University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Industrial Asset Management	Spring semester, 2019 Open / ~~Restricted access~~
Author: Lovita Ghassini	……………………………………… (Author's signature)
Faculty supervisor: Associate Professor Idriss El-Thalji	
Thesis Title: Technical Innovation Modeling of Energy System: A Simulation Approach of Building Cluster in Stavanger Komunne	
Credits (ECTS): 30	
Keywords: - System dynamics modeling & simulation - Cluster public building - Energy system (consumption & production) - Solar PV - Bio-coal - Geothermal heat pump	Pages: 46 + enclosure: 3 Stavanger, 15.06.2019 date/year

Technical Innovation Modeling of Energy System: A Simulation Approach of Building Cluster in Stavanger Komunne

By

Lovita Ghassini

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: Industrial Asset Management

University of Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

University of Stavanger

2019

Abstract

System Dynamics is a program approach to understand the system by analysing and designing with the multiloop and time-lag characteristic and program that been used in this thesis called Vensim PLE. The system dynamics model has been used to analyse the trend of the energy consumption and energy production of a case study in a cluster of the public building in an area in Stavanger city, Norway. The group of the building consists of four buildings that are the kindergarten, the sports hall, the town hall, and the school. Several factors influenced the energy consumption such as the activity of the building, the building condition, the design of the building, and the seasonal effect. The energy consumptions are getting increased as the time goes by as well as the greenhouse gas emission. Renewable energy is one the greatest solution for the energy source to quit fossil fuel. Therefore, the government of the country must have some approach to minimize the energy consumption and technical solution for reducing greenhouse emission gas.

This thesis intends to continue the previous study by improving the scope of the study. The previous relevant researches have a different focus, i.e., focus on the general condition of the town, the office buildings, a district in the city, and an office and a residential building. Whereas, this study concentrates on more than one structure of the few public building in the area of the city.

This thesis aim is to explain and predict the dynamic behaviour of the building energy system in a group of building with the involvement of understanding the solution to reduce greenhouse emission gas. The study conduct by simulating the system dynamic model of the relation between energy production and energy consumption. The relationship of both creates the balancing loop diagram, and the result of the model were examined according to the utilization pattern.

The methodology of the thesis has been done in three main stages that are (i) obtained the energy production data from the solar PV arrangement from the HelioScope program by managing the most optimum design from the tilt angle, type of racking, azimuth angle, and row spacing, (ii) organizing of each building energy consumption by hourly, seasonally and yearly, (iii) both of the energy production and the energy consumption has been computed in Vensim PLE program to analyse the dynamic behaviour.

The result from system dynamics modeling illustrates that the system establishes two balancing causal loop diagram, the main loop is the energy production and the energy consumption with several parameters that influence the system that are utilization factor, seasonal factor, holiday factor, and solar output. The other balancing loop is the presence of battery storage between energy production and energy consumption.

The seasonal factor is the essential key as a determinant of the amount of solar PV yield and the fluctuation of the energy consumption utilization pattern. When in summer time the energy

production reaches its peak due to the appearance of the sun, while the energy usage was on minimum value since it does not need much electricity. In comparison, when in winter, the condition was reversed, the solar PV output was difficult to generate energy, and the electricity was on maximum utilization. Hence, in the middle of the year, energy production might remarkably cover energy consumption.

Several technical solutions could be done to improve solar PV production and minimize energy usage. To maximize the ability of the solar PV to receive the solar radiation can be by designing the appropriate roof and managing the optimum parameter arrangement of the solar PV module. For instance, the design of the roof should be tilted facing the sun, build the stand-alone PV panel grid, use the battery storage to keep the energy, and many other solutions. To minimize the energy usage might be done by managing the ventilation, the heater position, reduce the activity of the building or reduce the student of the kindergarten and school.

The condition of the utilization profile for the four buildings has been analysed, and the electricity consumption peaks were classified according to the weekdays peak, weekend peak, and weekend or holidays. The organized summary of average in monthly was computed into the system dynamics program, and then the graph output has been used to explain the condition of the energy behaviour and prediction of the future pattern of the system. The graph illustrates that there is a utilization shift between the building that occurs due to this study focus on four buildings instead of 1 building, and they have a different activity and different holiday time.

The implication of this study is to support the city government to reduce greenhouse emission and reduce electricity consumption by converting the electric heater to the hydronic heater. The source of the electric heater is come from the electricity grid, while the hydronic heater is by using the water as the medium and the renewable energy for the source of energy. The energy sources considered for the hydronic heater are the bio-coal and geothermal heat pump. The concept of the bio-coal as the energy source for the hydronic heater is to use the bio-coal as a solid fuel to process the water boiler or to burn the furnace; while, the geothermal heat pump is by using the energy from the ground. Both of them has the ability to reduce greenhouse gas, yet the bio-coal has more benefit and less effort than the geothermal heat pump.

Acknowledgement

Foremost, I would like to express my gratitude to God Almighty, who is allowing me to pursue a master degree at the University of Stavanger. Also, giving me good health, strength, patience, and the ability to get through this thesis.

I am highly thankful to my supervisor, Associates Professor Idriss El-Thalji, that has given me the guidance and supervision throughout my study. His input, feedback, help, as well as the ideas, were really useful in completing my master thesis.

Special thanks were given to my husband, Andika Rachman PhD., for his advice, guidance, motivation, and continuous support during my study at UiS. His encouragement and patience gave me the energy to keep fighting during a hard time.

I would like to thank my parents and my parents in law that eternally support me. Their words of encouragement and prayers were the driving force that keeps me resilience and perseverance in any conditions. My motivation is always to make them proud and happy.

My deepest gratitude to Ernst Olsen, Espen Svendsen and Aud-May Stenhaug from Stavanger Kommune for kindly providing the energy data that used in this master thesis.

I would also like to thank the project coordinator, Helleik Line Syse, for the help in connecting with the Stavanger Kommune.

I am grateful to the University of Stavanger for giving me a wonderful study opportunity and experience. Also, for providing me the facilities and work support.

Lastly, many thanks to my fellow Indonesians students at the UiS for the remarkable days we spent together in Stavanger. The chatter and laughter were always brightened up my days.

Table of Contents

Table of Figures

List of Tables

List of Abbreviation

c-Si	Crystalline Silicon
CCTV	Closed Circuit TV
CO_2	Carbon dioxide
ET	Equation of time
GHPs	Geothermal heat pumps
GSHPs	Ground Source Heat Pump
GWh	Giga Watt hour
HTC	Hydrothermal carbonization
kJ	Kilo Joule
kWh	Kilo Watt hour
L_L	Longitude of the location
L_S	Standard meridian for a local zone
LT	Local standard time
MSW	Municipal Solid Waste
NASA	The National Aeronautics and Space Administration
NS	Norwegian Standard
PLE	Personal Learning Edition
PV	Photo Voltaic
SSB	Statistisk Sentralbyrå
ST	Local solar time
WTE	Waste-to-Energy

Nomenclature

δ	Declination angle
ω	Hour angle
γ	Solar azimuth angle
ϕ	Latitude
β	Tilt angle
Γ	The day angle in radians
n	The number of the day in the year

1 Introduction

1.1 Problem background

The climate change is one of the main problems for all over the world with the emergence indication of such as the rising of global temperature, arctic sea ice deterioration, sea level rise, and many others. Many factors influence global warming; according to NASA, this global warming phenomenon is 95 percent probability comes from the personal habit for over the past 50 years (NASA). The heat that comes from the solar, some of the heat are passes through the atmosphere, and some of them are supposed to be reflected back to space. Yet, due to the human activity, they donate the greenhouse effect and increase the volume of the greenhouse gasses which could make the heat trapped by the greenhouse gas in the atmosphere resulting in the rising the earth temperature.

To support the earth to reduce climate change, as a human should identify precisely what the leading causes are and know how to tackle the problem. The relationship between climate change and energy are related, that is the energy production, and consumption denotes the source of the greenhouse gases. Notably, the energy come from the fossil fuels that are used for the electricity, heating, industry, and transport are contributing around two-thirds of the global greenhouse gases emissions (EEA, 2017).

Nowadays, the technology for getting the energy source is increasingly evolved; hence, people start leaving fossil fuels and begin to develop renewable energy. The utilization of the energy source is depending on the natural wealth and also the government policy of a country. In Norway, for instance, has implemented the use of renewable energy. About 98 percent of the electrical production is obtained from the renewable resource with the most substantial proportion by hydropower (Energy, 2016). Although this alternative might sharply reduce the carbon emission, still we need to figure out how the dynamic behaviour of the energy system.

Energy production and energy consumption are related to each other. Generally, energy production exists due to the energy demand, and it is directly proportional when the government cannot fulfil people's needs, and they should have to find a way to solve this matter. Globally, industrial sector, transportation, and buildings/households are the highest energy consumption, and this also happens in Norway (BP, NVE, 2018). The energy needs and usage always increase as time goes by, as in Norway, the energy consumption inclines 16 percent since 1990 (Sentralbyrå, 2018). Hence, there is a tendency for the inhabitants to manage the solution for their house/building to be a green energy friendly such as install the solar cell, designing the eco-building, implementing the disruptive technology, etc.

Besides the human habit, there are many factors that affect the energy balance in a country such as a season, weather, population, technology of electrical appliances, etc. All of the element may create a causal relationship of this system. Hence, the author intends to forecast the leverage of future energy production and consumption of the chosen model case study by using the system dynamics modeling.

1.2 Research gap/literature review

The author has searched from the Scopus related to the "Energy Consumption Simulation", and has found 40 hits showing the concerned topic with the keywords that are sorted by subject area: energy, document type: article, review, and book chapter, source title: energy and buildings, as below keyword wording:

TITLE-ABS-KEY (**energy** AND **consumption** AND **simulation**) AND (LIMIT-TO (EXACTSRCTITLE , **"Energy And Buildings"**)) AND (LIMIT-TO (DOCTYPE , **"ar"**) OR LIMIT-TO (DOCTYPE , **"re"**) OR LIMIT-TO (DOCTYPE , **"ch"**)) AND (LIMIT-TO (SUBJAREA , **"ENER"**))

Table 1.1 shows some related title that relevant to this thesis:

Table 1.1 Relevant title regarding concerned thesis topic

No.	Document title	Authors	Year
1	System Dynamics modeling for urban energy consumption and CO2 emissions: A case study of Beijing, China	Feng, Y.Y. Chen, S.Q. Zhang, L.X.	2012
2	A systematic methodology for optimising the energy performance of buildings in Bahrain	Radhi, H.	2008
3	Proposal of a modeling approach considering urban form for evaluation city level management	Yamaguchi, Y. Shimoda, Y. Mizuno, M.	2007

The author conducts this research to continue the previous study by broadening the scope of the study. There was a similar topic related to the energy production and consumption that the last year master student did it for their master thesis. However, their focus was different. For example, Mahshid Hatamzad, did the master thesis regarding the "A simulation model and system risk analytics for a net zero energy office building: A case study" (Hatamzad, 2018). She was analysing the office building and concentrate only one building with four levels of floor. Another example, M. Okan Ilkic, the master thesis title was "Simulation model of hybrid energy production and consumption for passive house concept: a case study: "MyBox student house" in University of Stavanger (UiS) campus (Ilkic, 2018). He was analysing the residence building and concentrate only one small residential building with three levels of floor. Therefore, the author intends to expand the energy production and consumption relation by making the simulation of a cluster of different kinds of building in one of an area in Stavanger city, Norway. Figure 1.1 illustrates the classification chart of the system consumption for the types of buildings and the focus of the author is the public building with more than one building.

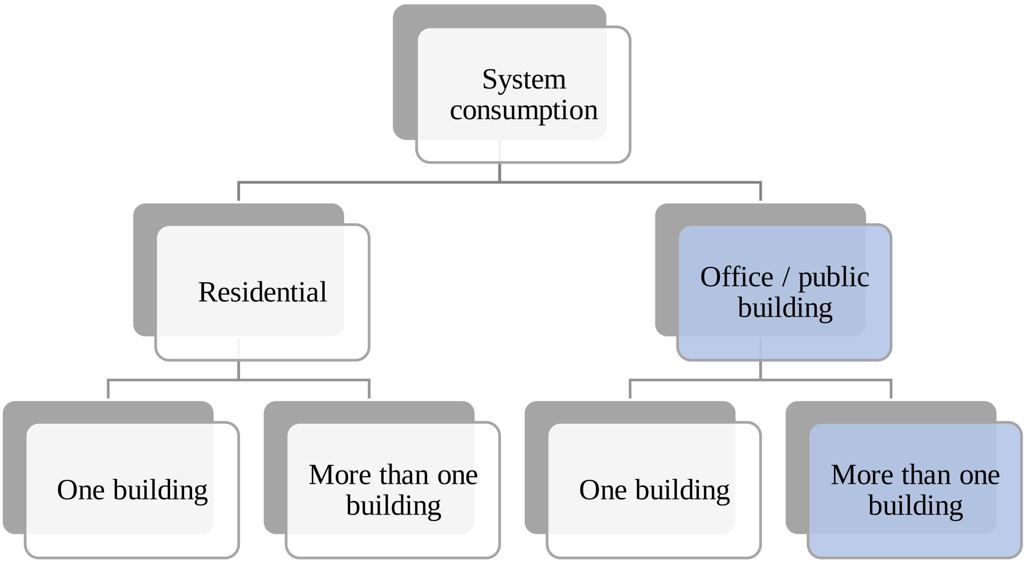


Figure 1.1 System consumption chart

1.3 Research objective and relevance

The main objective of the thesis is to explain and predict the dynamic behaviour of the building energy system in a cluster of building at Gautesete area, Stavanger city, Norway. This objective has some implication by supporting the city government to reduce greenhouse gas emission. In this case, the utilization of heater becomes the most substantial electricity consumption; therefore, the buildings which use the electric heater intended to convert to the hydronic heater by using either bio-coal or geothermal as a source. Both bio-coal and geothermal energy source still on research to execute in this building cluster.

1.4 Methodology

This thesis is based on a case study from the Stavanger Komunne, which a pilot project in the area called Gautesete that located in Stavanger city. The selection of the case is mainly used as a basis on the supporting of the smart city of Stavanger by reducing the greenhouse gas emission. In order to approach the objective, there are several ways that have been done, and Figure 1.2 shows the stage of the study.

- Firstly, the case study is in accordance with the Stavanger Komunne and the data related were gathered.
- After the case study was chosen, the academic literature review was needed to understand the subject, analyse the concept, and the ability to simulate the model.
- Next, getting the best potential energy production from the solar PV panels by using HelioScope program.

- The energy consumption data, in this case, electricity consumption data of each building were obtained from the Stavanger Komunne.
- Lastly, analysing the simulation model by using Vensim PLE software. This one is the most essential part to identify the dynamic behaviour of solar energy production and energy consumption.

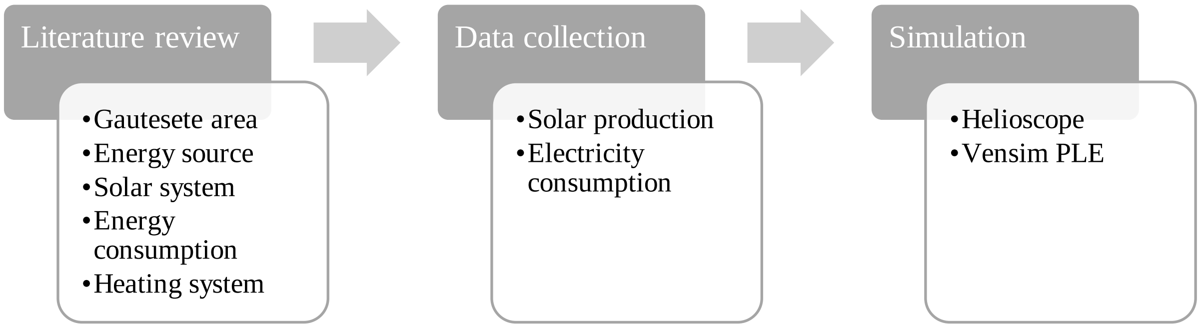


Figure 1.2 Methodology stage

1.5 Scope of thesis Limitation/Delimitation

There are several limitations that has been taken in the execution of this thesis in order to perform a reliable and valid analysis within limited data, including some of the limitations as follows:

- The calculation of energy production only relies on one source of renewable energy that is solar energy.
- The calculation of energy consumption was based on electricity usage not divided by the allocation and is from one past year only, which makes the simulation not optimum.
- The case study of this thesis did not consider the heat loss of each building that influences the usage of electricity, such as a heater.
- The case study of this thesis did not consider the cost evaluation of building energy center.

1.6 The Structure of The Thesis

The thesis consist of six chapters which will be structured as follows:

Chapter one covered the introduction that contains problem background, research gap/literature review, research objective, methodology, and thesis limitation/delimitation.

Chapter two will concern about the theoretical background regarding the building consumption in general, energy sources that consist of solar PV for energy production, bio-coal and geothermal for the technical solution of the hydronic heating energy source, and system dynamic concept.

Chapter three will contain the information of the case study, brief information regarding the Gautesete area, and the collection of the energy data.

Chapter four will provide about the data analysis, which contains the case study analysis and the simulation model. The case study analysis include the building analysis, technical solution, and consumption analysis; while, the simulation model covered the purpose, model development, result of the simulation, and the scenario.

Chapter five will discuss the result of the discussion and conclusion of the simulation model.

2 Theoretical Background

2.1 Building consumption

According to Søgnen, Norwegian buildings consume the electricity around 80 TWh in a year with the residential building about 46 TWh and non-residential building around 34 TWh, as shown in Figure 2.1 below (Ole-Gunnar Søgnen, 2001). The chart represents that 47 TWh in total is used for heating, and 32,5 TWh use heat by electricity for both types of buildings. Due to the rapid growth in building energy usage in Norway, hydropower utilization has started to end; then this country needs to import a sizable amount of electricity from the neighbouring country.

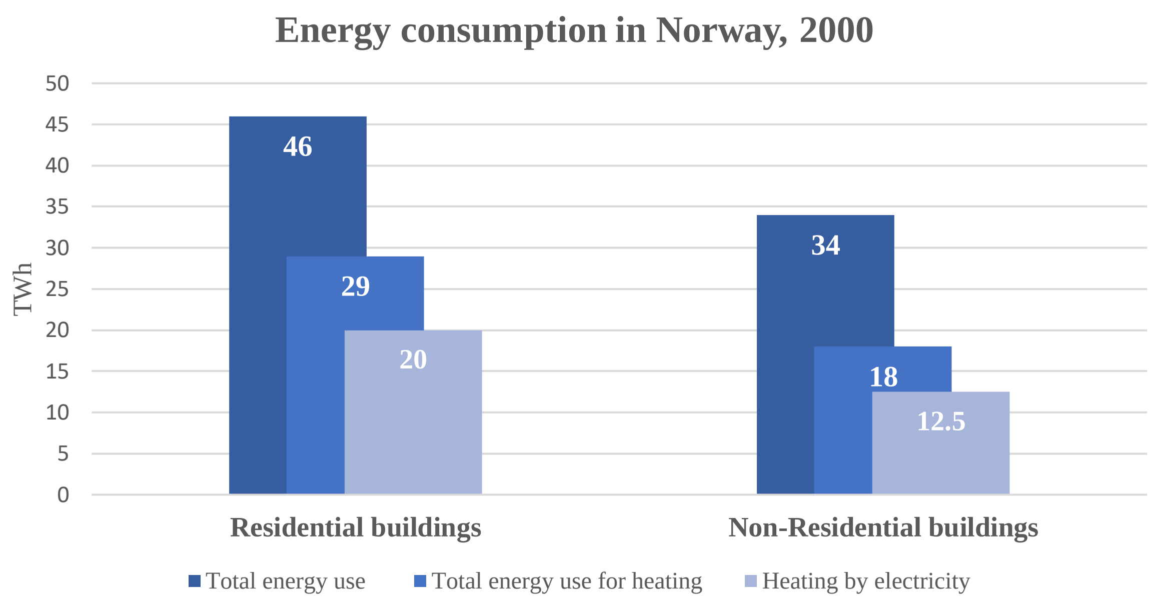


Figure 2.1 Norwegian buildings energy consumption in 2000 (Ole-Gunnar Søgnen, 2001)

Enova, a state-owned company under the Ministry of Climate and Environment that focuses on reducing greenhouse gas emissions, and other energy-related, they conduct a project called Model Building. There are 26 office buildings observed with seven categories according to Norwegian Standard (NS) 3031 that are heating, ventilation, hot water, fans/pumps, lighting, electrical equipment, and air conditioning. The result is shown in Figure 2.2 below. The chart shows the measurement result of the most energy consumption in the office buildings is heating, followed by fans and pump, and ventilation, with the least energy usage, is hot water.

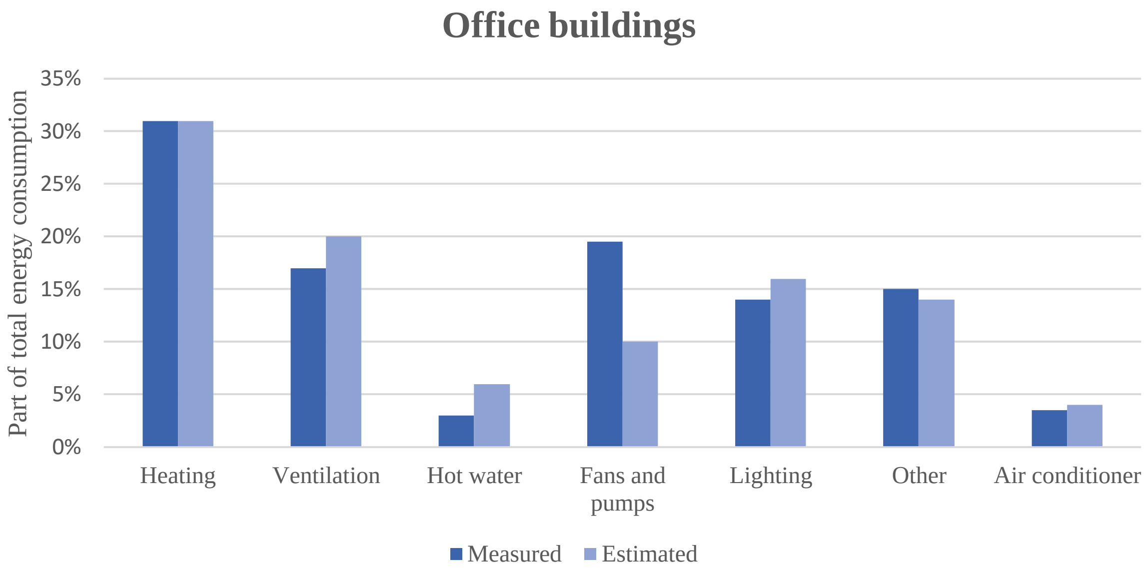


Figure 2.2 Energy consumption measured and estimates in office buildings (Ole-Gunnar Søgnen, 2001)

Refer to the energy statics in the year of 2000, the data was from 718 buildings with a total area of 5.8 mill m^2. Figure 2.3 denotes the energy consumption for various types of buildings that categories by energy constraint in kWh/m^2 heated area. The commercial building consumes the most the energy usage, while the school building was the least energy consumption. Furthermore, particularly, for electricity usage still commercial buildings was the highest, and followed by traffic and communication building, while the byggning for overnatting (accommodation building) was the lowest.

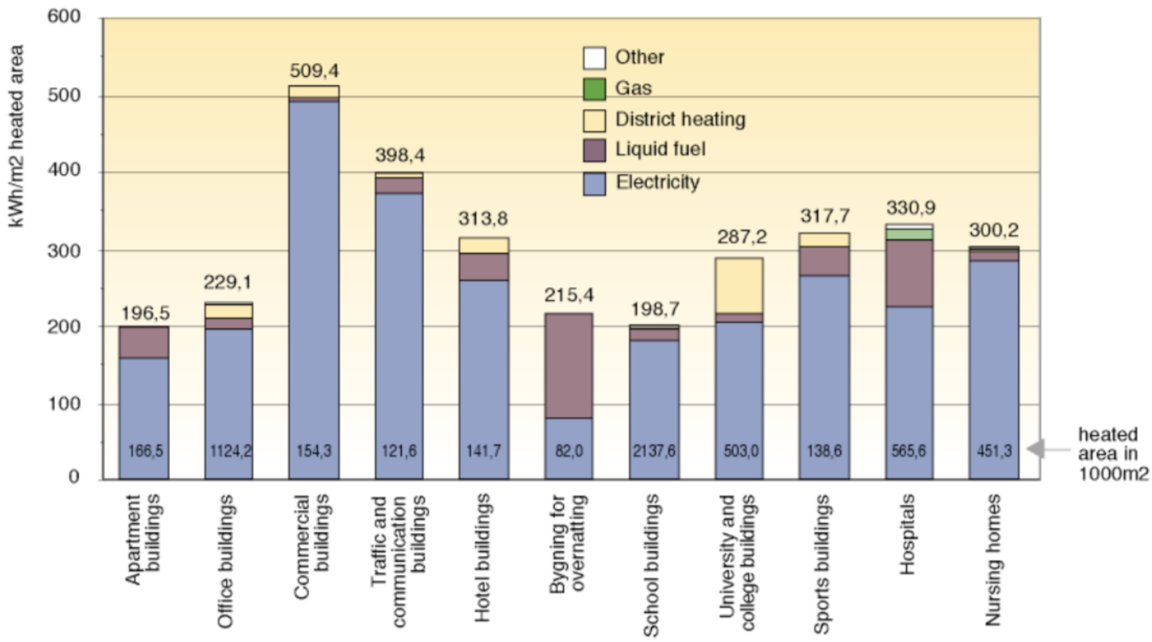


Figure 2.3 Energy consumption average specific temperature-corrected for several buildings in 2000 (Ole-Gunnar Søgnen, 2001)

Specifically, the energy consumption for the 202 samples of different types of buildings with different kinds of heating system expresses in Figure 2.4. The types of heating system in this data was divided into three categories that are direct electric heating, central energy heating, and both. Overall, the sports building spend the most energy consumption for the three types, while the school buildings spend the least energy usage for all of the group as well.

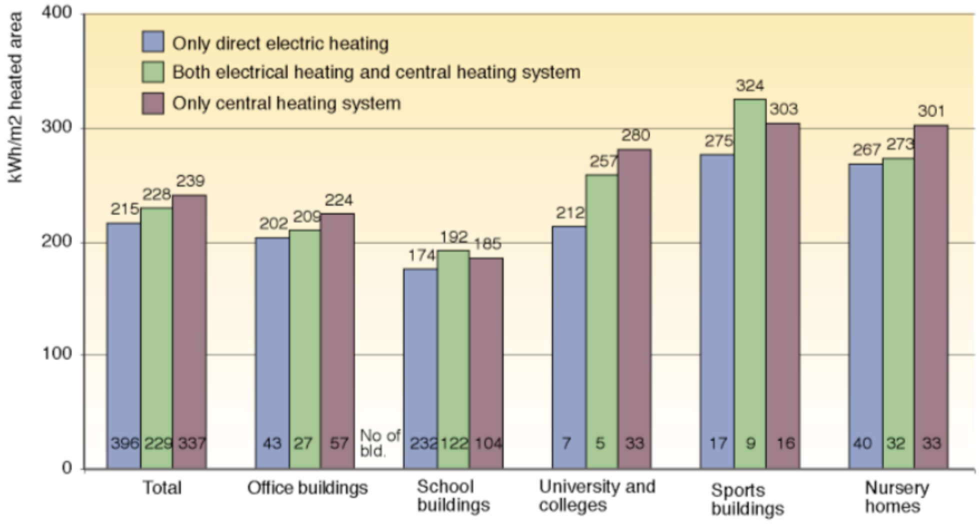


Figure 2.4 Energy consumption with different types of heating system in several buildings (Ole-Gunnar Søgnen, 2001)

2.2 Energy sources

There are two types of energy primary and secondary energy. Primary energy is the energy derived by the environment, while the secondary energy is the transformation from the primary energy (Demirel, 2016a), as in the illustration below
Figure 2.5.

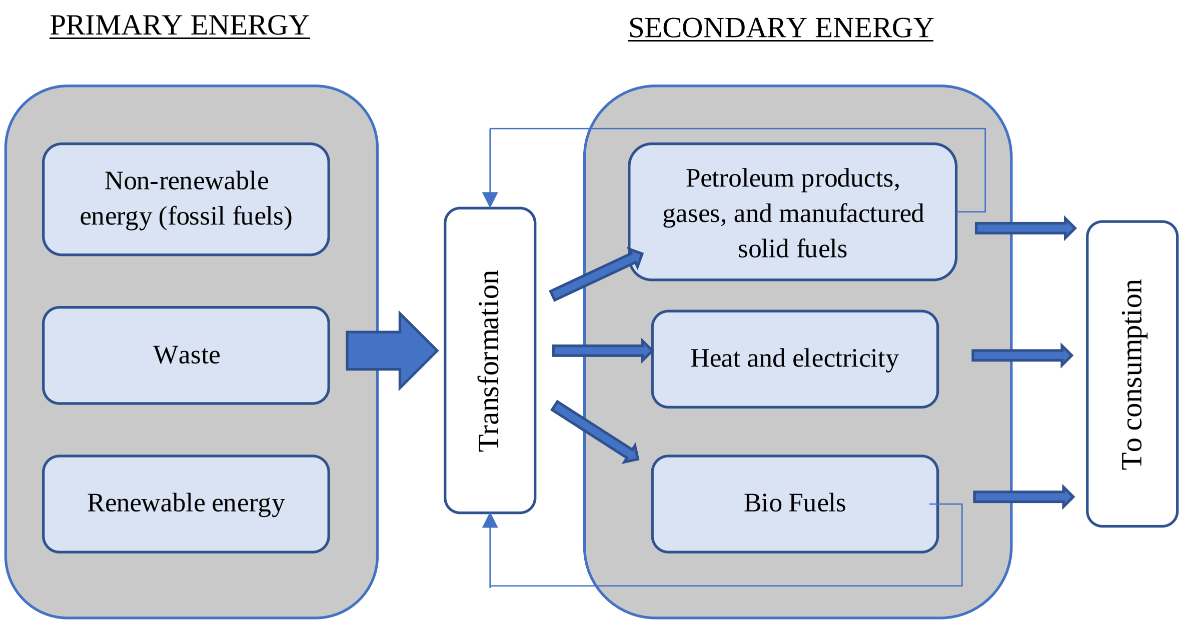


Figure 2.5 Primary and Secondary Energy (Demirel, 2016a)

The primary energy source consists of three groups that are:

1. Non-renewable energy
   Non-renewable energy or fossil fuels is the energy source formed by the organic remains' material, e.g., dead plants and animals which turned into fossil for over the hundreds of millions of years, then it decomposes under the earth surface. The types of fossil fuels depend on the combination conditions while decomposing, e.g., organic element, time, temperature, pressure condition, etc. (Energy, 2015). The main types of fossil fuels are oil, coal, and natural gas, which is the global primary energy source. However, burning fossil fuel is the most significant emissions source of carbon dioxide and is contributing to global warming.

2. Waste
   Waste or usually known as municipal solid waste (MSW) or waste-to-energy (WTE) is the energy that comes from the garbage which contains the biomass, e.g., food scraps, paper, wood, synthetic materials from petroleum, etc. This output energy will produce the electricity or heat by recycling and composting the MSW in particular plants (Demirel, 2016a).

3. Renewable energy
   Renewable energy is the power from the natural resource, which naturally replenished. The primary types of renewable energy source are hydro energy, solar energy, geothermal heat, wind, biomass, and ocean. The idea is to implement the technology to natural resources directly, e.g., solar energy that obtained from the sun, hydropower that comes from the water and geothermal heat that the heat produced from underneath the earth.

The secondary energy source is the transformation of the primary energy which converted to some form such as heat and electricity, petroleum product, gasoline, biofuels, and other chemical condition, and then they are ready to be used. The final energy generally called *useful energy* that in the form of electrical, thermal, chemical, and mechanical (Demirel, 2016a).

As mentioned previously, Norway has been using renewable energy to replace the fossil fuel for electricity production with the highest utilization on hydropower. According to SSB (Sentralbyrå, 2019) as per January 2019, 94.4% electrical production have come from hydropower, and the rest are thermal power and wind power, as depicted in the Table 2.1 below.

Table 2.1 Power Production in Norway as per January 2019 (Sentralbyrå, 2019)

Total power production	**Percentages**	**Production as per Jan 2019 (GWh)**
Hydropower	94.4%	13.881
Thermal power	1.8%	270

Wind power	3.8%	556
Total	100%	14.707

2.2.1 Solar

The energy from solar is obtained through solar radiation from the sun. The solar generates electrical power depends on PV (photovoltaics) and heat engines. The electricity can be used as space heating, lighting, solar hot water, solar cooking, and other purposes. The solar technology can be classified into (i) active solar and (ii) passive solar, depending on their way to catch, transform, and scatter the solar energy (Demirel, 2016d).

(i) Active solar
These techniques use solar thermal to utilize energy. The source of the heat comes from the sun, and the solar collectors gather solar radiation. Generally, conventional water heating contains solar collectors that perform with a pump, huge storage tank, and heat exchanger. The most common collector is mounted on the roof and is the called flat-plate collector. It comprises a flat thin transparent cover facing the sun. The heat transfer fluid that mostly water or air heated by the small tubes that carry out through the box.

(ii) Passive solar
The passive solar depends on the gravity and liquid tendency to naturally distribute as it is heated. This technique also facing the building to the sun by using the selected materials with excellent thermal mass or light dispersing characteristic and the design of the building need to have air circulation naturally.

The photovoltaic cell is a solar cell that is a solid state of electrical instrument that transforms the energy of light directly to the electricity. Solar PV changes the light into power by using the semiconductor materials. The set of cells generally called solar panels or solar modules that spread as an array of individual panels installed on the rooftops, building facades, or ground-based arrays. The PV system produces direct current, and if the output from the system is to be used in the grid, the direct current needs to be transferred into alternating current through an inverter (Demirel, 2016c). The PV is made from crystalline silicon (c-Si) and is by far the considerably broad used PV material (Isabella et al., 2016).

The solar PV has some parameters that need to be considered for calculation, which includes solar radiation and different angle. To reach the maximum energy generated, finding the optimum solar radiation and best angle is the most effective method since the solar radiation incident amount on a PV panel or solar thermal collector is highly determined by the orientation and angle (Mousavi Maleki et al., 2017). Below are the fundamental parameter of solar.

1. Declination angle (δ)

Declination angle is the angular gap between the sun north or south and the earth´s equator, as present in Figure 2.6 below. The declination range between 23.45° north and 23.45° south. The northern hemisphere is inclined 23.45° far away from the sun when around 21 December, while the southern hemisphere positioned is in a way 23.45 from the sun starting around 21 June. The δ can be calculated from Spencer´s equation in radians (Mousavi Maleki et al., 2017):

$$\delta = (0.006918 - 0.399912 \cos\Gamma + 0.070257 \sin\Gamma - 0.006758 \cos 2\Gamma + +0.000907 \sin 2\Gamma - 0.002697 \cos 2\Gamma + 0.00148 \sin 3\Gamma)\,(\frac{180}{\pi})$$

$$\Gamma = 2\pi\,(\frac{n-1}{365})$$

Γ : the day angle in radians
n : the number of the day in the year

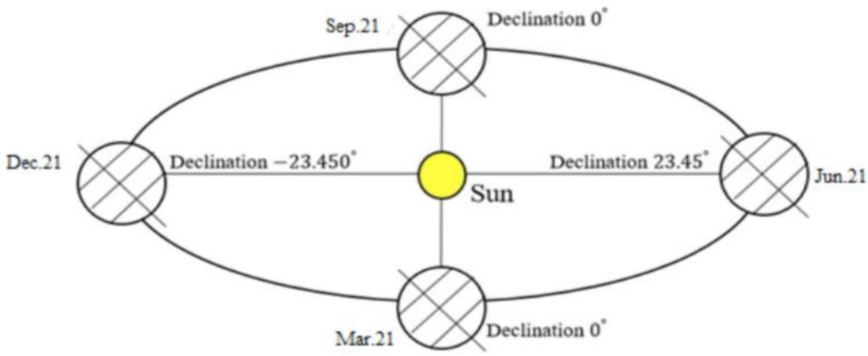


Figure 2.6 Maximum and minimum value of declination angle (Mousavi Maleki et al., 2017)

2. Hour angle (ω)

The function of hour angle is to describe the rotation of the earth around the polar axis that equal to +15° per hour while in the morning and -15° in the afternoon. Hour angle is the angular distance from the meridian to the observer´s that plane attached the sun, as illustrated in Figure 2.7, and the calculation of the hour angle in degrees as following (Mousavi Maleki et al., 2017).

$$\omega = 15(12 - ST)$$

$$ST = LT + \frac{ET}{60} + \frac{4}{60}\,[L_s - L_L]$$

$$ET = 9.87 \sin 2B - 7.53 \cos B - 1.5 \cos B$$

$$B = \frac{360\,(n-81)}{365}$$

ST : Local solar time
LT : Local standard time
L_s : Standard meridian for a local zone
L_L : Longitude of the location
ET : Equation of time

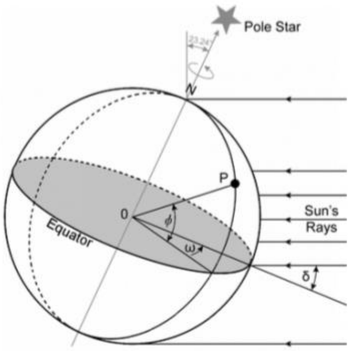


Figure 2.7 Hour angle (ω) for point P (Mousavi Maleki et al., 2017)

3. Solar azimuth angle (γ)

The solar azimuth angle is the angular shifting from the south of the beam radiation projection on the horizontal plane (Mousavi Maleki et al., 2017), as shown in Figure 2.8.

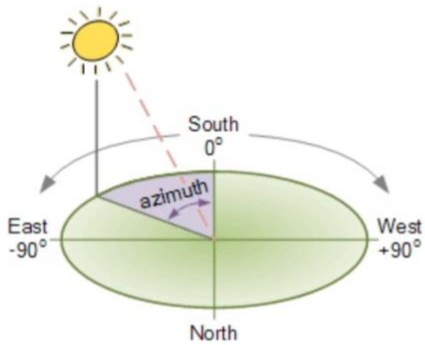


Figure 2.8 Azimuth angle (γ) illustration (Mousavi Maleki et al., 2017)

4. Latitude (ϕ)

The latitude is the position that relation to the north of the south of the equator. The divergence of the latitude is from 0° to ± 90° (the positive sign indicates northern and the negative sign indicates the southern hemisphere, 0° at the equator and ±90° at the poles (Mousavi Maleki et al., 2017).

5. Tilt angle (β)

The tilt angle is the deviation from the horizontal plane. The tilt angle could be modified from the latitude angle in order to maximize the annual value of electricity yield by collecting more of summer´s higher irradiation (Kalogirou, 2013). The solar radiation that scattered on the tilted surface is variation from 0° to 90° (Yadav and Chandel, 2013).

Generally, the goal of the solar PV is to achieve the highest energy output/yield at the lowest cost. The solar PV outcome is equal to the amount of solar irradiation that is obtained and can be inclined by implementing several tilting modes. However, the tilting mode can cause shading between the row gap of multiple PV modules; therefore, it is needed to evaluate the relation between the tilting, energy yield, shade, and row module spacing (Kalogirou, 2013).

2.2.2 Bio-coal

Bio-coal is the renewable energy source which the biomass that converts into solid fuel. The source of the biomass comes from organic raw material such as wood, food waste, garden waste, and other organic waste. The bio-coal can be achieved by some process that are pyrolysis, hydrothermal carbonization, or torrefaction. The differences are based on the medium used, whether taking place in the water condition or not. Pyrolysis is the most common prevalent method to convert the biomass to bio-coal by the form in a dry atmosphere (Krylova and Zaitchenko, 2018). Table 2.2 shows the distinction between the types of biomass thermal transformation.

Table 2.2 Biomass thermal transformations and the products produced (Krylova and Zaitchenko, 2018)

Process	**Conditions**		**Products (wt %)**		
	T (°C)	**Time**	**Solid**	**Liquid**	**gaseous**
Pyrolysis					
- Slow	~ 400	10 – 20 h	35	30	35
- Medium	~ 500	10 – 20 s	20	50	30
- Rapid	~ 500	1 – 3 s	12	75	13
Torrefaction	~ 300	1 – 2 h	60	20	20
Hydrothermal carbonization	~ 200	10 – 20 h	80	17	3

The pyrolysis process mostly produces the product of solid carbon and generally, the pyrolysis used for charcoal production (Krylova and Zaitchenko, 2018). Figure 2.9 illustrates the pyrolysis process. The raw biomass is processed in a combustion chamber by heating up to around 400°C - 500°C depends on the process stages and a specific period, which yield the bio-oil, gas or bio-coal.

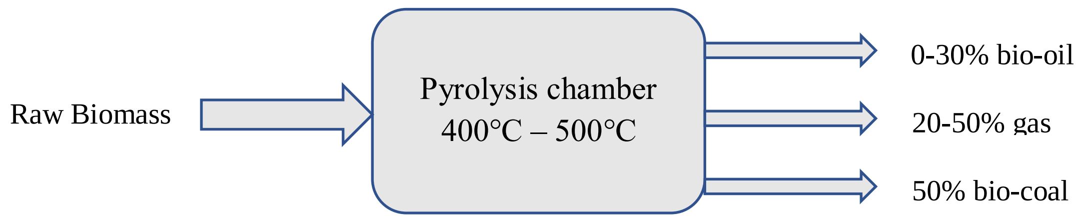


Figure 2.9 The pyrolysis scheme (Joner, 2015)

The torrefaction is a mild process of pyrolysis with the range of temperature around 200°C - 300°C. The main goal of this process is to increase the calorific value by drying out the fuelwood that removing the moisture and decompose the significantly reactive organic portion (i.e., hemicellulose). The main product of torrefaction is a solid material/grey coal. The illustration of the process as Figure 2.10 below.

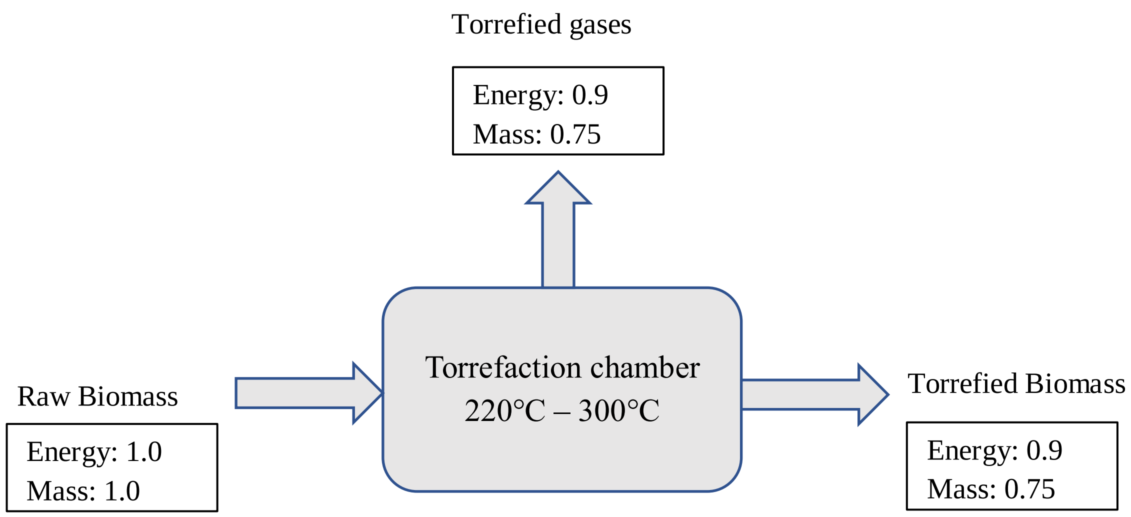


Figure 2.10 The torrefaction scheme (Agar and Gil, 2013)

Hydrothermal carbonization (HTC) also called wet torrefaction or cold carbonization, this bio-coal process happen with the presence of water and absence of air at a pressure around 25 atm and a temperature around 180°C – 220°C with a catalyst as an addition. This process is a bit complex due to the existence of water, and the water can act a catalyst, a solvent, a reactant, a medium for energy and mass transfer (Krylova and Zaitchenko, 2018).

Figure 2.11 illustrates a schematic example of the hydrothermal carbonization of lignocellulose biomass at 260°C for 5 minutes.

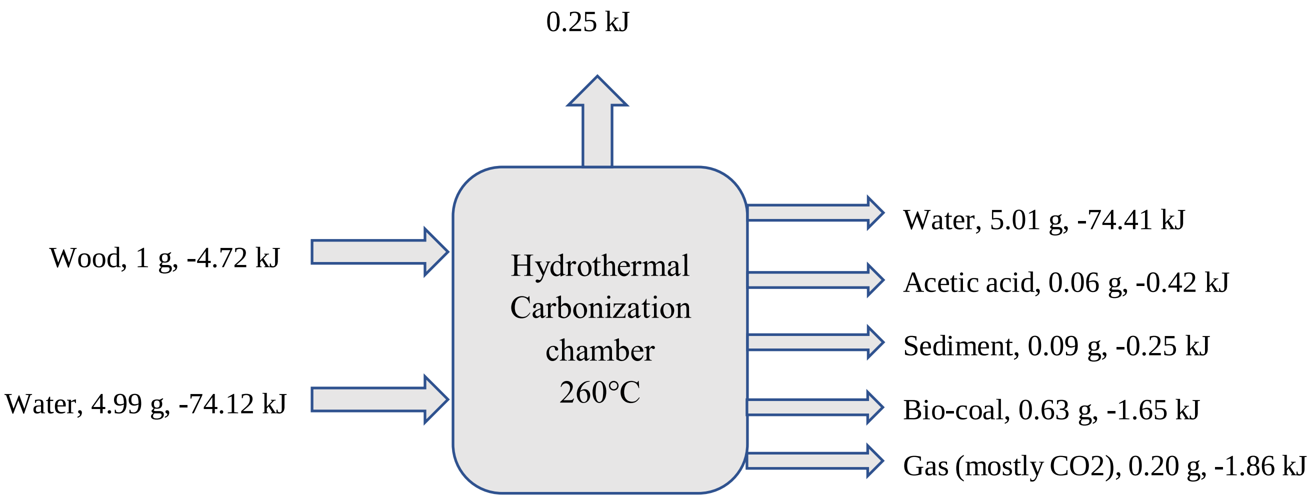


Figure 2.11 The hydrothermal carbonization scheme (Krylova and Zaitchenko, 2018)

Principally, the bio-coal replace the ordinary coal as the energy source, and the formed of bio-coal can be shaped as briquette or as pellets, as shown in Figure 2.12. The implementation of the bio-coal for the heater is by using the bio-coal as a solid fuel to ignite the water boiler or can be used for the furnace. The utilization of bio-coal has many advantages including, the bio-coal can minimize the CO_2 emission, environmentally friendly, easy to made and store, can utilize the waste, cost-effective, can become a job for farmers, can be a soil improver and many others benefits (Joner, 2015). Therefore, the Norwegian government considers using the bio-coal as renewable energy to reduce carbon emission by implementing the bio-coal, especially in supporting smart city project in Stavanger city.


Figure 2.12 The form of bio-coal: briquette (left) and pellets (right) (Agar and Gil, 2013)

2.2.3 Geothermal heat pump

Geothermal energy is the heat that comes from the derivative of the planet which in the form of volcanic activity, minerals radioactive decay, and from the solar energy penetrate at the surface. The temperature difference between the surface and the core of the planet creates the geothermal gradient, which encourages the continuous deduction of thermal energy heat (Demirel, 2016b).

Geothermal heat pumps (GHPs) also denoted as Ground Source Heat Pump (GSHPs) is another renewable energy alternative that has low emission and efficiently heat that could be used to heat the pump. The concept of the heat pump is similar to refrigerators by moving the thermal energy from a lower temperature to high temperature in a medium. The heat pump outcome is usable heat, which generally at a temperature that keeps maintaining the space environment (Self et al., 2013).

Figure 2.13 illustrates the basic scheme of the GHPs heating operation, and the brief stages are as follows (Self et al., 2013) :

1. The thermal heat energy is derived from the earth then carried to the evaporator.
2. The heat enters the evaporator in a liquid majority liquid/vapor state, inside the heat pump unit cold refrigerant. The heat is carried from the ground connection to the refrigerant and lead the refrigerant to boil and make a low-pressure vapor, then the temperature somewhat increase.
3. The vapor proceeds to an electrically steered compressor, while the pressure increased, that creates a high-pressure vapor and a high temperature.
4. Next, the high-temperature vapor proceeds to the condenser; then the refrigerant is at a greater temperature than space, which causes the heat transfer from the refrigerant to the building. The refrigerant is getting cold and condense create high pressure and a high-temperature liquid.
5. Finally, hot liquid come through an expansion valve, which reduces the pressure and yielding in a temperature inclined. The refrigerant enters the evaporator and then commence another cycle.

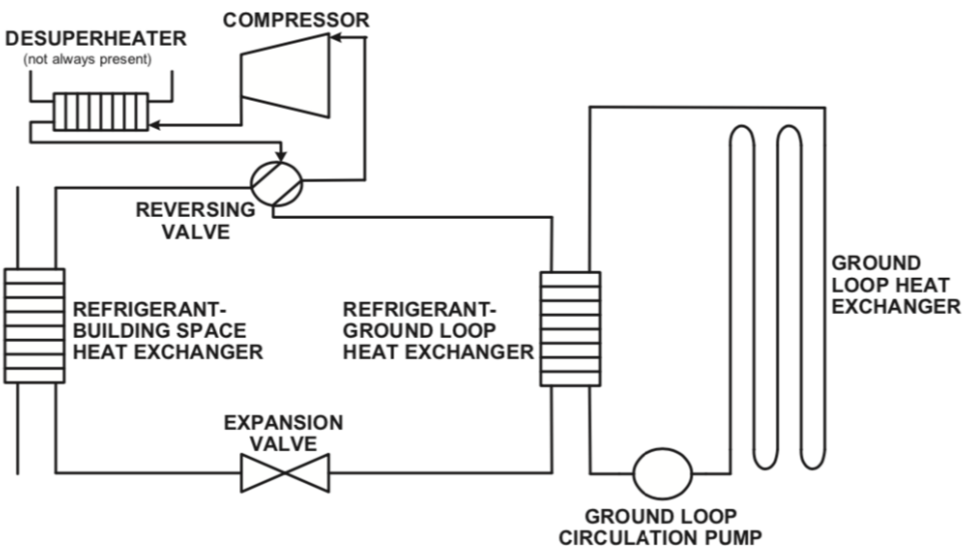


Figure 2.13 Geothermal heat pump system basic arrangement including desuperheater (Self et al., 2013)

The GHP heat distribution system shifts the heat supplied throughout the space by the heat pump. There are two primary types of the distribution system that are (i) water to air and (ii) water to water (Self et al., 2013).

(i) Water to air:
This system transfers the thermal energy as the medium from the ground to the air. Commonly, the heat pump condenser heated an air coil that warms the air which passes through it.

(ii) Water to water:
Water to water generally called hydronic system, this system uses the water or another fluid as the medium for heat transfer. The thermal energy obtained from the ground loop that processed by using the heat pump, then the water work as a carrier to distribute through the building. Specifically, the system pumps the water by using the heat pump unit condenser, then extracting the heat. Then, the water pumped over the building deliver the heat to the space that could be several ways such as in-floor radiant heating, by using radiators or localized air coils.

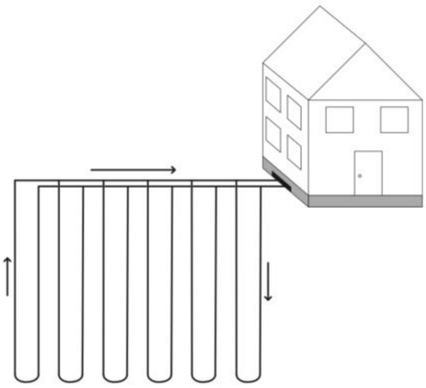
The earth connection or ground loop heat exchanger is consists of a set of pipes which transfer the fluid from the heat pump to the ground. There are two main ground loop design, the double loop, and the single loop configuration. Table 2.3 below is a brief summary of the earth connection types.

Table 2.3 The earth connection/ground loop types (Self et al., 2013)

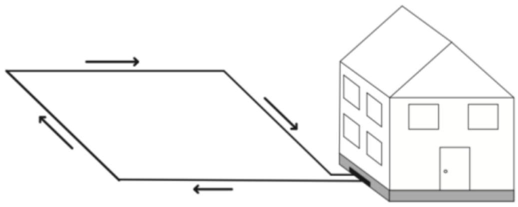
Types	Description
1. Double loop configuration	- The most common system. - The earth connection is separate from the heat pump. - The heat is carried out to the refrigerant through a heat exchanger from water or a water/antifreeze compound that is circulated from the heat pump to the ground by piping.
a. Closed loop system	- Commonly utilized. - No direct contact with the ground, the heat transfer of fluid is enclosed in a revolving loop. - The heat transfer connection to the land by using the piping material.

- Vertical closed loop	- A deep hole is bored in the field. - The gap between the borehole wall and the pipes are occupied with pumpable grout material to increase the heat transfer. Figure 2.14 a) illustrates the vertical closed loop heat exchange system. - (+) Reduce installation area, low landscape disturbance, and temperature tend to be constant that generates consistent heat pump performance. - (-) High installation cost due to the drilling process.
- Horizontal closed loop	- The ground loop lightly buried under the earth surface. - The configuration may vary e.g., basic loop, series loop, and parallel depending on the heat transfer requirements and area availability. As illustrated in Figure 2.14 b) to d). - (+) More cost-effective - (-) The heat transfer and system performance tend to be unstable due to the daily and annual variation in the land temperature (e.g., rain, shade, vegetation growth, and snow)
- Closed spiral loop	- Similar to horizontally oriented - The piping placed in a circular loop within the trench and there is a straight pipe at the end of each spiral to return to the heat pump. - This system implicates the loops placing in narrow vertical trenches. - (+) The vertical loop placement can reduce the horizontal area needed. - (-) Poor heat transfer and require greater area due to horizontal setup.
- Closed pond loop	- The least common closed loop. - Principally, this system is a spiral loop that submerges in a water body. - The piping loop is attached to the structure and sunken by using concrete anchors. - (+) Require less piping since it supports the eminent heat transfer and not require drilling and trenching. - (-) Need a large quantity of water and limitations to use for other purposes.

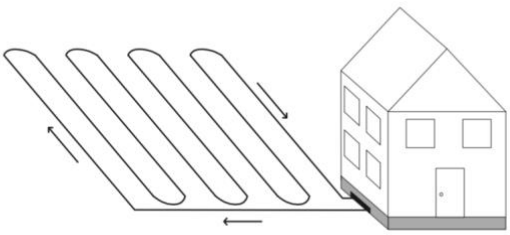
b. Open loop system	- The system has direct interaction with the ground and utilizes the surface water or local groundwater as a direct heat transfer medium such as ponds and lakes. - The water is extracted and transferred by using heat pump heat exchanger, then released back to the ground for irrigation or the source. - (+) The temperature of the water source tends to be constant. - (-) The limited amount of water, and need to protect the water quality.
2. Single loop configuration	- Also called a direct exchange system. - The heat pump is working fluid connected via the ground heat exchanger that prevents a requirement for ground loop to heat the heat exchanger pump. - This configuration does not include the ground loop circulation pump, yet depend on a bigger compressor.



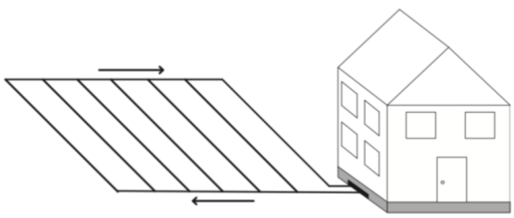
a). Vertical closed loop heat exchange



b). Basic horizontal loop



c). Horizontal loop piping in series



d). Horizontal loop piping in parallel

Figure 2.14 Vertical and horizontal closed loop system illustration (Self et al., 2013)

The heat production from heat pump depends on the season, as there are some factors that influence the ground temperature, including the solar radiation absorbed, air temperature, snow condition, and other ground thermal properties. Figure 2.15 depicts an example curve of the ground temperature range for different depth in Ottawa, Canada. The geothermal heat pump production reaches a peak in summer and with the least depth that is 0,3 m.

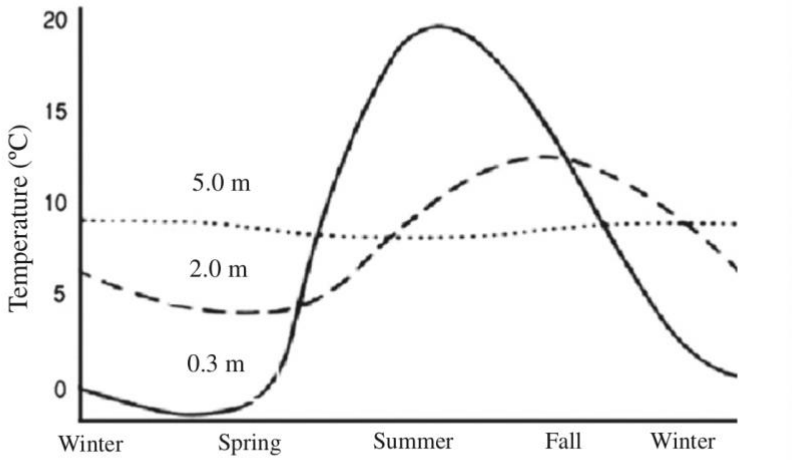


Figure 2.15 Ground temperature range for different depths in Ottawa, Canada, in a year (Self et al., 2013)

2.3 System Dynamics

The field of system dynamics founded and developed by Jay Wright Forrester in the 1950s. The system dynamics is a mathematically modeling to understanding a complex system as a holistic and is related to the system thinking. This can be implemented on the diverse field including engineering, economics, biology, physics, psychology, etc. (Sterman, 2000).

The concern of system dynamics is to represent the real world and to improve system performance. In order to understand the dynamic behaviour of a system, a simulation model is essential which could exhibit the real-life situation (Forrester, 1994). Basically, a simulation model is a mathematical model that comes from a set of equations which include some unknown parameters and a set of known input and specified outputs (Ogata, 1998).

System dynamics methodology is based on feedback system approach which has the ability to work on nonlinear dynamics, complex dynamics system with multiloop and time-lag characteristic, this also could handle the management policy for development (Bala et al., 2017). Also, it is having some conceptual tools including feedback thinking, stock and flows, feedback loop dominance concept, and endogenous point of view. System dynamics modeling can be run in some program such as STELLA and iThink, Vensim PLE, PowerSim, and AnyLogic (Richardson, 2013). In this thesis, the author will use Vensim PLE as system dynamics modeling program.

The system means an integrated set of components which act together in order to undertake a specific purpose. While, the dynamics mean that the output of the system will changes only if the input changes, hence it is dependable. If the system is not in the equilibrium state, the output of the dynamic system changes along the time (Ogata, 1998).

Generally, the system could be divided as an open system and feedback system. The open system means that the output reciprocates the input, yet the output does not affect the input, and the prior action does not alter the future activity. The feedback systems are the closed-loop system in which the inputs are changed according to the output. The result of the previous activity force the future action; thus this action become a closed loop structure (Bala et al., 2017). The illustration of the systems showed in Figure 2.16 and Figure 2.17 below.

Figure 2.16 The open system/open loop concept (Forrester, 2009)

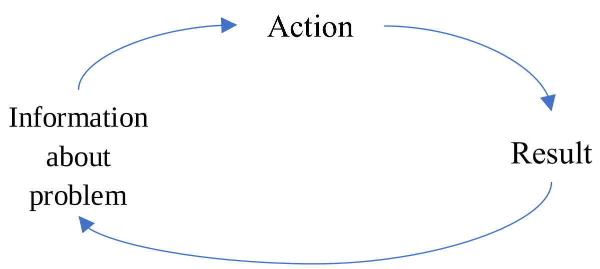


Figure 2.17 The feedback system/closed loop concept (Forrester, 2009)

According to Forrester, here are the framework for organizing system structure (Forrester, 1968):

The closed boundary
- *The Feedback loops (the basic component)*
  - *Levels*
  - *Rates*
    - *Goal*
    - *Observed conditions*
    - *Discrepancy between goal and observed conditions*
    - *Desired action*

The closed boundary concept here means that the concerning behaviour modes are produced inside the determined system boundaries and should not jump across the border (Forrester, 1968). The variables within the boundary are endogenous variables while in the outside the boundary are exogenous variables (Bala et al., 2017). The feedback loops work as the primary structural component of systems. The system is seen as one structured of feedback loops inside the boundary which every decision occur under single or more loops. The interaction between the loops generates system behaviour (Forrester, 1968).

The stocks (levels) and the flow (rates) are the critical components of the system structures. The flow or rates variables are the activity, while the stocks or levels are the accumulations and integrations of the flow or rates outcome (Forrester, 1968). The simple stocks and flows feedback loop relation illustrated as Figure 2.18 below. The goal and the present condition of the system drive the decisions that control actions, while the flow determined by the information about the stock of the system. The amounts in the stock are controlled by the flow and the movement adjust the condition of the system (Forrester, 2009). The dynamic behaviour that occurs from the feedback loops has two types of interactions that are positive feedback loop and negative feedback loop. The positive feedback loop (+) creates exponential growth while the negative feedback loop (-) are oppose the change, which is goal seeking (Bala et al., 2017).

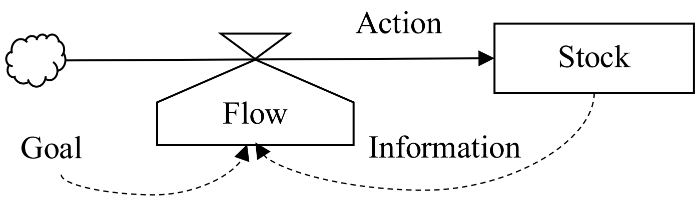


Figure 2.18 Simple stock and flow diagram (Forrester, 2009)

The first order feedback system equations can be outlined to a simple level and two rate equations (Forrester, 1968). This illustrates as in the following Figure 2.19 and the notation as in table Table 2.4.

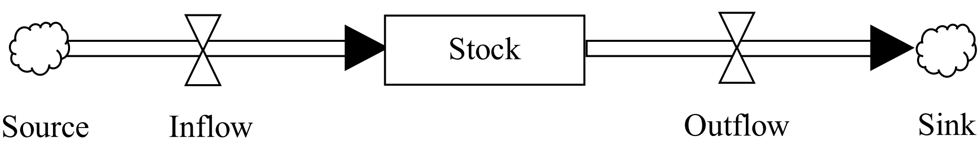
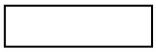
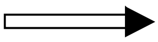


Figure 2.19 General structure of stock and flow diagram (Sterman, 2000)

Table 2.4 Stock and flow denotation (Sterman, 2000)

Stock		Denoted by rectangles.
Flow		• Inflow: denoted by a pipe pointing into the stock. • Outflow: denoted by pipes pointing out of the stock.
Valve		Control the flows.
Cloud		Cloud denote the sources and sinks for the flows. • "Source: denotes the stock from which a flow originating outside the boundary of the model arises". • "Sinks: denotes the stocks into which flows leaving the model boundary drain". Both are assumed holding infinite capacity and can never limit the flows they support.

3 The Case Study and Data Collection

3.1 The case study: The Gautesete area

The modeling in this thesis will focus on the Gautesete area and the data collection has been gathered from the buildings in this location. Gautesete is an area in Hinna region located in Stavanger municipality, Norway. This area is one of the pilot projects regarding the reduction of greenhouse emission gas.

The area mainly consists of residential buildings in the form of private buildings (i.e., homes and apartments). There are also 5 public buildings including two barnehage (kindergartens), skole (a secondary school), kirke and bydelshus (a church with a town hall), and idrettshall (a sports hall). However, in this thesis, the area covered is the 4 public buildings which show in Figure 3.1 and Table 3.1 represent the basic information of Gautesete buildings.

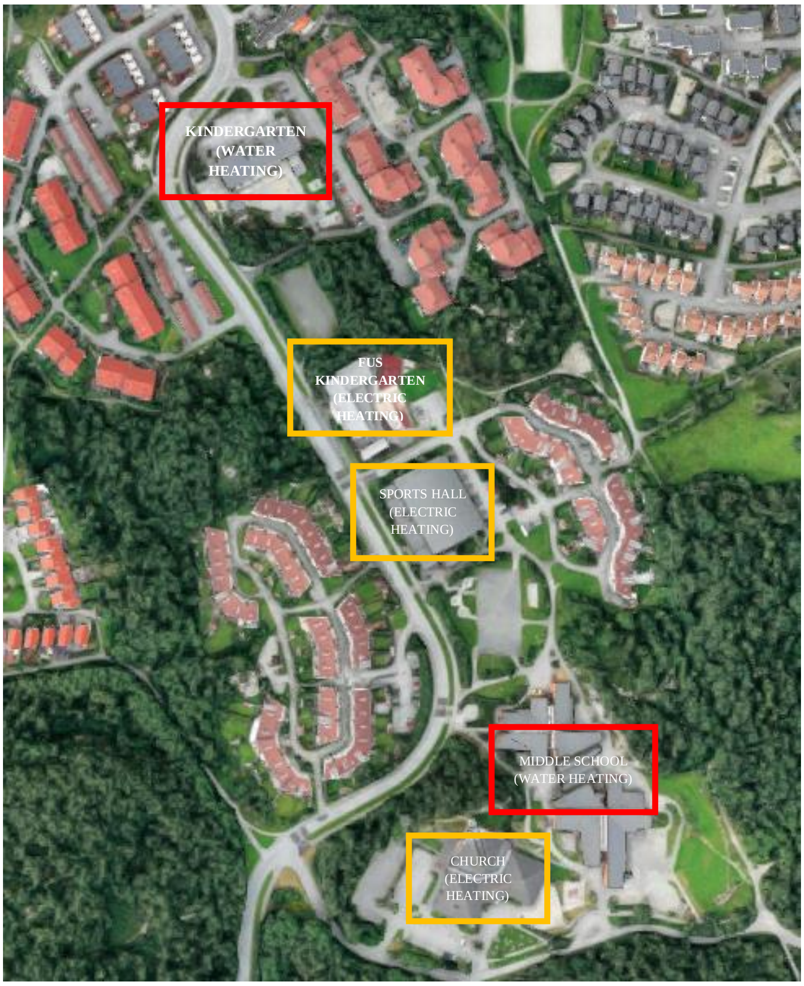


Figure 3.1 Gautesete area

Table 3.1 Gautesete buildings information

Building	Purpose	Heating system	Area (m2)	Working hours
Gautesete Barnehage	Kindergarten	hydronic heating	760	Mon – Fri: 07.00 – 16.00
Gautesete Idrettshall	Sportshall	electric heating	1700	Weekday: 08.00 – 22.00 Weekend: 10.00 – 17.00
Gautesete Skole	School	hydronic heating	2110	Mon – Fri: 07.00-14.00
Gautesete Kirke & Bydelshus	Church and the town hall	electric heating	940	Mon – Fri: 09.00 – 15.30

3.2 Data collection

This study is based on empirical research by observing and organizing the behaviour and pattern of the data using the simulation modeling program. The data collection of this case study was by using the quantitative data collection method. First of all, the observation method is used to collect the data. The author directly visits the case study location to familiarize the environment and understanding the building condition. Then the author obtained the electricity consumption data from Stavanger Komunne. There was two focus of the data collection, including solar production and electricity consumption.

The solar production data were collected using HelioScope program. This program is a solar energy production generator which can be used for a particular location by simulating the solar array output according to some parameters including architectural, environmental, technological design (Gibbs, 2012). In this thesis, there are several alternative combinations of design of each building has been simulated, including the tilt position, row spacing, and racking types. Then the best result has been used to compute on Vensim PLE program.

The energy consumption data for the four buildings obtained from the Stavanger Komunne. The data provided was basically the electricity data without knowing the allocation of the data, e.g., heating, lighting, or equipment. The data was the total kWh in hourly during one year period. The data of The Barnehage, The Idrettshall, and The Kirke & Bydelshus were from 2018, while The Skole data was from 2017 due to they started renovation in 2018. The author was organizing the data by making the average of the weekday peak and holiday peak, which could be the weekend or the holiday time for every month of each building. Finally, the average amount of peak hour assigned on Vensim PLE Program.

4 Analysis Chapter

4.1 The case analysis

4.1.1 The building analysis

In this thesis, the analysis covered for four buildings that are The Gautesete Barnehage, The Gautesete Idrettshall, The Gautesete Kirke & Bydelshus, and The Gautesete Skole. The brief information regarding the premises has been mentioned in Chapter 3.1.

The Gautesete Barnehage is a kindergarten that opens since August 2009. Currently, The Barnehage accommodate 72 pupils for the group of children from 0 years to 6 years (Minbarnehage, 2019). The building consists of 2 floors which equipped with several playing rooms, living room, wardrobe, kitchen, and other office rooms. The activity of this Barnehage start from Monday to Friday, and there is no activity during the weekend and holiday.

The Gautesete Idrettshall is a sports hall that can be used for some sports activities such as basketball, indoor football, handball, and there is a gym area inside the building. This building also can be rented for an event. The building consists of one and a half floors, the first floor is the hall, gym room, toilet, and changing room, while the half floor is the mezzanine floor that equipped with the chairs for audience area.

The Gautesete Kirke & Bydelshus is the church and the town hall, and both are in the same building. The town hall has some room that available for rent, including small and big hall, assembly room, kitchen & café, DJ room, and a meeting room. This building has only one floor.

The Gautesete Skole is the secondary school from grade 6 to grade 10, which have around 410 students in the school year 2018/2019. The school has 3 floors that are the ground floor, first floor and the second floor that only consist of the music room and staff room. This building was originally built in 1995 and currently under reconstruction and renovation that expected to open in August 2019 (Arne, 2018).

4.1.2 Technical solution

The primary purpose of this thesis is to explain and predict the dynamic behaviour of the cluster of building as well as to understand some option for reducing the carbon gas emission and to minimizing the usage of electricity. In this study, the main focus is on the energy supply and heating. The Gautesete area intended to build the energy center near the area to give the solution for this matter.

In order to reduce the electricity consumption from the grid, the Stavanger Komunne intended to utilize the solar PV to meet the electricity needs. The solar PV panel will be installed on the roof of each building, then the energy generated will be stored on the battery at the energy center. The power generated can be used either for the building itself or for other building near the area which connected through the energy center.

Generally, one of the most electricity usages in the commercial building is for space heating by using the heater electric. Therefore, to reduce the electricity and the carbon emission, The Stavanger Komunne intend to change the heater electric to the hydronic heating with the source of energy either by the bio-coal or geothermal pump. There will be a piping system to drain the water for hydronic heating which connected between the four building and the energy center. Referring to the Stavanger Komunne report, the bio-coal could be the solution due to the ability to significantly reduce the carbon gas emission up to around 75% to the current emission level, while the geothermal heat pumps can reduce the carbon gas emission approximately 9% (Norconsult, 2019).

4.1.3 Consumption

4.1.3.1 Utilization pattern

As mentioned previously, the electricity from heating space as well as lighting has the most significant consumption, and each building has a different utilization pattern. In general, the pattern was formed from the weekday activity, weekend or holiday for every building, and some building has weekend activity.

The Gautesete Barnehage (kindergarten) has a clear utilization pattern due to routine activities from Monday to Friday, and the working hour is from 07.00 – 16.00, and there was no activity during the weekend. However, while on weekend and holiday, the building still needs to use some electricity on weekend or holiday such as outdoor lighting, the exit sign, CCTV, and the heater might always be on to keep the room warm during the winter season.

Unlike the kindergarten or school, The Gautesete Idrettshall (sports hall) did not have the specific routine activity that leads to the peak working hour, the data analysis only referring to the opening time which cannot show the precise peak hour. From the data, this building has three types of peak hour:

Table 4.1 The Gautesete Idrettshall peak hour

	Jan - June	**July - Dec**
Weekday peak	Monday – Friday : 07.00 – 22.00	Monday – Friday : 07.00-14.00
Weekend peak	Saturday : 10.00 – 17.00 Sunday : 11.00 – 18.00	Saturday : 09.00-17.00 Sunday : 10.00-18.00
Holiday	00.00 – 23.00	00.00 – 23.00

The consumption utilization pattern was different from January to June and July to December as in table Table 4.1. Since this building is open for public, there was some activity on the weekend and while on some of the public holiday, the sports hall still opens e.g. Christmas and new year.

The Gautesete Kirke & Bydelshus (the church & the townhall) are in the same building, yet the author only obtains the electricity consumption data for Bydelshus. Although the opening hour of the Bydelshus is around 09.00 to 15.30, the data shows the pattern of the peak hour as Table 4.2 table below. This building was not rented on weekends and holidays except in November and December, still while on holidays, like other building, this building needs the electricity to keep the building safe.

Table 4.2 The Gautesete Bydelshus peak hour

	Jan - Oct	**Nov - Dec**
Weekday peak	Monday – Friday : 08.00 – 15.00	Monday – Friday : 07.00-19.00
Holiday	00.00 – 23.00	00.00 – 23.00

The Gautesete Skole data represent that the school electricity consumption pattern was different from January to June and July to December, as mention in Table 4.3. Moreover, there is any indication that there was some activity while on Saturday and Sunday. The weekend activities produce the utilization pattern that nearly the same with the weekday consumption.

Table 4.3 The Gautesete Skole peak hour

	Jan - June	**July - Dec**
Weekday peak	Monday – Friday : 07.00 – 20.00	Monday – Friday : 07.00-14.00
Weekend peak	Saturday/Sunday : 10.00 – 18.00	Saturday/Sunday : 10.00 – 18.00
Holiday	00.00 – 23.00	00.00 – 23.00

4.1.3.2 Data

4.1.3.2.1 The energy production data

To obtain the optimum alternative of solar PV production, some of the arrangement has been considered by using the HelioScope program. The design array alternative of four buildings is shown as in Table 4.4 below. The best result of the solar PV production for each building shows the same parameter that are, tilt: 15°, azimuth:180°, row spacing: 0 and fixed tilt racking. Figure 4.1 represents an example of the solar PV arrangement for the Barnehage roof. This roof with the setting parameter can accommodate 275 pcs of solar PV module and consist of three current to generate the energy.

Figure 4.1 Solar PV arrangement at Barnehage roof

Table 4.4 Solar design arrangement of four buildings

No.	Buildings	Area (m^2)	Tilt	Azimuth	Raw spacing (m)	Type of racking
1	Gautesete Barnehage	760	15°	180°	0	Fixed tilt
2	Gautesete Skole	2110	15°	180°	0	Fixed tilt
3	Gautesete Idrettshall	1700	15°	180°	0	Fixed tilt
4	Gautesete Kirke & Bydelshus	940	15°	180°	0	Fixed tilt

Table 4.5 illustrates the reference data prediction from Stavanger Komunne and data obtained from the HelioScope, the example of the HelioScope result could be found in Appendix A. Overall the result shows not too different between both, the potential energy production of Gautesete Skole, Idrettshall and Kirke & Bydelshus from HelioScope result depict the more considerable amount compare to Gautesete report as illustrates in Figure 4.2.

The Gautesete Barnehage shows around 6000 kWh/year gap of potential production and the maximum capacity of the PV module has the same amount for both results. Both Gautesete Skole and Gautesete Idrettshall generate the enormous difference of the potential energy production with almost 40.000 kWh/year gap as well as the maximum capacity for both of them shows a similar gap that is around 80 kWp.

Table 4.5 Gautesete report (Norconsult, 2019) vs HelioScope result

No.	Buildings	Gautesete report		Helioscope result	
		Potential yearly production (kWh/year)	Installed power (kWp)	Potential yearly production (kWh/year)	Installed power (kWp)
1	Gautesete barnehage	66.000	88	59.661	88
2	Gautesete Skole	182.000	243	221.528	323
3	Gautesete Idrettshall	147.000	196	186.136	274
4	Gautesete Kirke & Bydelshus	81.000	108	118.151	172

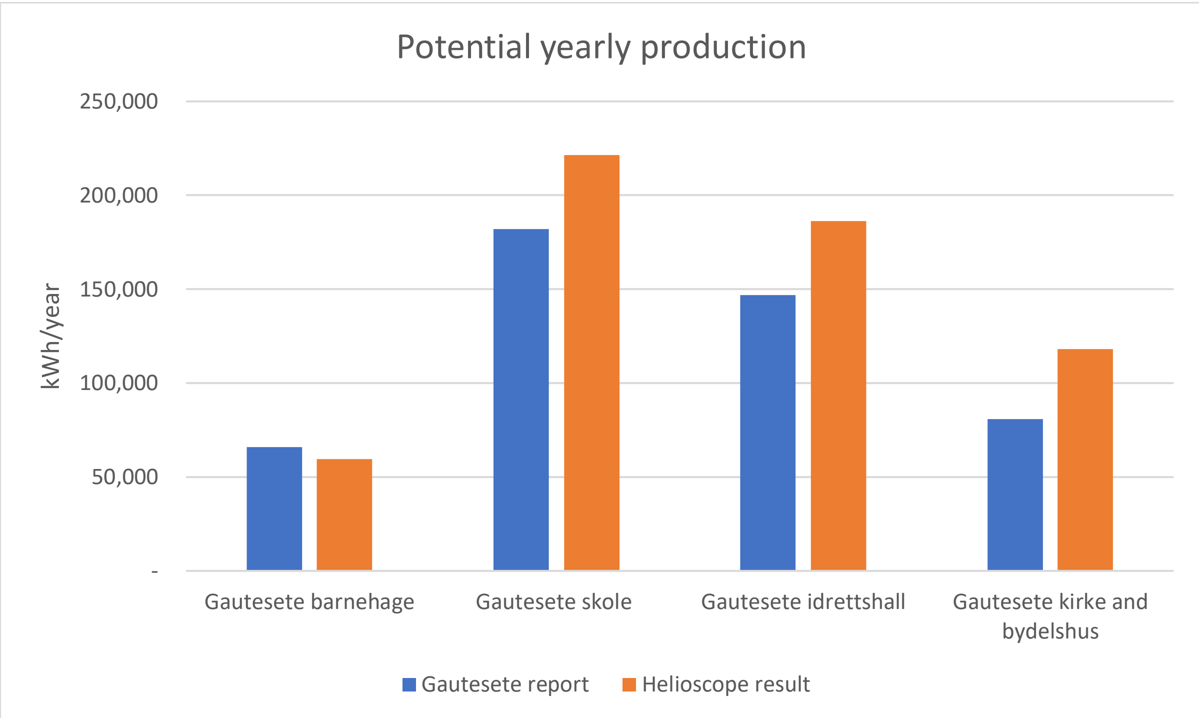


Figure 4.2 Gautesete report vs Helioscope result chart

4.1.3.2.2 The energy consumption data

Figure 4.3 illustrates the data of The Gautesete Barnehage electricity consumption. From the chart, we can see that most electricity usages were in February for about 42 kWh average. The weekday peak consumption was getting declined in the middle of the year, yet in June and August the usage went up while summer, then increased again towards December. The holiday consumption in the middle of the year was the lowest especially from June to August that has an average of 3 kWh due to the summer holiday.

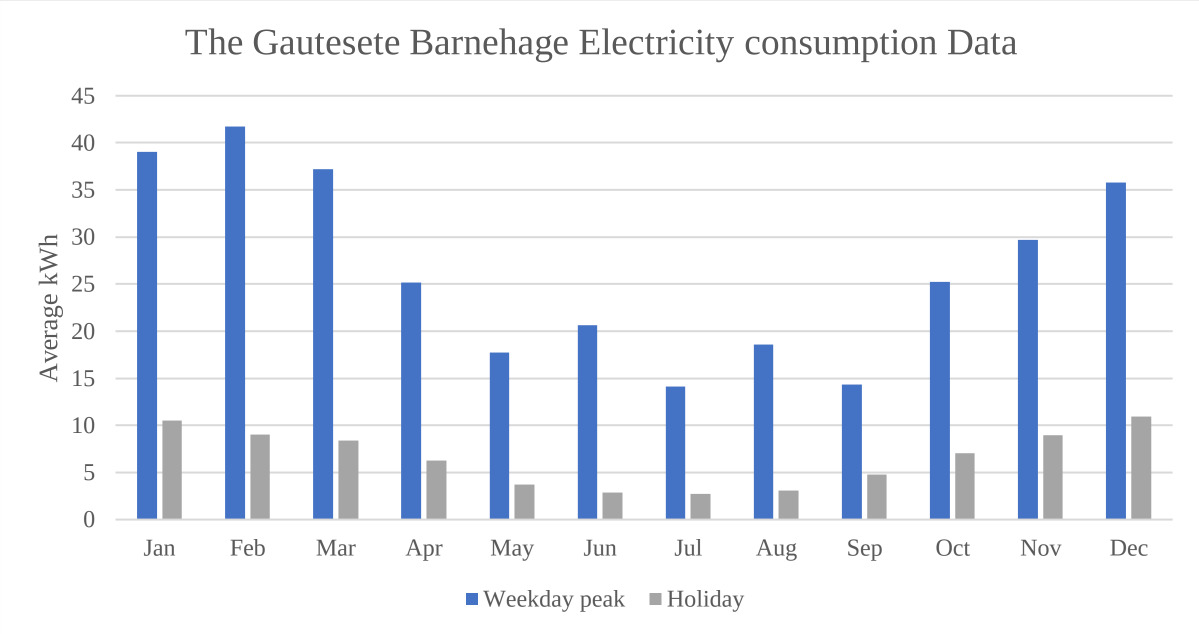


Figure 4.3 The Gautesete Barnehage electricity consumption data chart

Figure 4.4 illustrates the data of The Gautesete Idrettshall electricity consumption. Overall, the weekday peak hour pattern getting decreased towards the middle of the year and getting increased facing the end of the year. The most weekday peak usage was in January, and the least was on July with 59 kWh and 19 kWh respectively. From April to December, the weekend peak consumption was inclined, even for August and October the usage pass through the weekday peak. The holiday pattern arises from May to October, and the consumption tends to be stagnant between 5 and 6 kWh.

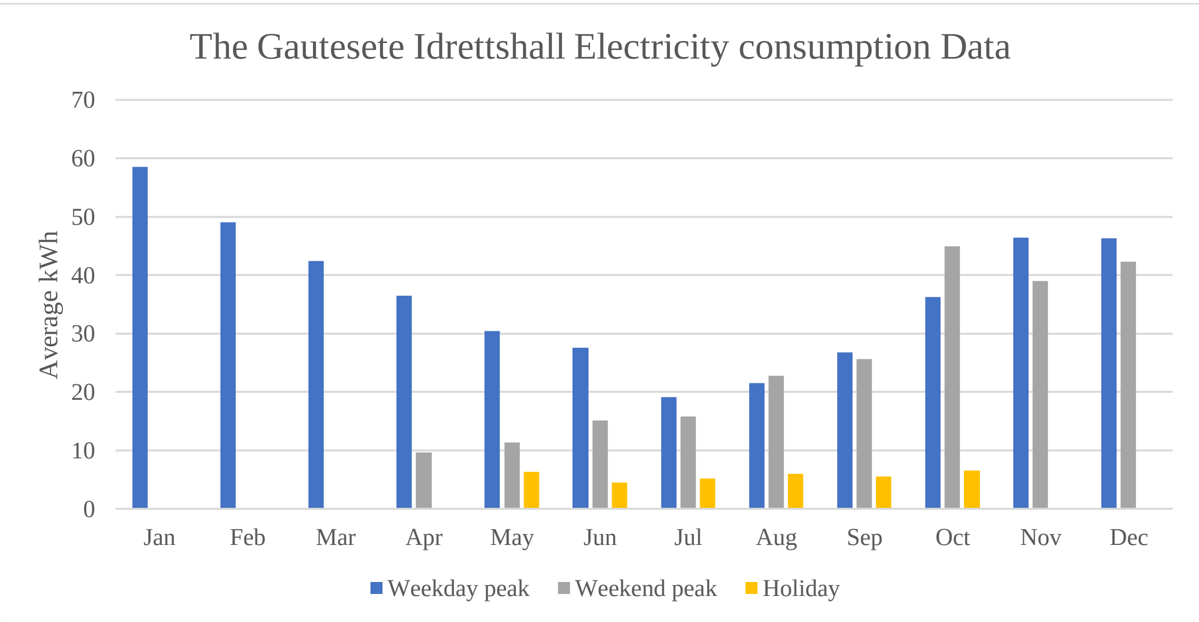


Figure 4.4 The Gautesete Idrettshall electricity consumption data chart

Figure 4.5 illustrates the data of The Gautesete Bydelshus electricity consumption. The highest weekday peak consumption was in February, while the lowest was in July. The pattern tends to similar with other buildings, getting declined while in the middle of the year and inclined again until December yet there was a peak in October. There was no holiday in November and December. From the data, both of the months still have some activities even though during the weekend.

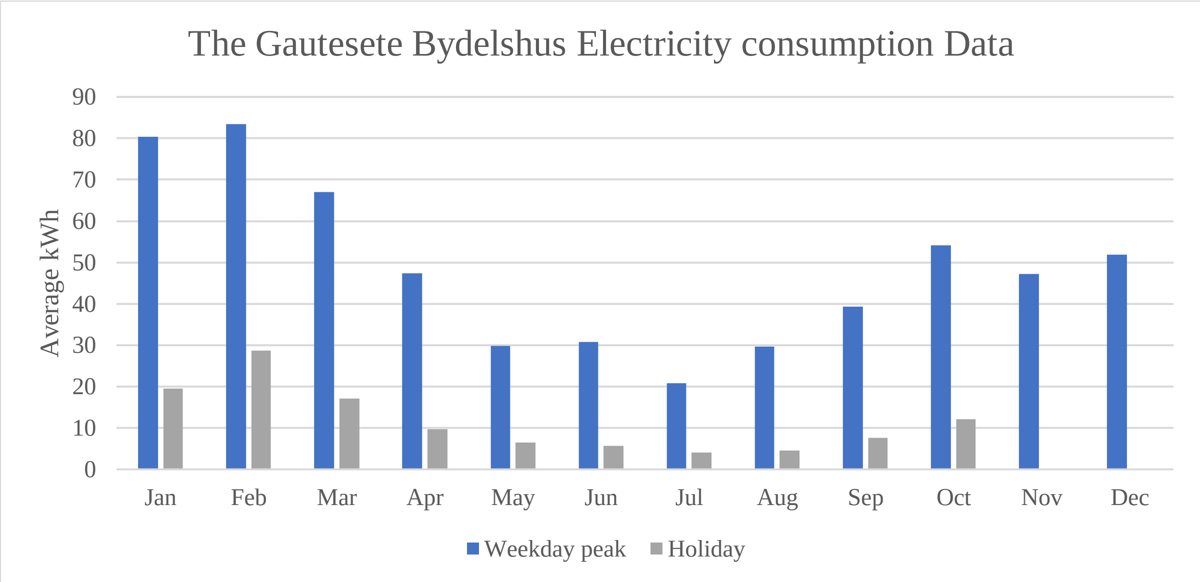


Figure 4.5 The Gautesete Bydelshus electricity consumption data chart

Figure 4.6 illustrates the data of The Gautesete Skole electricity consumption. Both January and February indicates the most weekday electricity usage followed by November with 65 kWh and 62 kWh respectively. Towards the middle of the year, the weekday consumption getting declined with the least usage 21 kWh in July, then getting inclined against the end of the year. Overall, the weekend peak shows the close amount with the weekday peak, and this might be due to the school has some routine weekend activity, as stated in Table 4.3. However, in July, there was no weekend activity because of the school holiday. During the whole year, the data indicates that the holiday peak arises in 4 months only.

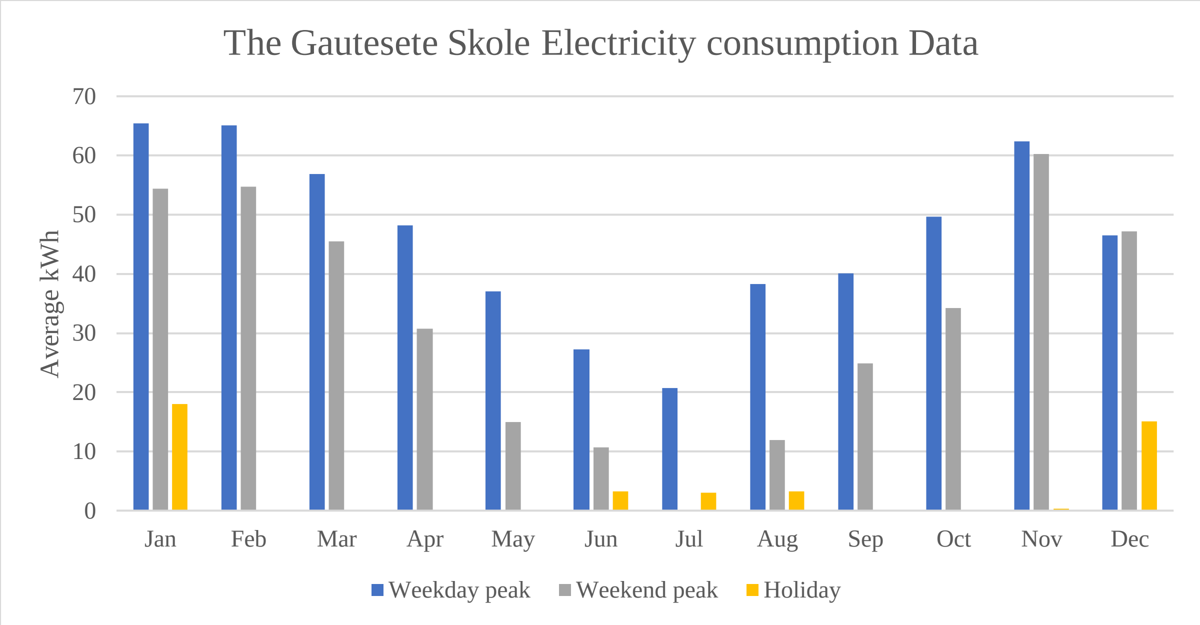


Figure 4.6 The Gautesete Skole electricity consumption data chart

4.2 Simulation model

4.2.1 Purpose

The primary purpose of the modeling is to identify the dynamic behaviour by analysing energy consumption and energy production. The simulation model of the energy consumption will be divided based on two categories, the building working hour pattern and the holidays as well as seasonal demand.

4.2.2 Model development

Figure 4.7 illustrates the main model of The Gautesete energy concept scheme. The relationship between energy production and consumption creates the causal loop diagram of the system. The loop is the balancing loop that marked with the B with the clockwise sign. The positive sign indicates the increased value, and the negative sign indicates the decreased amount. In this case, the possible source of the energy production is from the solar PV, which can be stored on the battery located in the energy center in Gautesete area. The solar PV production is dependent on the seasonal condition. While, the primary source of energy consumption is from the electricity grid and the energy usage is used mainly for heating (i.e., electric heating and hydronic heating) and electricity (e.g., television, gadget, kitchen equipment, etc.). The utilization pattern is formed due to the consumption of both heating and electricity that influenced by the activity of the building, holiday, and seasonal effect.

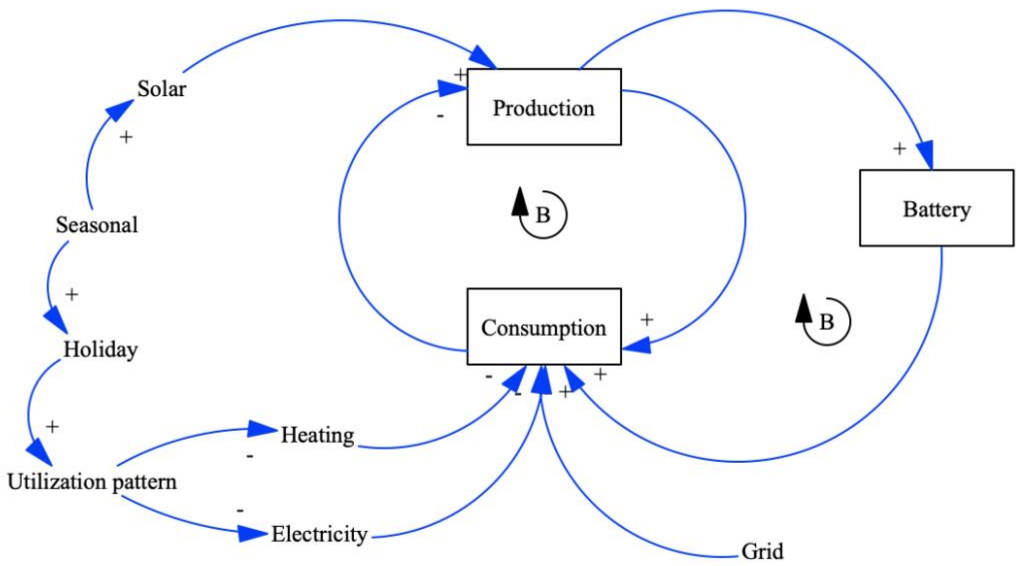


Figure 4.7 The main model of Gautesete energy

Figure 4.8 represents an example of the energy consumption model from each building for the first week of January. Each building has each rate that been formulized by using pulse train function on Vensim PLE. The time setting for this model was set to be seven days from each first month of the season. Furthermore, each building rates was connected to the integrated rates, and the results of each first week were shown in Chapter 4.2.3.1.

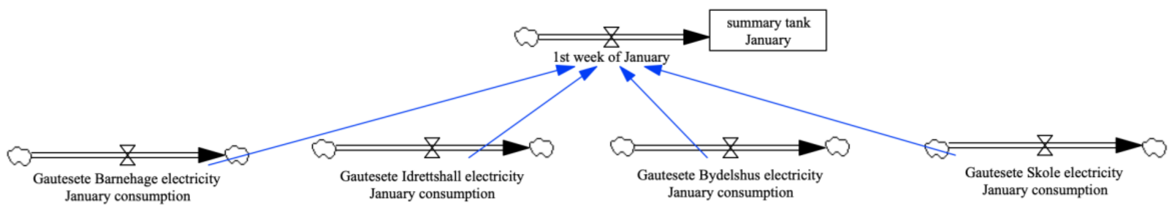


Figure 4.8 The model of the first week of January

Figure 4.9 shows an example of the energy consumption model from each building for winter usage. The modeling concept is the same as the first week of the month by using pulse train function, yet for this model, the integrated rates was a summary from every three months of each season.

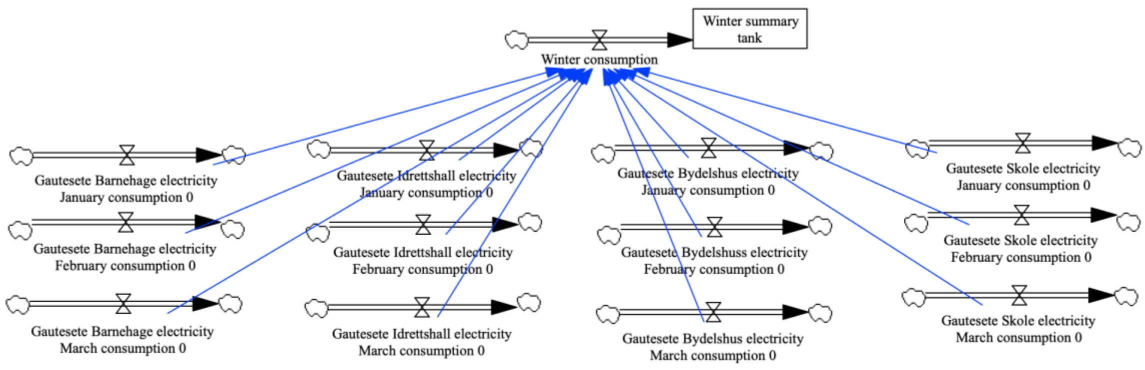
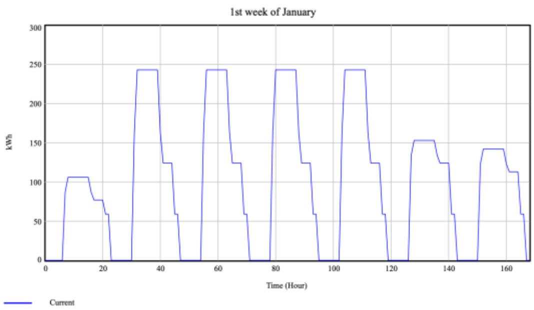


Figure 4.9 The model of winter consumption

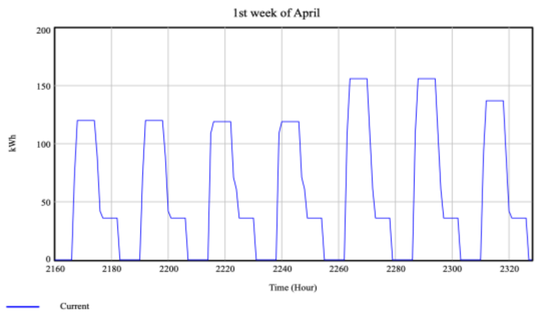
4.2.3 Simulated result

4.2.3.1 Estimate total energy consumption

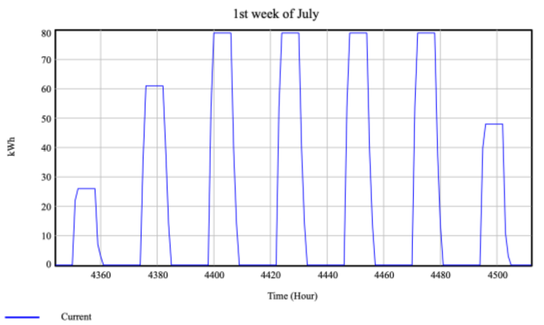
a. First week of every season for all buildings during one year.



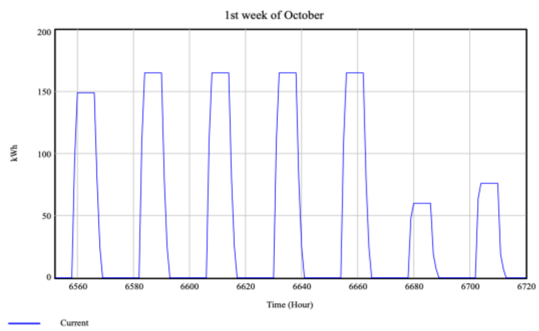
a). 1st week of January



b). 1st week of April



c). 1st week of July



d). 1st week of October

Figure 4.10 First week of every season consumption

Figure *4.10* depicts the dynamic behaviour of the electricity consumption for all building in the first week of every first month of the season, the y-axis shows the summary of electricity usage in kWh and the x-axis depict the time in hourly. January represents the winter consumption, April represents the spring consumption, July represents summer consumption, and October represent the fall consumption. All of the buildings were in the same year of data collection in

2018 except The Skole was from 2017 due to the building under renovation. However, the gap day was only one day different.

The first week of January enters the Winter season, 1st of January 2018 was Monday while 1st of January 2017 was Sunday. The first week of January denote the most electricity usage among other weeks. The first peak was the lowest total consumption this week around just over 100 kWh that represent the 1st of January, which was the public holiday. The weekday has an average of total consumption just under 250 kWh.

The first week of April enters the Spring season, 1st of April 2018 was Sunday while 1st of April 2017 was Saturday. The early two days was the public holiday, and it was the Easter holiday; therefore, some of the building were still on holiday for the next two days. The fifth and the sixth day was returning to typical weekday which reaches almost 160 kWh.

The first week of July enters the Summer season, 1st of July 2018 was Sunday while 1st of July 2017 was Saturday. The first day in July was the least usage with roughly 26 kWh due to the weekend, which some of the building was on holiday. The average of a weekday was the lowest among other seasons with a total nearly 80 kWh.

The first week of Fall enters the Fall season, 1st of October 2018 was Monday while 1st of October was Sunday. The average of total weekend consumption was around 170 kWh, and it was higher compared to the first week of April. However, the weekend total consumption was lower than the first week of April with the total amount on Saturday and Sunday 60 kWh and 75 kWh respectively.

b. Seasonal consumption for all buildings.

Figure 4.11 to Figure 4.14 exhibit the dynamic behaviour of the electricity consumption for all building for every season. The vertical axis illustrates the complete summary of the four building in kWh, and the horizontal axis demonstrate the time in hourly. The seasonal can be categorized as follow:

a. Winter consumption represents January, February, and March,
b. Spring consumption represents April, May, June,
c. Summer consumption represents July, August, September, and
d. Fall consumption represents October, November, December.

Obviously, on the winter season as Figure 4.11, the electricity usage was the highest compared to other three seasons, and the consumption tends to be dense due to there was no public holiday during this season except on the 1st of January. The usage of January and February have a constant trend, yet when it started in March, the consumption was getting decrease. Overall, the total average of the peak is around 250 kWh.

The electricity usage on the spring season as Figure 4.12 has dramatically dropped compared to the winter season. In April, weekday consumption tends to be at the same level, yet some peaks indicate the accumulation on the weekend due to some building still have some activities. Entering May, the graph shows many lower peaks, which shows the numbers of holidays. When June, the pattern tends to be clear, which one was on the weekend and which one was the holiday. At a glance, the average of the total energy consumption for this season was around 110 kWh.

Refer to Figure 4.13, the summer consumption signifies the distinct usage, especially the least in July. At the end of July, the electricity really minimum due to the seasonal change and summer holiday. Entering August, the weekday peak gradually inclined, yet dropped at the end of August. Then, the September consumption went up to 120 kWh weekday peak with no sign of public holiday, only weekend.

Figure 4.14 exhibit fall electricity consumption. Overall, the fall season usage has a compact high peak with the average of total consumption about 150 kWh, the low peak seen only at the beginning of October, which represents the weekend or holiday consumption. November and December tend to have high peak due to some of the building still open while on public holiday.

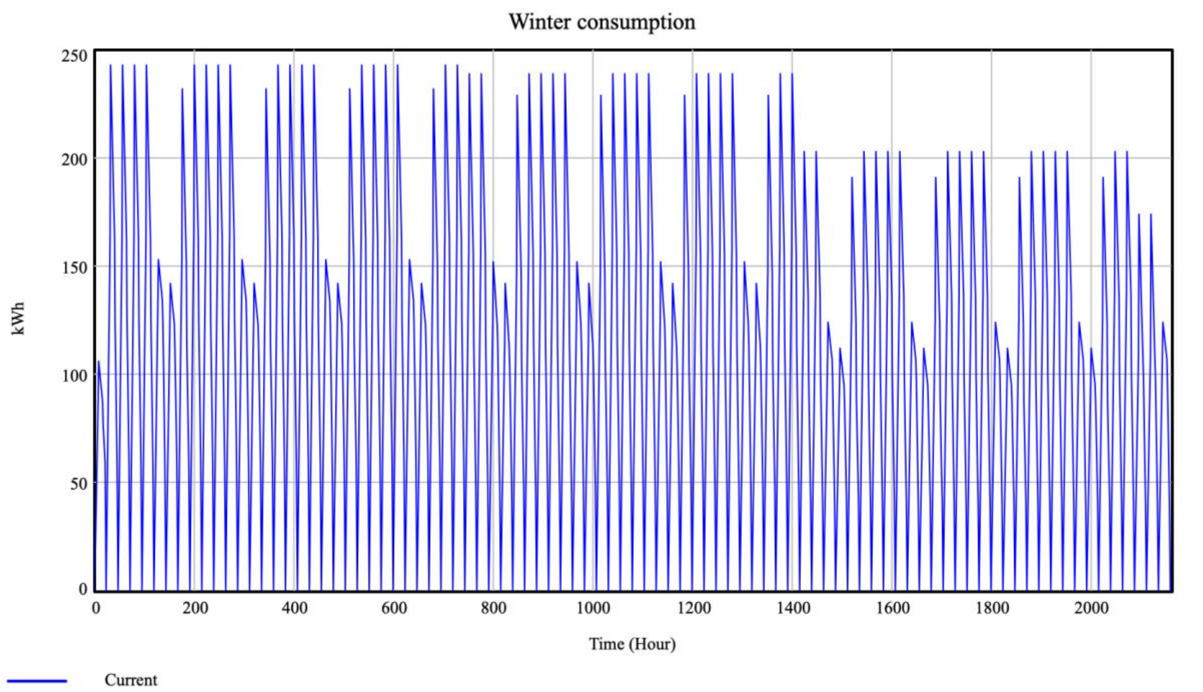


Figure 4.11 Winter electricity consumption

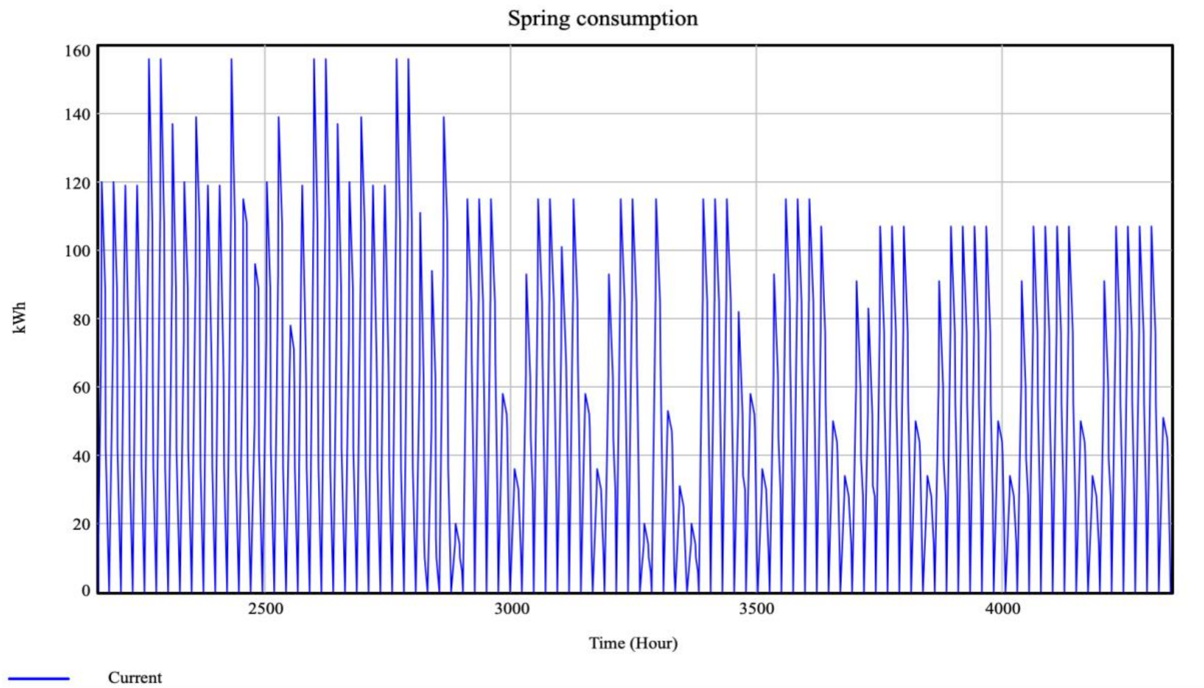


Figure 4.12 Spring electricity consumption

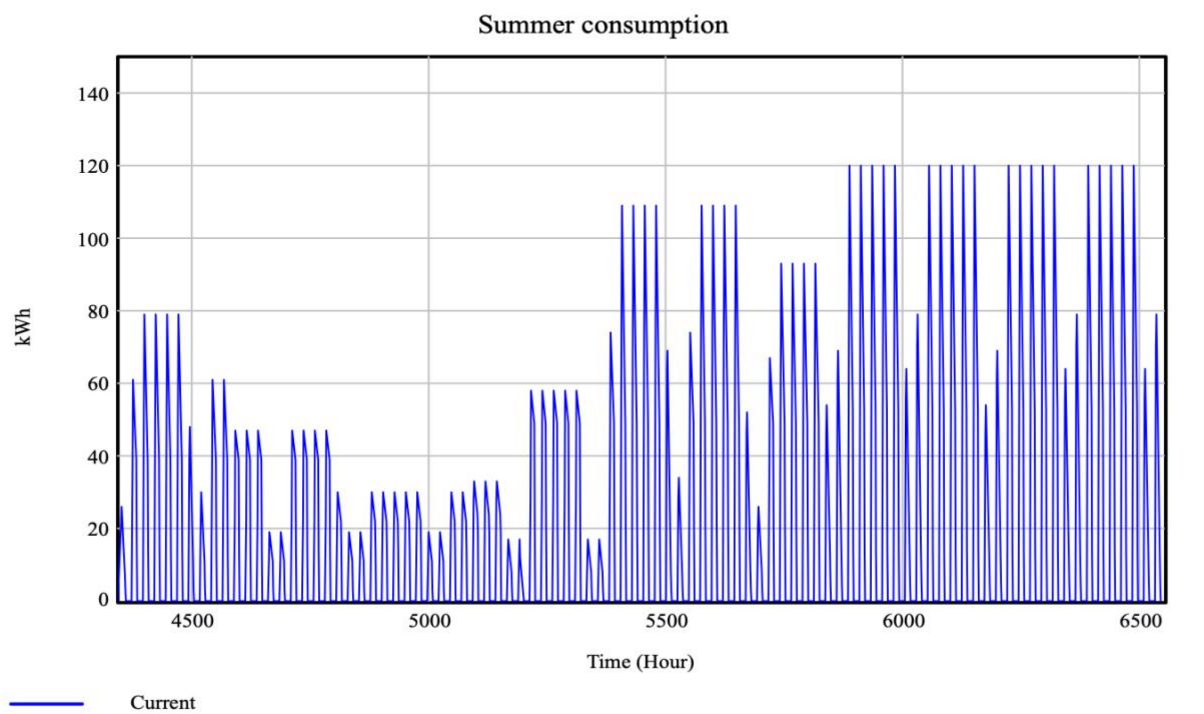


Figure 4.13 Summer electricity consumption

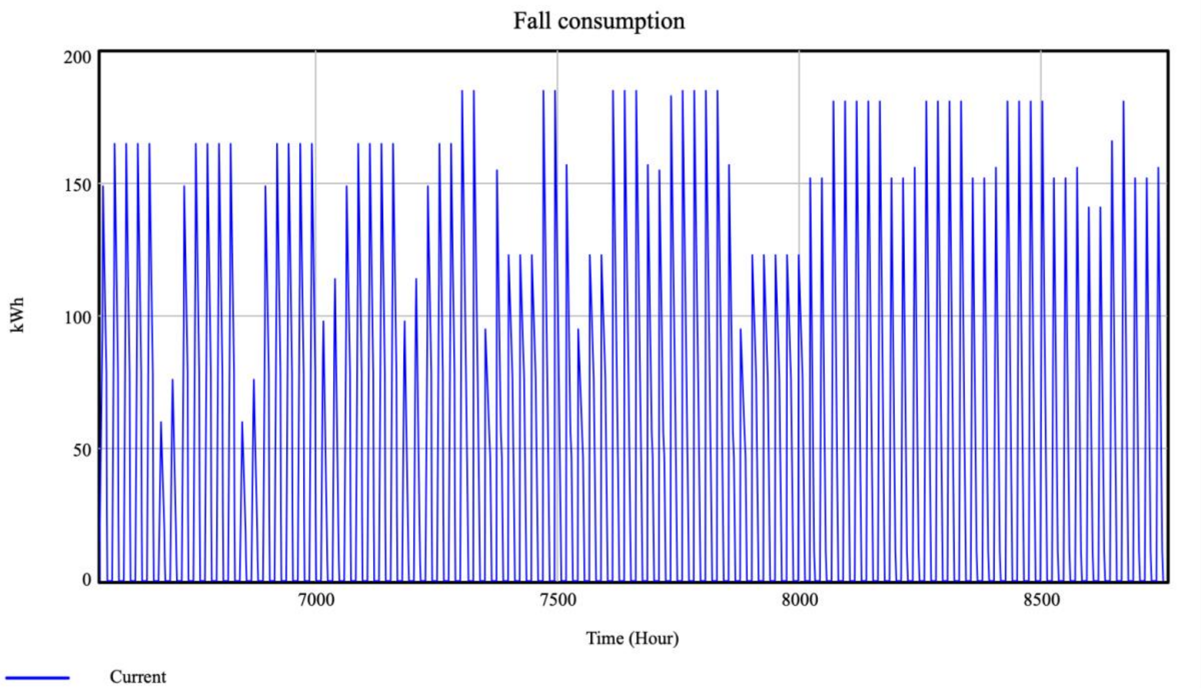


Figure 4.14 Fall electricity consumption

c. One year consumption

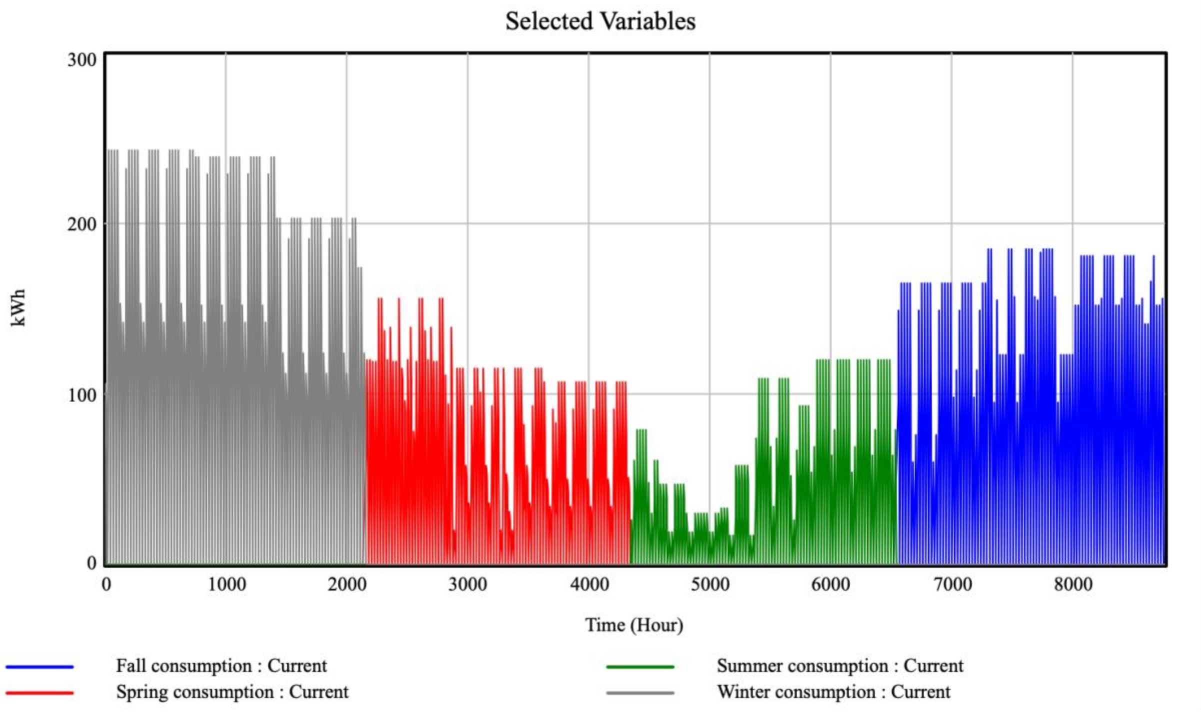


Figure 4.15 One year of electricity consumption

Figure 4.15 illustrates the consumption for the whole building during one year period. The vertical axis represents the total accumulation of the four building in kWh, and the horizontal axis shows the time in hour. The chart is classified into four seasons that are Winter (January to March), Spring (April to June), Summer (July to September), Fall (October to December).

Winter season shows considerable consumption with an average of about 250 kWh. This value was reasonable since while in winter, the building needs more electricity to heat the building, and more lighting due to the sun sets quickly. While the least electricity usage was in the summer season, especially in July, all of the building spent minimum electricity consumption due to the summer holiday. The average of spring, July and August were similar around total 120 kWh. The fall season consumption was getting inclined, the usage was marginally above the previous two seasons with the overall average about 150 kWh.

4.2.3.2 Estimate total energy production

The solar PV energy production result from the HelioScope program and the energy consumption data has been input to the Vensim PLE and generate the chart as Figure 4.16 below. Both the energy production and consumption are cumulative in kWh of the four buildings observed with the duration of 12 months from January to December. The energy consumption has the highest value when in winter and the lowest in summer, with the value just above 100.000 kWh and around 20.000 kWh respectively. In contrast, solar PV production has the highest yield in summer, up to slightly over 100.000 kWh and the lowest in winter and fall with almost no production. The solar PV production can cover the consumption considerably around the end of March until September. While, in February until the middle of March and October, the energy from solar PV might only cover the usage of half of the day. The excess of energy production can be stored on the battery, yet it depends on the capacity of the battery. Assume that the battery cannot keep the energy for a long time, only for a week capacity. Therefore, the surplus energy yield from summer cannot be used on the winter utilization, and need another energy supply, i.e., electricity from the grid.

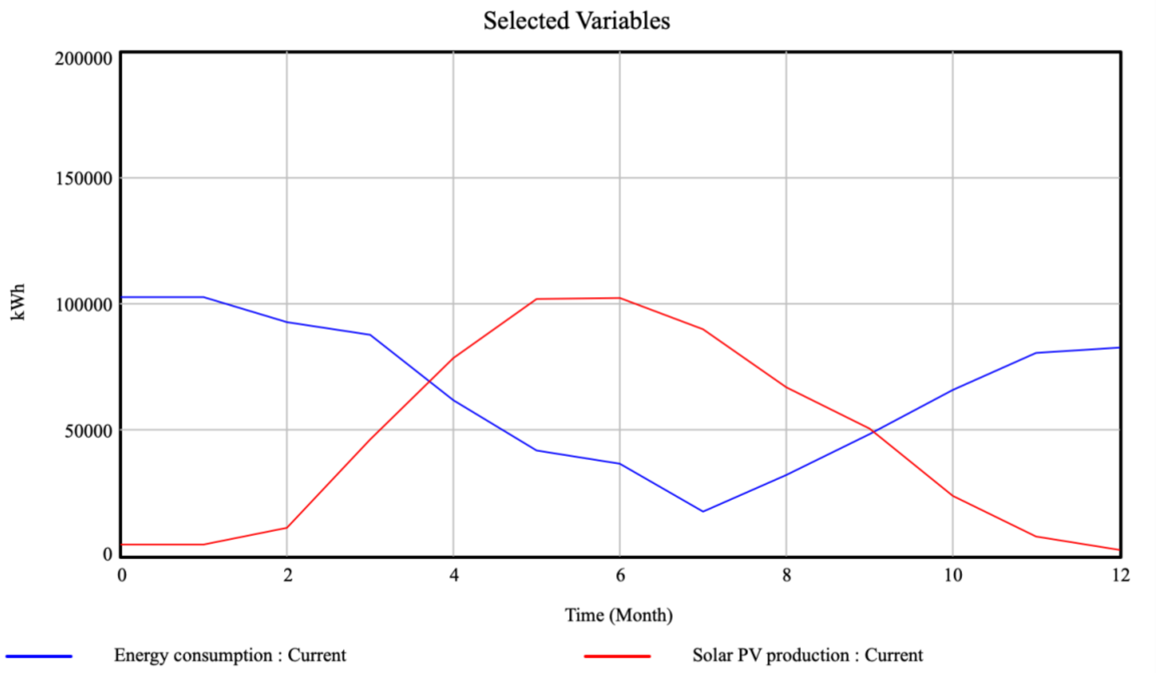


Figure 4.16 The solar PV production vs, energy consumption from Vensim PLE

Figure 4.17 express the comparison of the electricity need (El. behov - the blue bar) and the electricity production (El. prod – the orange bar) from the Gatuesete report. The amounts of electricity need or energy consumption are most likely the same as the Vensim PLE chart Figure 4.16, with the maximum 100.000 kWh and the minimum around 20.000 kWh. However, the electricity production or energy production shows the amounts that far below the Vensim PLE chart, this is due to the Gautesete report only consider the Barnehage and the Bydelshus without the Skole and the Idrettshall which has the tilted roof and curved roof respectively. Therefore, if the solar PV is installed only on two buildings, the energy production is not enough to cover the energy usage, except in July that has slightly more capacity.

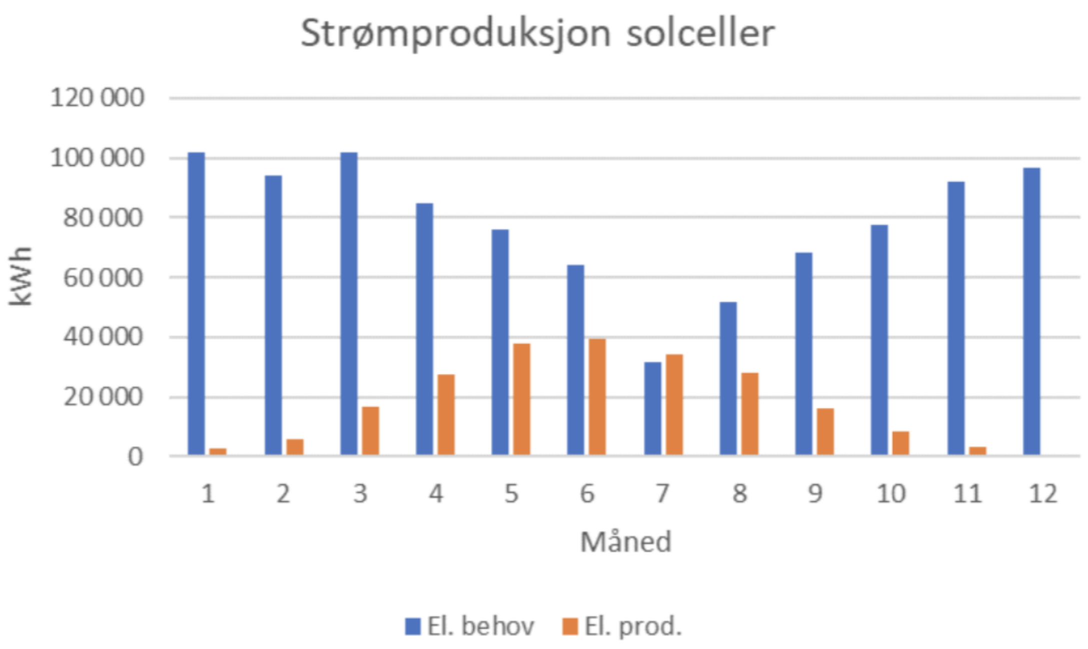


Figure 4.17 The solar PV production vs. energy consumption from Gautesete report (Norconsult, 2019)

4.2.4 Scenario

In this thesis, the scenario used was only one scenario. The data used was the original electricity consumption data from the building that compared to the solar production generated from the program without any additional parameter or comparison with other data.

5 Discussion & Conclusion

The purpose of this study is to explain and predict the dynamic behaviour of a cluster of building in the Gautesete area, Stavanger, by modeling the energy production from solar PV and energy consumption of the four buildings using the Vensim PLE, a system dynamic program. In conclusion, the main result from this simulation is that I have gained the understanding that the relationship of the energy production and the energy consumption has generated the balancing causal loop diagram, the seasonal effect is the most crucial thing for both state that influence the solar PV production and electricity usage, and the utilization profile might lead to have a consideration for the technical solution.

On system dynamics program, the energy production generates the positive value means there is an increase in production that leads to an increase in consumption, while the energy consumption generates the negative value means there is an increase in consumption that leads to a decrease in production. This relation of the value creates the balancing causal loop diagram as shown in Figure 4.7. Another balancing loop happened between energy production, battery storage, and energy consumption. The concept is the same that the positive amount from the energy production leads to an inclined amount in the battery storage, and the battery storage gives the positive amount to the energy consumption to be used.

The essential thing to be considered in the system is the seasonal changes, and this brings a significant effect on the utilization pattern. As explained in section 4.2.3.1, the electricity consumption data shows that the winter reaches the total average of usage almost 250 kWh followed by the cumulative average in the fall around 150 kWh. Although the data was only for one year, the utilization scheme most likely will reoccur with the same pattern due to the activity, season and holiday time is the same for every year. Hence, the model could be used to predict future energy behaviour. As a country that has four seasons, Norway has a strong dependency for heating purposes by electricity. Especially while in the winter the temperature could reach under 0°C, and has long dark time, which makes the usage of heating and lighting increased. The Norwegian Ministry of Petroleum and Energy has the energy policy that objective is *"…to provide a suitable framework for maintaining an efficient, climate-friendly and reliable energy supply system*" (Energy, 2018). Thus, the government encourages to reduce climate change, supporting the energy consumption reduction, and promote the smart city project.

The seasonal changes also donate the prominent amount of solar PV production, as shown in Figure 4.16. The energy yield has the most generated value in June, which is the peak around 100.000 kWh total in a month, while, the early and the end of the year the energy production almost zero. The yield of solar PV production is in June which is happened at the end of spring and the early of summer. This indicates that the solar radiation is at its peak at that period, and this pattern has a tendency to reappear in the future years. Moreover, the author obtained the optimum design with the same arrangement for all of the buildings, that is tilt: 15°, azimuth:180°, row spacing: 0 m and fixed tilt racking. The tilt 15° shows the most energy yield compared to other tilt angles, with the maximum number of PV modules and generated the installed power in kWh. There are four types of racking types, and the fixed tilt racking was generated the most energy. These arrangement using the fixed tilt racking, which means each the PV module stands up to the angle, and the result will produce the shades that cause the energy, not in an optimum value. Therefore, the 0 m row spacing could minimize the shadows that occur as a result of the gap between the PV module and the tilt angle. The result data from the program were compared to the Gautesete pilot project report, and it is shown that the result was not too different.

The graph output illustrates the utilization pattern that indicates there is a fluctuation of the peak for the weekly, seasonally, and yearly as in Chapter 4.2.3. The fluctuation formed as a result of the consumption behaviour of each building. The four-building has different utilization pattern since the function of the building is different, as explained in section 4.1.3.2.2. The average of electricity usage of four buildings for each month according to the weekend peak are Barnehage: 27 kWh, Skole: 46kWh, Idrettshall: 37 kWh, Bydelshus: 48 kWh. Among all of the four building, the most energy consumption is the Bydelshus and followed by the Skole. If we see the consumption behaviour model of all buildings in one model as in section 4.2.3.1, the pattern is different for every first of the week of the season, and even it was not uniform in each one frame. This is because there was a shift between the buildings since they have a different activity and different holiday time that leads to the peak consumption hour. Moreover, since the author gains the data from the real utilization, the data of the school was from 2017 while the other buildings were from 2018; hence this could make the pattern of the model not uniform. The consumption behaviour is an important part that needs to be considered to be observed in the system dynamics to predict the coverage of energy production. The system dynamics program can predict the trend of energy behaviour. Therefore, it is concluded that by knowing the consumption behaviour, the system dynamics could indirectly estimate the pattern and assess the technical solution of the relation between the production and the consumption, although it was from only one-year historical data. It would be better if the historical data is more than one year.

The thesis is focused on the cluster of buildings with different types and different functions. The character of the building also influences the usage of electricity, such as how large the building is, how many floors, how the ventilation working is, the design of the roof is, and many other factors. The Barnehage has 2 floors, the Idrettshall has 1.5 floors, the Skole has 3 floors, and the Bydelshus has 1 floor. In this case, the roof of all building has a tilted roof except the Barnehage has a flat roof. In terms of the energy production from PV panel, the tilt roof building is great if the building directly facing the sun, if the tilted roof opposite the sun, the PV panel will work hard to receive the energy that could make it not be optimum. To minimize the electricity usage, one of the options that could be done is by reducing the number of the student for the Skole or Barnehage, and reduce the activity of the Idrettshall and the Bydelshus. As we can see from the simulation model result in section 4.2.3, the model result indicates the shifting pattern between the buildings due to this study dealing with four building, instead of one building. Moreover, referring to Hatamzad´s, previous master thesis, she mentioned that to adopt the renewable energy and to reduce the energy consumption, it would work optimum for the building has 2 floors, since her project case building is an office building with 4 floors (Hatamzad, 2018). Therefore, it is concluded that in designing a building, the approach of system dynamics is the right things to do to study the utilization profile to reach the maximum energy production and could manage the energy consumption.

The architecture design of the building could be the technical solution to increase the energy production and to reduce the energy consumption that influenced by the utilization profile. The tilt of the roof for generating the energy output from solar PV and the angle of the solar PV modules plays an important role. To support the increase of energy production, several option can be done such as the position of the roof should facing the sun, build the tilt roof that facing the sun instead of opposite, build the stand alone solar PV grid, build the energy center for the battery storage, arrange the 0 row spacing to keep the maximum number of solar PV module, etc. Whereas, to reduce the electricity usage that could be done by changing the building design, the arrangement of the ventilation, window position, the heater type, position of the heater, and reduce the activity.

The implication of analysing the system dynamics of this case study is to understand the technical solution to reduce the energy consumption and reduce the greenhouse gas emission. In this case, there are two options for a heating solution that might be considered is by using the hydronic heating with the source of bio-coal or geothermal. According to the literature review, the bio-coal has many advantages and could prominently reduce the greenhouse emission, as mentioned in section 2.2.2. Compared to the geothermal heat, although it can reduce the emission as well, yet there are some drawbacks of the implementation of geothermal as mentioned in section 2.2.3. Thus, the bio-coal outweigh the geothermal, and the Stavanger city government seems to tend to use the bio-coal.

,

References

AGAR, D. A. & GIL, J. 23 May 2013 2013. *RE: Bio-coal Versus Conventional Pellet Production: Energy and Greenhouse Gas Emission Balance.* Type to CONFERENCE, A.-E.

ARNE, K. Y. 2018. *Velkommen til Gautesete Skole* [Online]. Norway: Minsckole. Available: https://www.minskole.no/gautesete/artikkel/230595 [Accessed 2019].

BALA, B. K., ARSHAD, F. M. & NOH, K. M. 2017. *System dynamics*, Singapore, Springer Science+Business Media.

BP. *Energy demand by sector* [Online]. BP. Available: https://www.bp.com/en/global/corporate/energy-economics/energy-outlook/demand-by-sector.html [Accessed 2019].

DEMIREL, Y. 2016a. Energy Sources. *Energy: Production, Conversion, Storage, Conservation, and Coupling.* Cham: Springer International Publishing.

DEMIREL, Y. 2016b. Geothermal Energy. *Energy: Production, Conversion, Storage, Conservation, and Coupling.* Cham: Springer International Publishing.

DEMIREL, Y. 2016c. Photovoltaic. *Energy: Production, Conversion, Storage, Conservation, and Coupling.* Cham: Springer International Publishing.

DEMIREL, Y. 2016d. Solar Energy. *Energy: Production, Conversion, Storage, Conservation, and Coupling.* Cham: Springer International Publishing.

EEA. 2017. *Energy and mitigating climate change* [Online]. Denmark: European Environment Agency (EEA). Available: https://www.eea.europa.eu/signals/signals-2017/infographics/energy-and-mitigating-climate-change/view [Accessed 2019].

ENERGY, M. O. P. A. 2016. Renewable energy production in Norway. Available: https://www.regjeringen.no/en/topics/energy/renewable-energy/renewable-energy-production-in-norway/id2343462/.

ENERGY, N. M. O. P. A. 2018. *Main Elements of Norwegian Energy Policy* [Online]. Norway: Norwegian Ministry of Petroleum and Energy. Available: norwegian energy policy [Accessed 2019].

ENERGY, S. 2015. *Fossil Fuels 101* [Online]. Student Energy. Available: https://www.youtube.com/watch?v=zaXBVYr9Ij0 [Accessed 2019].

FORRESTER, J. W. 1968. Industrial dynamics—after the first decade. *Management Science,* 14**,** 398-415.

FORRESTER, J. W. 1994. System dynamics, systems thinking, and soft OR. *System Dynamics Review,* 10**,** 245-256.

FORRESTER, J. W. 2009. Some basic concepts in system dynamics. *Sloan School of Management, Massachusetts Institute of Technology, Cambridge***,** 9.

GIBBS, P. 2012. *RE: HelioScope: Mathematical Formulation.* Type to USER, H.

HATAMZAD, M. 2018. *A simulation model and system risk analytics for a net zero energy office building: A case study.* Master, University of Stavanger.

ILKIC, M. O. 2018. *Simulation Model of Hybrid Energy Production and Consumption for Passive House Concept: A Case Study: "MyBox Student House" in University of Stavanger (UIS) Campus.* Master, University of Stavanger.

ISABELLA, O., SMETS, A., JÄGER, K., ZEMAN, M. & VAN SWAAIJ, R. 2016. Solar Energy: The physics and engineering of photovoltaic conversion, technologies and systems. *UIT Cambridge Limited*.

JONER, E. 2015. *RE: Biokull - en ny mulighet.* Type to BIOFORSK.

KALOGIROU, S. A. 2013. Photovoltaic system. *Solar energy engineering: processes and systems.* Academic Press.

KRYLOVA, A. Y. & ZAITCHENKO, V. 2018. Hydrothermal Carbonization of Biomass: A Review. *Solid Fuel Chemistry,* 52**,** 91-103.
MINBARNEHAGE. 2019. *Gautesete Barnehage* [Online]. Norway: Minbarnehage.no. Available: https://www.minbarnehage.no/gautesetebhg [Accessed 2019].
MOUSAVI MALEKI, S., HIZAM, H. & GOMES, C. 2017. Estimation of hourly, daily and monthly global solar radiation on inclined surfaces: Models re-visited. *Energies,* 10**,** 134.
NASA. *A blanket around the Earth* [Online]. California: NASA. Available: https://climate.nasa.gov/causes/ [Accessed 2019].
NORCONSULT 2019. Energiforsyning Gautesete. Stavanger: Stavanger Komunne.
NVE. 2018. *Energy Consumption in Norway* [Online]. Norway: The Norwegian Water Resources and Energy Directorate (NVE). Available: https://www.nve.no/energy-consumption-and-efficiency/energy-consumption-in-norway/ [Accessed 2019].
OGATA, K. 1998. *System Dynamics*, Prentice hall Upper Saddle River, NJ.
OLE-GUNNAR SØGNEN, P. 2001. *RE: Norwegian building energy statistics; specific energy consumption and consumption by category of use.* Type to ENOVA.
RICHARDSON, G. P. 2013. System Dynamics. *In:* FU, S. I. G. A. M. C. (ed.) *Encyclopedia of Operations Research and Management Science*. Third Edition ed. New York: Springer Science + Business Media.
SELF, S. J., REDDY, B. V. & ROSEN, M. A. 2013. Geothermal heat pump systems: Status review and comparison with other heating options. *Applied energy,* 101**,** 341-348.
SENTRALBYRÅ, S. 2018. Production and consumption of energy, energy balance. 2018 ed. Norway: Statistisk Sentralbyrå (SSB).
SENTRALBYRÅ, S. 2019. Electricity. *Januari 2019.* 2019 ed. Norway: Statistisk Sentralbyrå (SSB).
STERMAN, J. D. 2000. *Business dynamics: systems thinking and modeling for a complex world*, McGraw-Hill.
YADAV, A. K. & CHANDEL, S. 2013. Tilt angle optimization to maximize incident solar radiation: A review. *Renewable and Sustainable Energy Reviews,* 23**,** 503-513.

APPENDIX A Helioscope Result

HelioScope Annual Production Report produced by Lovita Ghassini

Barnehage Gautesete Barnehage, Heddeveien 165, 4032 Stavanger, Norway

Report

Project Name	Gautesete Barnehage
Project Address	Heddeveien 165, 4032 Stavanger, Norway
Prepared By	Lovita Ghassini lovitaghassini@gmail.com

System Metrics

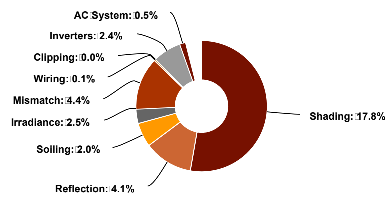
Design	Barnehage
Module DC Nameplate	88.0 kW
Inverter AC Nameplate	80.0 kW Load Ratio: 1.10
Annual Production	59.66 MWh
Performance Ratio	70.9%
kWh/kWp	678.0
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Simulator Version	9a48172b35-98a3557fac-5d8c9dbf0d-bca5500d7c

Project Location

Monthly Production

Month	GHI (kWh/m²)	POA (kWh/m²)	Shaded (kWh/m²)	Nameplate (kWh)	Grid (kWh)
January	6.7	8.5	6.5	536.2	449.5
February	16.1	20.7	15.2	1,251.8	1,123.6
March	61.7	76.8	60.6	5,007.7	4,733.8
April	110.8	126.7	102.9	8,526.9	7,992.4
May	153.2	164.4	135.5	11,239.4	10,387.4
June	156.7	162.5	137.6	11,400.3	10,439.3
July	136.8	142.6	122.0	10,097.8	9,167.4
August	97.5	107.1	90.9	7,537.2	6,809.4
September	69.7	82.5	68.0	5,620.0	5,136.8
October	34.2	42.8	32.3	2,669.9	2,413.8
November	10.7	16.4	10.9	895.0	772.4
December	3.7	4.9	3.7	300.2	234.9

Sources of System Loss



Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	857.7	
	POA Irradiance	955.7	11.4%
	Shaded Irradiance	786.0	-17.8%
	Irradiance after Reflection	754.1	-4.1%
	Irradiance after Soiling	739.1	-2.0%
	Total Collector Irradiance	**739.1**	**0.0%**
Energy (kWh)	Nameplate	65,082.5	
	Output at Irradiance Levels	63,464.2	-2.5%
	Output at Cell Temperature Derate	64,297.9	1.3%
	Output After Mismatch	61,483.4	-4.4%
	Optimal DC Output	61,406.2	-0.1%
	Constrained DC Output	61,405.6	0.0%
	Inverter Output	59,960.6	-2.4%
	Energy to Grid	**59,660.7**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		10.7 °C
	Avg. Operating Cell Temp		14.7 °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
East-West	-3.56	-0.075	3°C
Carport	-3.56	-0.075	3°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
TSM-PD14 320 (May16) (Trina Solar)	Spec Sheet Characterization, PAN

Component Characterizations

Device	Characterization
Sunny Tripower 20000TL-US (SMA)	Modified CEC

Components

Component	Name	Count
Inverters	Sunny Tripower 20000TL-US (SMA)	4 (80.0 kW)
Strings	10 AWG (Copper)	19 (450.5 m)
Module	Trina Solar, TSM-PD14 320 (May16) (320W)	275 (88.0 kW)

Wiring Zones

Description	Combiner Poles	String Size	Stringing Strategy
Wiring Zone	12	5-19	Along Racking

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Landscape (Horizontal)	15°	180°	0.0 m	1x1	275	275	88.0 kW

Detailed Layout