University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Offshore Technology / Industrial Asset Management	Spring semester, 2018 Open
Writer: M. Okan ILKIC	…………………………………………… (Writer's signature)
Faculty supervisor: Associate Professor Idriss El-Thalji	

Simulation Model of Hybrid Energy Production and Consumption for Passive House Concept: A Case Study: "MyBox Student House" in University of Stavanger (UIS) Campus

Credits (ECTS): 30

Key words: PV, Solar Energy Production, Wind Energy Production, Systems Dynamics Simulation, Net Zero Energy Building	Pages: 71 (seventy one) + enclosure: 11 (eleven) Stavanger, 15.6.2018….. Date/year

Simulation Model of Hybrid Energy Production and Consumption for Passive House Concept: A Case Study: "MyBox Student House" in University of Stavanger (UIS) Campus

By

M. Okan ILKIC

Thesis is submitted to the Faculty of Science and Technology
University of Stavanger
In Fulfilment of the Requirements for the degree of
Master of Science
(M.Sc.)
Specialization: Offshore Technology - Industrial Asset Management

University of
Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

University of Stavanger

2018

Abstract

It was believed in that the level of the consumed energy was a proof for each country to show the technical, economic and social development indicator for many years in the past. Unfortunately this approach could be applicable as the “limited” resources such as Oil, Coal, Gas etc. exist on the planet on earth or at least inside the country’s borders. The main objectives related to the energy policy of the counties were increasing the produced energy, using own resources to produce energy and creating new alternative energy resources to achieve first two targets. As a result of that the countries paid attention to increase the number of facilities which uses these resources and pollute the environment beyond the control and unpredictable ways. Also this intellection were caused countries to use nuclear energy which was developed as a weapon at the Second World War. Unfortunately, the pollution gas and other chemicals to the environment showed their results earlier than expected and introduced us with a new term of “Global Warming” at the end of 90s. Nuclear accidents and other industrial chemical accidents which effect the huge number of inhabitants and environments for many years, helped us to understand about their risks and the “Black Swans” they still have.

Green energy concept was invented during that time as the precision about environment was increased first in public then among the governments. The researches about the wind, solar, wave, deep water streams were seen as a solution for the increased energy consumption, polluted environment and changed climates. The researches for this alternative resources started many years especially for space industry but elapsed time proved that the especially wind and solar can be critical and implacable for countries for their energy policy.

It was also understood that to diversify the energy resources and increase the efficiency of the green energy resources might not be useful without proper energy efficiency policy and energy saving policy. Using wind turbines, PV Panels and other mentioned alternative green energy resources can be effective and useful to make “Off-Grid” houses which produces its own energy and disconnect to the grid line, only when this two policies are fallowed strictly by users and governments.

There are many names to describe a house which produces its needed energy for all year by using the wind, PV panels, rain, waves and others with some differences. They can be listed as “Passive House”, “Green House”, “Zero Energy Building”, “and Low Energy Building” and “Off- Grid House”. With current technology, it is much easier to design a “Passive House” by following the energy saving and energy efficiency politics, using the simulation and 3D drawing software. It is possible to simulate the design a building to maximize the energy production and minimize the energy consumption by considering the climate and environment of the related country and energy consumption behaviors of inhabitants.

This thesis can be considered to be the first step of converting an existing house (A student house called Mybox) at university of Stavanger (Norway) to explore how it is possible and how applicable to utilize PV panels and wind turbines to produce the energy demand. This is done by exploring the seasonable changing of energy productions and energy consumptions using predictive analytics i.e. a system dynamics simulation model.

Thesis purpose is to understand the produced, utilized, stored, grid supplied and the total consumed energies during the whole year in hourly time span, in order to prove how applicable the developed hybrid energy production solutions to compensate the energy consumption. The energy efficiency and energy saving applications are not mention on this thesis but it is good to remind that these applications will be as critical and important as energy production systems to utilize the produced energy.

The developed simulation model estimate three issues: (1) the produced energy by two renewable energy resources i.e. solar and wind energy, (2) consumed energy due to lighting, heating, electrical equipment use, (3) utilized energy due to living style i.e. daily, weekend, and yearly holidays consumptions, which also indicate the stored and grid supplied energies. Thus, the system dynamics simulation model using VENSIM PLE simulation package links all three parts together in order to gain the big picture i.e. systemic view of the whole energy system on that specific house. Finally, the simulated results were compared to the actual measurements (production and consumption) to verify and iteratively enhance the simulation model.

The architecture and energy consumption related to the case building were given, beside the information about the procured wind turbine. However, the solar energy system was not selected by the building developer and therefore several design concepts of different design parameters i.e. tilt angles, pitch spacing, were explored using Helioscope package (solar energy production calculator) and the optimal concept was selected. The design parameters were also used to simulate the energy production and mimic the estimated energy production by Helioscope. In order to simulate the solar and wind energy production, the model utilized historical weather data. The main first result of this thesis is that the mismatch between the energy production hours and consumption hours leads to low utilization energy rate e.g. energy is produced with the day but not utilized as students are at school or outside house. Thus, the estimation that are provided by Helioscope are good to solar energy developer, however, the building operators or residential need to match their living style in order to estimate what would be the utilized energy. Second result is simulating the energy utilization over time is effective way to provide recommendations for redesign energy production systems, building concept and may be consumption style. It was concluded that this building needs, five wind turbines beside the installed solar system to achieve the energy demand. Third, the simulation model is also helpful to estimate the need for the storage battery and its utilization rate and what is the expected grid supplied energy. Such information is useful to estimate the payback period of the installed energy systems and energy cash flow.

It is hoped that the developed simulation model can be used later to as energy utilization calculator to estimate produced, utilized, consumed energies for the whole university buildings (University of Stavanger) which could be taken further to be a digital twin to university campus.

Acknowledgement

I came to Norway to study about Offshore Technology to combine Offshore Industrial Management with my mechanical engineering, Welding and Inspection experience and Rope Access Techniques knowledge which contains a lot of adrenalin and used for offshore platforms for maintenance and inspections. As a results of Oils price crises, I chose my lectures about renewable energy resources and tried to choose my projects among renewable energy topics for Offshore and Onshore.

I will be putting my last stones to my education path in University of Stavanger, with this thesis.

I learnt a lot during my master education in Norway just not academic, technique and engineering. I also learnt and pushed my limit ahead to live in a different country with different culture. Even only this experience taught to me adapt myself for different conditions.

There are many people I'd like to thank but I want to start with my supervisor, Associate Professor, Mr. Idriss El-Thalji for his guidance and support before and during master thesis studies. He was always helpful and guided me with his academic and industrial experiences. I am grateful to him for his support during my unmotivated times.

I would like to thank to my family, to my mother Ferda ILKIC, my father Mehmet ILKIC and my brother Hakan ILKIC to support me always for my all decisions in my life before and after even I get bad results and also I'd like to thank to Mr. Hakan SARI and his family who help me a lot my student life in Stavanger.

List of Figures

List of Tables

Nomenclature

ϕ Latitude

δ Declination Angle

n Day of the year

ω Hour Angle

θ_z Zenith Angle

α Altitude

ϒ Surface Azimuth Angle

Υ_S Solar Azimuth Angle

β Slope (Tilt Angle)

N Sunshine (Daylight) Time

θ_i Angle of Incident

ω_s Total Angle between Sunrise and Sunset

H_0 Solar Radiation on Horizontal Surface

I_{SC} Solar Constant

P Power Output

c_p Power coefficient

ρ Density of Air

A Swept Area

u Wind Speed

v_1 Velocity at reference height

v_2 Velocity at required height

z_1 Height of reference point

z_2 Height of required point

α Wind Shear Exponent

c Weibull Distribution scale parameter

k Weibull Distribution shape parameter

List of abbreviations

Abbreviations	**Explanation**
ST	Solar Time
TWh	Tera Watt Hour
PV	Photo Voltaic
CEST	Central European Solar Time
ZEB	Zero Energy Building

1. Introduction

1.1. Problem background

Increasing demand for using renewable energy is bringing new challenges and new opportunities for society, government and companies. The biggest opportunity about green energy is the increasing attention of public and increasing energy cost for inhabitants. As a result of that, inhabitants want to produce their own energy at least to reduce their dependence to their energy provider from Grid-Line. For existing building, reducing energy consumption is more difficult, more time consuming and more expensive than the installation of small size wind turbines and PV panels for houses.

Today, it is getting more important day by day to design Off-Grid houses which produces its own energy by renewable energy resources and have a low energy consumption load for heating and lighting especially.

Designing a building contains many uncertainties. Having experience team members about design and implies the EN standards and other regulations are only way to minimize these uncertainties. Today each EU counties has strict regulations for electrical equipment producers for all electrical components used in the houses and for architectures - engineers to calculate the Energy loads of buildings.

The used engineering equations for designers gives the results for critical maximum and minimum levels and cumulative results for a physical factor. Most of these data are taken from a chart simply at most of the cases in the standards. This easily found data helps designer to choose an equipment or component but does not give how the system will behave when the conditions is changes internally and/or externally. The most important question for System Dynamic is to identify the correct variables and to create a mathematical equations.

Making a mathematical equation can be comparatively easier for mechanical and / or electrical system. But Simulating Energy consumption of a house and Energy production from PV panels and Wind turbines contains two main uncertainty which cannot be found on the standards as an equation or in a chart. These two important and critical variances are “Energy Consumption Behaviors of the Inhabitants” and “Weather Conditions”.

These thesis is prepared to answer the following research questions;

How can the energy production, consumption and utilization of passive housing system may change hourly, daily, weekly, seasonal and yearly changes in both weather conditions (variation in sunlight, cloud and wind speed) and living style e.g. low and high demand periods.

1.2. Objectives

Main objective of the thesis can be listed as,

1) Simulate the hourly variance of the Energy Consumption,
2) Simulate the hourly variance of Photo voltaic Energy and Wind Energy Production for different system configurations,
3) Simulate the hourly variance of Energy Demand from Norwegian Grid Line,
4) Simulate the hourly variance of Battery System,
5) Simulate the different Hybrid System Configurations,
6) Simulate the effects of design variables on PV Energy Production.

1.3. Methodology

After the thesis subject was chosen the academic research were focused on three main topics. They are solar radiation calculation - PV panels, Wind Energy, Passive house - Zero Energy Building concepts and Hybrid Energy Systems with Batteries. Among these subject, solar radiation calculation is the most time consuming headline because of containing more calculations than wind energy production for thesis. Wind energy production contains less calculations as a result of the wind turbine has already been selected. The success of the simulations are depends on the how succeed the mathematical equations of the physical events. For solar radiance calculations only the beam radiation is considered. The Diffuse radiation from ground to the panels and from other building to the panels are ignored.
The total energy consumption values were given at the beginning of the thesis. Unfortunately these data was unable to give me idea about the effect of the heating, lighting, personal usage and energy consumption in the kitchen. In order to solve this problem, self-energy consumption for April was recorded and compared with the given data.

The PV panel alignments are inspected on Helioscope software to see the energy production variance for different tilt angle and row space between panels. At the same time, wind speed records for between 2017-2012 were recorded and analyzed on MATLAB to find the distribution functions for each months. These value are used on VENSIM PLE as random data creator for wind energy production.

VENSIM PLE software is the next chapter of the thesis. The software manual was a helpful tool for self-learning process. First simulation was completed for April which is reference month for Energy Consumption and Solar Radiation. After the success of this short simulation, the simulation is extended for all year. In order to be understandable and easy tracking for the third part users, "Shadow Variable "properties were used often and many sub-system was created.
Once the simulation is completed, the main system inputs has been changed to how the energy production is changed and reported by the graphics.

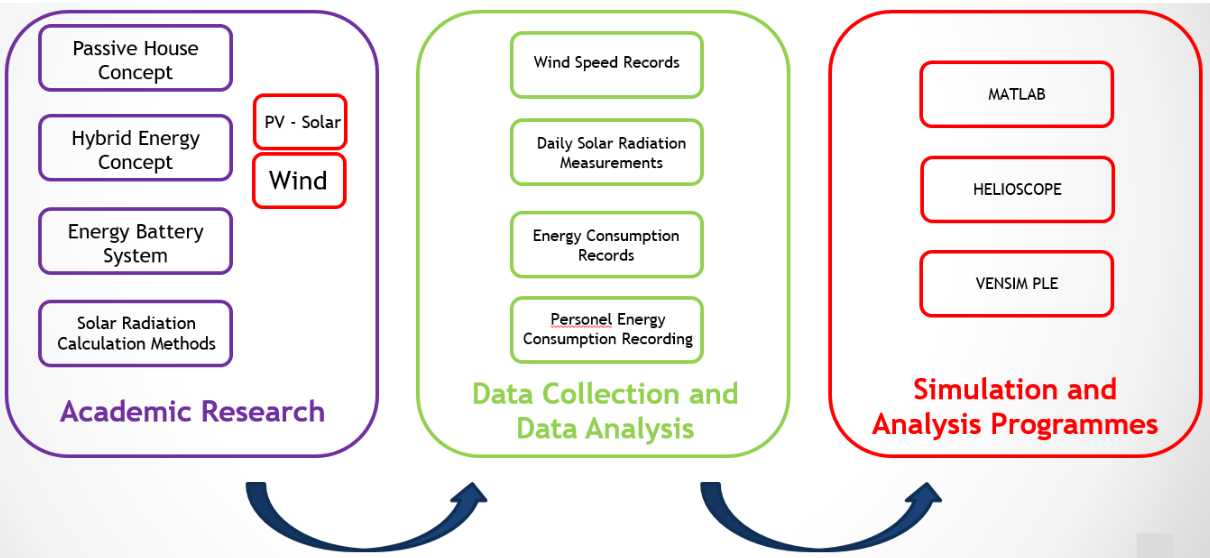


Figure 1. Methodology Diagram for Thesis

1.4. The Structure of the Thesis

Thesis contains four main chapter and Appendix section at the end.

First chapter contains Problem background, Objective of the thesis, Methodology and the structure of the thesis which gives general information about the thesis.

Second chapter contains information about the designed system and its components. The sub-headings are “Passive House concept and Zero Energy Buildings”, “Solar – Wind –Battery Hybrid Energy Concept”, “Solar Energy Calculations”, “Wind Energy Calculations” and “Energy Consumptions”

Third Chapter is where the alternative solutions are assessed to increase the energy production.

Fourth Chapter contains Conclusion, Discussion and Future Research sections

2. Theoretical background and literature review

2.1. Zero Energy Building (ZEB) Concept and Passive House Concept

The basic definition of the Zero Energy concept is to design houses which produces own energy more than its needs by using the renewable energy technologies annually. Other purposes of the Net Zero Energy Building concept are the increase the maintenance of the renewable energy systems and increase the efficiency of the energy production systems. These two goals are directly affect the annual energy production. (U.S. Department of Energy, 2015)

On the other hand, the building energy efficiency is related also to energy consumption. The Net Zero Building Approach and Passive House concept also aim to minimize the energy consumption as well. The standards for Passive House is identified by the “Passive House Institute (Passivhaus Institut)” in Germany. These standards put some limitation about energy consumption for each main energy consumption branch such as heating, HVAC etc.

The main passive house criteria according to the Passivhaus Institut can be listed as (Feist, W. PHPP Handbook, PHI Darmstadt; 2007),

- Theoretical heat demand is cannot exceed more than 15 kWh/m^2 of net living area per year.
- The total energy consumption must not exceed 120 kWh/m^2 per year.

The Passive house criteria is accepted as a standard for new designed buildings for architectures. According to the second condition of the Passive House concept, My Box student house uses between 2.4 and 3 times higher than it should be.

Table 1. Energy Consumption Value for per square meter

Year	Energy Consumption per m^2 (kWh/m^2)
2017	284,87
2016	355,83
2015	369,44

2.2. Solar – Wind Hybrid Energy Systems

Hybrid energy production is an energy production method by combining more than one different renewable energy resources which has different production characteristic as a function of time to have sustainable energy for consumption demand. As a result of that, during the planning and design period of the system, it is important to consider the different energy production characteristic by considering the reliability and cost perfective. (Gang Maa, Guchao Xua, Rong Jua, Tiantian Wua, 2015)

The hybrid energy system can be combination of Photovoltaic (PV), Wind, Hydro, and Biomass. The energy production percentage for hybrid system can vary related to capacity of each renewable system and energy consumptions behavior (Lazarov, Notton, Zarkov, Bochev, 2005). Among these energy resources, wind energy and PV energy have the largest potential but have limitations of intermittency and volatility which may result with the poor reliability of power supply. (Gang Maa, Guchao Xua, Rong Jua, Tiantian Wua, 2015)

In order to increase the reliability and sustainability of the complete energy production system, Hybrid system can be supported by battery if the energy production is higher than the energy consumption in a period of service time.

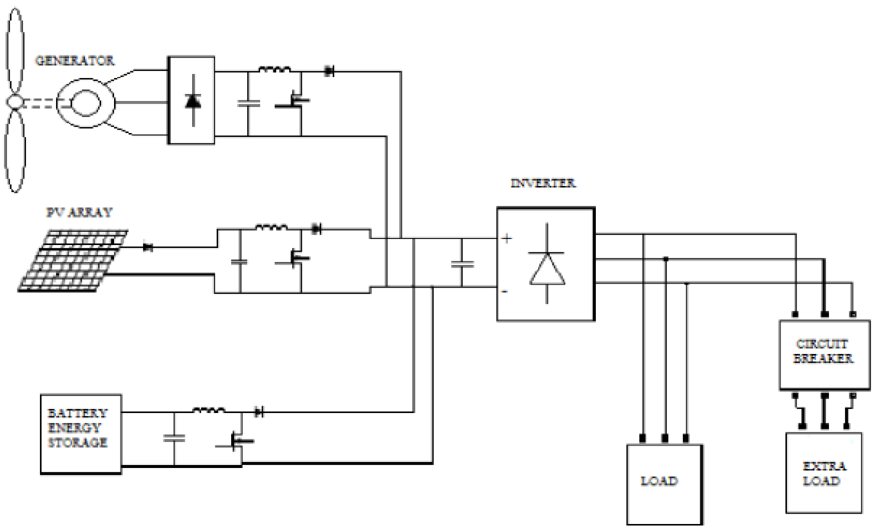


Figure 2. Configuration of Hybrid Energy System designed on the VENSIM PLE (Marisarla, Kumar, 2013)

3. Data Collection and Analysis

3.1. MY BOX Student House

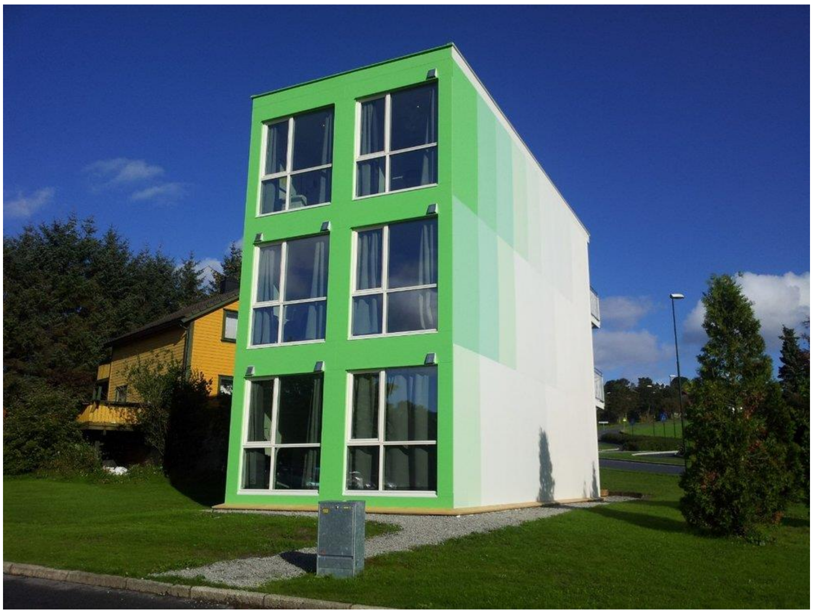


Figure 3 Front View of My Box Student House

My Box student house is one of the student house inside the University Of Stavanger (UIS), Ullandhaug Campus in Stavanger, Norway. The student house was opened in 2013 by using the container materials and on the container size. There are five inhabitants in 2017-2018 academic year.

Table 2. Coordinates of My Box Student House

Latitude (ϕ)	58,93 North
Longitude	5,69 East

Figure 4 Sketch of My Box Student House from North View

Figure 5 Architectural Sketches of Third Floor and First Two Floor

3.2. Weather Condition Data

The weather condition data contains the wind speeds records from “yr.no” and solar radiation measurement from “meteoblue.com” website which is the only solar radiation measurement data provider for Stavanger region.

The wind speed data is used to make the Weibull distribution functions for each month by considering the last five years measurements which is set as Table 21. Solar radiation measurements for reference months (April, May and June) are shown with Figure 13, Figure 14 and Figure 15. The values are used to calculate the average solar radiation value one day for clean and cloudy sky. The results are listed on Table 11 and Table 12.

3.3. House Consumption Data

The first two rows of given on Table 3 is the only data received during the thesis preparation. The data contains measurement time, counter value. By considering the number of the two measurement day, daily average consumption and individual daily average are calculated and added to table 3.

Table 3. Measurement of the Energy Consumption for My Box

Measured Date	Counter Value	Differences	Number of Days	Daily Average Consumption (kWh)	Individual Daily Average Energy Consumption (kWh)
01/03/2014	25055	0	0	-	-
6/2/2014	31738	6683	93	71.86	14.37
6/30/2014	34140	2402	28	85.79	17.16
9/1/2014	37925	3785	63	60.08	12.02
11/3/2014	43330	5405	63	85.79	17.16
12/1/2014	46377	3047	28	108.82	21.76
1/5/2015	50310	3933	35	112.37	22.47
3/2/2015	57647	7337	56	131.02	26.20
5/4/2015	65635	7988	63	126.79	25.36
6/1/2015	68344	2709	28	96.75	19.35
8/3/2015	73440	5096	63	80.89	16.18
9/1/2015	75545	2105	29	72.59	14.52
10/1/2015	78408	2863	30	95.43	19.09
11/1/2015	82401	3993	31	128.81	25.76
1/4/2016	90948	8547	64	133.55	26.71
2/1/2016	94850	3902	28	139.36	27.87
3/1/2016	99186	4336	29	149.52	29.90
4/4/2016	103860	4674	34	137.47	27.49
5/2/2016	107522	3662	28	130.79	26.16
6/3/2016	110459	2937	32	91.78	18.36
7/4/2016	113622	3163	31	102.03	20.41
8/3/2016	115888	2266	30	75.53	15.11
10/3/2016	118532	2644	61	43.34	8.67
11/1/2016	122838	4306	29	148.48	29.70
12/1/2016	125731	2893	30	96.43	19.29
1/2/2017	130089	4358	32	136.19	27.24
3/1/2017	138985	8896	58	153.38	30.68
4/3/2017	144104	5119	33	155.12	31.02
5/2/2017	147545	3441	29	118.66	23.73
6/1/2017	150593	3048	30	101.60	20.32
7/3/2017	153350	2757	32	86.16	17.23

8/2/2017	155819	2469	30	82.30	16.46
9/1/2017	159008	3189	30	106.30	21.26
10/2/2017	161385	2377	31	76.68	15.34

3.4. Solar Energy

3.4.1 Solar Radiation Theory

According to the International Energy Agency Report in 2011 and International Energy Agency Current Policies Scenario, The amount of the energy which is radiated from the Sun and reached to the surface of the planet Earth in one year is about 885 million terawatt hours (TWh). This amount is 6200 times more than what is needed by all population in the world in 2008 and 4200 time more than the level of energy which will be needed in 2035. (International Energy Agency, 2011)
Figure 6 from National Petroleum Council, 2007, shows the comparison of the total amount of energy capacity for different resources and annual global energy consumptions.

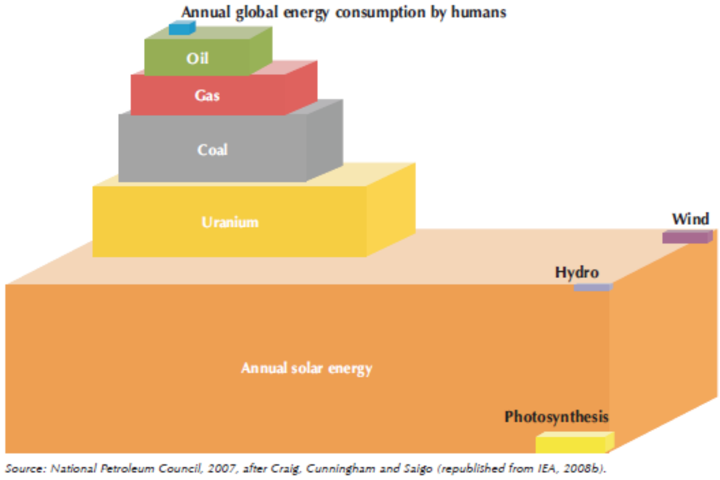


Figure 6. Comparison of different energy resources capacity and annual global energy consumption (National Petroleum Council, 2007)

This amount of energy is the results of nuclear fusion reaction which converts the 4 million tonnes of matter into the energy each second. (Bolonkin A., Friedlander J., 2013)

This reaction can be written as (Tiwari G.N., 2002),

$$4(\,_1H^1) \rightarrow \,_2He^4 + 26.7\ MeV \qquad (2.1)$$

Even though, the sun diffuse this energy to the planet Earth continuously and theoretically 10.8 billion year more (Bolonkin A., Friedlander J., 2013), only around 51 % of the energy reaches to the surface of the planet Earth. According to the Nahar, % 30 of the energy is lost in the space (20 % reflected back to the space by clouds, 6% scattered upward by air and 4 % reflected by Earth itself), 19 % is absorbed by the atmosphere (16 % absorbed by gases and dust, 3% absorbed by clouds) (Nahar, 2008)
This percentages will be varied by the Earths elliptical orbit which varies between January 3rd as minimum and July 3rd as maximum by about 3.4 % (Stamnes K., Stamnes J., 2008) This variable is accepted as a constant for all months in the VENSIM simulation as % 60 of solar radiation by considering the effect of diffusion energy from other buildings and environment.

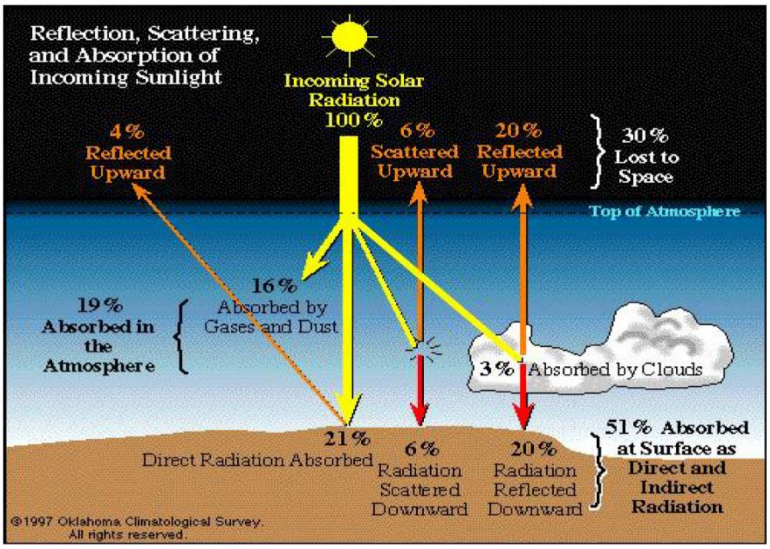


Figure 7. Reflection, Scattering and Absorption of the Incoming Sunlight (Oklahoma Climatological Survey, 1997)

3.4.2. Sun – Earth Angles

3.4.2.1 Latitude (φ)

The latitude of a location is the angle made by the radial line with its projection on the equatorial plane. The latitude is positive for Northern hemisphere and negative for southern hemisphere. (Tiwari G. N., 2002) The Latitude varies between -90 ° (Southern Hemisphere) and + 90 ° (Northern Hemisphere)

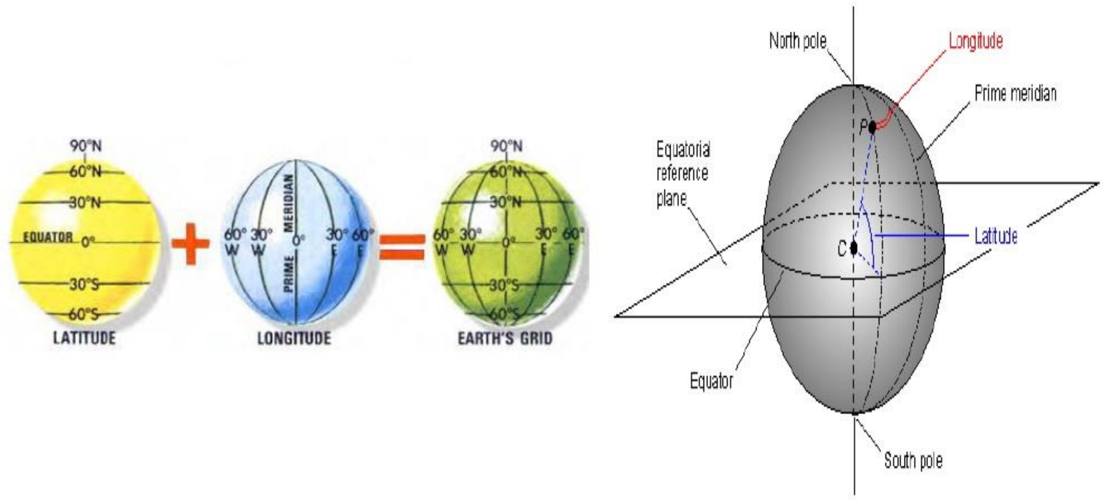


Figure 8. Latitude, Longitude and The Representation of one point on the planet by its Latitude and Longitude (Mesut Abuska, Solar Energy, 2017)

3.4.2.2. Declination Angle (δ)

According to the Tiwari, The Declination angle is the angle between the line joining the centers of the sun and the earth and its projection on the equatorial plane. The declination angle varies between -23.45 ° as minimum on 21 December and +23.45° as maximum on June 21 for northern hemisphere. The declination angle can be calculated by the equation below for every day.

$$\delta = 23.45 \sin\left[\frac{360}{365}(284 + n)\right] \qquad (2.2)$$

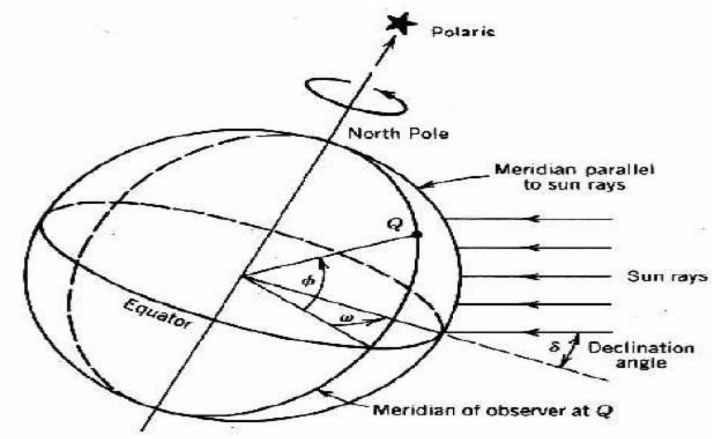


Figure 9. Figure of Declination Angle on the Planet of Earth (Shadi Albarqouni, Mohammed Tawfik Hussein, 2010)

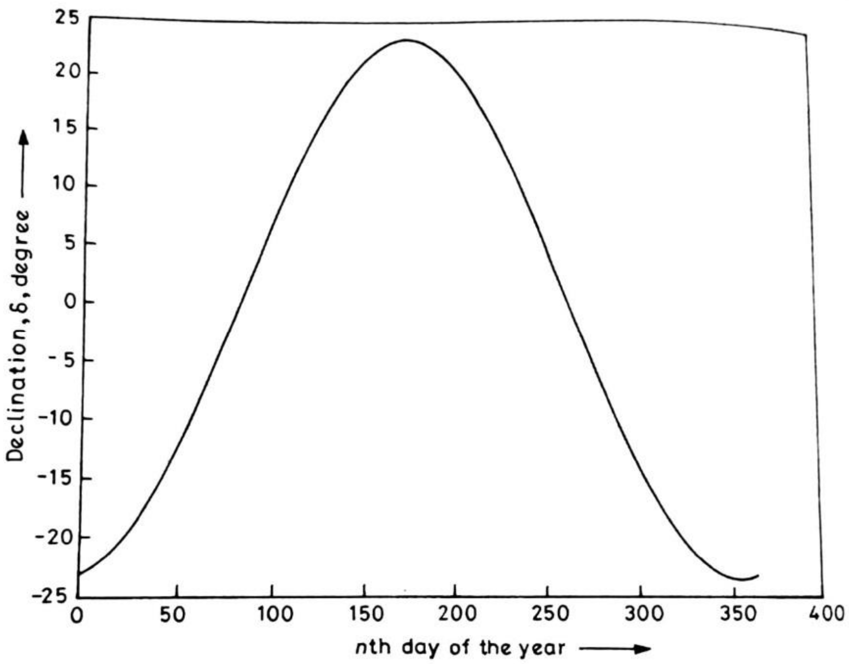


Figure 10. Variation of the Declination angle with the nth day of the year (Tiwari G.N., 2002)

Table 4. The declination angle values of the average days for each months (Tiwari G.N., 2002)

Month	Date	Day of the Average days of the month	Declination Angle (δ)
January	17	17	-20.9
February	16	47	-13.0
March	16	75	-2.4
April	15	105	9.4
May	15	135	18.8
June	11	162	23.1
July	17	198	21.2
August	16	228	13.5
September	15	258	2.2
October	15	288	-9.6
November	14	318	-18.9
December	10	344	-23.0

3.4.2.3. Hour Angle (ω)

Hour angle is the angular displacement of the sun east or west of the local meridian, due to the rotation of the earth on its axis at 15 ° per hour. (Tiwari G.N., 2002)

For any specific solar time (ST), the hour angle can be calculated as,

$$\omega = (ST - 12)\ 15^{o} \qquad (2.3)$$

Table 5. Hour angle values for each solar time used by the VENSIM Simulation (Tiwari G.N., 2002)

The Value of hour angle with time of the day (Northern Hemisphere)							
Time of the day (hours)	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Hour Angle (degree)	-90	-75	-60	-45	-30	-15	0
Time of the day (hours)	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Hour Angle (degree)	0	15	30	45	60	75	90

3.4.2.4. Zenith (θ_z)

It is the angle between suns ray and perpendicular line to the horizontal plane. (Tiwari G.N., 2002)

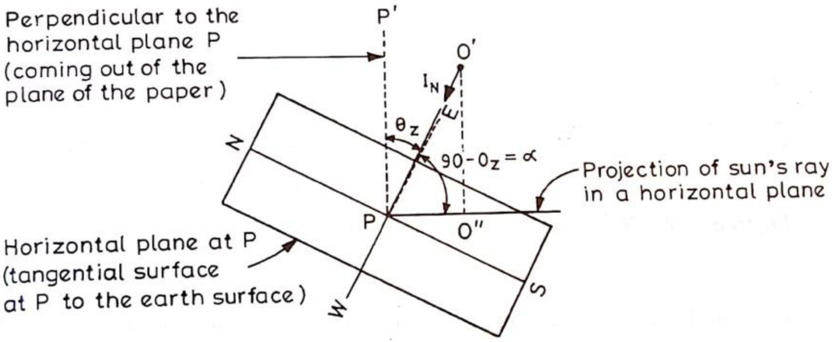


Figure 11. View of Zenith Angle (Tiwari G.N., 2002)

3.4.2.5. Altitude (α)

Altitude is the angle between suns ray and a horizontal plane. (Tiwari G.N., 2002)

The geometric relation between Zenith and Altitude can be shown as,

$$\alpha = 90 - \theta_z \qquad (2.4)$$

3.4.2.6. Surface Azimuth Angle (ϒ)

It is the angle in the horizontal plane, between the line due south and the projection of the normal to the surface (inclined plane) on the horizontal plane. (Tiwari G.N., 2002) The PV Panels must be installed as sloped to the south if the longitude of the project area is on the northern hemisphere. (Jayanta Deb Mondola, Yigzaw G. Yohanisa, Brian Norton, 2006)

Table 6. Surface azimuth angle for various orientation in the Northern hemisphere (Tiwari G.N., 2002)

Surface Orientation	ϒ
Sloped towards South	0°
Sloped towards North	-180 °
Sloped towards East	-90 °
Sloped towards West	+90 °
Sloped towards South- East	-45 °
Sloped towards South- West	+90 °

3.4.2.7. Slope (β)

Slope angle is used as Tilt angle to shown the angle between the surface (PV Panel) and the horizontal surface where the panel is mounted. The optimum tilt angle value will be changing regularly for each month, As a result of that choosing an optimum tilt angle for all year is critical for producing maximum energy from system. Tilt angle is an important parameter for shading effect also if PV Panels are installed one after another. The yearly optimum slope (tilt) angle can be found by using longitude (ϕ) of the project area as (Olcay Kincal, Solar Energy Lecture Notes, 2017)

$$\beta = 0{,}9\,\Phi \qquad (2.5)$$

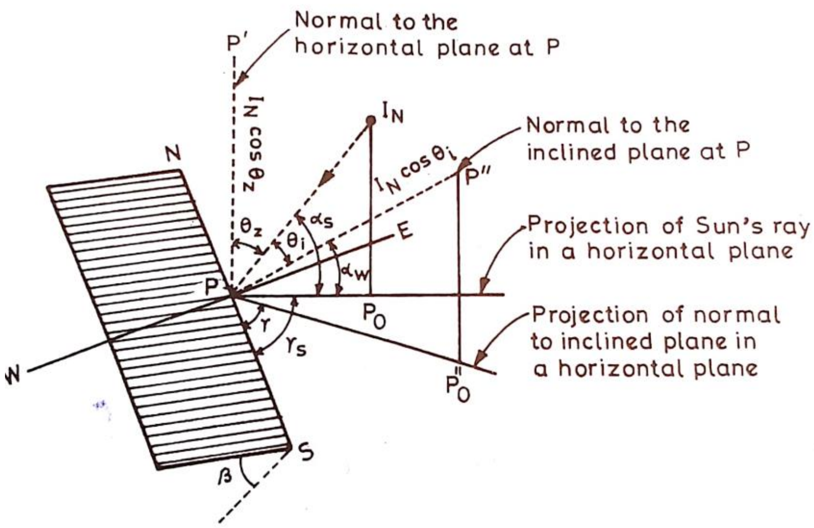


Figure 12. View of Slope (β), Surface Azimuth (ϒ) and Incident Angle (θ_i) (Tiwari G.N., 2002)

3.4.2.8. Sunshine (Day Light)

Daylight (N) value is the time between sunrise and sun set. The Daylight value can be calculated by,

$$N = \frac{2}{15}\, cos^{-1}\,(-\tan\Phi \tan\delta) \qquad (2.6)$$

Table 7. Calculated and Measured Day Time Values for Latitude of My Box Student House, Stavanger (Decimally)

Month	Calculated Day Time (Hour)	Measured Day Time (Hour)
January	6.8	7
February	9	9.2
March	11.46	11.75
April	15	14.5
May	16.6	16.54
June	18	18.5
July	17.3	17.75
August	15.1	15.5
September	12.5	13
October	9.8	10.35
November	7.4	7.75
December	6	6.25

Table 8. Sun Rise and Sun Set Hours for Reference Days

Reference Day of the Month		Sun Rise Time (h:m)	Sun Set Time (h:m)	Differences (h:m)
January	17	09:14	16:20	07:06
February	16	08:09	17:34	09:25
March	16	06:50	18:41	11:50
April	15	06:24	20:51	14:27
May	15	05:06	22:01	16:55
June	11	04:26	04:26	18:21
July	17	04:53	22:31	17:38
August	16	05:58	21:23	15:25
September	15	07:05	19:51	12:51
October	15	08:13	18:30	10:17
November	14	08:23	16:16	07:50
December	10	09:18	15:40	06:22

3.4.2.9 Angle of Incident (θ_i)

It is the angle between beam radiation on surface and the normal to that surface.
General formulations for Angle of incident can be shown by Tiwari as,

$$\cos\theta_i = (\cos\phi\ cos\beta + sin\phi\sin\beta\cos\Upsilon)\cos\delta\cos\omega + \cos\delta\sin\omega\sin\beta\sin\Upsilon + \sin\delta\,(\sin\phi\cos\beta - cos\phi\sin\beta\ cos\Upsilon) \quad (2.7)$$

The general formulation for angle of incident can be simplified if the surface facing to the south, ϒ=0 (Table 6)

$$\cos\theta_i = (\cos(\phi - \beta)\,)\cos\delta\cos\omega + \sin\delta\sin(\phi - \beta) \quad (2.8)$$

For a horizontal plane facing to the south, ϒ=0, β=0, $\theta_i = \theta_z$

$$\cos\theta_z = \cos\phi\ cos\delta\cos\omega + \sin\delta\sin\phi \quad (2.9)$$

According to the Tiwari, the equation 1.8 can be solved for the sunset hour angle $\omega = \omega_s$ for $\theta_z = 90\,°$

$$0 = \cos\phi\cos\delta\cos\omega_s + \sin\phi\sin\delta \quad (2.10)$$

ω_s is the total angle between sunrise and sunset.

2.4.2.10 Solar Azimuth Angle (Υ_S)

Solar Azimuth angle is the angle between the north or south position of the sun and the direct solar radiation. (Karafil, Kesler, Parmaksiz, 2014)

$$\Upsilon_S = cos^{-1}[(\sin\alpha\ \ sin\phi - sin\delta)/(\cos\alpha\cos\phi)] \quad (2.11)$$

3.4.3. Solar Radiation Data for Stavanger Area

In order to simulate the energy production by using solar irradiation on VENSIM, The solar irradiance must be converted to a mathematical equations for each months. As this can be seen on Figure 13, Figure 14 and Figure 15, the Solar Irradiance between sun set and sun rise behaves like a proper bell shape for each months when the sky is clean for April and May.

Conversely Solar Irradiance behavior on a clear sky, the shade effect of clouds on Solar Irradiance comparatively non – regular. The days are eliminated related to clean sky days and % 100 cloudy days to create the mathematical equations for both of the situations. On VENSIM Simulations the days are assigned as either clear sky or % 100 cloudy sky according to the cloud probability of each months which is assigned by previous year data for Stavanger.

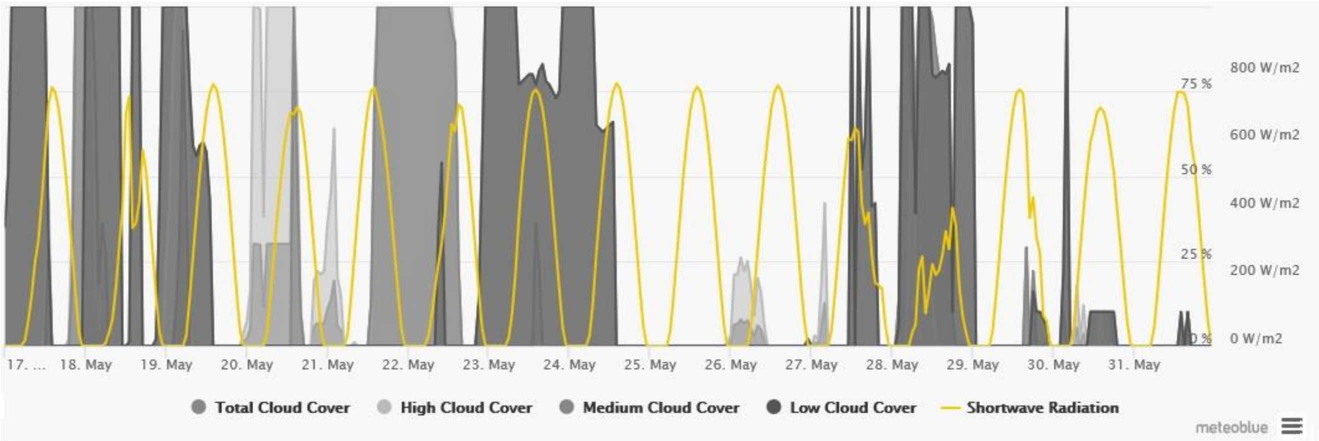


Figure 13. Solar Irradiance Measurement for Stavanger between 17th and 31st May (meteoblue.com)

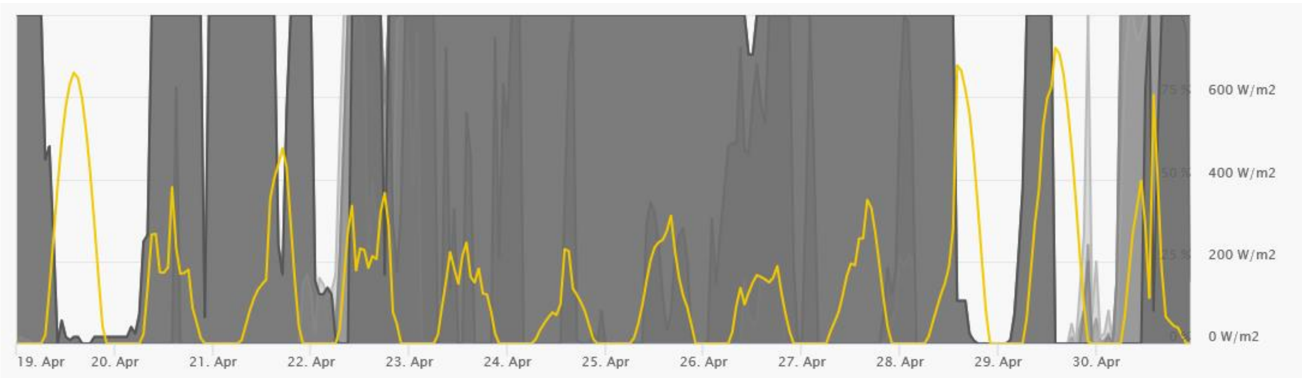


Figure 14. Solar Irradiance Measurement for Stavanger between 19th and 30th April (meteoblue.com)

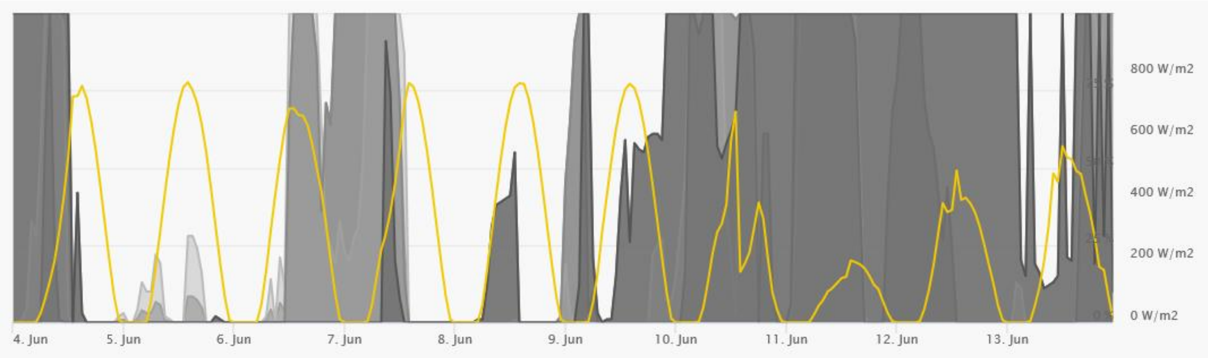


Figure 15. Solar Irradiance Measurement for Stavanger between 4 th and 13th June (meteoblue.com)

Table 9. Solar Irradiation Values in April for Clean Sky Days

Hour	Full clear sky 1 (Watt/m2)	Full clear sky 2 (Watt/m2)	Average Value for clean sky day
6	0	0	0
7	20,5	3,6	12,05
8	130,8	96,1	113,45
9	257,2	226,1	241,65
10	382,7	349,8	366,25
11	492,2	458,4	475,3
12	577,6	546,5	562,05
13	632,8	602,5	617,65
14	659,5	626,6	643,05
15	646,1	618,8	632,45
16	596,3	569,6	582,95
17	516,2	491,3	503,75
18	413,9	394,3	404,1
19	291,9	274,1	283
20	162	142,2	152,1
21	40,9	22,3	31,6
22	0	0	0

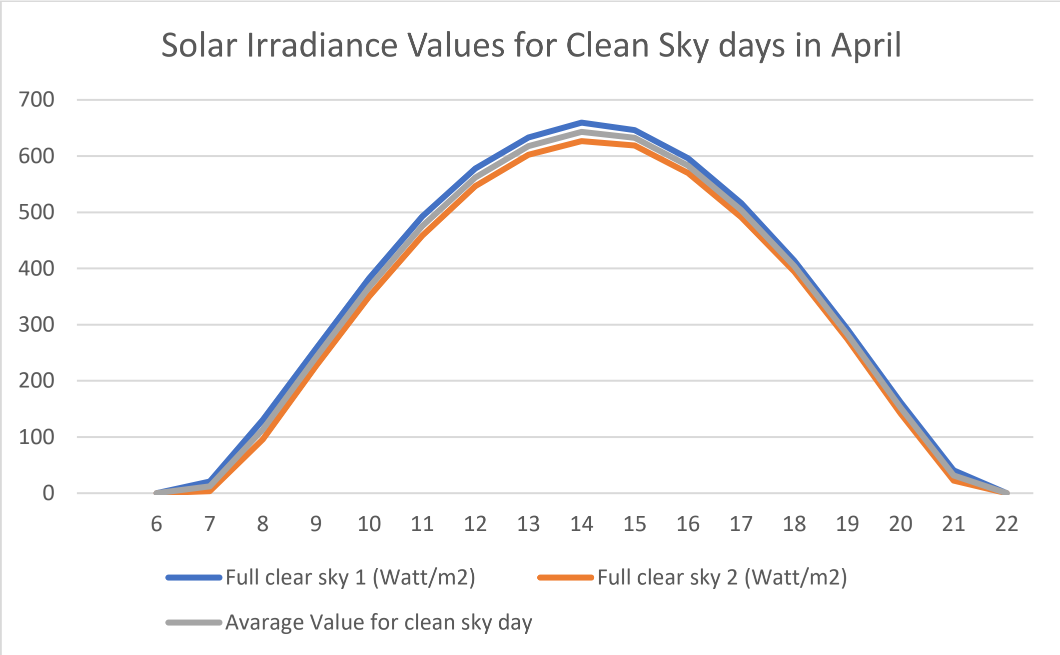


Figure 16. Solar Irradiance Variation between Sun Rise and Sun Set in Clear Sky Days in April

Table 10. Solar Irradiation Values in April for % 100 Cloudy Sky in April

Hour	%100 cloudy sky 1 (Watt/m2)	%100 cloudy sky 2 (Watt/m2)	%100 cloudy sky 3 (Watt/m2)	%100 cloudy sky 4 (Watt/m2)	%100 cloudy sky 5 (Watt/m2)
6	0	0	0	0	0
7	8	31,2	0	39,2	36,5
8	38,3	108,6	31,2	90,8	113
9	40,1	166,4	80,1	146,9	113
10	65	186	121	167,3	164,7
11	170	190,5	159,3	156,6	203,8
12	170,9	151,3	186,9	145,1	232,3
13	200,3	161,1	194,9	152,2	249,2
14	211,8	161,1	178	162	255,4
15	227	200,3	185,1	156,6	256,3
16	213,6	156,6	178,9	148,6	349,8
17	170	116,6	163,8	160,2	330,2
18	139,7	92,6	138	188,7	267,9
19	100,6	67,6	105	124,6	189,6
20	53,4	81,9	60,5	73	108,6
21	10,7	28,5	8	29,4	39,2
22	0	0	0	0	0

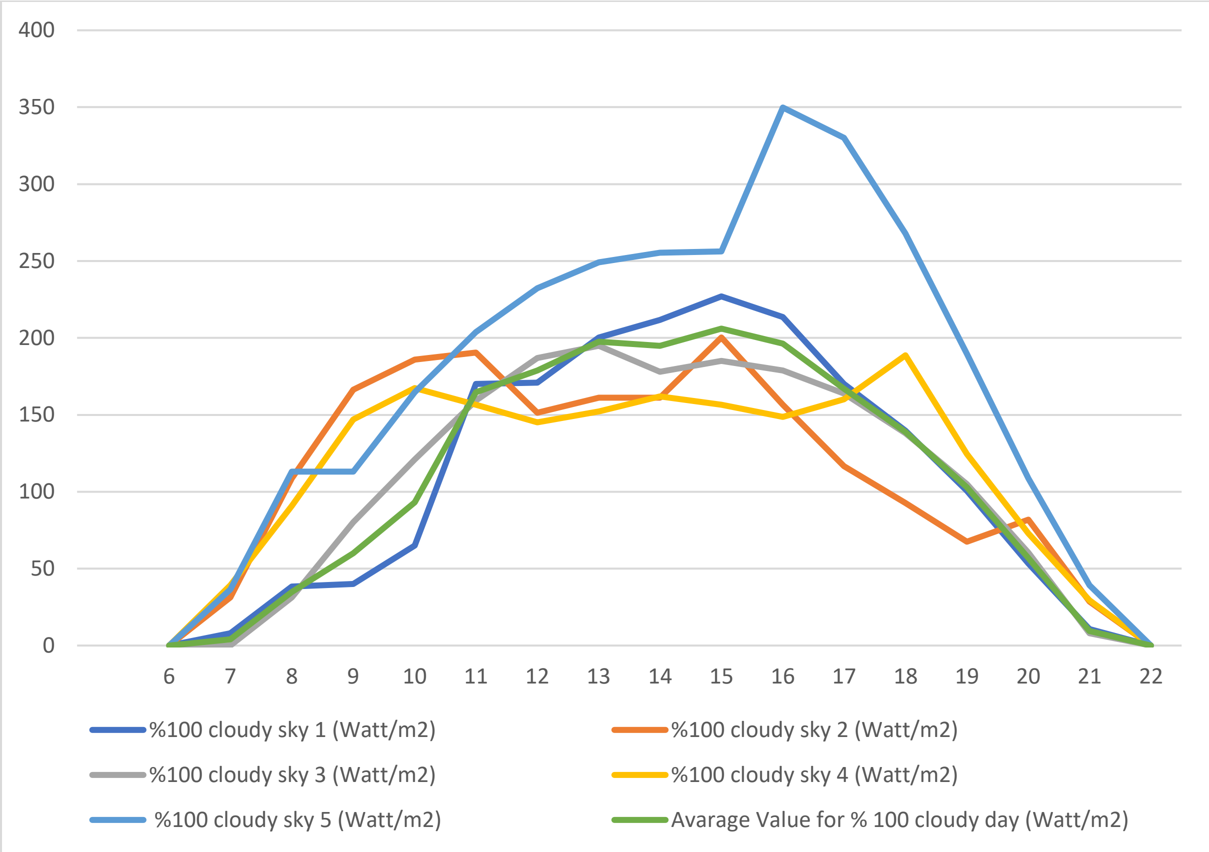


Figure 17. Solar Irradiance Variation between Sun Rise and Sun Set in % 100 Cloudy Sky Days in April

3.4.4. Solar Radiation Equations

The equations for months were calculated on MATLAB to take integral between the sun rise and sun set values of the reference day for each month.

$$y_{cloud_{April}} = 218.98 * e^{\left[-1\left(\frac{(x-14.41)^2}{(2*3.44^2)}\right)\right]} \quad (2.12)$$

$$y_{clean\_sky_{April}} = 689.95 * e^{\left[-1\left(\frac{(x-14.14)^2}{(2*3.49^2)}\right)\right]} \quad (2.13)$$

Total Average Solar Irradiance for clean sky and %100 cloudy sky can be calculated as shown,

$$H_{cloud_{April}} = \frac{\int_{sunrise}^{sun\ set} y_{cloud_{April}}}{(Sun\ Rise - Sun\ Set)} \quad (2.14)$$

$$H_{clean\_sky_{April}} = \frac{\int_{sunrise}^{sun\ set} y_{clean\_sky_{April}}}{(Sun\ Rise - Sun\ Set)} \quad (2.15)$$

Table 11. Average Solar Irradiance Value for April and May for both case

Month	Average Solar Radiation in Clean Sky (watt/m2)	Average Solar Radiation in %100 Cloudy Sky (watt/m2)
April	**334.54**	**122.46**
May	**406.25**	**245**
June	**423.23**	**244.02**

3.4.5. Theoretical Solar Irradiation Calculation for Reference Day of April

According to the Tiwari, The total solar radiation to a horizontal surface in the absence of atmosphere in one day can be calculated as,

$$H_0 = \frac{24 \, x \, 3600}{\pi} I_{SC} \left[1 + 0.033 \cos\left(\frac{360 \, n}{365}\right)\right]\left(\cos\phi \cos\delta \sin\omega_s + \left(\frac{2 \, \pi \, \omega_s}{360}\right) \sin\phi \sin\delta\right) \qquad (2.16)$$

I_{SC} The solar constant with value of 1367 ${}^{watt}/_{m^2}$

Table 12. Calculated values for Average Solar Radiation Values and Comparison for April and May

Month	Solar Radiation Calculation (Open Sky) (watt/m2)	Measured Average Solar Radiation (Open Sky) (watt/m2)	Differences Between Calculation and Measured Values (watt/m2)
January	**94.8**	**-**	**-**
February	**166**	**-**	**-**
March	**251.7**	**-**	**-**
April	**328.05**	**334.54**	**% 1.93**
May	**383.02**	**406.25**	**% 5.72**
June	**405.3**	**423.23**	**% 4.37**
July	**377**	**-**	**-**
August	**357**	**-**	**-**
September	**280**	**-**	**-**
October	**194.1**	**-**	**-**
November	**106.2**	**-**	**-**
December	**83.3**	**-**	**-**

As seen Table 12, the measured average solar radiation and calculated average radiation has close results to each other. The calculated average values and sun set and sun rise times for each reference day of the month are used to create the solar radiation equations on MATLAB for other months.

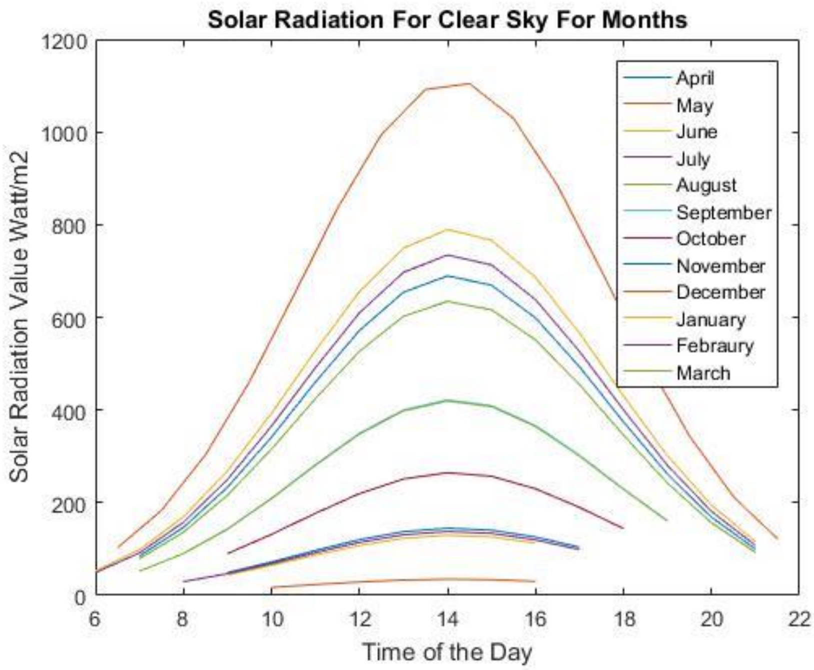


Figure 18. Solar Radiation Chart for Clear Sky

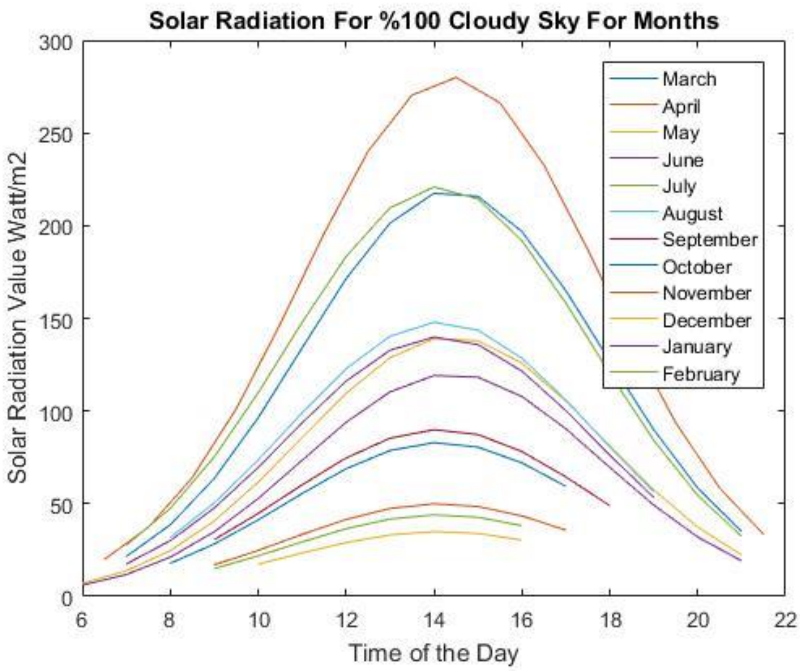


Figure 19. Solar Radiation Chart for % 100 Cloudy Sky

3.4.6. Analysis by Using Helioscope Software for Optimum PV Panel Alignment

In order to find the optimum PV panel alignment to the roof of the My Box student house, Helioscope simulation software has been used on internet. This software help user to choose the related area where the PV panels will be installed, to see the results for different Tilt angle, azimuth angle and to see the shade effect of modules to each other and other physical obstacles like houses and trees.

Totally 20 different PV Panel alignment have been investigated by changing the tilt angle, azimuth angle, distance between panels.

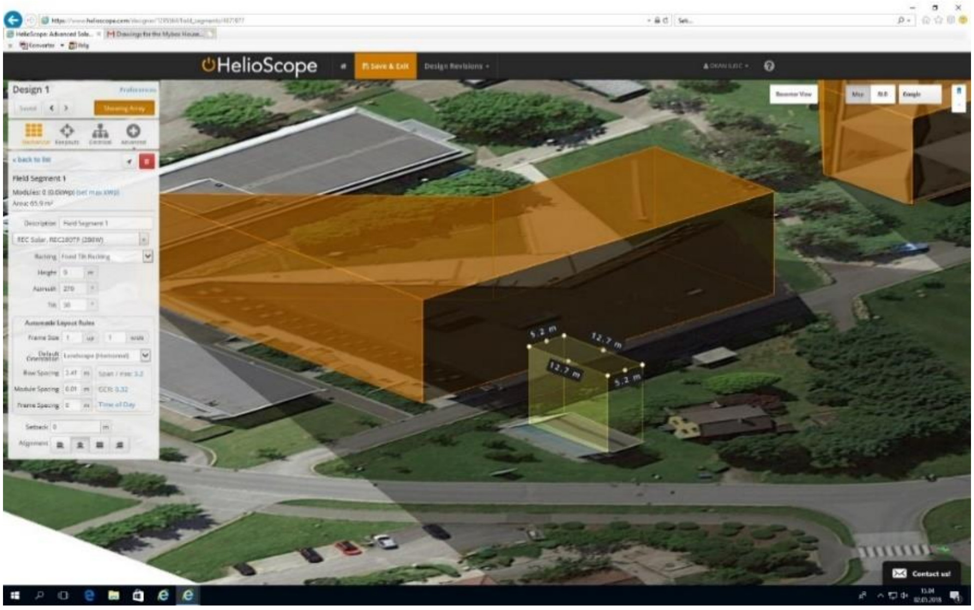
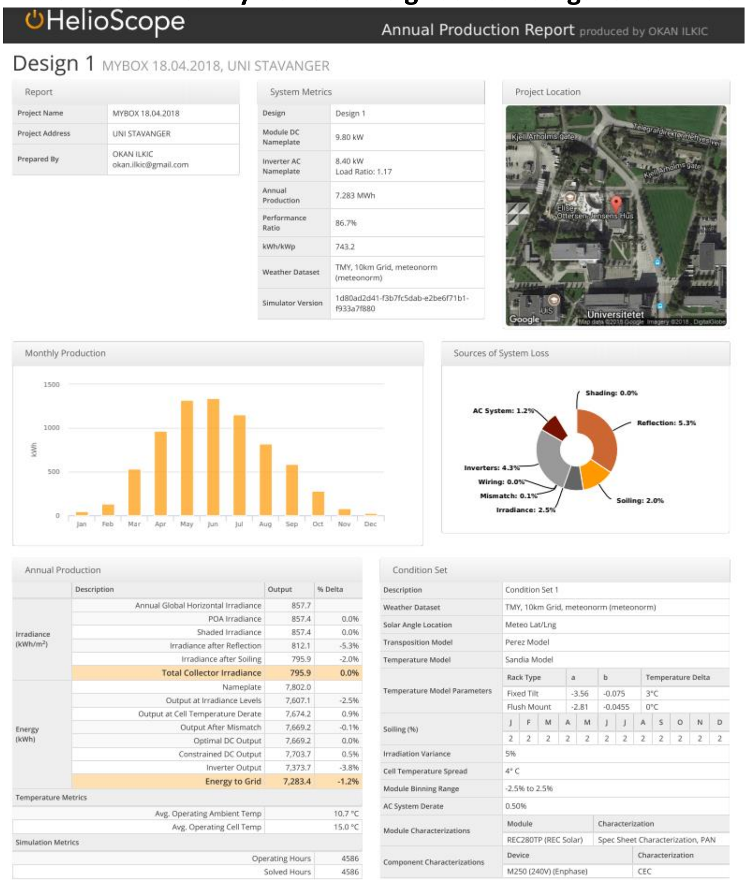


Figure 20. 3D sketch of My Box and Neighbor buildings for Shade analysis



HelioScope — Annual Production Report produced by OKAN ILKIC

Design 1 MYBOX 18.04.2018, UNI STAVANGER

Report	
Project Name	MYBOX 18.04.2018
Project Address	UNI STAVANGER
Prepared By	OKAN ILKIC okan.ilkic@gmail.com

System Metrics	
Design	Design 1
Module DC Nameplate	9.80 kW
Inverter AC Nameplate	8.40 kW Load Ratio: 1.17
Annual Production	7.283 MWh
Performance Ratio	86.7%
kWh/kWp	743.2
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Simulator Version	1d80ad2d41-f3b7fc5dab-e2be6f71b1-f933a7f880

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	857.7	
	POA Irradiance	857.4	0.0%
	Shaded Irradiance	857.4	0.0%
	Irradiance after Reflection	812.1	-5.3%
	Irradiance after Soiling	795.9	-2.0%
	Total Collector Irradiance	**795.9**	**0.0%**
Energy (kWh)	Nameplate	7,802.0	
	Output at Irradiance Levels	7,607.1	-2.5%
	Output at Cell Temperature Derate	7,674.2	0.9%
	Output After Mismatch	7,669.2	-0.1%
	Optimal DC Output	7,669.2	0.0%
	Constrained DC Output	7,703.7	0.5%
	Inverter Output	7,373.7	-3.8%
	Energy to Grid	**7,283.4**	**-1.2%**
Temperature Metrics			
	Avg. Operating Ambient Temp		10.7 °C
	Avg. Operating Cell Temp		15.0 °C
Simulation Metrics			
	Operating Hours		4586
	Solved Hours		4586

Condition Set

Description	Condition Set 1											
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)											
Solar Angle Location	Meteo Lat/Lng											
Transposition Model	Perez Model											
Temperature Model	Sandia Model											
Temperature Model Parameters	Rack Type	a	b	Temperature Delta								
	Fixed Tilt	-3.56	-0.075	3°C								
	Flush Mount	-2.81	-0.0455	0°C								
Soiling (%)	J	F	M	A	M	J	J	A	S	O	N	D
	2	2	2	2	2	2	2	2	2	2	2	2
Irradiation Variance	5%											
Cell Temperature Spread	4° C											
Module Binning Range	-2.5% to 2.5%											
AC System Derate	0.50%											
Module Characterizations	Module	Characterization										
	REC280TP (REC Solar)	Spec Sheet Characterization, PAN										
Component Characterizations	Device	Characterization										
	M250 (240V) (Enphase)	CEC										

Figure 21. Pdf report of Helioscope simulation software for one case

Table 13. Different PV panel alignment and results after simulation by Helioscope

	TILT	DISTANCE	AZIMUT	NUMBER OF PANEL	ENERGY (kwh)	Racking Type	Orientation	Energy/ panel
CASE 1	50	0.8	180	35	6547	Fixed Tilted	Portrait (Vertical)	187.1
CASE 2	50	1.5	180	25	5008	Fixed Tilted	Portrait (Vertical)	200.3
CASE 3	45	1	180	30	5311	Fixed Tilted	Portrait (Vertical)	177.0
CASE 4	30	1	180	25	5308	Fixed Tilted	Portrait (Vertical)	212.3
CASE 5	15	1	180	25	5667	Fixed Tilted	Portrait (Vertical)	226.7
CASE 6	0	1	180	25	5219	Fixed Tilted	Portrait (Vertical)	208.8
CASE 7	0	0	180	35	7283	Fixed Tilted	Portrait (Vertical)	208.1
CASE 8	15	0	90	36	5566	Fixed Tilted	Portrait (Vertical)	154.6
CASE 9	30	0	90	40	7714	East- West	Portrait (Vertical)	192.9
CASE 10	45	0	90	50	8572	East- West	Portrait (Vertical)	171.4
CASE 11	45	0	90	48	7380	East- West	Horizontal	153.8
CASE 12	0	0	0	36	7468	Fixed Tilted	Horizontal	207.4
CASE 13	15	0	0	39	6524	Fixed Tilted	Horizontal	167.3
CASE 14	30	1	0	21	2854	Fixed Tilted	Horizontal	135.9
CASE 15	45	1	0	24	2313	Fixed Tilted	Horizontal	96.4
CASE 16	15	0.4	270	28	5554	Fixed Tilted	Horizontal	198.4
CASE 17	15	0.2	180	33	7079	Fixed Tilted	Horizontal	214.5
CASE 18	30	0.2	180	36	6739	Fixed Tilted	Horizontal	187.2
CASE 19	45	0.3	180	39	6513	Fixed Tilted	Horizontal	167.0
CASE 20	50	0.8	180	27	5520	Fixed Tilted	Horizontal	204.4

3.4.7. Efficiency Factor for Tilt Angle & Azimuth Angle

PV Panels can be installed in many ways such as fixed tilt angle and solar tracking systems. (S.A. Sharaf Eldin, M.S. Abd-Elhady, H.A. Kandil, 2016) In some cases, the solar tracking systems are not chosen because of the system complexity, higher investment cost and complexity. Also the Solar Irradiances between solar tracking and fixed tilt angle does not change extremely. As a result of that, the fixed tilt angle system are used more frequently than solar tracking systems. (S.A. Sharaf Eldin, M.S. Abd-Elhady, H.A. Kandil,2016)

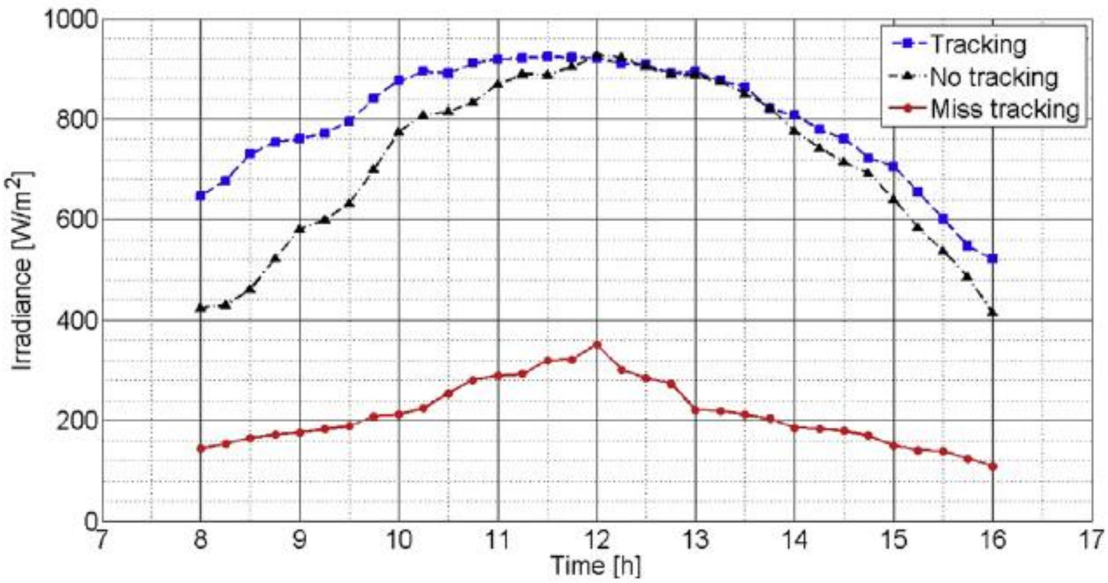


Figure 22. Solar Irradiance measurements on 15th July 2013 in Cairo for No Tracking (Fixed Tilt Angle), Tracking and Miss Tracking Systems (S.A. Sharaf Eldin , M.S. Abd-Elhady , H.A. Kandil, 2016)

Solar radiation and solar is a function of the time and It is changing regularly from hour to hour in a one year period. Even though fixed tilt angle reduces the investment cost, it is much important to identify the optimum tilt angle and azimuth angle.

PV panels on the northern hemisphere should look at the south as the azimuth angle (ϒ) is zero. In some cases, the buildings, trees and other physical obstacles may avoid to apply to use optimum tilt angle and azimuth angle (Mondol J., Yohanisa Y.G., Norton B, 2006)

For the countries which has high solar energy resources, many academic researchers were completed by processing the measurement data and mathematical calculations. After this researches, the optimum tilt and azimuth angles can be easily read from the prepared manuals and PV panel installation completed according to the prepared charts.

As a result of that, in order to calculate the effect of the tilt and azimuth angle to solar radiation to the PV panel, one co-efficient factor can be used by multiplying with solar radiation to the horizontal surface. (Mondol J., Yohanisa Y.G., Norton B, 2006)

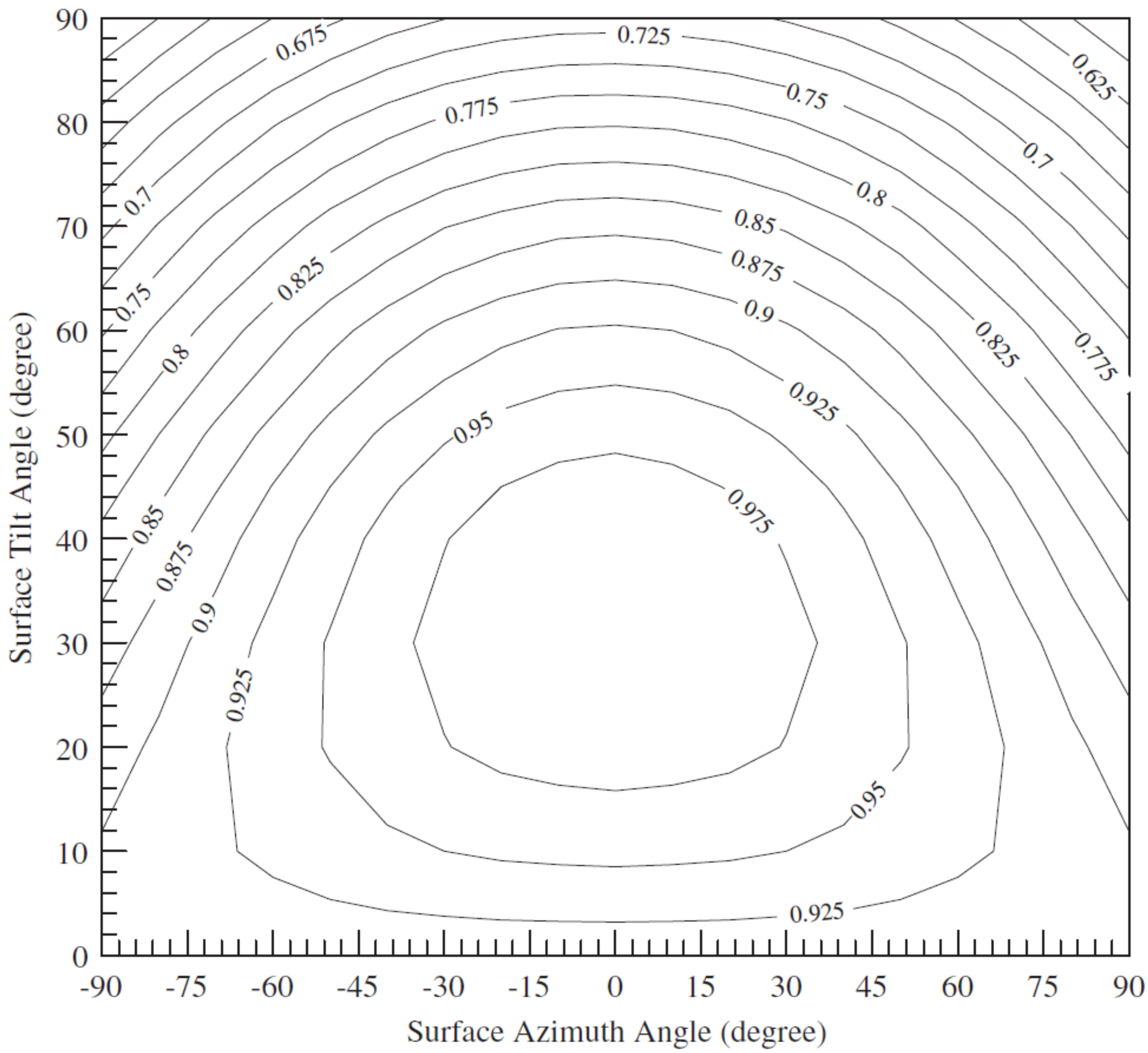


Figure 23. Efficient factor charts for Surface Tilt angle and Surface azimuth angle (Mondol J.D., 2006)

3.4.8. Statistic Values of Cloud Index

The measurements and the created equations are based on the horizontal surface. As a result of that Case 7 which has horizontal panel alignment, was used to check the equation suitability to use at the VENSIM simulation model. Helioscope uses the last 22 years of weather forecast to calculate energy production for given coordinates. In order to compare the Helioscope Case 7 and Theoretical calculation, the number of the cloudy days and cloudiness days are evaluated from last six years recorded data by the Norwegian Meteorological Institute and web data base of the YR.no. The number of fair days are shared equally to the number of clean days and to the number of cloudy days to calculate the ratios of cloudy days and clear sky days for probability function on VENSIM PLE.

Table 14. Number of Cloudy, Fair and Cleans Sky Days for different years for each month

January	Cloudy days	Fair days	Clean days
2017	17	11	3
2016	10	11	10
2015	18	12	1
2014	22	9	0
2013	15	9	7
2012	21	9	1

July	Cloudy days	Fair days	Clean days
2017	10	17	4
2016	15	13	3
2015	14	14	3
2014	8	11	12
2013	14	10	7
2012	19	11	1

February	Cloudy days	Fair days	Clean days
2017	15	11	2
2016	15	10	4
2015	18	6	4
2014	17	11	0
2013	14	4	10
2012	22	5	2

August	Cloudy days	Fair days	Clean days
2017	8	20	3
2016	14	16	1
2015	7	16	8
2014	12	16	3
2013	12	14	5
2012	14	17	0

March	Cloudy days	Fair days	Clean days
2017	19	11	1
2016	14	10	7
2015	14	12	5
2014	15	13	3
2013	10	7	14
2012	25	4	2

September	Cloudy days	Fair days	Clean days
2017	8	17	5
2016	7	18	5
2015	11	14	5
2014	11	9	10
2013	14	16	0
2012	20	9	1

April	Cloudy days	Fair days	Clean days
2017	13	13	4
2016	9	13	8
2015	13	14	3
2014	10	10	10
2013	9	13	8
2012	19	6	5

October	Cloudy days	Fair days	Clean days
2017	13	15	2
2016	8	14	8
2015	15	9	7
2014	17	11	3
2013	21	5	5
2012	16	14	1

May	Cloudy days	Fair days	Clean days
2017	15	9	7
2016	7	15	9
2015	14	14	3

November	Cloudy days	Fair days	Clean days
2017	11	17	2
2016	9	17	4
2015	15	13	2

2014	9	15	7
2013	17	11	3
2012	13	10	8

2014	17	10	3
2013	15	13	2
2012	22	8	0

June	Cloudy days	Fair days	Clean days
2017	16	11	3
2016	9	16	5
2015	14	13	3
2014	1	21	8
2013	18	7	5
2012	14	12	4

December	Cloudy days	Fair days	Clean days
2017	12	15	4
2016	23	6	2
2015	18	11	2
2014	14	13	1
2013	23	8	0
2012	22	7	2

Table 15. Number of Clean and Cloudy Days for each month to use as a probability for weather situation on VENSIM PLE

	January	February	March	April	May	June
number of days with open sky	9	9	10	12	12	11
number of the days with %100 cloudy	21	21	20	18	18	19
	July	**August**	**September**	**October**	**November**	**December**
number of days with open sky	12	11	8	9	7	6
number of the days with %100 cloudy	18	19	22	21	23	24

3.4.9. Comparing Results between Helioscope and Calculations

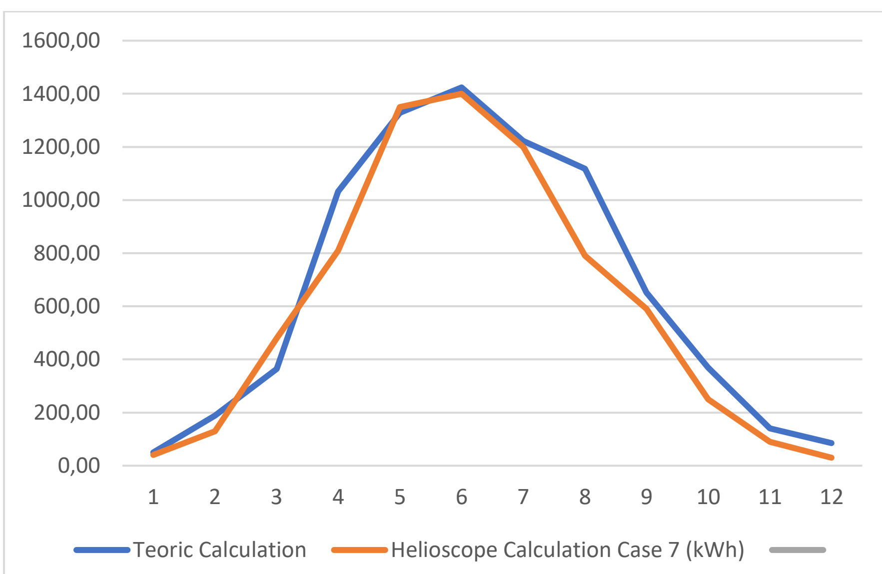


Figure 24. Comparison of Theoretical Calculation and Helioscope Case 7 results

Figure 24 shows that the selected Helioscope results and theoretical calculation by using the cloudy sky and clean sky probabilities in the VENSIM, gives close results. The Helioscope result for CASE 7 is 7280 kWh annually as the theoretical energy calculation is 7975 kWh. The main reason to see this differences is to share the average number of fair days equally to the clean and cloudy days. Because on a clean day, the solar radiation to a horizontal surface is three times higher than the solar radiation on a cloudy day. This approach causes VENSIM simulation to assign more clean days than expected in real cases.

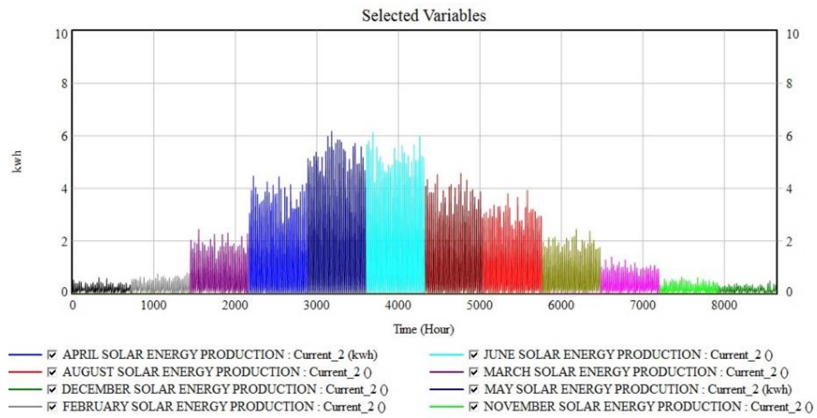


Figure 25. Monthly Variance of Energy Production from PV Panels

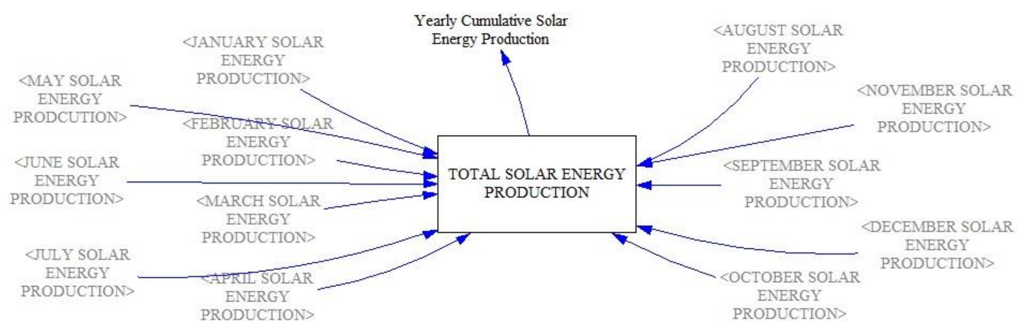


Figure 26. VENSIM interface about solar energy production

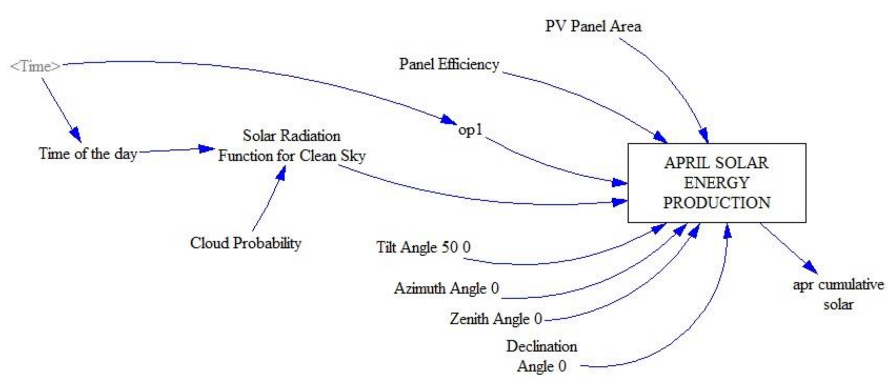


Figure 27. VENSIM interface for PV Energy Production for April as an sub-system interface

3.5. Wind Energy

Norway is one of the biggest Oil producer in Europe and One of the important Oil producer in Norway. Even though Norway exports Oil as an energy resources, the required energy is produced by renewable energy resource. According to the IEM report in 2016, 97.7 % of required energy was produced by renewable energy resources. The share of the energy produces by the wind turbines is 1.4 %. (IEA WIND, 2017)

The high potential of the wind energy comes from the high wind speed on both Onshore and Offshore which can be seen on Figure 28 by SINTEF. As a result of this high potential and having offshore experience, technical infrastructure and personal, the number of the wind farms and the number of new license in Onshore and Offshore is increasing regularly.

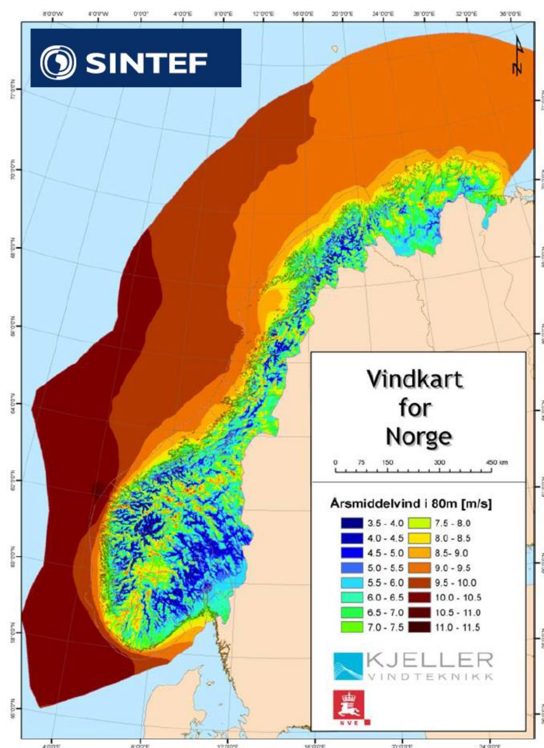


Figure 28. Wind Speed Map of Norway (SINTEF)

Rogaland area and Stavanger has also good wind resources. As a result of that, installation of a Wind turbine for My Box student house is evaluated inside the Hybrid Energy production system.

The wind turbine model has been chosen before the thesis research started. The technical information for the selected turbine can be found below,

Table 16. General Information about selected wind turbine

Name of the Producer	KLIUX ENERGY (SPAIN)
Name of the Product	GE0 1300
Turbine Type	VAWT Silvious Type
Cut in Speed (m/s)	4
Cut Out Speed (m/s)	11

Annual total energy generated								
	Annual average wind (m/s)							
	4	5	6	7	8	9	10	11
Total (kWh)	5.787	6.017	6.334	6.765	7.303	8.018	8.559	9.170

Figure 29. Energy Outcome for annual average wind speed for selected turbine model (Kliux Geo 1800)

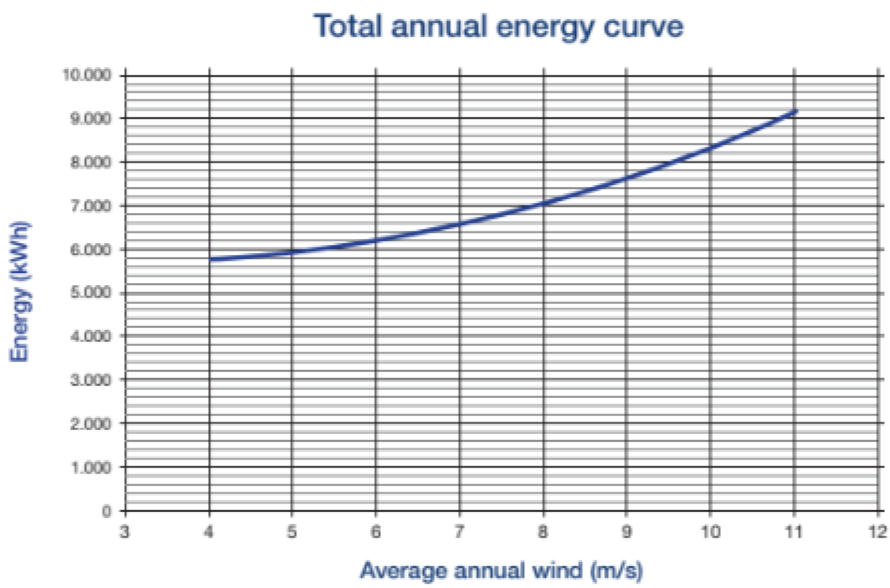


Figure 30. Total Annual Energy Curve for Selected Turbine (Kliux Geo 1800)

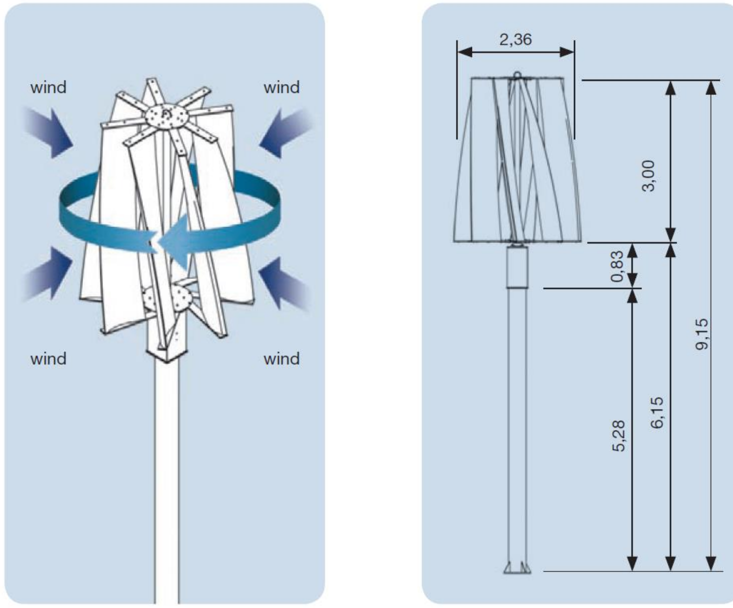


Figure 31. General Dimensions of the Wind Turbine (Kliux Geo 1800)

The power output equation for the wind turbine,

$$P = \frac{1}{2}\, c_p\, \rho\, A\, u^3 \qquad (2.17)$$

Where the ρ is the density of the air (1.225 $^{kg}/_{m^3}$), c_p is the power efficient, A is the rotor swept area and u is the wind speed.

This theoretical equation cannot be used for VENSIM PLE simulation as a results of not having data for power efficient factor and swept area of the turbine. As a result of that, instead of this equation, given at Figure 30, annual energy curve is used by calculating energy outcome for each wind speeds between cut-in and cut out speeds.

Table 17. Energy outcome (kWh) for wind speed for selected wind turbine

Wind Speed (m/s)	Energy Outcome (kWh)	Wind Speed (m/s)	Energy Outcome (kWh)
< 4	0	8	0.8
4	0.662	9	0.868
5	0.685	10	0.948
6	0.708	11	1.05
7	0.753	≥12	0

Solar radiation is a time function of the sun for all year and can be calculated by the equations. On the other hand energy production by the wind speeds needs to identify which average time span will be used for simulation. Using an average wind speed for a wider time span causes the energy output to deviate more from the real energy production.

Table 18. Monthly Average Wind Speed for Previous Years

	January	February	March	April	May	June
Monthly Wind Speed Average 2017	7,02	6,8	4,8	5,1	3,5	4,1
Monthly Wind Speed Average 2016	6	5,4	4,7	4,2	4,8	3,5
Monthly Wind Speed Average 2015	9	7,7	6,5	5,9	6,8	6,3
Monthly Wind Speed Average 2014	12,52	9,9	6,3	5	4,6	5
Monthly Wind Speed Average 2013	5,32	4,9	5,2	5,7	5,81	4,92
	July	**August**	**September**	**October**	**November**	**December**
Monthly Wind Speed Average 2017	4,1	4,2	4	5,8	5,7	5,1
Monthly Wind Speed Average 2016	3,8	4,5	4,8	4	6,3	7,2
Monthly Wind Speed Average 2015	6,1	5,5	4,8	5,1	5,7	7,7
Monthly Wind Speed Average 2014	3,4	6,3	4,2	7,51	7,91	7,42
Monthly Wind Speed Average 2013	4,51	5	4,78	6,08	6,8	9,61

Table 19. Annual Wind Speed for previous years

Annual Wind Average Speed 2017	5,01
Annual Wind Average Speed 2016	4,93
Annual Wind Average Speed 2015	6,43
Annual Wind Average Speed 2014	6,67
Annual Wind Average Speed 2013	5,72

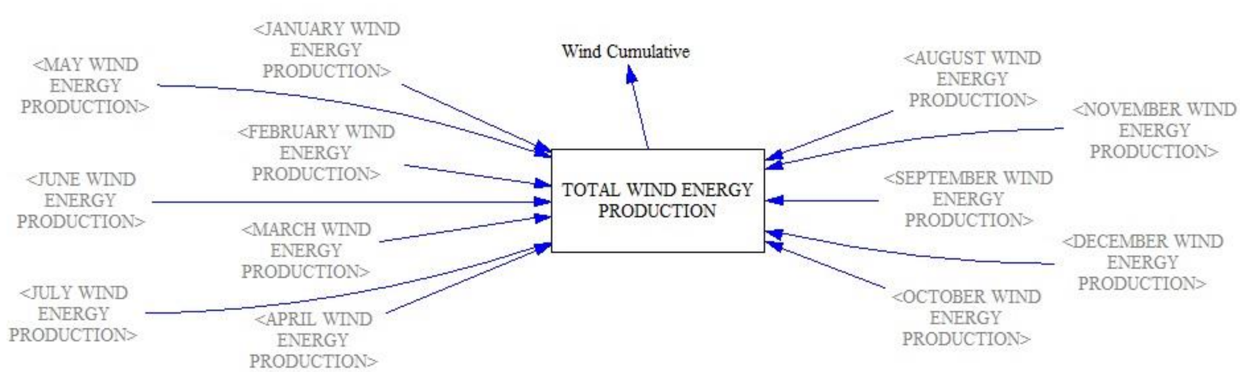


Figure 32. VENSIM PLE Simulation Interface for Wind Energy Production

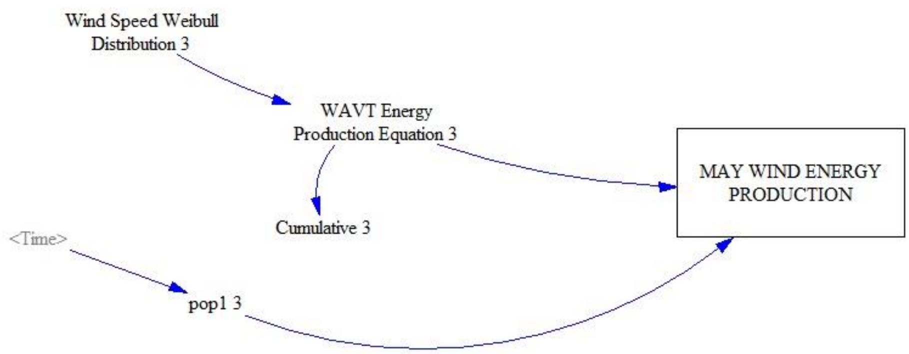


Figure 33. VENSIM PLE Simulation Interface for Wind Energy Production for May as a sub-system

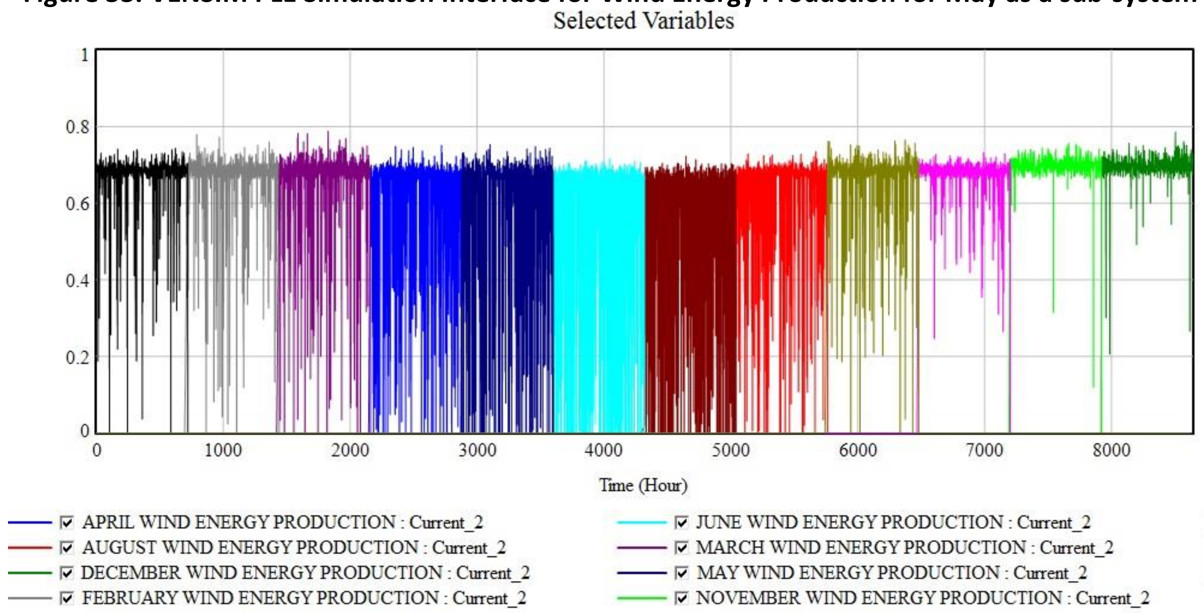


Figure 34. Wind Energy Production Variance for one year simulation time

Table 20. Energy Production Comparison of VENSIM PLE against theoretical calculation values for yearly and monthly average wind speeds.

Wind Energy Production Monthly	**January**	**February**	**March**	**April**	**May**	**June**	**TOTAL (kwh)**
VENSIM	480,953	474,65	467,28	423,56	405,5	357,3	
Yearly Average Wind Speed 2017	492,48	492,48	492,48	492,48	492,48	492,48	
Monthly Average Wind Speed 2017	542,46	534,24	484,93	550	0	476,71	
Wind Energy Production Monthly	**July**	**August**	**September**	**October**	**November**	**December**	
VENSIM	349,76	439,65	474,5	486,5	501,83	510	**5371,483**
Yearly Average Wind Speed 2017	492,48	492,48	492,48	492,48	492,48	492,48	**5909,76**
Monthly Average Wind Speed 2017	476,71	480	470	509,6	515	550	**5589,65**

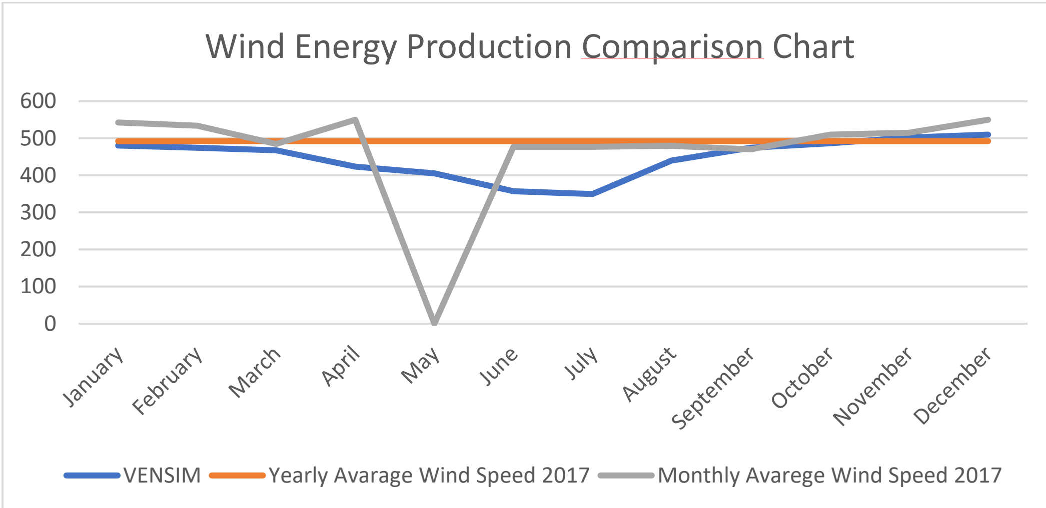


Figure 35. Wind Energy Production Comparison Chart for VENSIM PLE, yearly and monthly average wind speeds

Table 21. Weibull Distribution Values for Different Months

January		**February**		**March**	
Shape Factor (k)	2.189	Shape Factor (k)	1.936	Shape Factor (k)	2.273
Scale Factor (c)	2.059	Scale Factor (c)	2.292	Scale Factor (c)	2.160
April		**May**		**June**	
Shape Factor (k)	2.0247	Shape Factor (k)	2.093	Shape Factor (k)	2.148
Scale Factor (c)	1.667	Scale Factor (c)	1.721	Scale Factor (c)	1.961
July		**August**		**September**	
Shape Factor (k)	2.54	Shape Factor (k)	2.019	Shape Factor (k)	2.163
Scale Factor (c)	2.027	Scale Factor (c)	1.931	Scale Factor (c)	2.144
October		**November**		**December**	
Shape Factor (k)	2.28	Shape Factor (k)	2.1381	Shape Factor (k)	1.994
Scale Factor (c)	2.235	Scale Factor (c)	2.119	Scale Factor (c)	2.573

3.6. Energy Consumption

3.6.1. Energy Consumption Data

Unfortunately, the only reachable data at the first phases of the thesis was cumulative energy consumption values for one in a month for last five years. As a result of that, as a second phase of the thesis, I had to write my own energy consumption amounts for each mentioned branch in Ugleveien 2B Student house in April.

Energy consumption of My Box student house has four sub-branch. These are Heating, Lighting, Kitchen Usage and personal Usage.

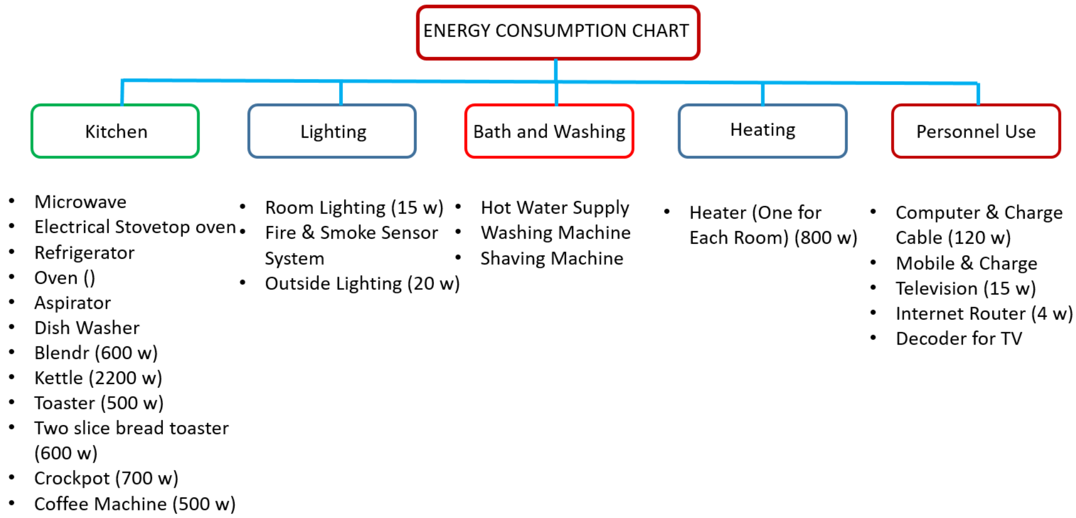


Figure 36. Energy Consumption Sub Branch Chart

The approach for VENSIM simulation for energy consumption is to create one users energy consumption profile and multiple this data with number of the inhabitants, which is accept as a variable, related to the season of the year. During the academic year of UIS, between August and June, the number of the inhabitants are five for the My Box Student house. It is considered that all inhabitant are living alone and official holidays are evaluated as a regular energy usage day in one year. Total consumption was divided equally if the consumption measurement was done in two months.

Table 22. Total Energy consumption for past years

	January	February	March	April	May	June	TOTAL (kWh)
2017	4448	4448	5159	3441	3048	2757	
2016	3902	4336	4674	3662	2937	3163	
2015	3668.5	3668.5	3994	3994	2709	2548	
	July	**August**	**September**	**October**	**November**	**December**	
2017	2469	3189	2377	0	0	0	31336
2016	2266	1322	1322	4306	2893	4358	39141
2015	2548	2105	2863	3993	4273.5	4273.5	40638

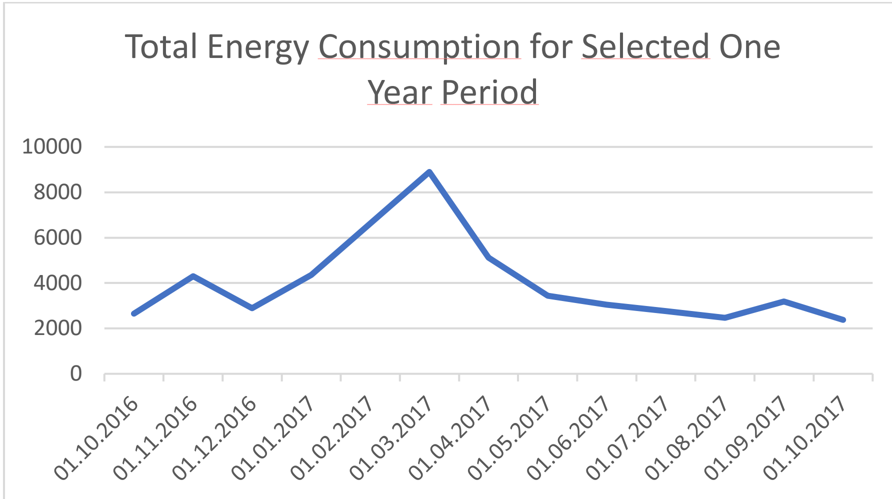


Figure 37. Total Energy Consumption Values from given data

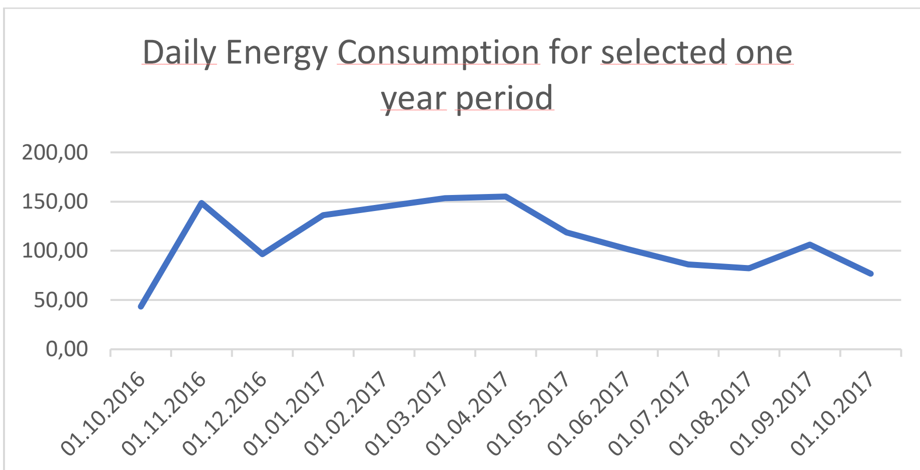


Figure 38. Daily Energy Consumption for per person in My Box Student House from Given data

According to the Figure 31, the energy consumption is reduced in summer between May and July and started to increase in August when the academic year is started. Even though the value of the energy consumption changed for each one year of period, this behavior of energy consumption is similar for all years from given data.

3.6.2. Personal Energy Consumption Records

The data given Table 3 does not include the data to find the hourly energy consumption variation and main branch percentage on consumption during the year. In order to simulate consumption and find how the consumption variances during one year, the consumption of April for one student has been recorded and compared with data given on Table 3.The list of the equipment, energy capacity of the equipment and usage duration and frequencies are shown at Table 23-26.

Table 23. Energy consumption records for Kitchen in April for one student in Ugleveien

KITCHEN CONSUMPTION									
	Elk. Capacity (watt) / (min)	Monday (hour) / (times)	Tuesday (hour) / (times)	Wednesday (hour) / (times)	Thursday (hour) / (times)	Friday (hour) / (times)	Saturday (hour) / (times)	Sunday (hour/ (times))	Energy Consumption
Refrigerator working	225 6	24	24	24	24	24	24	24	3.780
Refrigerator stand by	35 54	24	24	24	24	24	24	24	5.292
Dish Washer	330 60	0	1	0	1	0	1	0	0.990
Microwave	1500 4	1	1	2	1	2	2	2	1.100
Electrical Oven Small	1300 45	2	2	2	2	2	2	2	13.650
Electrical Oven Big	2000 30	1	0	1	0	1	0	1	4.000
Oven	2000 60	0	0	1	0	0	0	1	4.000
Coffee Machine	1000 2	1	1	2	1	2	1	1	0.300
Water Boiler (Kettle)	500 3	6	6	6	6	6	8	8	1.150
Electrical Pot (Reis Cooker)	900 30	0	0	1	0	0	0	0	0.450
Toaster	400 10	0	1	0	0	0	0	0	0.067
								TOTAL (Week) kWh	29.487

Table 24. Energy Consumption Records for Lighting in April for One Student in Ugleveien

LIGHTING									
	Elk. Capacity (watt)	Monday (hour)	Tuesday (hour)	Wednesday (hour)	Thursday (hour)	Friday (hour)	Saturday (hour)	Sunday (hour)	Energy Consumption
Saloon	30	5	5	5	5	5	5	5	1.050
Kitchen	30	3	3	3	3	3	2	2	0.570
WC-Banyo	30	1	1	1	1	1	1	1	0.210
Sleeping Room	30	2	2	1	2	1	2	2	0.360
Table Light	15	0	1	1	0	0	0	0	0.030
TOTAL (week) kWh									1.650

Table 25. Energy Consumption Records for Heating in April for one student in Ugleveien

HEATING									
	Elk. Capacity (watt)	Monday (hour)	Tuesday (hour)	Wednesday (hour)	Thursday (hour)	Friday (hour)	Saturday (hour)	Sunday (hour)	Energy Consumption
Electrical Heater Saloon- Sleeping Room	500	20	20	20	20	20	20	20	70.000
Electrical Heater Kitchen	500	14	14	14	14	14	14	14	49.000
TOTAL (Week) kWh									119.000

Table 26. Energy Consumption Records for personal Usage in April for one student in Ugleveien

PERSONEL USAGE									
	Elk. Capacity (watt)	Monday (hour)	Tuesday (hour)	Wednesday (hour)	Thursday (hour)	Friday (hour)	Saturday (hour)	Sunday (hour)	Energy Consumption
Ironing	1000	0	0	0	1	0	2	0	3.000
Clothes Washer	225	0	0	1	0	0	0	1	0.450
Hair Dryer	700	0	0	0	0	1	1	0	1.400
Television	150	5	5	5	5	5	5	5	5.250
Laptop Charger	25	8	8	8	8	8	10	10	1.500
Mobile Charger	20	14	14	14	14	14	14	14	1.960
Router	6	24	24	24	24	24	24	24	1.008
Vacuum Cleaner	550	0	0	0	0	0.5	0	0.5	0.550
TV Receiver	28	24	24	24	24	24	24	24	4.704
TOTAL (Week) kWh									19.372

It can be seen on Table 27 that the recorded energy consumption for April for one student is matched with the recorded energy consumption in 2017 and maximum 15 % lower than 2015 and 2016.

Table 27. Energy Consumption Comparison in reference month (April) for different years

Energy Consumption April (kwh)	
Self-Records for OKAN in April 2018	678,035
April 2017	688,2
April 2016	732,4
April 2015	798,8

3.6.3. Energy Consumption Model on VESNIM PLE

Simulation of the energy consumption part of the VENSIM, simulate four main branch separately from January to December. Similar to the energy production part of the VENSIM, Each sub-branch for the energy consumption model have 12 different sun system that symbolize the different months of the year.

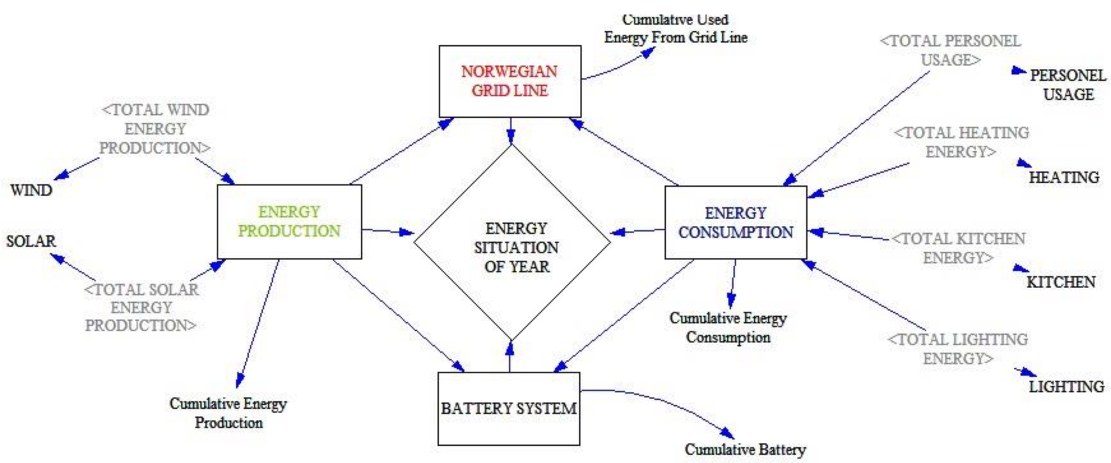


Figure 39. Main Page of VENSIM PLE Simulation Software

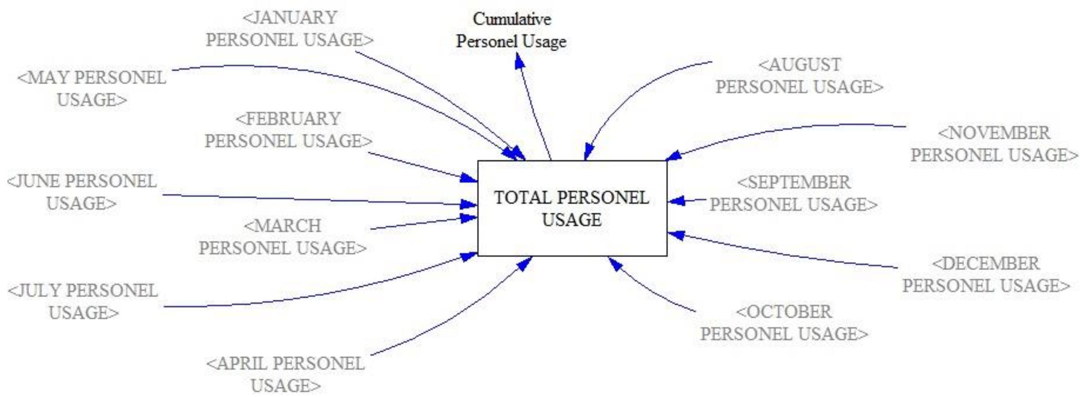


Figure 40. VENSIM Interface for Total Energy Usage for personal Usage

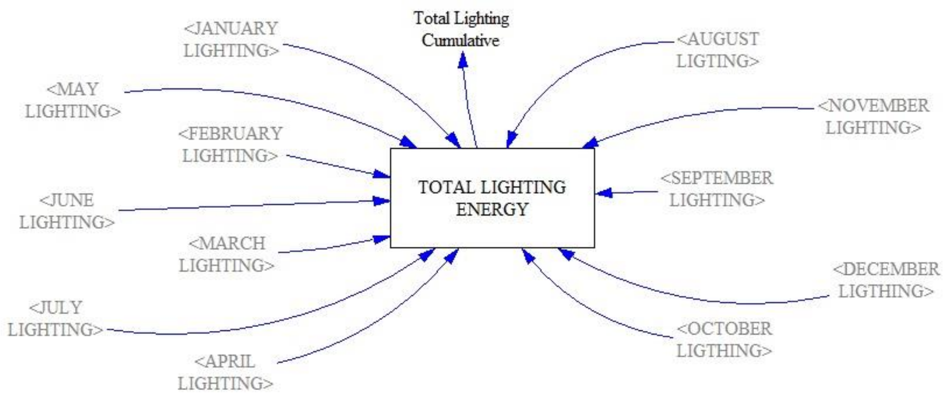


Figure 41. VENSIM PLE Interface for Total Energy Usage for Lighting

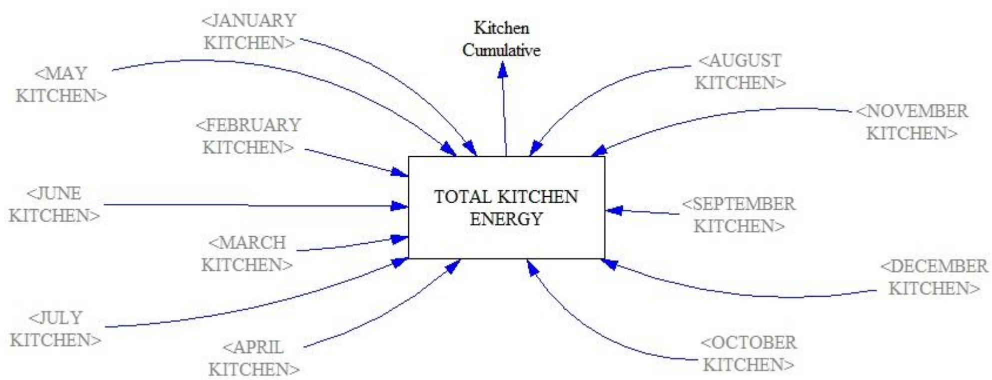


Figure 42. VENSIM PLE Interface for Total Energy Usage for Kitchen

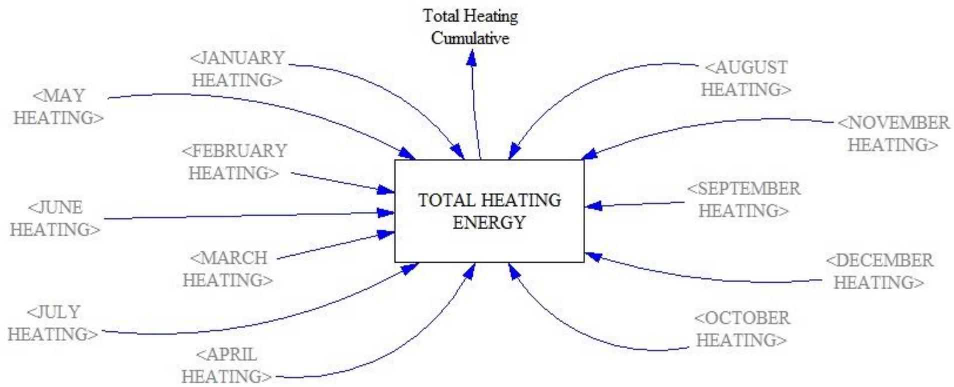


Figure 43. VENSIM PLE Interface for Total Energy Usage for Heating

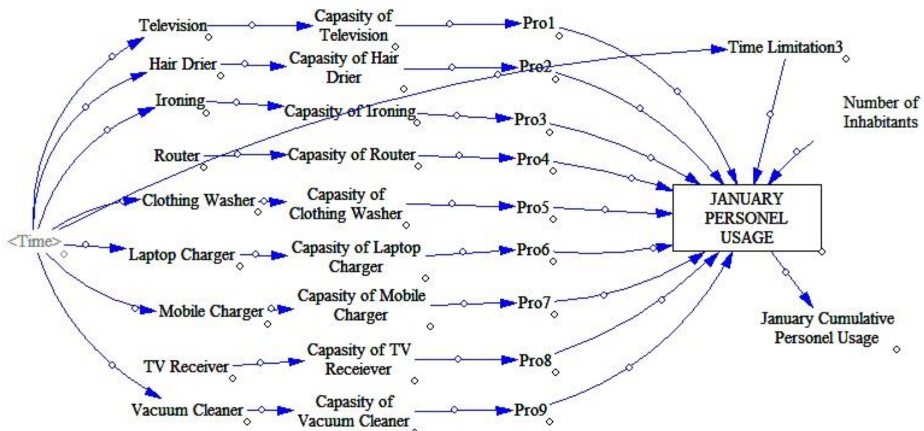


Figure 44. VENSIM PLE Interface of January Energy Consumption for personal Usage

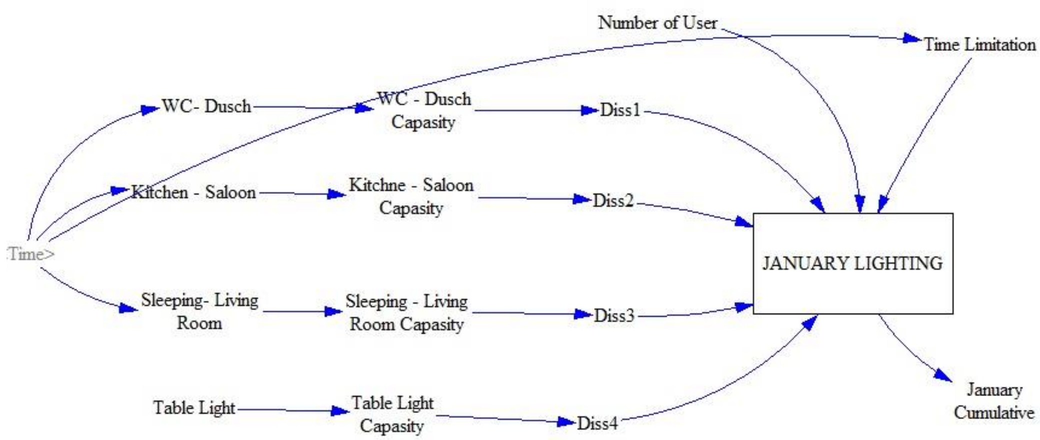


Figure 45. VENSIM PLE Interface of January Energy Consumption for Lighting

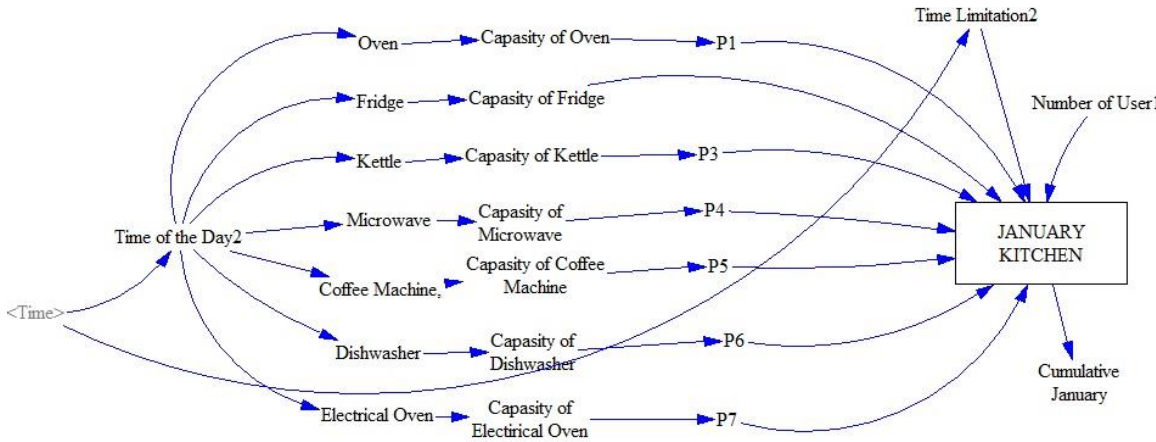


Figure 46. VENSIM PLE Interface of January Energy Consumption for Kitchen

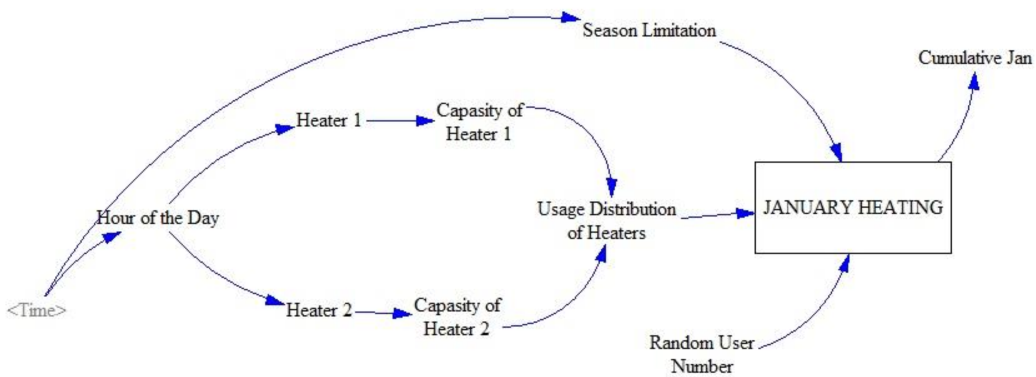


Figure 47. VENSIM PLE Interface of January Energy Consumption for Heating

VENSIM Energy results can be compared with the real energy consumption. We have two full year measurement and two half year, which were evaluated as full year related the time and energy value.

3.6.4. Energy Consumption Results on VENSIM PLE

According to the VENSIM PLE simulation results, one-year energy consumption for My Box student house will be more than 35000 kWh /annual. Table 28 and Figure 48 gives comparison for VENSIM PLE simulation and measured data for previous years. The highest deviation from previous year's energy consumption occurs in June and July where the UIS academically close. The real consumption is expected to be 25 % higher than VENSIM PLE simulation. The main reason for this deviation is related to the number of the inhabitants who expected to not be in My Box during the summer vacation.

Table 28. Energy Consumption Differentiation from VENSIM results

	Time Span	Value (kWh)	Expected Value for all year (kWh)	Differentiation from VENSIM results (%)
VENSIM PLE Results	12 months	35000	**35000**	0
01.03.2014-05.01.2014	10 months	23255	**27906**	-20.27
05.01.2014-04.01.2015	12 months	44571	**44571**	+27.35
04.01.2015-02.01.2016	12 months	43330	**43330**	+23.71
02.01.2016-02.10.2017	9 months	31296	**41728**	+19.22

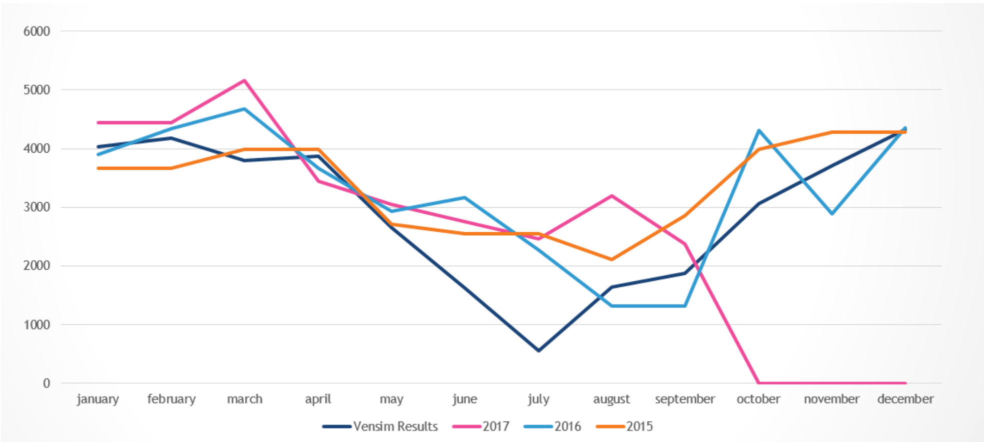


Figure 48. Monthly Comparison of Energy Consumption between VENSIM PLE Results and Measurements

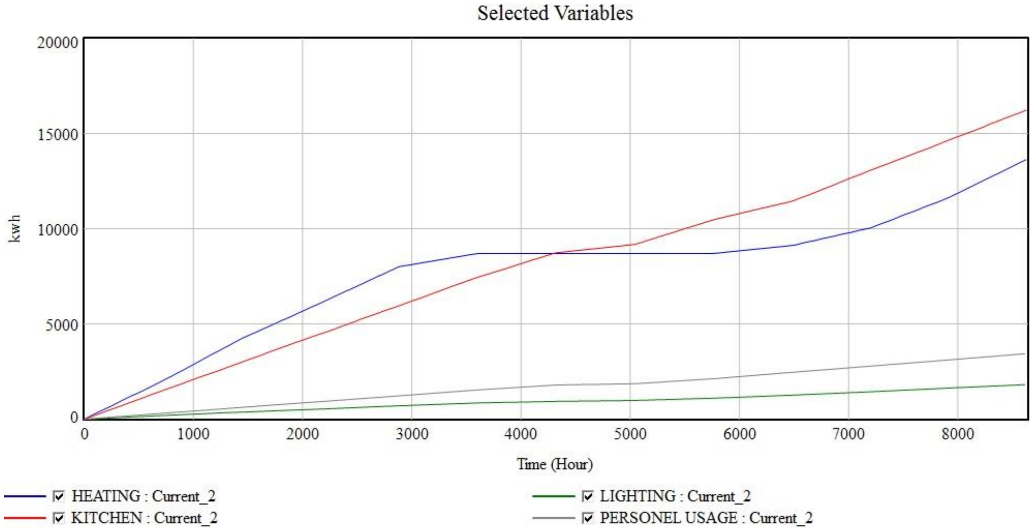


Figure 49. Cumulative Energy Consumptions for Each Main Consumption Lines

Figure 50 shows us the cumulative values of each main energy consumption branch. According the figure 50, the highest energy consumption is kitchen with around 17000 kWh, followed by energy consumption for heating with around 13000 kWh event though the heating demand is zero between middle of May and August.

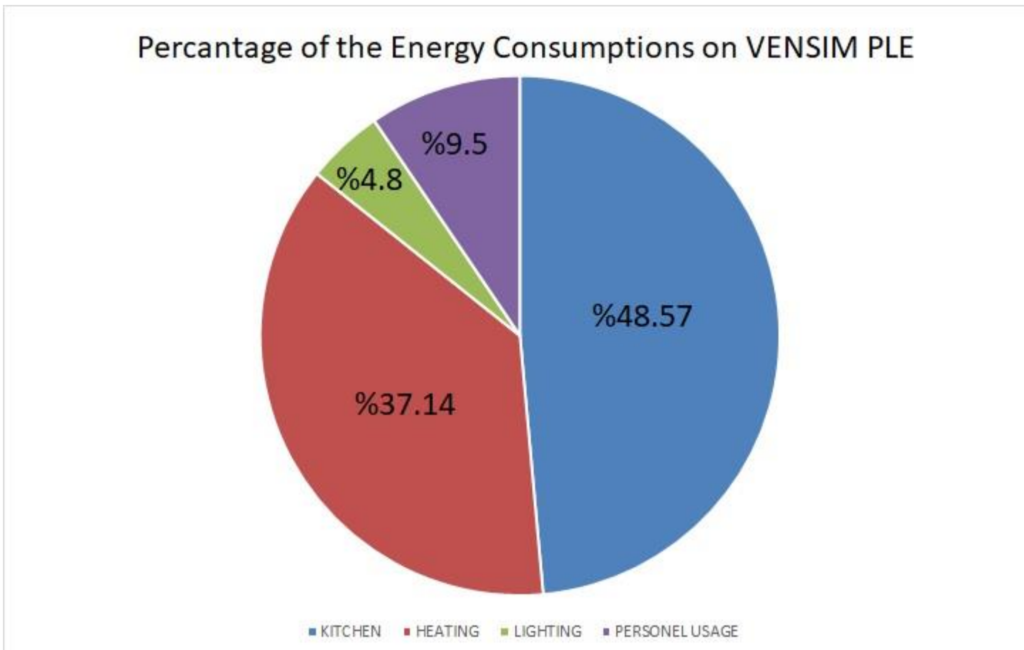


Figure 50. Percentage of Energy Consumptions on VENSIM PLE for each branch

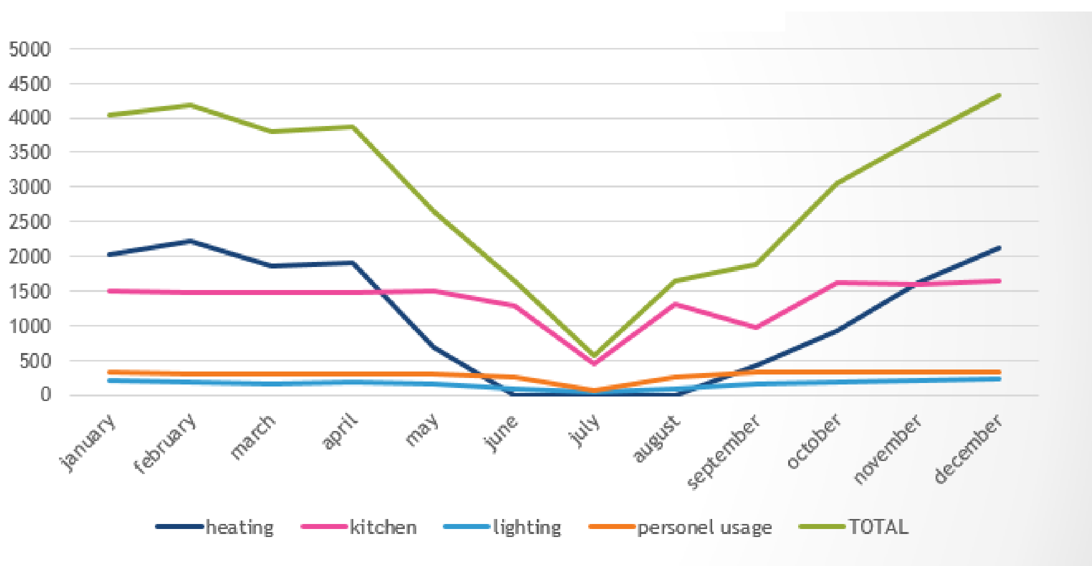


Figure 51. Monthly Variation of Main Branch of Energy Consumption

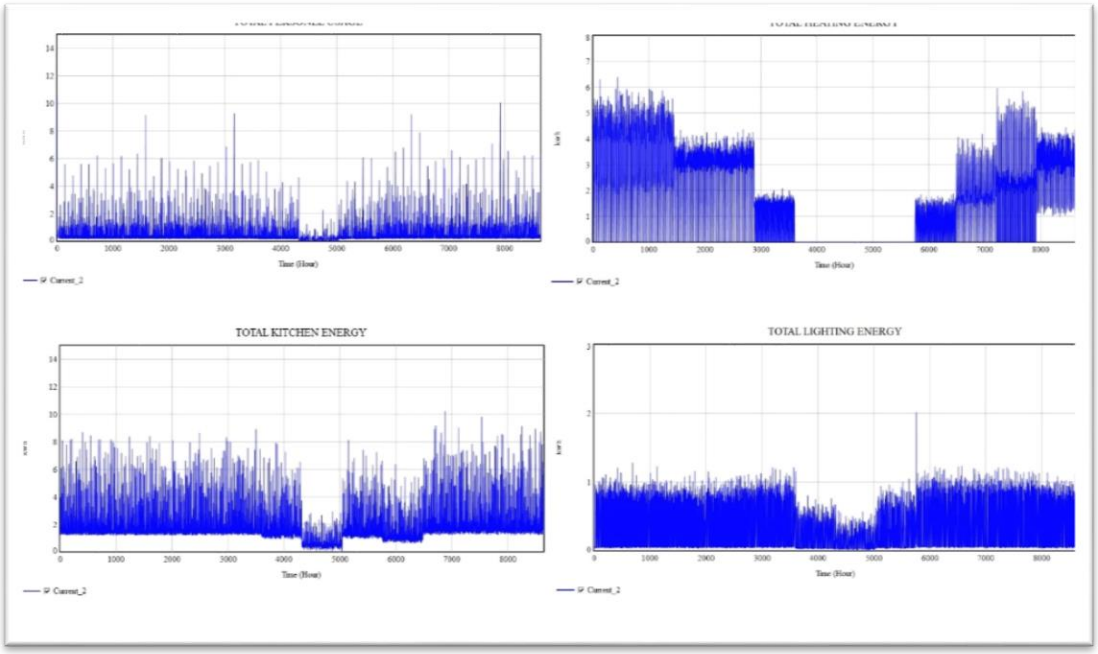


Figure 52. Hourly Variance of Main Branch of Energy Consumption

4. Different Scenarios to Increase the Energy Production

4.1. Default System Configuration Results

On Default condition, VENSIM simulation was prepared related to have 56 m2 PV panel with azimuth angle 0 (to the south) and 50 degrees tilt angle with one Silvius type VAWT turbine. According to the first simulation results, the hybrid energy production would be maximum 10888 kWh / annual as the total energy demand would be around 35000 kWh / annual. The energy consumption is reduced in summer time between 4000 – 5000 simulation hours as a results of zero heating energy consumption, less lighting needs during day and the reduce of number of inhabitant during summer vacation.

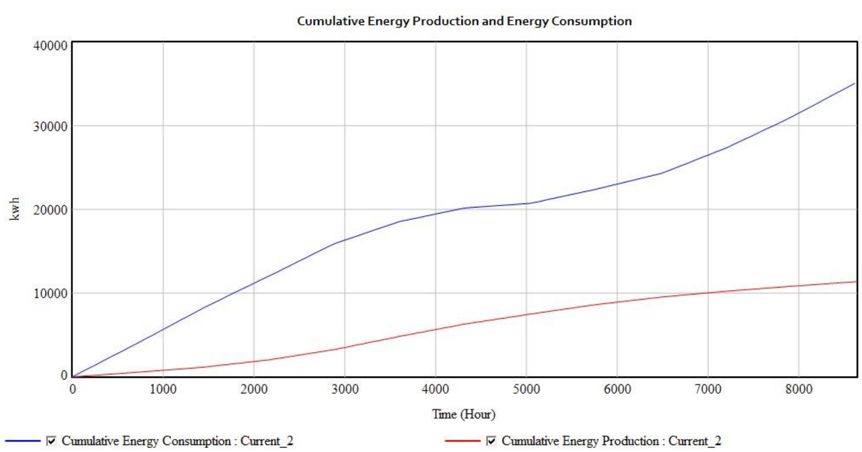


Figure 53. Cumulative Energy Consumption and Cumulative Energy Production Chart

VENSIM PLE allowed user to compare any kind of data either cumulative or hourly during selected time span. As a result of that it is easy to see the seasonal differentiation of the energy consumption and production by considering sub- components of each section. This properties help user to understand the effect of each sub-component to the system in general.

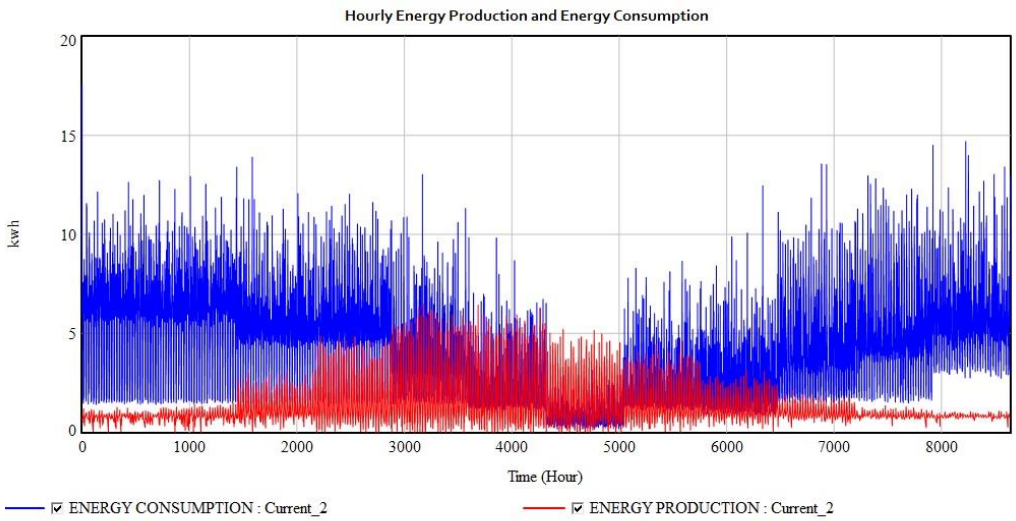


Figure 54. Hourly Variance of Energy Consumption and Energy Production

Figure 47 shows the variance for production and consumption hourly based. Figure 50 can be converted to hourly cumulative energy production and energy consumption to be more understandable of annual behavior of production and consumption.

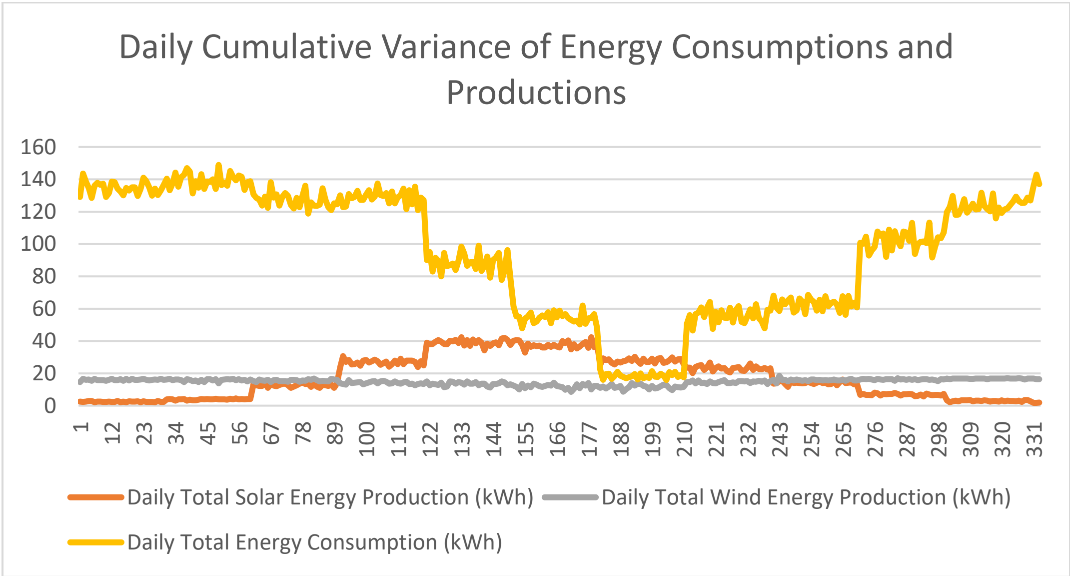


Figure 55. Daily Cumulative Variance of Energy Consumptions and Production

After identifying the optimum alignment for PV panels on Helioscope, It was decided to choose the Case 1 with Tilt Angle 50, Azimuth Angle 0 (to the south) and 56 m2 panel area. After simulation is completed, it was seen that the VENSIM PLE results are closely matched with the CASE 1 results on Helioscope.

Table 29. Monthly Energy Production Calculations for PV system on VENSIM PLE and Helioscope for selected case

	January	February	March	April	May	June	Total Energy Production (kWh)
VENSIM PLE Results (kWh)	78.83	123.78	405.	802.6	1172.6	1127.18	
Helioscope Case 1 Results (kWh)	44	142.5	551	947	1131.6	1108.7	
	July	**August**	**September**	**October**	**November**	**December**	
VENSIM PLE Results (kWh)	832.14	694.34	422.1	219.74	89.7	5,50	**6171.52**
Helioscope Case 1 Results (kWh)	871.5	720.5	590.5	286.5	99.5	22.9	**6559**

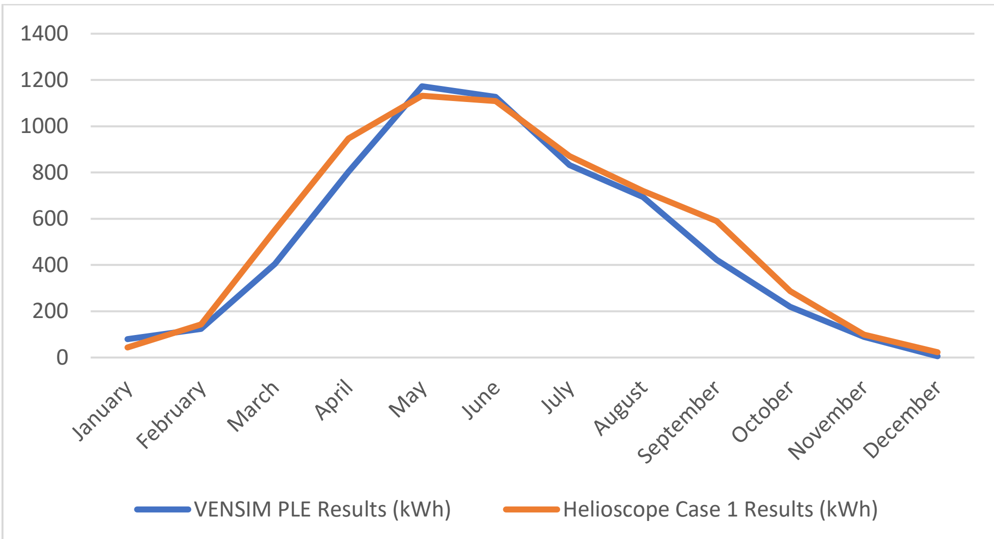


Figure 56. Monthly Energy Production Calculation for PV System on VENSIM and Helioscope

VENSIM simulation is designed as if the system has a battery system. One of the purpose of the thesis is to find optimum battery capacity and to see the charge and re-charge behavior of the system.

According to VENSIM PLE simulation results, the battery can be used only summer time when the energy consumption is less compared to other seasons and PV Solar energy production is maximum. It was seen that the stored energy in the battery will be used directly in the evening of the day. The stored energy can reach maximum 5 kWh and total stored energy for all year will be 2081 kWh as the energy used from Norwegian Grid line will reach up to around 25000 kWh. Related to the simulation results, the optimum battery capacity must be 20 kWh for the maximum stored day energy from Figure 53.

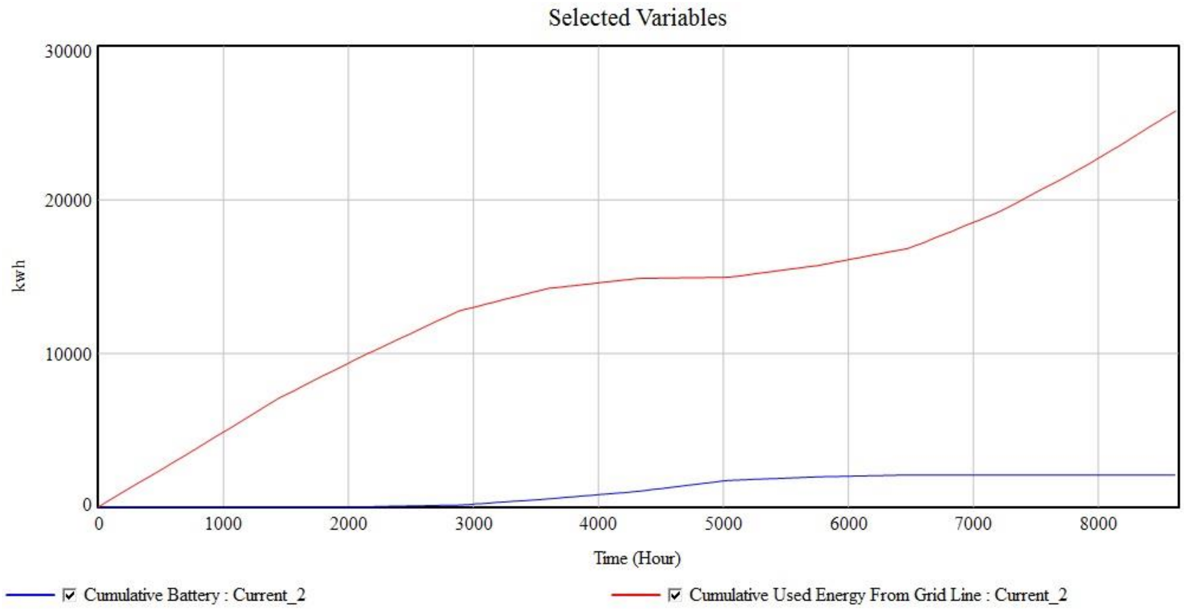


Figure 57. Cumulative Amount of Energy stored at the Battery System and used from Norwegian Grid Line

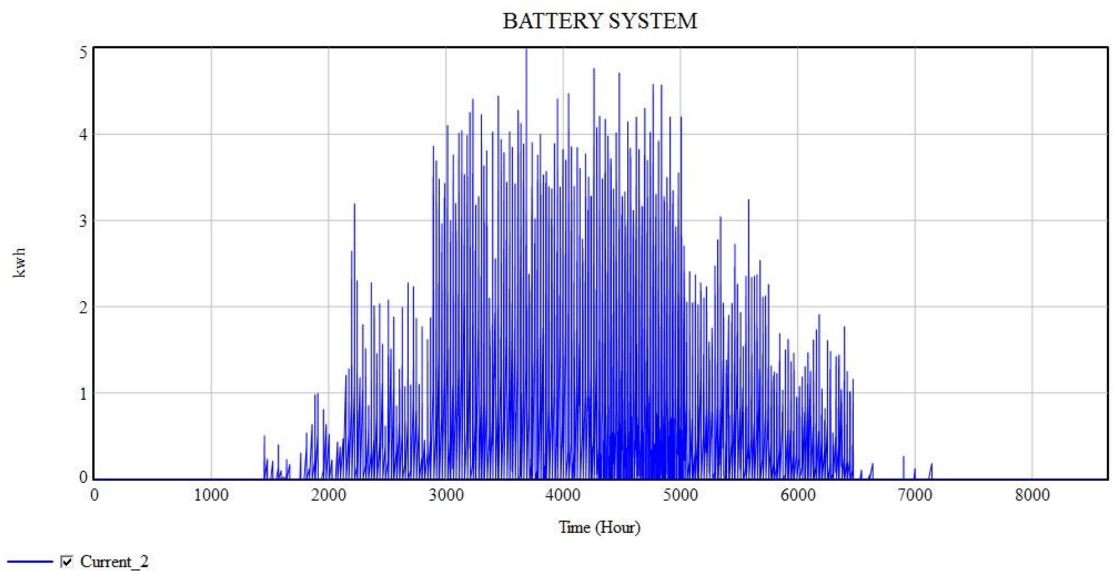


Figure 58. Hourly Energy Variance of Battery System

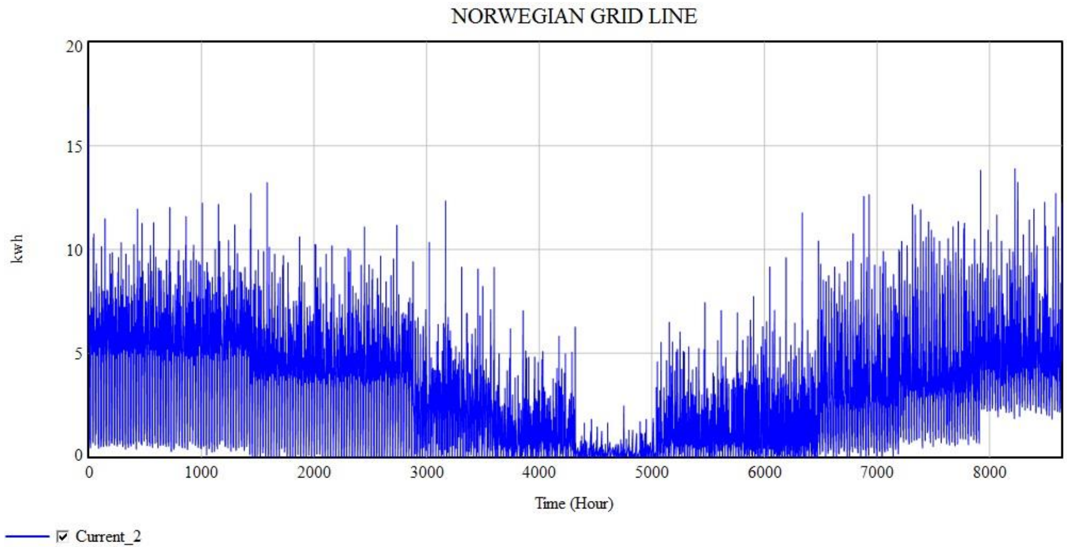
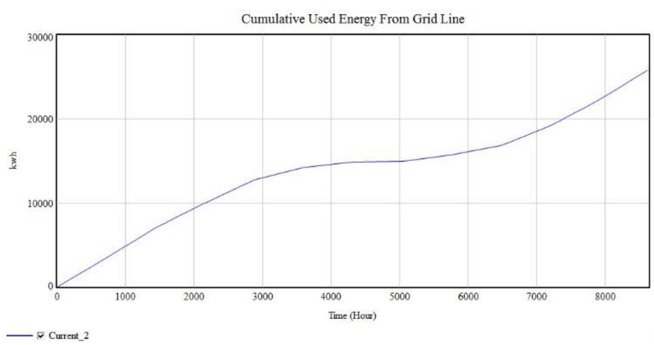


Figure 59. Hourly Used Energy Variance from Norway Grid Line



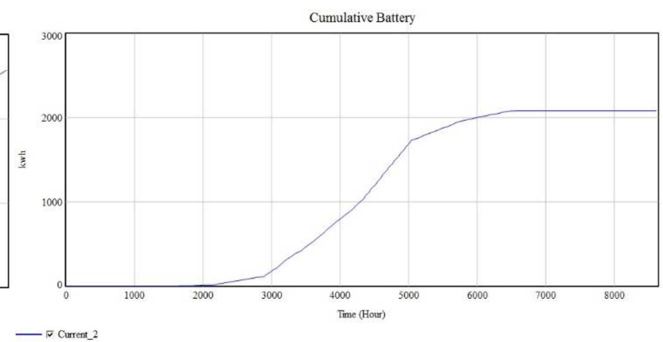


Figure 60. Cumulative Value of Stored Energy and Cumulative Stored Energy from Norwegian Grid Line on Separate Charts

4.2. Possible Solutions to Increase the Energy Production

The one of the main purpose of the thesis is to prove that if the My Box Student house can be converted to a Passive House which does not use energy from grid line. It is proved that with one WAVT turbine and 56 m2 PV panels, the system can produce only around % 30 of the energy demands.

On this thesis, only energy production section was investigated to increase the amount of the energy which can be produced by wind turbine(s) and solar panel. In order to have equal amount with the energy consumption, many alternatives has been worked on VENSIM PLE with many configurations. The alternatives and their results are listed below from basic to complex.

In order to increase to turbine numbers or PV panel areas, two more variables were added to the main screen of the VENSIM PLE.

4.2.1. Increasing the Number of the Wind Turbine

The number of the selected turbines, has been increased one by one until the energy production became higher than the first five months where the energy consumption for heating starts to reduce in summer.

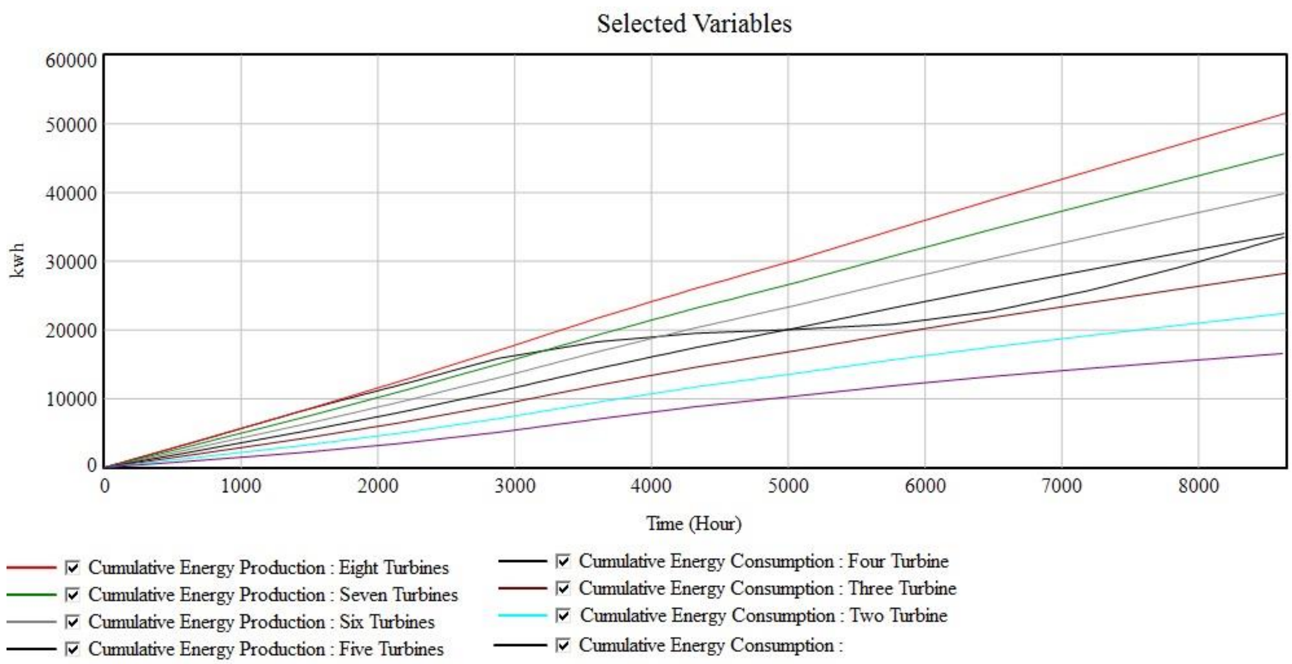


Figure 61. Cumulative Energy Production Results as the Number of the Turbine Increased

As the number of the turbine increased, the cumulative energy production chart becomes straight as the percentage of the PV energy reduces. According to the Figure 61, the cumulative energy consumption will be equal to cumulative energy consumption when five turbines are used. Unfortunately Figure 62 (Simplified version of Figure 61) shows that even though five turbines produce energy as much as needed cumulatively at the end of the year, the system will be "Passive" after the 5000th hours of simulation time. Before 5000th hour, the system still needs energy from Norwegian Grid Line.

According to the Figure 61, using eight turbines will produce energy as much as energy consumption until around 3000th simulation hours. After that hour, the system will produce more than it's needed by the My Box student house.

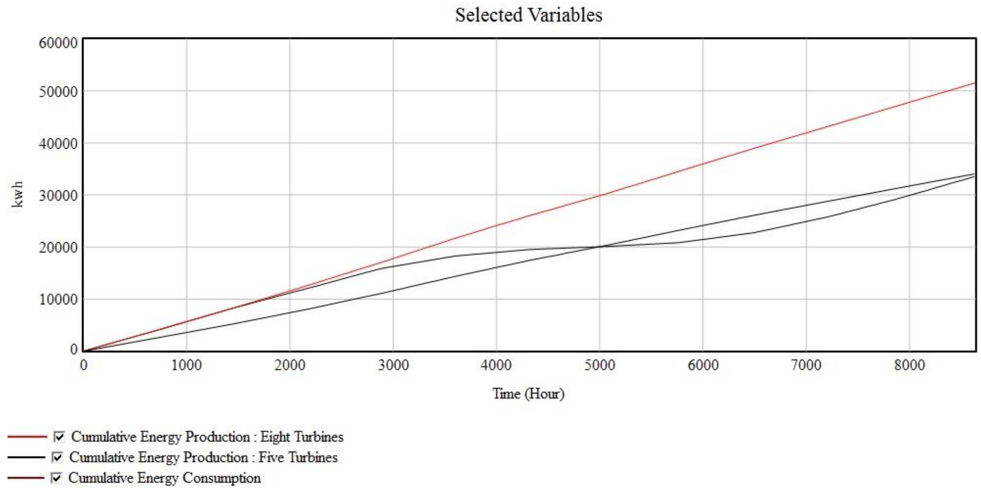


Figure 62. Cumulative Energy Production with Five and Eight Turbine

Table 30. Cumulative Energy Production, Cumulative Energy Storage for different number of Turbines.

Number of Turbines	Produced Energy (kWh)	Energy Consumption (kWh)	Stored Energy on Battery (kWh)
2	16613		3518.4
3	22293		5548.3
4	28293		7940
5	34933	35000	10718.3
6	40293		13852.4
7	46293		17356.1
8	51653		21267.2

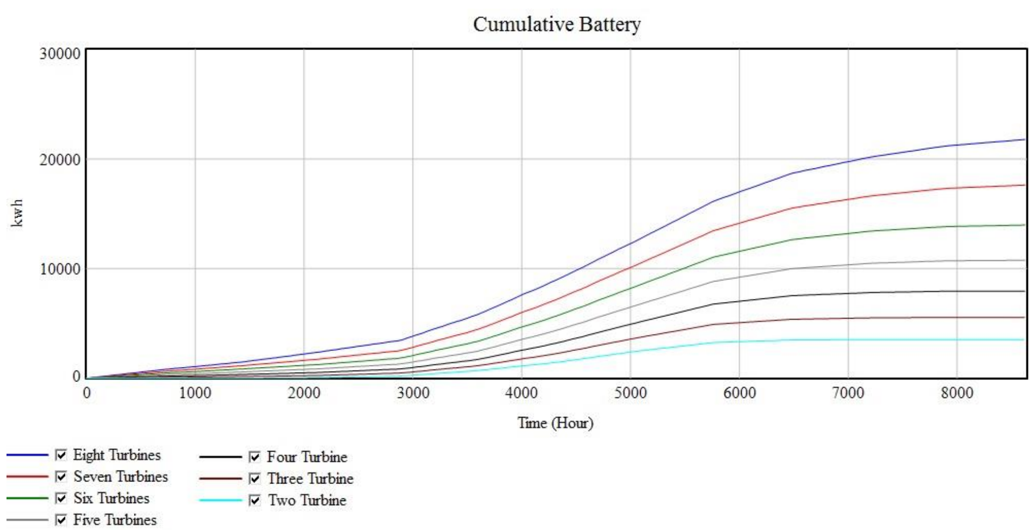


Figure 63. Cumulative Stored Energy on Battery System

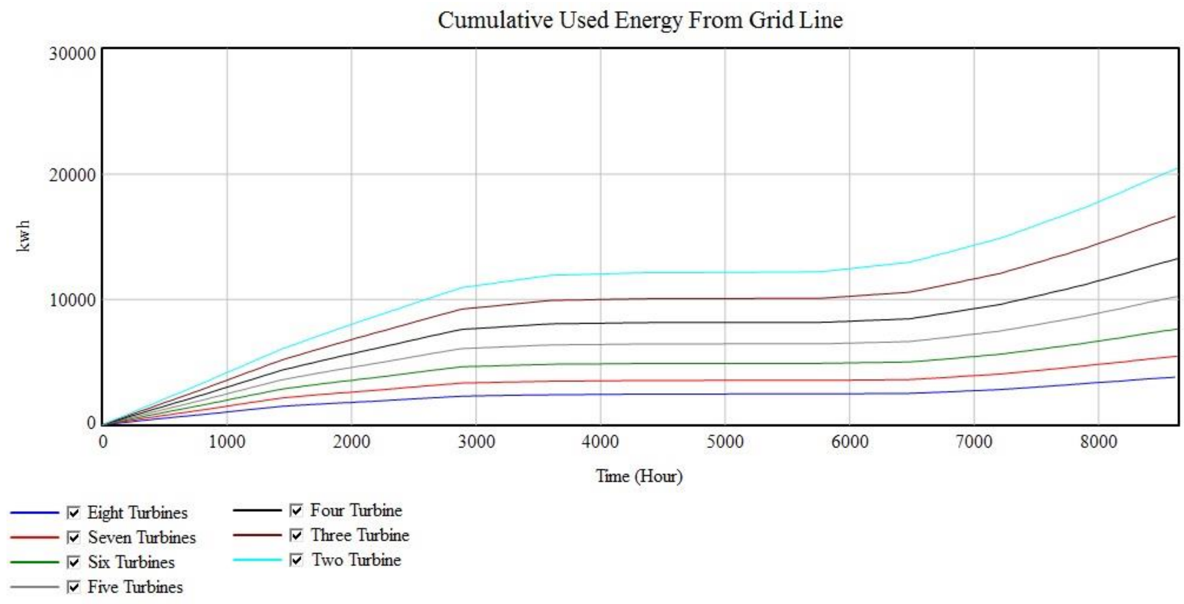


Figure 64. Cumulative Used Energy from Norwegian Grid Line for Different Number of Turbines

4.2.2. Changing the Position of the Turbine

The selected turbine, Kliux Geo 1800, can be installed to the ground with a tower with 6.15 meters. The total height of the turbine will be 9.15 meters which is almost equal with the Sola Airport where the wind speed measurements are recorded.

For previous designs, it is accepted that the turbine(s), are mounted to the ground level with tower and working at 10 meters height from the ground. As a second option, the turbine location has been investigated and accepted as mounted at the top of the My Box student house with tower and total height of the turbine is reached to 21 meters.

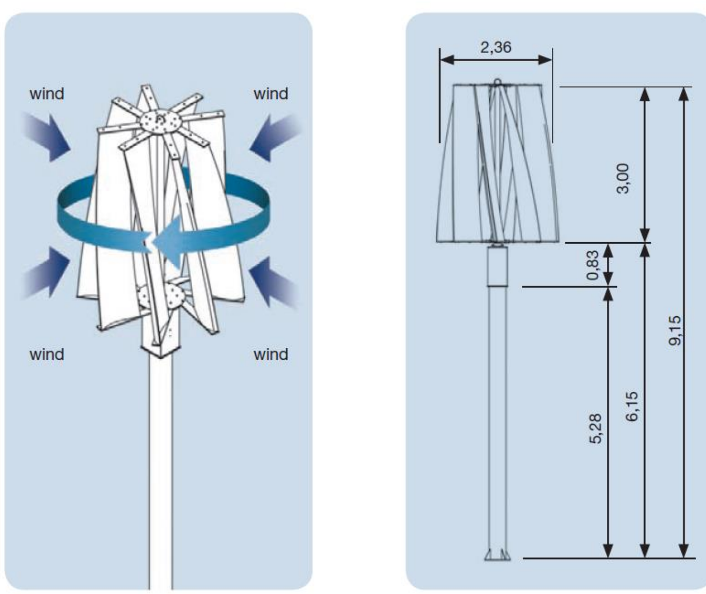


Figure 65. Technical Drawing of Kliux Geo 1800

Wind speed at the 21 meters is calculated by the Wind Shear Exponential Method and equation included as a constant to the original wind speed data created by the Weibull Distribution function for each hour.

$$v_2 = v_1 \left(\frac{z_2}{z_1}\right)^{\alpha} \qquad (2.18)$$

Where,

$$v_2 = velocity\ at\ height\ z_1$$

$$v_1 = velocity\ at\ height\ z_2$$

$$z_1 = Height\ at\ measurement$$

$$z_2 = Height\ at\ requested$$

$$\alpha = Wind\ Shear\ Exponent$$

Table 31. Wind Shear Exponent Shear Values for different areas (Davenport, 1960)

Terrain	Wind Shear Exponent (α)
Coastal waters of inland sea	0.95
Flat shore of ocean small islands	0.121
Open grasslands without trees	0.130 – 0.135
Open slightly rolling farm land	0.143
Open level agricultural land with isolated trees	0.128 – 0.170
Open fields divided by lost stone walls	0.170
Rough coast	0.200
Gently rolling country with bushes and small trees	0.220
Relatively level meadow land with hedges and trees	0.230
Level country uniformly covered with scrub oak and pine	0.250 – 0.303
Wooded and treed farm land	0.357

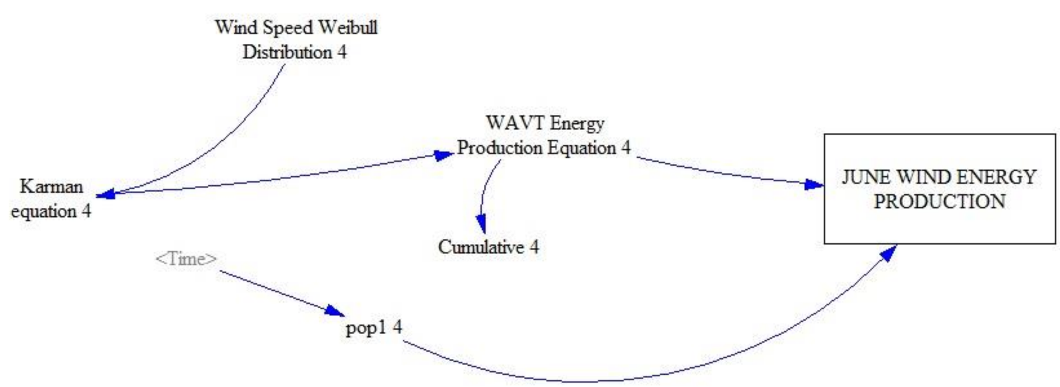


Figure 66. Sub-System Changing on the VENSIM PLE Wind Energy Production Section

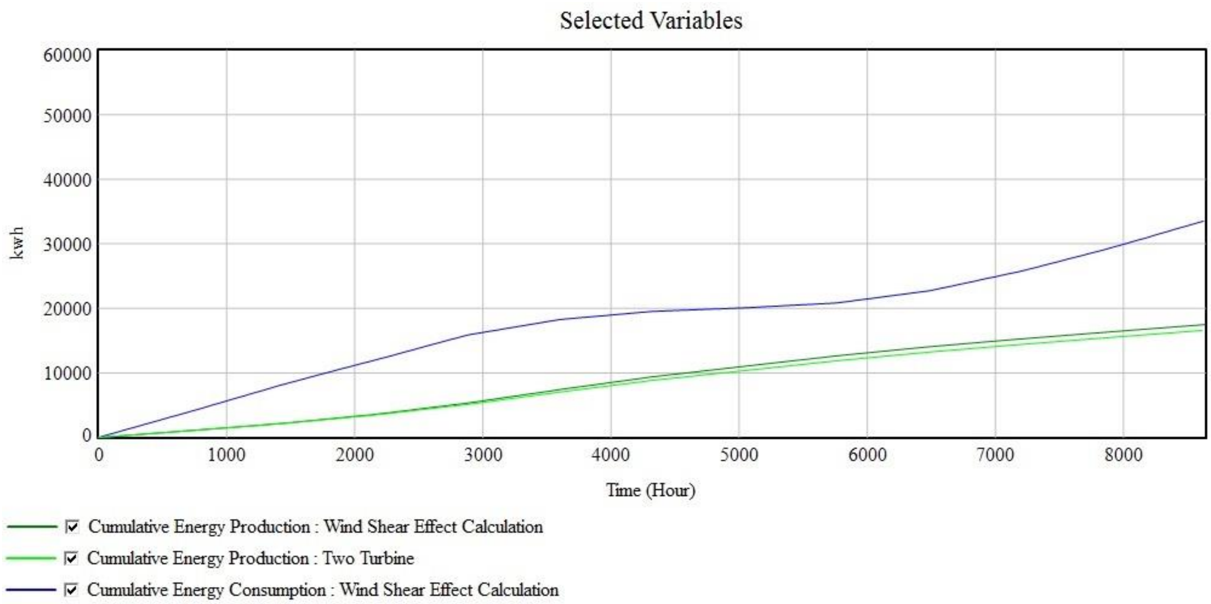


Figure 67. Wind Shear Effect on Energy Production of Wind Turbines for Different Heights

According to the VENSIM PLE simulation, mounting the two turbine to the top of the My Box with tower will increase the total energy production from 16613 kWh to 17801.1 kWh which equals to % 7.15 energy increment.

4.2.3. Installation of Different Type of Wind Turbines

Four different type of turbine has been simulated on VENSIM PLE to see the energy productions for same weather conditions. The chosen turbines are recommended for household by their producers and technical information of each turbine can be found on Appendix section.

The type of the turbines has been listed below,

Table 32. Specifications of simulated wind turbines on VENSIM PLE

Producer	Turbine Model Name	Number of Turbine	Turbine Type	Axis Type	Cut In Speed (m/s)	Cut Out Speed (m/s)
KLIUX	GEO 1800	1	Silvius	Vertical	4	11
HIVAWT	DS-3000	1	Darrius	Vertical	3	12
TUGE	TUGE - 10	1	Three Blade	Horizontal	5	11
ZSERES	SKYSTREAM 3.7	1	Three Blade	Horizontal	3	11

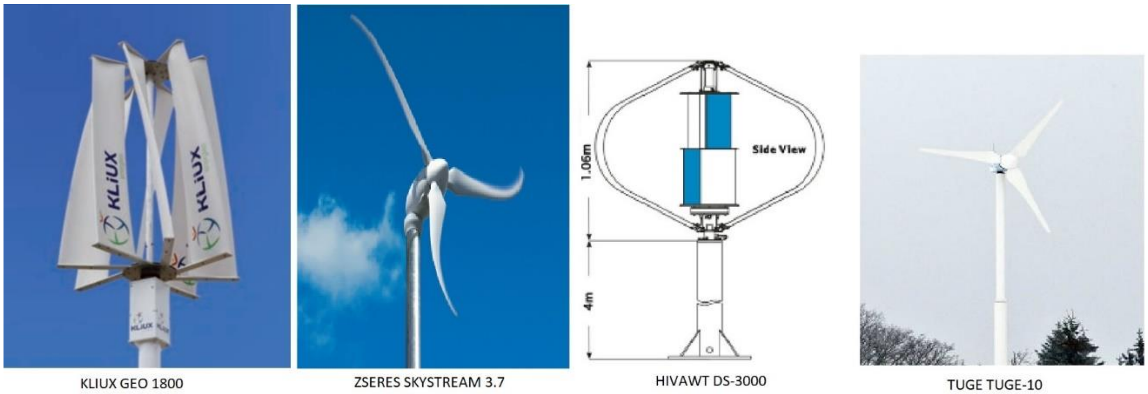


Figure 68. View of Simulated Wind Turbines

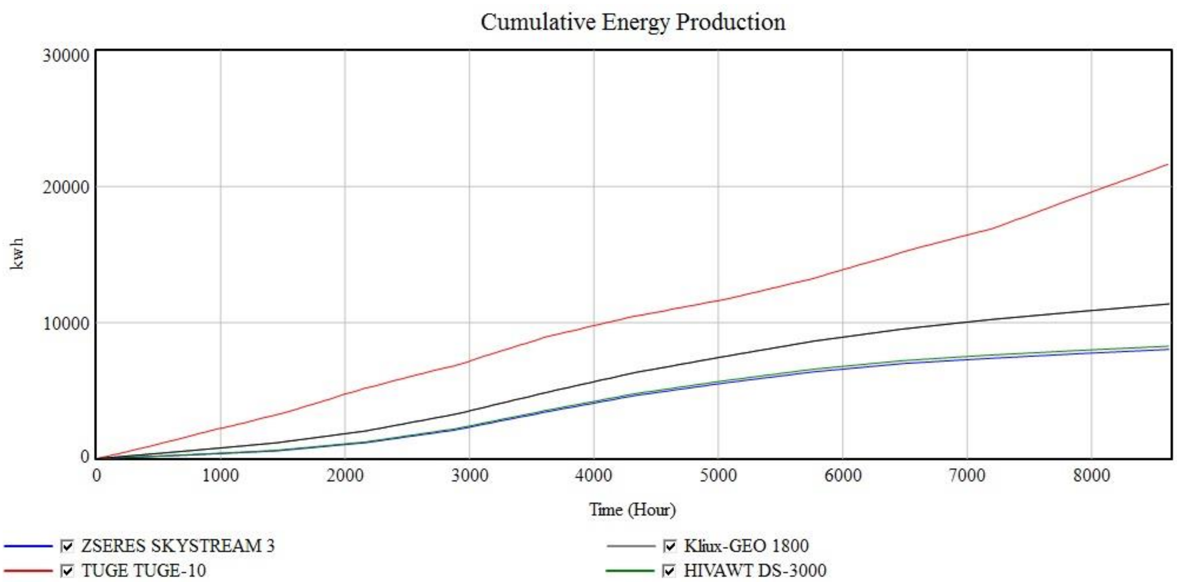


Figure 69. Cumulative Energy Production for Different Wind Turbines

Table 33. Cumulative Energy Production Values for Different Wind Turbines

Model	GEO 1800	DS-3000	TUGE-10	SKYSTREAM 3.7
Energy Production (kWh)	**11335.7**	**8184.22**	**21255.6**	**7928**

4.2.4. PV Panel Alignment to the West Wall of the My Box Student House

It is accepted on previous simulation models that only the roof of the My Box student house was used to mount the PV panels with a fixed tilt angle. As an alternative to increase the energy production, the simulation has been changed as if the east wall of the My Box is also used with tilt angle of 30, 45 and 90 degrees as azimuth angle is 90 degrees.

Figure 70. PV Panel Alignment for East Wall of My Box Student House

As a first step of the Energy production, Helioscope has been used for different tilt angles. The simulation started for new panel area given on Table 34, azimuth angle (ϒ), tilt angle (β) and incident angle (θ_i).

Table 34. Simulation Properties for PV Panel Alignment on East Wall

	TILT	AZIMUT	Total Real Area m2
CASE 1	90	90	115,3
CASE 2	60	90	133,15
CASE 3	45	90	163,08
CASE 4	30	90	230,62

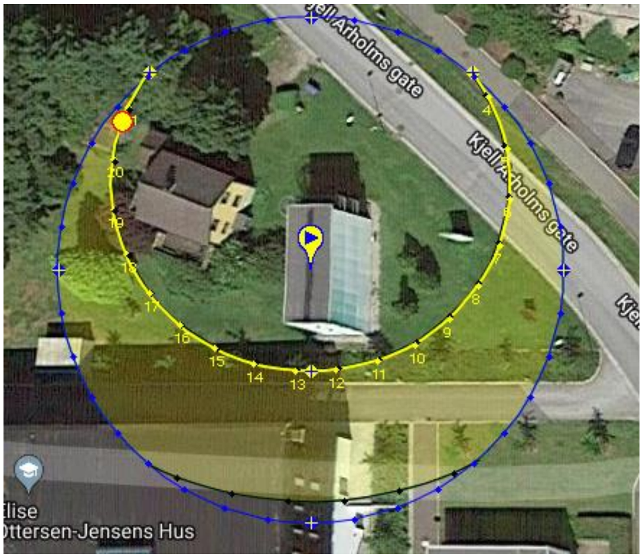


Figure 71. Sun Path Diagram on Google Map for My Box Student House

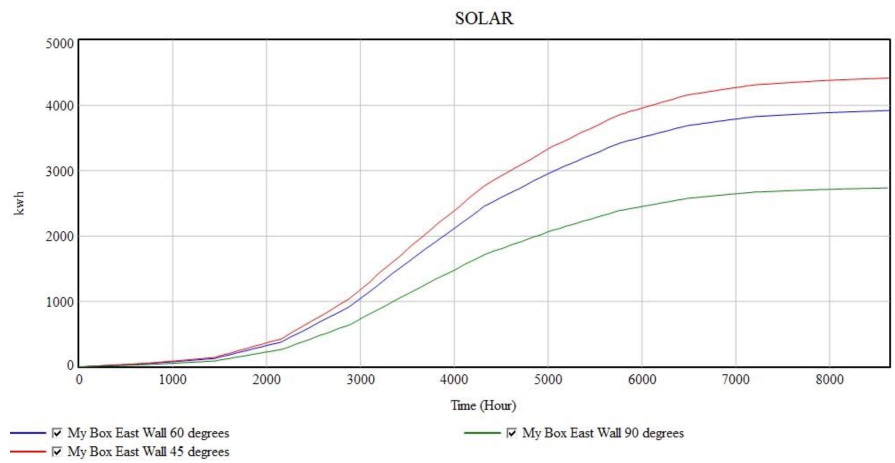


Figure 72. Cumulative Energy Production by PV Panels mounted on the East wall of the My Box student House

4.2.5. Changing Tilt Angle of the Panels

Solar energy production is calculated by considering that the PV panel tilt angle (β) is stable during all year of period. In order to produce more energy, the tilt angle can be adjusted as a results as of each months has different solar radiation values and different sun angles. The PV panels can be mounted on a frame which is guided by Servo engines, PIC Microprocessors and sensors. (Senpinar, 2012)

According to the VENSIL PLE results, if the tilt angle of the PV panels is changed every month, the total energy production increment from PV panels will be 370 kWh / annual.

The optimum tilt angle can be calculated for North hemisphere as (Karafil, Kesler, Parmaksiz, 2014),

$$tan\beta = tan\theta_i \, |cos(\gamma - \gamma_s)| \qquad (2.19)$$

The optimum angle for each month is calculated by reference day of each month at 13.00 CEST time of the day.

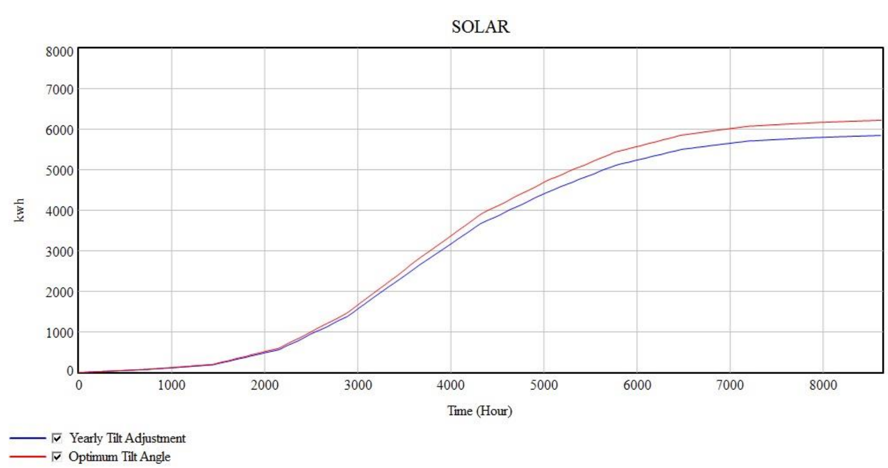


Figure 73. VENSIM PLE simulation for cumulative energy production from PV Panels for Optimum Tilt Angle for each month and optimum tilt angle for each year

5. Conclusion and Discussion

The first conclusion is to answer the formulated research question "How can the energy production, consumption and utilization of passive housing system be estimated to predict hourly, daily, weekly, seasonal, and yearly changes in both weather conditions (variation in sunlight, cloud, and wind speed) and living style e.g. low and high demand periods?" The energy production, consumption and utilization of passive housing system can be estimated by the developed simulation model which has combined hourly energy production and consumption estimations together. the simulation model can be developed in five stages: (1) system analysis of the building system to determine the design parameters for potential energy production systems e.g. roof area, installation type, site location and potential consumption rate e.g. heating, lightning, electric equipment, (2) explore energy production concepts and select optimal one, (3) estimate the potential produced energy, (4) estimate the potential consumed energy, (5) estimate the potential utilized energy.

According to the VENSIM simulation results, Converting My Box Student house to a Passive House category is technically possible but cannot be applicable from engineering economic analysis. The simulation results show that using PV panels as only energy resources cannot be applicable for My Box as a results of its season demand energy production characteristic for Passive House concept. PV panels can be used to reduce the amount of the energy taken from the Norwegian Grid Line in the spring and summer seasons on daylight time of the days. The system will be demanding the required energy from grid line.

On the other hand, selected wind turbine model offers less energy than the PV panels but the produced energy is less dependent to seasonal changings. It is shown that using five selected type wind turbine can produced energy as much as energy consumption at the end of the year but the system needs grid line energy for first five months. The simulation results shows that the system need minimum eight selected type turbine to be passive house from beginning of the year to end of the year. In this case system became uneconomic from first four month as the gaps between produced energy and energy demand from house increase. In this case, the required energy storage system will be increased. This cannot be applicable because of environment risk of the using acidic characteristic of the batteries. The amount of the battery will required an extra facility to install the battery components. Another limitation for using battery system is the lifetime of the battery systems. The turbines and PV Panels are designed to produced energy minimum 15 years of service. Unfortunately, the lifetime of the battery systems is limited to five years and it depends on the charging and recharging times and amounts.

Converting an existing house to a passive house by using hybrid energy production systems can be achieved without energy saving and energy efficiency politics. Reducing the energy demand especially heating and kitchen which are the first two highest energy demanding items will be as effective as the using PV panels and wind turbines.

Changing the kitchen equipment with higher efficient ones, changing the heating system to the hot water based system instead of electrical heater will reduced the kitchen and heating energy demands significantly during the year. Even renting conditions of the students between landlord (SIS Bolig) of the house may cause inhabitants to be less careless about the energy consumptions.

The simulation results show that the turbine which produces the highest amount of energy is Three Blade horizontal type wind turbine. Unfortunately this type of turbines cannot be installed because of their size and noise effect to the environment.

The main discussion is related to simulation technique and simulation result is the using the previous year wind speed data and number of cloudy days and cloudiness day in each month. As discuss in Risk Analysis lecture, these data gives information about the past and it is not certain that the next year data will be matched with the Weibull distributions and cloud day ratios for each month.

Another discussion is about the energy consumption model and number of the inhabitants. In 2017-2018 Academic year, the number of the inhabitants is five. The simulation is based on one student energy consumption and multiplying this with the number of the inhabitant which is accepted as a variance according to the month of the year. The most deviation in summer period between VENSIM PLE results and real data measurements occurs accordingly to that approach.

The electrical equipment list is accepted as same for all inhabitant in the My Box student house. Also the possible energy consumption changings related to the weekdays and holiday are ignored. It is accepted that all days in the simulation have same pattern.

Two months are used as reference to write the solar radiation equation which will be used on the VENSIM PLE. These months are April and May. The equation for other months were written after the approach gave close results to the measurements. The equations used on the VENSIM can be updated regularly by the measurements for other months.

My Box Student House is located near by the Elise Ottesen Jensen Hus – Department of Media and Social Sciences. On the Helioscope software simulation, this building is added as a shape effect parameter. Shade effect is a function of location of sun and height of the building. The shade effect calculation is not evaluated at the thesis. Even though the results between Helioscope and VENSIM PLE is close, writing a shade effect and consider as a parameter for hourly Solar Energy Production, the results will be more reliable.

One of the purposes of the thesis is to find the applicability to convert the My Box student house to an Off-Grid House from energy perfective. On the section 2.5, many alternatives has been simulated to increase the energy production from basic to complex methods. All the combinations are inside the definition of the Hybrid Energy system which has Wind, Photovoltaic and Batteries. The simulation results just changed the production rate for each in the total energy production. As a future research, the selected systems must be also be inspected by cost, pay-back time, reliability, system sensitivity and risk perspective to find the best Hybrid system for My Box.

VENSIM PLE simulation charts show user to see the hourly variance of PV Energy Production, Wind Energy Production, Energy Consumption and Battery Charge - discharge situation. Among these, created data can be used for battery system most effectively compared the others. After the simulation results it is easy to see the maximum capacity and average charge- discharge times of the system. These data can be used for further analysis for battery systems in Hybrid Systems.

The simulation time is limited into one year period. (8640 hours) It is clear that all the system components are mounted to use until their minimum service years provided by the manufacturer. During these service years, maintenance stops, repairs and aging of the system absolutely will cause the reduction of the produced energy and system efficiency drops yearly.

On this thesis, effectiveness of the photo voltaic panel is accepted as a constant, which is average 0.17 (Fraunhofer ISE, 2018). It is known that the efficiency of the PV panels is also depend on the electrical configuration of the PV cells and PV panels. The system must be inspected for different panel material technologies and different panel alignment configuration (serial- parallel connection) which affect the electrical output.

My Box is a student component of the University of Stavanger Ullandhaug Campus. Same analysis can be completed for all buildings individually and together. The layout of the buildings inside the campus may change the wind speeds and solar reflection to PV panels mounted on the other buildings (Mirroring Effect)

APPENDIX

Helioscope Case Reports CASE 7 Production Report by Helioscope Page 1

HelioScope — Annual Production Report produced by OKAN ILKIC

Case 7 MYBOX 18.04.2018, UNI STAVANGER

Report

Project Name	MYBOX 18.04.2018
Project Address	UNI STAVANGER
Prepared By	OKAN ILKIC okan.ilkic@gmail.com

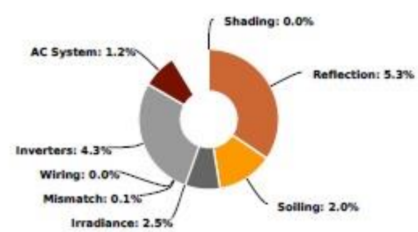
System Metrics

Design	Design 1
Module DC Nameplate	9.80 kW
Inverter AC Nameplate	8.40 kW Load Ratio: 1.17
Annual Production	7.283 MWh
Performance Ratio	86.7%
kWh/kWp	743.2
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Simulator Version	1d80ad2d41-f3b7fc5dab-e2be6f71b1-f933a7f880

Project Location

Monthly Production

Sources of System Loss



Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	857.7	
	POA Irradiance	857.4	0.0%
	Shaded Irradiance	857.4	0.0%
	Irradiance after Reflection	812.1	-5.3%
	Irradiance after Soiling	795.9	-2.0%
	Total Collector Irradiance	**795.9**	**0.0%**
Energy (kWh)	Nameplate	7,802.0	
	Output at Irradiance Levels	7,607.1	-2.5%
	Output at Cell Temperature Derate	7,674.2	0.9%
	Output After Mismatch	7,669.2	-0.1%
	Optimal DC Output	7,669.2	0.0%
	Constrained DC Output	7,703.7	0.5%
	Inverter Output	7,373.7	-3.8%
	Energy to Grid	**7,283.4**	**-1.2%**
Temperature Metrics			
	Avg. Operating Ambient Temp		10.7 °C
	Avg. Operating Cell Temp		15.0 °C
Simulation Metrics			
		Operating Hours	4586
		Solved Hours	4586

Condition Set

Description	Condition Set 1
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Solar Angle Location	Meteo Lat/Lng
Transposition Model	Perez Model
Temperature Model	Sandia Model
Irradiation Variance	5%
Cell Temperature Spread	4° C
Module Binning Range	-2.5% to 2.5%
AC System Derate	0.50%

Temperature Model Parameters

Rack Type	a	b	Temperature Delta
Fixed Tilt	-3.56	-0.075	3°C
Flush Mount	-2.81	-0.0455	0°C

Soiling (%)

J	F	M	A	M	J	J	A	S	O	N	D
2	2	2	2	2	2	2	2	2	2	2	2

Module Characterizations

Module	Characterization
REC280TP (REC Solar)	Spec Sheet Characterization, PAN

Component Characterizations

Device	Characterization
M250 (240V) (Enphase)	CEC

 1/2 April 18, 2018

HelioScope

Annual Production Report produced by OKAN ILKIC

Components

Component	Name	Count
Inverters	M250 (240V) (Enphase)	35 (8.40 kW)
AC Panels	2 input AC Panel	1
AC Home Runs	1/0 AWG (Aluminum)	1 (213.7 m)
AC Branches	10 AWG (Copper)	2 (24.2 m)
Module	REC Solar, REC280TP (280W)	35 (9.80 kW)

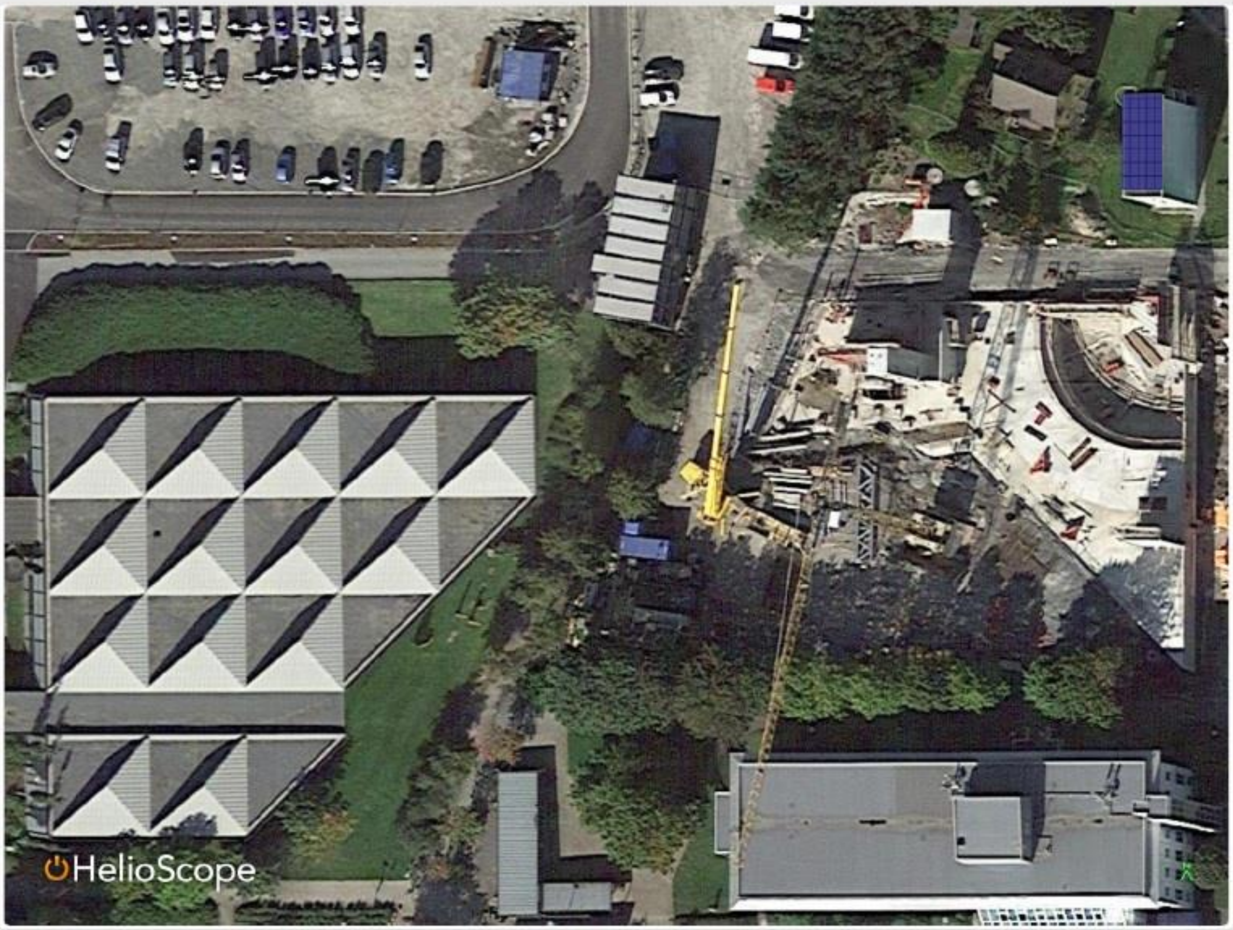
Wiring Zones

Description	Combiner Poles	String Size	Stringing Strategy
Wiring Zone	12	1-1	Along Racking

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Portrait (Vertical)	0°	180°	0.0 m	1x1	35	35	9.80 kW

Detailed Layout



HelioScope

Annual Production Report produced by OKAN ILKIC

CASE 1

Master Thesis Presentation, University of Stavanger

Report

Project Name	Master Thesis Presentation
Project Description	UiS MyBox PV Panel Alignment Analysis
Project Address	University of Stavanger
Prepared By	OKAN ILKIC okan.ilkic@gmail.com

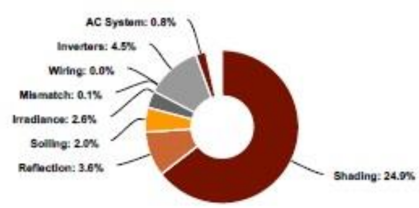
System Metrics

Design	MyBox UiS
Module DC Nameplate	9.80 kW
Inverter AC Nameplate	8.40 kW Load Ratio: 1.17
Annual Production	6.559 MWh
Performance Ratio	66.4%
kWh/kWp	669.3
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Simulator Version	49a1a0dd51-5f189a99ca-3f3161f7bf-a49332ed44

Project Location

Monthly Production

Sources of System Loss



Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	857.7	
	POA Irradiance	1,007.9	17.5%
	Shaded Irradiance	756.5	-24.9%
	Irradiance after Reflection	729.0	-3.6%
	Irradiance after Soiling	714.4	-2.0%
	Total Collector Irradiance	**716.7**	**0.3%**
Energy (kWh)	Nameplate	7,028.2	
	Output at Irradiance Levels	6,842.7	-2.6%
	Output at Cell Temperature Derate	6,890.1	0.7%
	Output After Mismatch	6,885.5	-0.1%
	Optimal DC Output	6,885.5	0.0%
	Constrained DC Output	6,928.7	0.6%
	Inverter Output	6,614.3	-3.8%
	Energy to Grid	**6,559.0**	**-0.8%**
Temperature Metrics			
	Avg. Operating Ambient Temp		10.7 °C
	Avg. Operating Cell Temp		14.6 °C
Simulation Metrics			
	Operating Hours		4586
	Solved Hours		4586

Condition Set

Description	Condition Set 1
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Solar Angle Location	Meteo Lat/Lng
Transposition Model	Perez Model
Temperature Model	Sandia Model
Temperature Model Parameters	Rack Type / a / b / Temperature Delta Fixed Tilt / -3.56 / -0.075 / 3°C Flush Mount / -2.81 / -0.0455 / 0°C
Soiling (%)	J F M A M J J A S O N D 2 2 2 2 2 2 2 2 2 2 2 2
Irradiation Variance	5%
Cell Temperature Spread	4° C
Module Binning Range	-2.5% to 2.5%
AC System Derate	0.50%
Module Characterizations	Module: REC280TP (REC Solar) Characterization: Spec Sheet Characterization, PAN
Component Characterizations	Device: M250 (240V) (Enphase) Characterization: CEC

 1/2 May 12, 2018

HelioScope

Annual Production Report produced by OKAN ILKIC

Components

Component	Name	Count
Inverters	M250 (240V) (Enphase)	35 (8.40 kW)
AC Panels	2 input AC Panel	1
AC Home Runs	1/0 AWG (Aluminum)	1 (19.8 m)
AC Branches	10 AWG (Copper)	2 (25.4 m)
Module	REC Solar, REC280TP (280W)	35 (9.80 kW)

Wiring Zones

Description	Combiner Poles	String Size	Stringing Strategy
Wiring Zone	12	1-1	Along Racking

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Portrait (Vertical)	50°	180°	0.8 m	1x1	35	35	9.80 kW

Detailed Layout

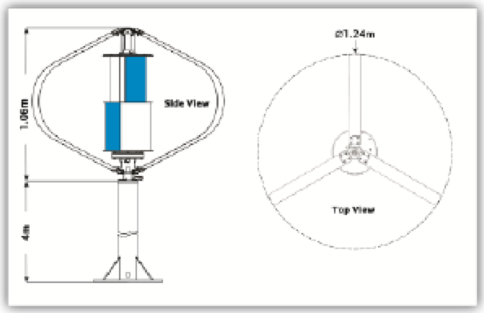
HIVAWT

Vertical Axis Wind Turbine Power System
Model number: DS300

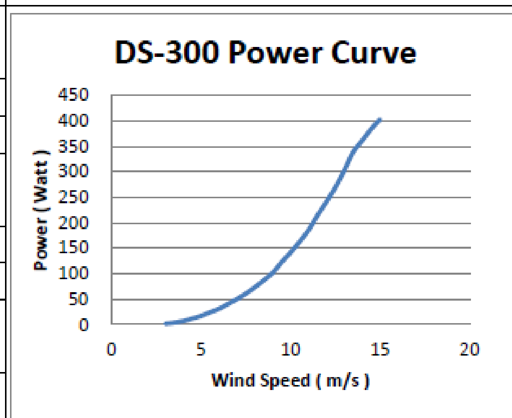
PRODUCT SPECIFICATIONS

General Specifications			
Rated Power	300W	**Rated Wind Speed**	13.5 m/s
Rated Speed	835 rpm	**Cut in Wind Speed**	<3 m/s
Cut out Wind Speed	15.5 m/s	**Survival Wind Speed**	60 m/s

Dimensions/Weight	
Rotor Diameter	1.24 m
Rotor Height	1.06 m
Tower Height	4.00 m (minimum)
Total Height	5.06 m (minimum)
Turbine Weight	25.5 kg w/o tower
Rotor Specifications	
External Darrieus	3 blades
Internal Savonius	2 layers
Blades Material	Anodized aluminum
Axis Material	Galvanized steel SS400
Generator Specifications	
Generator Type	AC, 3phase, Synchronism PMG
Rated Output	300W
Braking System	
Automatic	3-phase short circuit braking system
Manual	Optional
Operation Conditions	
Ambient Temperature	-10~40℃
Ambient Humidity	95% max.



Power Curve



----Page 1 of 2

HIVAWT Vertical Axis Wind Turbine Power System
Model number: DS300

PRODUCT SPECIFICATIONS

Wind Power Controller	
Model Number	WG0400
Rated Power Output	400W
Input Voltage Range	0~50V
Power Charge (Start/Stop)	6V/4V
Rated Input Voltage	28V
Rated Input Current	15A
MPPT Efficiency	>92%/>95%
Sleeping Mode| (Wake-up Voltage)	5Vdc @ 1 min. (from turbine)
Power Activate Voltage	5V
Battery Suggestion	12VDC/100AH/150AH/200AH
Maximum Battery Charging Current	10/15/30 Amp
Battery Protection Voltage	13.8V ±0.5V
Float Charging Voltage	14.4V ±0.5，1min charging per 10min
Loading Output Current	DC 16Amax,
Discharging Limit	11.5VDC ±0.5
Loading Control Set-up	14 sections
Sleep Mode Activate Voltage	11.5Vdc ±0.5 (from battery)
Current of Stand-by Mode	<1mA@Sleep Mode
Additional Outdoors Requirement	Optional
Package Interface	20cm PVC line to line
Dimensions(L×W×H) mm	200×142×50
Weight	1.5 kg

----Page 2 of 2

TUGE TUGE-10 Wind Turbine Product Specifications Page 1

TUGE

OPERATING PARAMETERS

Nominal power	9.9 kW
Nominal rpm	69
Nominal wind speed	11 m/s

DIMENSIONS

Hub height	18 or 22 m
Rotor diameter	10.2 m
Rotor area	82 m²

ENVIRONMENTAL CONDITIONS

Active wind range	3-25 m/s
Survival wind speed	50 m/s
Operational temperature	-25…+60°C

CONTROL
stall, active inverter, active dump load, tip-brake, active yaw, rotor brake

BLADES
from fiber glass with fail-safe tip-brakes by Olsen Wings

ROTOR BRAKE
fail-safe electromagnetic brake by Intorq

YAW
electric drive with encoder

GENERATOR
permanent magnet synchronous generator

INVERTER
active inverter with TMC3 controller and online SCADA by Orbital

TOWER
tilt-up steel tower in 3 parts and base section

MAINTENANCE
once in every two years due to automatic lubrication system by SKF

CERTIFICATION
IEC61400-2 certification in progress by Intertek

M/S	KW	KWH
5	2.43	27 597
6	4.20	36 261
7	6.37	42 808
8	7.85	47 395
9	8.78	50 423
10	9.36	52 247
11	9.82	52 995

WWW.TUGE.EE

KLIUX Energies GEO 1800 Product Specification Page 1

Products

Kliux Geo 1800 vertical-axis wind turbine

Rotor:
Maximum energy without noise

Own design and patent, uniquely combines drag-type vertical-axis model and lift-based model in one single rotor. Has eight blades with two different alternating profiles, alpha and beta.

- The alpha receives, drives, and retains the wind for a longer period. It performs the drag function to obtain maximum energy.
- The beta picks up the winds coming from the alpha, enhancing the turn of the rotor, "making it fly" (like the wings of a plane). It performs a lift function.

The rotor speed is slow and rarely exceeds 60 rpm, providing **structural integrity, no noise, less wear and tear, and less maintenance required** during its useful life.

The rotor limits its speed naturally, without the need for brakes. It reduces the risk of damage and increases energy production time.

Its modern, sculpture-like appearance means it is easily integrated into the landscape, as well as being an **excellent advertising medium.**

Generator:
Efficiency and durability

With permanent magnets, it is one of the most efficient electricity-generating technologies. It is simple to operate and requires little maintenance.

It provides a three-phase output voltage, and its amplitude and frequency vary with the rotational speed. A low starting torque enables the rotor to start turning at low wind speeds.

Support:
Strength and aesthetics

The rotor and generator are supported by a steel structure with mechanical resistance to withstand the force of the wind. It is anchored to the ground with a footing, thus eliminating the need for cables, making it more aesthetically pleasing and integrated into the landscape.

It has a coating of anti-corrosion paint.

Technical specifications at **www.kliux.com**

KLiUX energies

Kliux Hybrid wind and solar system

Kliux Energies recommends using any natural resources available at each location thus optimizing the flow of generating hours, cost efficiency ratio, and equipment depreciation periods.

It has therefore designed a hybrid system of energy generation by integrating a Kliux Geo 1800 vertical-axis wind turbine and solar photovoltaic panels.

This is the most recommended configuration for an off-grid installation of the network, as it provides the option of incorporating a battery bank which gives a supply autonomy of between 3 and 5 days.

Components of the Kliux Hybrid installation:

- Kliux Geo 1800 wind turbine.
- 15 photovoltaic panels, monocrystalline, at 265 W each. (3975 W total).
- Electronics: wind inverter, solar inverter, inverter protection, communication module, and weather station.

Annual total energy generated

	Annual average wind (m/s)							
	4	5	6	7	8	9	10	11
Total (kWh)	5.787	6.017	6.334	6.765	7.303	8.018	8.559	9.170

Technical specifications at **www.kliux.com**

References

Tiwari G. N. (2002) Solar Energy Fundamentals, Design, Modelling and Applications, Alpha Science

Smets A., Jager K., Isabella O., Swaaij R.N., Zeman M. (2016) Solar Energy The Physics and Engineering of Photovoltaic Convertion Technologies and Systems, UIT Cambridge

U.S. Department of Energy, National Institute of Building Sciences. (2015) “A common definition for Zero Energy Buildings”

Feist, W. PHPP Handbook, PHI Darmstadt; 2007

Gang A., Guchao X., Rong J., Tiantian W., (2017). “Study on optimal configuration of the Grid –connected wind- solar- battery hybrid power system” International Journal of Sustainable Energy 36 (7): 668-681

Lazarov V., Notton G., Zarkov Z., Bochev I. (2005). “Hybrid Systems with Renewable Energy Sources – Types, Structures, Trends for Research and Development” ELMA Sofia 2005: 515-520

Stamnes K., Stamnes J.J., (2008) “Transport of Solar Radiation through the Atmosphere Aspects Relevant for Health” Solar Radiation and Health: 9-22

Nahar S. N., (2008) “Solar Irradiation of the Earth’s Atmosphere” International Symposium on Climate Change and Food Security of South Asia

Chaitanya Marisarla, Kumar K.R. (2013). “A Hybrid Wind and Solar Energy System with Battery Energy for an Isolated System” International Journal of Engineering and Innovative Technology (IJEIT) 3 (3): 99-104

International Energy Agency Current Policies Scenario, 2011

Bolonkin A., Friedlander J. (2013). “Explosion of Sun” Computational Water, Energy and Environment Engineering 2: 83-96

Albarqouri S., Hussein T. M., (2010) “Enhanced Model of One Axis- Two Positions Manual Tracking Photovoltaic Panels for Lighting Project in Palestine” Proceeding of the Second IASTED International Conference, Solar Energy (SOE 2010): 937-943

Abuska M. (2017) Solar Energy, University of Manisa Celal Bayar

Mondol J., Yohanis G.Y., North B. (2007) “The Impact of Array Inclination and Orientation on the Performance of a Grid-connected Photovoltaic System” Renewable Energy 32 (2007): 118-140

Karafil A., Ozbay H., Kesler M., Parmaksiz H. (2015) “Calculation of Optimum Fixed Tilt Angle of PV Panels Depending on Solar Angles and Comparison of the Results with Experimental Study Conducted in Summer in Bilecik, Turkey” 2015 9th International Conference on Electrical and Electronics Engineering (ELECO): 971-976

Eldin S.S.A., Abd- Elhady M.S., Kandil H.A. (2016). «Feasibility of Solar Tracking Systems for PV Panels in Hot and Cold Regions» Renewable Energy 85 (2015): 228-233

Senpinar A., Cebeci M. (2013)."Design Consideration for Stand Alone Photovoltaic (PV) Cell Applications" Scientific Bulletin of the Petru Maior University of Tirgu Mures 10 (28): 40-46

Fraunhofer Institute for Solar Energy Systems, ISE, Freiburg, Germany (2018) "Photovoltaic Reports": 27