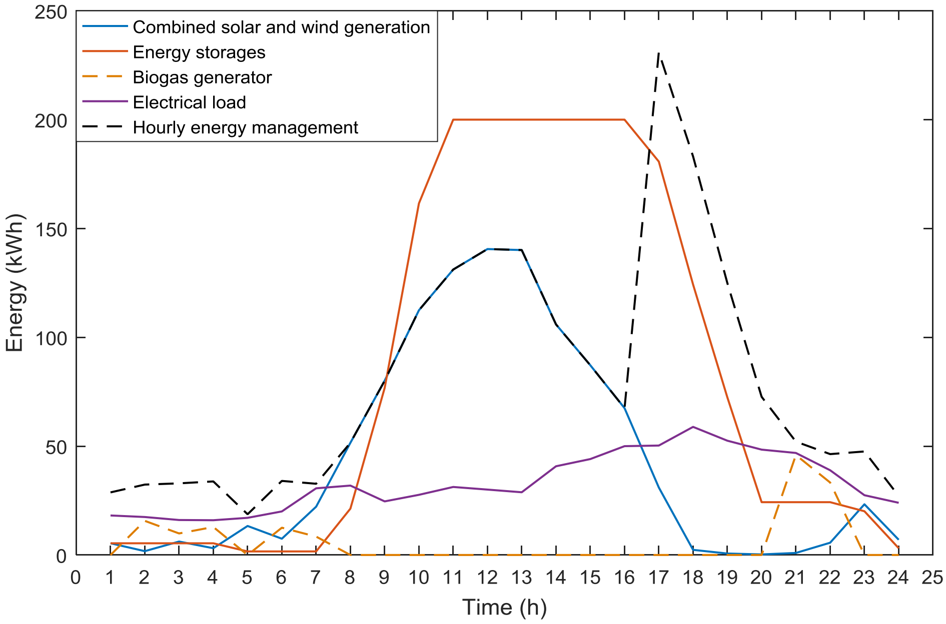

Figure 5-16 *Curves of energy generation from solar and wind, energy consumption, energy storage in batteries and energy management with hybrid system in October*

The percentage of each integrated resource used independently in three quarters (i.e. January to April, May to August and September to December) in case Colorado are given in table 5-3.

Table 5-3 *Percentage of each resources used in three quarters in case Colorado*

Resource (%)	PV and wind turbine	Energy storages	Gas generator
First quarter	36.12 %	50.9 %	12.87 %
Second quarter	45.25 %	54.16 %	0.609 %
Third quarter	30.1 %	47.13 %	22.79 %

The selection of source for load is changed as compared to the selection on previous day. It depends on the availability of solar and wind generation and available stored energy in batteries. If there is more energy in battery then battery will operate if there is less solar and wind generation. Similarly for all days of week or months energy management can be done based on estimated solar irradiance and wind speed.

6. CONCLUSIONS

This chapter gives an overview of some main points that are necessary while planning and installing renewable energy based hybrid energy generation system in high-rise building.

There is need of proper planning and literature review to be done before installing solar energy generation system in high-rise building. Weather condition of that area must be very critically examined and data for at least one complete year must be collected to examine the behavior of solar irradiance at desired location. Tilt angle is also necessary to calculate in order to increase the generation of solar panels or the second solution is to install solar tracking system, which is more costly and makes the system more complex. The location of installation of solar panels in the building is also important to examine and to decide. This can be done by installing sensors to calculate solar irradiance on each side of the building at different time of the day and then making decision for location based on those measurements. However, the optimal direction of solar panels is usually towards south. There must be enough space available for other instruments connected to the system like inverters, controllers etc. and that space is also used for maintenance operations.

Installation of vertical axis wind turbines (VAWT) in high-rise building is more feasible than installing horizontal axis wind turbine. It is because VAWT has the ability to catch wind from any direction and it does not require high poles and occupy less space than HAWT. There might be issue of vibration and turbulence in VAWT which must be evaluated and examined. In addition, the weather condition of that area need to be examined for wind energy generation.

Energy storages needs enough space and they must be kept in isolation with proper HVAC system which is needed to maintain the temperature of energy storage devices. There must be enough space available also for other instruments connected to the system like inverters, controllers etc. and that space is also used for maintenance operations.

In addition, the structure of the building is necessary to consider and examine, as extra weight of all the instruments of solar energy generation system may need extra support. It is easy to install renewable energy resources in a new building which is under construction but it might be difficult to install renewables in old buildings. For the new building, contractors take into the account the installation and requirements of building strength and cabling requirements for renewables while in old building extra work required to be done for calculating strength and finding ways to install cables and renewables.

From both cases (i.e. case Tampere and case Colorado), it is concluded that having two or more energy generation resources is worthy and practical for high-rise building in order to meet their energy requirements. A hybrid system is therefore proposed in this thesis. The hybrid system also reduces the green house gas emissions and reduces the cost on CO_2.

As conclusion, using hybrid system in a high-rise building as micro grid is feasible, but it carries some challenges related with weather conditions and costs. The main goal of installing a hybrid power generation system is to reduce the cost of energy production and to provide more reliable and continuous flow of energy for the customer. The costs and payback analysis of a system is very important before a system has been installed. The costs of all components, including investments, operational and maintenance costs are considered along with the lifetime of the project and then payback time is calculated. If the payback time is less than life cycle of the system than it is consider to be profitable. The repay period may be long. It can be reduced, if the cost on manufacturing the instruments used in energy production from renewable energy resources is reduced. There is a need of research to know the effects of hybrid system on the supplying grid and vice versa. A proper switching system and information system is also needed which switch the supply from hybrid system to grid supply. There will be more attraction towards hybrid system once the above question are answered with more practical solutions.

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APPENDIX A: QUARTERLY STATISTICAL ANALYSIS OF ENERGY GENERATION IN FINALAND

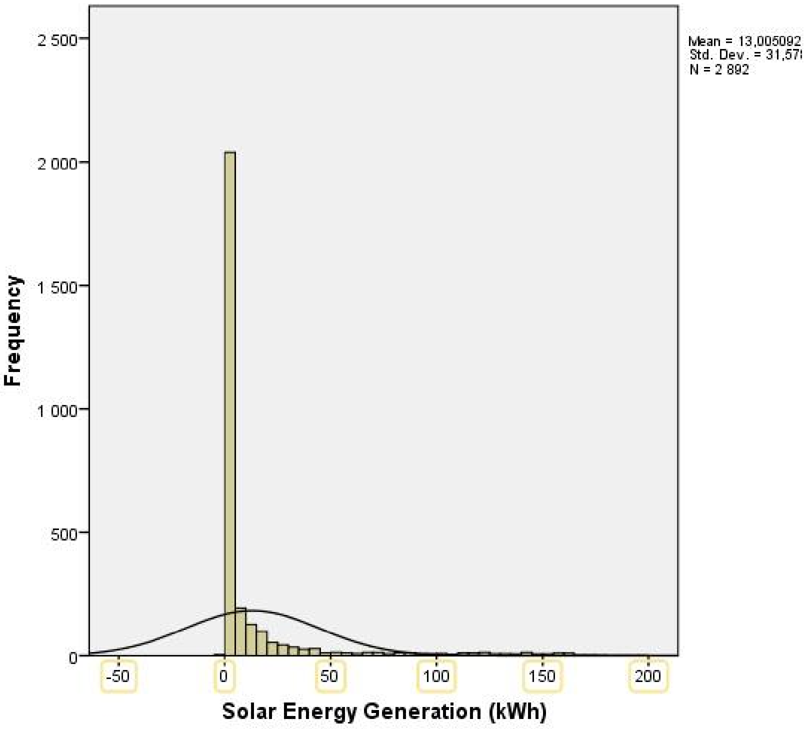

Figure a1.1 Energy generation from solar panels in first quarter (January to April)

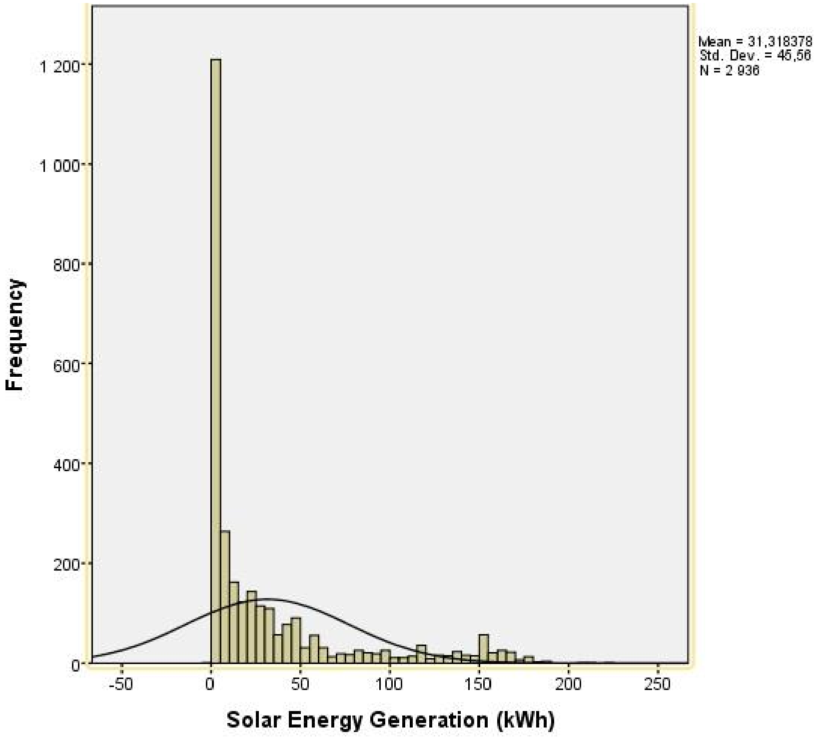

Figure a1.2 Energy generation from solar panels in second quarter (May to August)

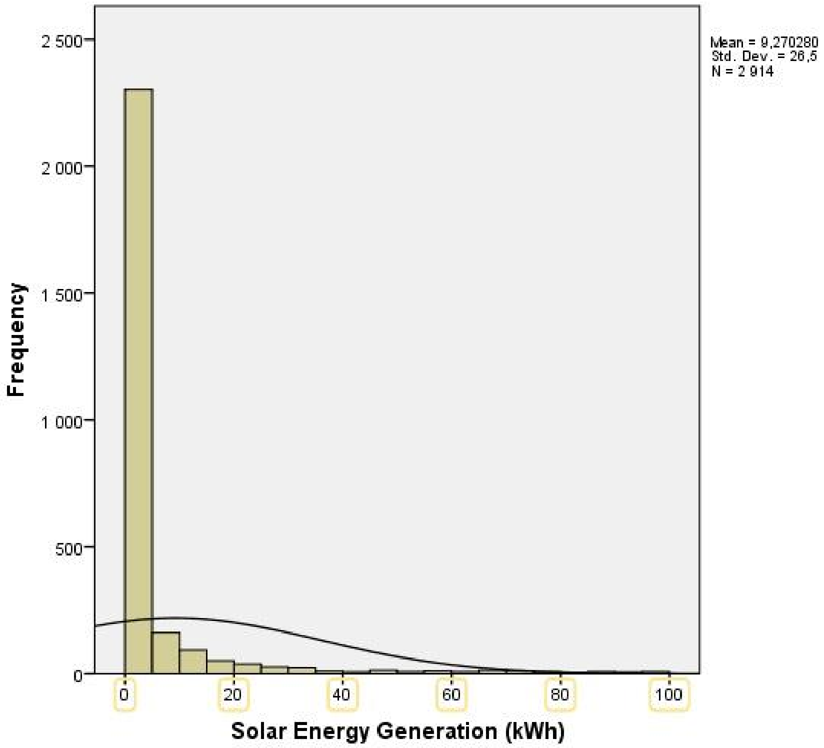

Figure a1.3 Energy generation from solar panels in third quarter (September to December)

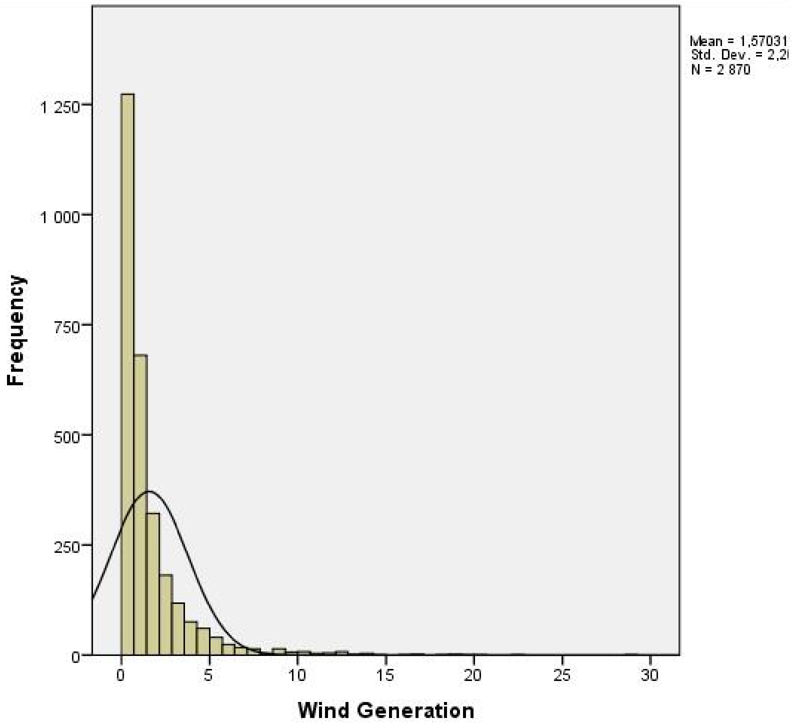

Figure a1.4 Energy generation from wind turbines in first quarter (January to April)

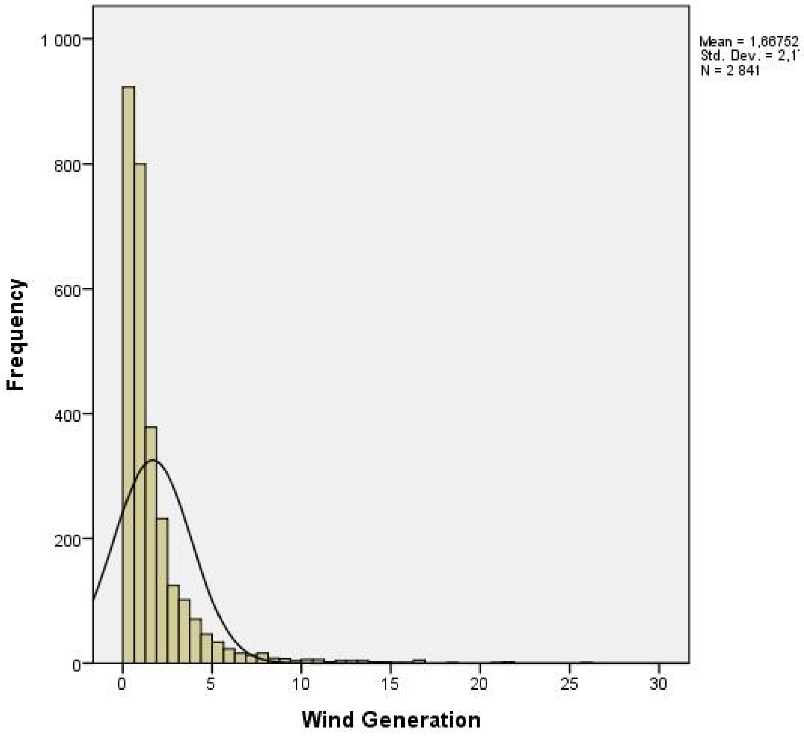

Figure a1.5 Energy generation from wind turbines in second quarter (May to August)

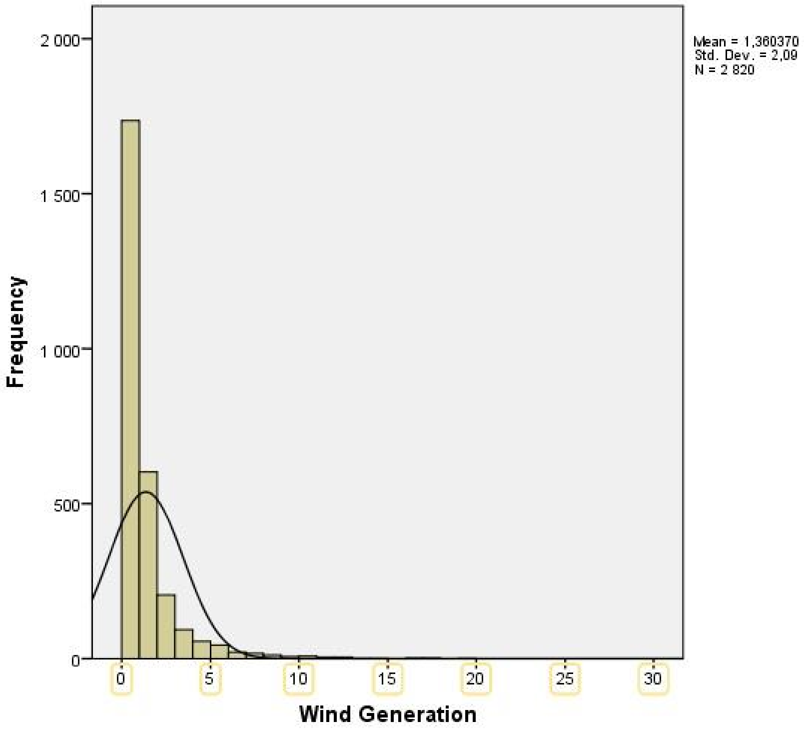

Figure a1.6 Energy generation from wind turbines in third quarter (September to December)

APPENDIX B: QUARTERLY STATISTICAL ANALYSIS OF ENERGY GENERATION IN COLORADO, USA

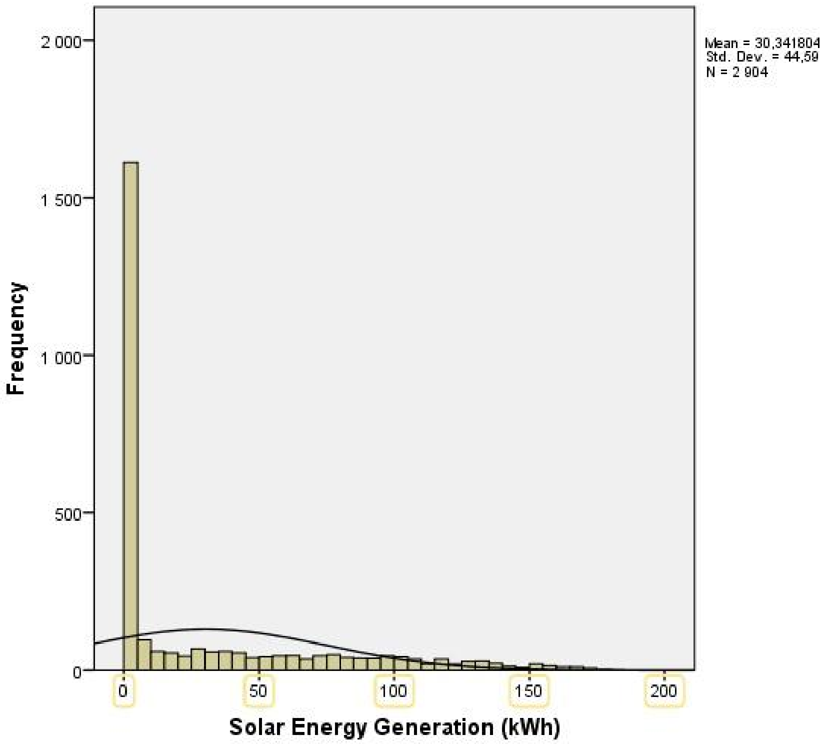

Figure a2.1 Energy generation from solar panels in first quarter (January to April)

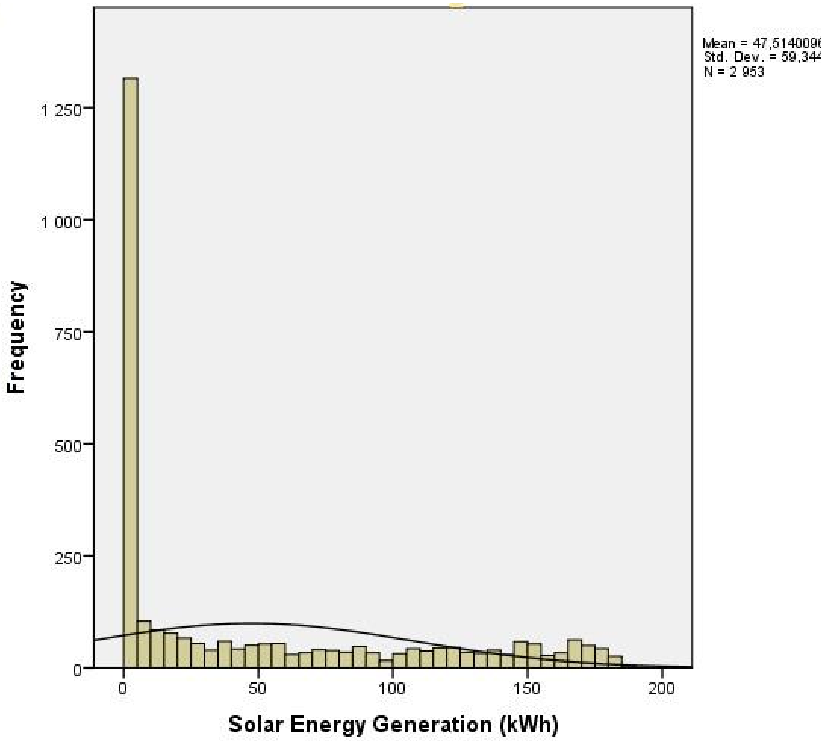

Figure a2.2 Energy generation from solar panels in second quarter (May to August)

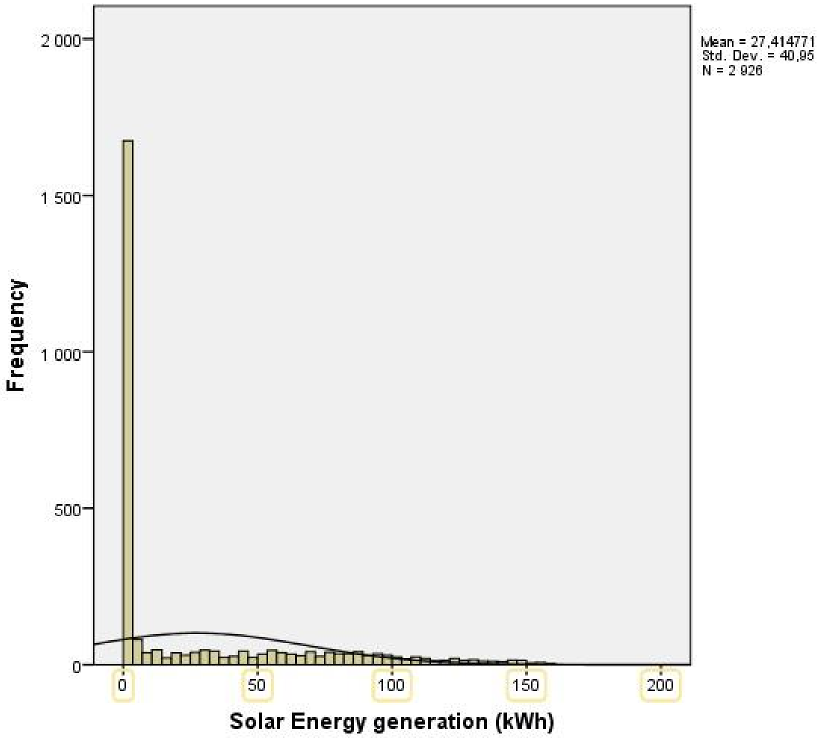

Figure a2.3 Energy generation from solar panels in third quarter (September to December)

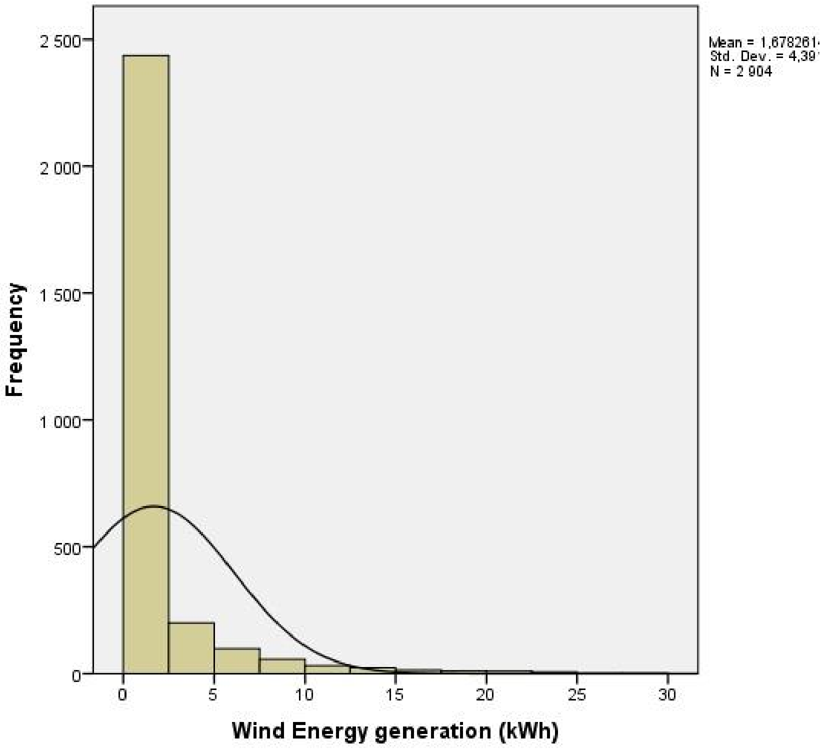

Figure a2.4 Energy generation from wind turbines in first quarter (January to April)

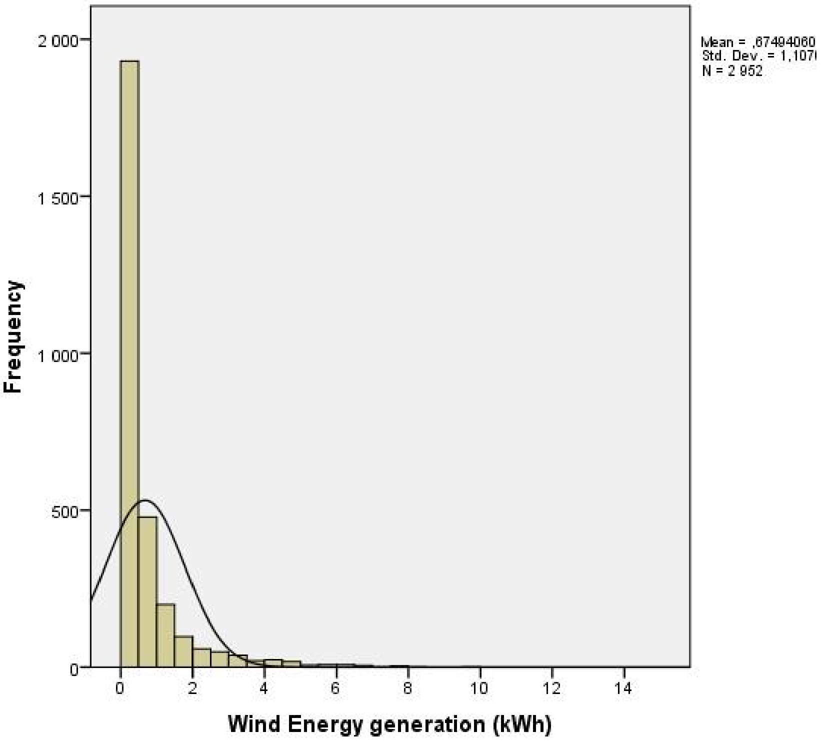

Figure a2.5 Energy generation from wind turbines in second quarter (May to August)

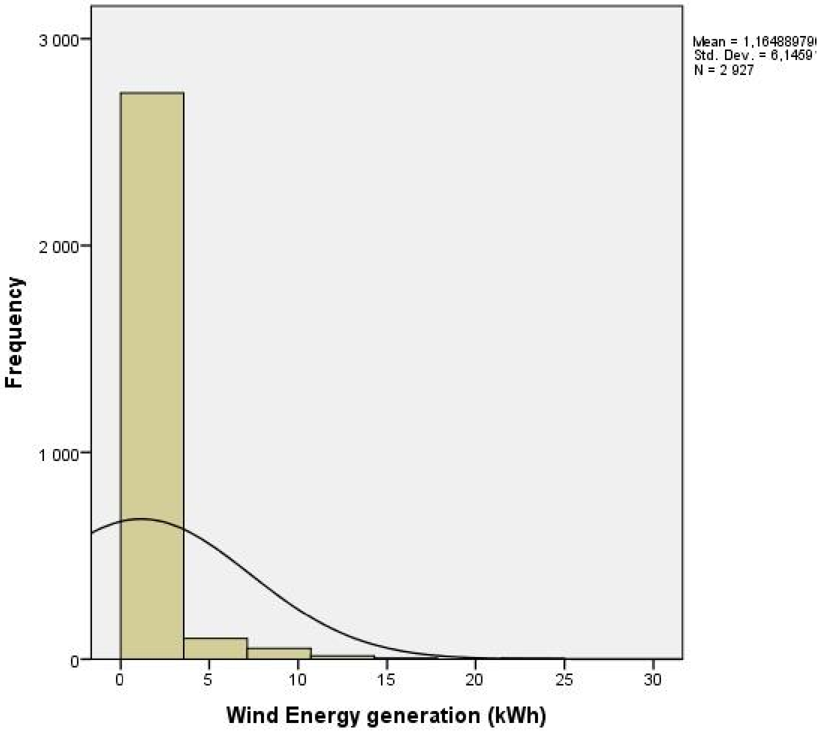

Figure a2.6 Energy generation from wind turbines in third quarter (September to December)