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A simulation model and systemic risk analytics for a net zero energy office building: A case study

By

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Abstract

Net zero energy building is becoming one of the most interesting concept to design new residential and commercial buildings where natural energy sources are able to supply the energy demand. Solar energy is a recent innovative technology to meet the energy demand in order to achieve the vision of net zero energy building. There are several attributes which have effects on solar energy production such as geographical site conditions, building area and shape of the roof. In addition, there are some factors that influence on energy consumption such as number of offices, number of equipment and climatic condition. Several solar energy simulators can estimate the solar energy production rate per hour (KWh) and multiply hourly energy production rate by average number of producing hours per each month in order to predict the maximum solar energy production rate (KW) over the whole year. These simulators estimate the energy production rate based on design factors. These factors are including tilt angle, pitch, azimuth, racking type and weather conditions. For example, if a specific solar panel's design (specific tilt angle, pitch, azimuth and racking type) produces 40 KW energy per hour in April (30 days) and the expected number of producing hours in this month is 5 hours per day, the expected total solar energy production in April is 6000 KW. However, there are three issues that have been taken into account in such energy estimations: (1) Considering the expected monthly production overlooks daily and weekly production rate which decrease our understanding of hourly production behavior within a day and during the week. (2) The utilization of energy production is dependent on energy consumption which means there are some time intervals when solar energy is produced but there is no consumption. Therefore, the produced energy in these time intervals is wasted, if storage is not installed. In order to have an efficient system, we need to understand hourly energy production rate and hourly energy consumption rate. It is hard to have an efficient system in monthly base. (3) In order to conduct revision for the building and solar energy design, we should understand the impact of each design factor on both energy production and energy consumption. Different design factors may have contradictory effect or systemic impact on whole system. For instance, reduction in building area can decrease the consumption in one hand and reduce the solar energy production in the other hand. Hence, we need to understand the dynamic behavior of energy production and energy consumption

per hour which can lead to revise the conceptual design in a more effective manner i.e. to have effective operational energy management and to avoid economical risk.

Thus, the objective of this thesis is to develop a cost-oriented model to estimate the hourly solar energy production rate and hourly energy consumption rate for specific office building and solar energy design over a whole year.

In order to develop this model, a case study has been selected to extract the real solar energy production and energy consumption profiles which have been mimicked by simulation model and to be used as a reference for testing the model i.e. comparing the simulated results with the measured data (real data).

The work first has been started with system analysis for office building design (architecture data) and potential alternatives in solar energy designs. Second, the optimal solar energy design has been determined which has been used in simulation model to estimate its potential energy production rate. Third, the building design concept has been simulated to estimate the energy consumption. Then, the energy production model and energy consumption model have been integrated together in order to specify the systemic energy building profile which includes the utilized energy profile, purchased energy from the grid, stored energy. Fourth, the economic risk analysis has been conducted to identify the aspects of systemic risk.

The system analysis for the building design has shown that the building roof area and its shape (flat roof or tilted/sloped roof) play a crucial role for solar energy production i.e. tilt angle is the most important design factor which affects the solar energy production system. It is significant to mention that tilted solar panels with different angles (10° to 45°) need spacing between the panels (pitch) to minimize the total shade losses. Thus, tilted (slopped) roof can provide an option to use the entire roof without spacing between the solar panels (pitch).

The system analysis for solar energy design has illustrated that the most significant design factors which influence the solar energy production are tilt angle, pitch, racking type and site climatic conditions (sunlight, clouds). However, the most critical factor is tilt angle which is 10° in our system due to site location.

The simulation model for solar energy production has indicated that there are a lot of fluctuations in estimation of hourly energy production over the month. However, the monthly accumulated energy production rate is almost similar to monthly estimation. Hence, the energy production model underlines that there is a difference between energy utilization rate and the production rate.

The simulation model for energy consumption has shown that there are not considerable fluctuations in hourly estimation and accumulated seasonal consumption rate proves it since the seasonal accumulated energy consumption rate is almost similar to the seasonal real energy consumption rate. In addition, it is worth to highlight that the minimum hourly energy consumption rate is approximately the same over the year (60 KWh to 75 KWh) and also there is no big gap between maximum hourly energy consumption rate during the year (220 KWh to 245 KWh).

The proposed systemic energy building is including the utilized energy profile, purchased energy from the grid and stored energy which have illustrated that if the minimum energy consumption rate over the day is higher than maximum solar energy production rate, then the design needs to be revised and/or the energy consumption needs to be minimized.

The utilized energy profile has shown that the utilization rate is high in office building. It is obvious that high energy demand with limited flat roof area cannot achieve the zero energy building vision and it will be dependent on grid supply.

The systemic risk analysis has demonstrated that in calculation of energy consumption and energy production, there are several uncertain factors which need to be taken into more consideration to reduce the risk. However, amongst all uncertain factors, tilt angle in energy production and number of offices in energy consumption are the most uncertain ones. That is why, the uncertainty assessment has been carried out for these selected factors to evaluate the possibility to have a cost-effective system and results show that number of offices needs to be considered for more treatment and evaluation, if time, budget and resources permits.

The developed simulator is an effective and simple model to estimate the expected solar energy production, energy consumption, storage and grid dependencies in monetary terms.

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Abbreviations	Explanation
ZEB	Zero Energy Building
NZEB	Net Zero Energy Building
nZEB	Nearly Zero Energy Building
NZEOB	Net Zero Energy Office Building
E(NPV)	Expected Net Present Value

1. Introduction

1.1 Problem background

Net zero energy building is an innovative generation design where renewable energy production have the capability to meet the energy demand (Marszal et al., 2011). Solar energy is a significant source of renewable energy which is produced from the sunlight and it is the main source to achieve the net zero energy building. There are some calculators which have the capability to predict the highest solar energy production rate in different time units by considering the sun radiation and cloud's effect. In addition, estimation of solar energy production is dependent on solar design factors which include tilt angle for solar panels and/or building's roof, spacing between solar panels i.e. pitch, building roof area, racking type i.e. east-west or fixed racking and geographical site condition. However, solar energy production is not an only element to attain a net zero energy building which means power/energy consumption in the building plays an important role in this mission. Energy consumption is dependent on several factors in the building i.e. lighting, ventilation, equipment, number of offices. Therefore, we need to understand the dynamic behavior of expected solar energy production and energy consumption rates at hourly bases which can be achieved by simulation of solar energy production and energy consumption in the office building. Simulation of solar energy production looks at the behavior of hourly energy production rate within the day or over the week. Simulation of energy consumption shows several time intervals which there are production without any consumption, and the produced energy is wasted in these specific situations. Simulation models represent systemic energy building profile i.e. the utilized energy profile, stored energy and purchased energy from the grid in terms of money in the office building. Moreover, uncertain factors in simulation models need to be considered for further assessment to evaluate the possibility of having economically beneficial system.

1.2 Problem formulation and objectives

Thus, based on the above described situation, the research question is formulated as follows:

How can energy systems for a net zero energy office building be developed in a cost-effective and low risk manner?

This research question leads to the following objectives:

1) To determine the best design for solar panel/PV installation on a flat roof to achieve the best production
2) To simulate the demand-supply power resulting from PV integration
3) To present systemic energy building vision i.e. the utilized energy profile, stored energy and purchased energy from the grid
4) To estimate the expected energy production, energy consumption, storage and grid dependencies in monetary value
5) To determine the most uncertain factor in simulation model based on systemic risk analysis

1.3 Methodology

Several methods have been used in order to answer the formulated research question and achieve the objectives of this project.

First of all, a case study is a Måltidets hus which located in Ipark, Stavanger for system analysis and to collect the required data.

Second, a literature review is an important method that helps us to understand the implications, theoretical points, collect useful information about the thesis topic and explore various approaches to understand, analyze and solve the formulated problem.

Thrid, finding the best design for mounting PV panels using Helioscope software.

Fourth, using Matlab software to compute distributions for solar energy production and energy consumption to be used as inputs for the simulation model.

Fifth, developing the simulation model in Vensim software to understand the dynamic behavior of solar energy production and energy consumption rates per hour to achieve the systemic energy building profile which consists of the utilized energy, storage and grid dependencies in monetary rate.

Sixth, calculation of payback time for solar energy design and computing the expected net present value to consider uncertainty assessment for the most uncertain factors in simulation model.

1.4 Limitation/ Delimitation

There are several limitations which can be delimited in future research. Following are the barriers for this study:

First, considering solar energy as an only source for energy production.

Second, calculating total energy consumption which can overlook dynamic behavior of each energy consumer in datail in the office building.

Third, selecting one building as a case study to evaluate the achievement of net zero energy building.

Fourth, using Vensim PLE for simulation model which does not provide users with specific options e.g. sensitivity simulations and export/import external.

1.5 The structure of the thesis

This thesis includes five chapters. Chapter one is an introduction of this research which contains problem background, research question, objectives and methodology. Chapter two consists of literature review including zero energy building, system dynamics, solar energy and systemic risk analytics. Chapter three is the case study (Måltidets hus) and data collection chapter which includes system analysis for office building to extract influencing design parameters for solar energy production and energy consumption. Chapter four is data analysis chapter which includes:

- Studying several solar energy designs using HelioScope and determining the best solar energy design
- Estimating/simulating the daily, weekly and yearly energy production of the best design and comparing the estimated production with the real/estimated production provided by HelioScope.
- Estimating/simulating the daily, weekly and yearly energy consumption of Måltidets hus and comparing the estimated consumption with the real consumption.
- Compare energy production vs energy consumption for providing the big picture (overall energy supply system) of Måltidets hus and how much it complies with NZEB systems

- Calculating the payback time for solar energy system and to determine the uncertain factors in simulation models and conducting uncertainty assessment to determine the most uncertain factors

Chapter six provides conclusion, discussion and recommendations to achieve the target as NZEB systems.

2. Theorical background and literature review

This chapter provides necessary theoretical background for understanding the research topic. It starts with a general theory about zero energy building and then explanation about solar energy system, system dynamics and system dynamics for energy buildings. Finally, this chapter is ended with a short summary about risk management and uncertainty assessment.

2.1 Zero Energy Building (ZEB)

A term ZEB is an abbreviation of a Zero Energy Building or a Zero Emission Building. The first one refers to the operation of daily energy consumption and the second one refers to the amount of carbon dioxide emissions in the air as an outcome of its operation (D'Agostino, 2015). The concept of a Zero Energy Building (ZEB) first used in the year 2000 and this concept has become an interesting idea since 2006 (Torcellini, Pless, Deru, & Crawley, 2006). A ZEB is a novel generation design that is a combination of using renewable energy and traditional green energy building (Marszal et al., 2011). A zero energy building (ZEB) can be either a residential building or a commercial building that the amount of energy demand can be produced by renewable energy sources (Torcellini et al., 2006). In zero energy buildings, energy consumption is mostly supplied by clean energy. The main clean energy sources for ZEBs are solar energy and wind energy (Marszal et al., 2011). There are some benefits to use renewable energy such as decreasing the level of carbon emissions that can result into having clean air. There are four requirements in order to have a ZEB. These requirements are including "low-cost", "locally available", environment friendly and green energy sources (Torcellini et al., 2006).

There are two types of supply options for a ZEB: 1)"On-site supply options": The sources of clean energy for a ZEB is inside of the building. These kinds of buildings are referred to as ZEBs and 2)"Off-site supply options": The sources of clean energy for a ZEB is outside of the building such as a building which purchases all its required energy from wind farm. These kinds of buildings are referred to as "off-site ZEBs"(Torcellini et al., 2006).

Another classification of ZEB is Autonomous ZEB and Net ZEB. Autonomous ZEB is not connected to the grid (Laustsen, 2008). Grid connection (grid connected ZEB is also called a net ZEB (NZEB) (Laustsen, 2008) is a keystone in a ZEB as sometimes on-site clean energy generation does not meet the demand. Therefore, to satisfy the loads, a ZEB has to use another source of energy. When the on-site energy generation is more than the consumption, excess electricity is sent to the utility grid. Thus, it is really hard to have a ZEB without a grid (Torcellini et al., 2006).

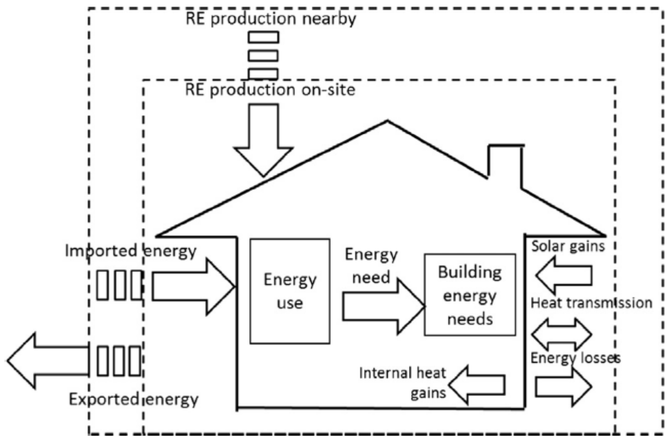
Lund et al. mention four types of ZEB as follow (Lund, Marszal, & Heiselberg, 2011):

Installed Renewable Typology	**Electricity Demand**	**System**
PV-ZEB	Relatively low	Photovoltaic (PV)
Wind-ZEB	Relatively low	Small on-site wind turbine
PV-Solar thermal-heat pump ZEB	Low	Combination of: PV installation Solar thermal collector Heat pump Heat storage
Wind-Solar thermal-heat pump ZEB	Low	Combination of: Wind turbine Solar thermal collector Heat pump Heat storage

Table 1: Four types of ZEB (Lund et al., 2011)

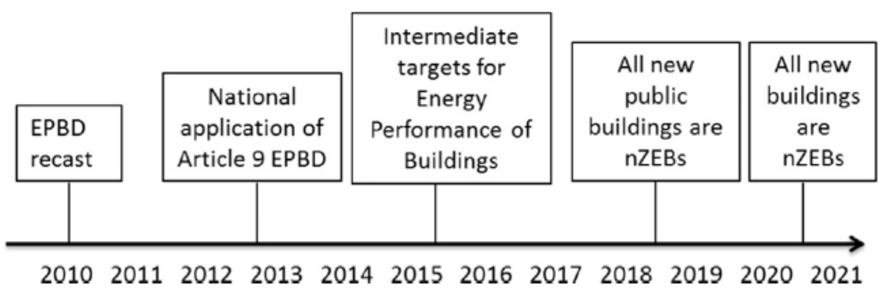
The other type of ZEB is called Nearly Zero Energy Buildings (nZEB). A nZEB is defined as "the building which has a very high energy performance with a low amount of energy required covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby (EU, 2010). These buildings have been considered as a major target in order to enhance energy saving and reduce the greenhouse gas emissions(D'Agostino, 2015). Figure 1 shows nZEB with possible system boundaries (D'Agostino, 2015).

Figure 1. A schematized nZEB with possible system boundaries (D'Agostino, 2015)



Most recent reviews consider the role of lifecycle assessment, using smart grid, saving the energy by storage and load match to evaluate how the energy system can perform (Deng, Wang, & Dai, 2014). According to Energy Performance of Buildings Directive (EPBD) recast, it is going to implement nZEBs for all new buildings in future. Figure 2, shows the timeline for implementing of nZEBs (D'Agostino, 2015):

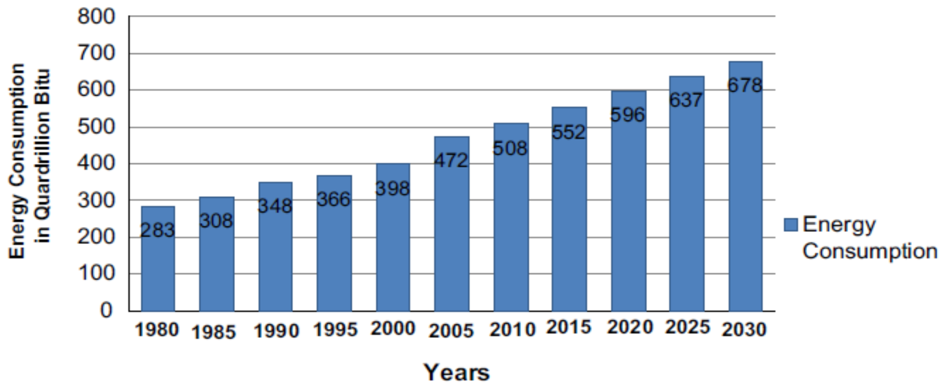
Figure 2. Timeline for nZEBs implementation based on the EPBD recast (D'Agostino, 2015)



2.2 Energy production

Energy plays a crucial role in economic situation for every country. An increase in the number of population leads to an increase in the energy demand all over the world. It has been reported in the International Energy Outlook in 2009 by the US Department of Energy, the total energy consumption increases by 44% between the year 2006-2030 (US Department of Energy, 2009).

Figure 3. Projected world energy consumption chart (US Department of Energy, 2009)



Using fossil fuels to produce energy has some disadvantages such as negative impacts on the climate change. In addition, the usage of nuclear power plants has different major impacts on environment due to radioactive emissions. In this situation, it is wise to use renewable energy to produce electricity. In recent years, clean energy sources have been considered in many researches and projects (Chu & Meisen, 2011). Renewable energy consists of solar energy, wind energy, rainfall energy and etc. Rain power can play an important role in the high rainfall zones where are difficult to utilize solar energy production. Generator turbines and piezoelectric generator are used to extract the kinetic energy of dropping rain water (Tinaikar, 2013). Wind energy extracts mechanical power from air flow through wind turbines. The wind energy can be used in different areas such as residential buildings, commercial buildings and schools (Fthenakis & Kim, 2009). Although, rain power and wind energy are two important sources of clean energy, solar energy is an only source that has been used in this thesis. Due to the importance of solar energy in this study, the following section has been considered for complete theory of solar energy.

2.2.1 Solar Energy

According to recent innovative technologies and the extensive research in the world, solar energy is available naturally as well as having an enormous potential to supply energy demand in future (Chu & Meisen, 2011). Research has shown that the energy of the sun that arrives to the earth is 1000 times more than the energy we consume(Häberlin, 2012). Sun is a great source of energy for the earth. The amount of energy that reaches the surface of Earth is 120 petawatts. This means that amount of energy received from the Sun is able to satisfy the energy demand globally for about 20 years(Chu & Meisen, 2011).

Solar energy includes many parameters that need to be calculated. These parameters include solar radiation and the different angles. Actually, estimating of them plays an important role over a year because the positions of sun in the sky are changing throughout time and it leads to different absorbed amount of radiation. The parameters are as follow:

1. Solar Declination Angle (**δ) :**This angle is defined as an angle between the equatorial plane and direction of sunlight (Abood, 2015). This angle can be calculated as follow (Duffie & Beckman, 2013):

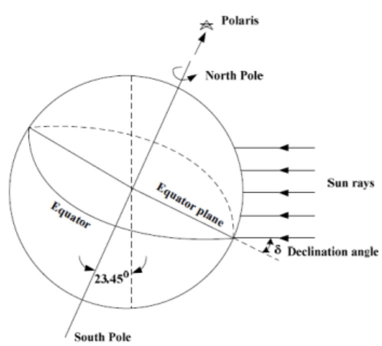
$$\delta = 23.45° Sin\left[\frac{360}{365}\ (n + 284)\right]$$

where, n = the number of day in a year and 1st January is accepted as the start(Karafil, Ozbay, Kesler, & Parmaksiz, 2015).

$\delta = 23.45°\ on\ 21th\ June$

$\delta = -23.45°\ on\ 22nd\ December$

Figure 4. Declination angle(Karafil et al., 2015)



2. Solar Hour Angle **(h)**

"It is the angle through which the Earth has rotated since solar noon"(Abood, 2015)

The 360° rotation of the Earth in 24 hours:

$$\frac{360°}{24} = 15°h$$

This angle can be calculated as follow (Duffie et al., 2013):

$$h = (Local\ time - 12)15°$$

where

$h > 0$ In the evening

$h < 0$ In the morning

3. Solar Altitude Angle **(α)**

   It is the angle between the sun and the Earth's horizon (Duffie & Beckman, 2013).

4. Solar Zenith Angle **(Φ)**

   It is the angle of the sunlight relative to the normal on the horizon (Abood, 2015)

   Solar altitude angle (α) and solar zenith angle (Φ) are complement i.e. $\alpha + = 90°$ and it has been estimated as follow (Duffie & Beckman, 2013):

   $sin\alpha = \cos\Phi = \sin L \sin\delta + \cos L \cos\delta \cosh$

   L shows the local latitude and it varies between -90° and 90° (-90°≤L≤90°) from south of the equator to north of the equator.

5. Solar Azimuth Angle **(Z)**

   It is the angle of the solar beam relative to the longitude meridian.

   Research have shown that in the northern hemisphere, *for a surface facing due southZ* $= 0°$ *and for a surface facing due south* $= 180°$

   and it has been calculated as follow:

   $sinz = {}^{cos\delta\ \sinh}/_{cos\alpha}$

   Solar altitude angle, solar zenith angle and solar azimuth angle change during the day and year (Abood, 2015).

6. Tilt angle **(β)**

   It is the angle of the panels relative to the horizontal plane.

   "This angle is south oriented in the Northern Hemisphere and north oriented in the Southern Hemisphere"(Karafil et al., 2015)

   $0° \leq \beta \leq 180°$

7. Surface Azimuth Angle **(Z_S)**

   It is the angle between the projection of the normal to the surface on a horizontal plane and the local longitude meridian (Karafil et al., 2015).

   where,

Zs < 0° in East

Zs = 0° in South

Zs > 0° in West

And,

0° ≤ Zs ≤ 180°

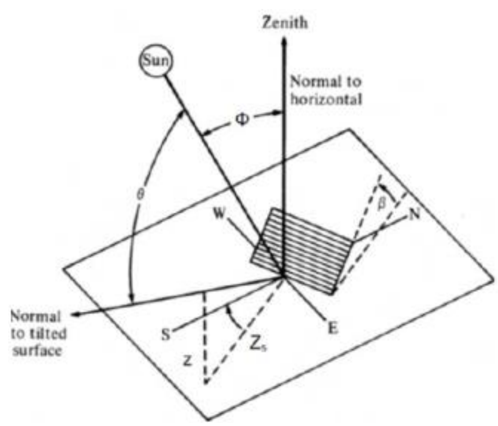
8. Incidence Angle **(θ)**

It is the angle between sunlight and surface normal (Karafil et al., 2015)

It has been calculated as follow (Duffie & Beckman, 2013):

$$cos\Theta = \sin L \, sin\delta \cos\beta - \cos L \sin\delta \; sin\beta \; cosZ_s +$$
$$cosL \cos\delta \cosh cos\beta + .. + \cosh sin\beta \; cosZ_s + cos\delta \sinh sin\beta \; sin\, Z_s$$

Figure 5. Zenith angle, angle of incidence, Tilt angle, solar azimuth angle and Surface azimuth angle for a tilted surface (Duffie & Beckman, 2013)



2.2.2 Solar energy production simulator: HelioScope

HelioScope is a solar energy production simulator which has been designed to calculate solar array outcome for a location based on specific design factors of PV panels, architecture factors of building and geographical assumptions. The calculation is according to a "component-based system model" which starts the simulation with each electrical element inside the solar panels and it allows them to collaborate in a realistic direction in order to compute losses and dynamic performance within the solar array (Gibbs, 2012). HelioScope is the only simulator in the market which calculates the solar system performance based on mismatch losses i.e. shading losses, orientation differences between PV panels in the same circuit and baseline mismatch which can be created by variables (folsomlab.com, 2018).

2.2.3 Analytical method for selection of best solar design

The cost of electricity generated by solar cells can be estimated based on following formula (Smestad, 2008)

$$\frac{Cost}{KWh} = \frac{Cost\ of\ System\ \$/m2}{KWh\ produced\ each\ year} * amortization + O\&M$$

In addition, non-tracking PV panels do not need too much operation and maintenance (Mekki & Virk, 2016). Therefore, if operation and maintenance cost is neglected and amortization is similar for all options, the formula changes to:

$$\frac{Cost}{KWh} = \frac{Cost\ of\ System\ \$/m2}{KWh\ produced\ each\ year}$$

And the cost is constant for each PV panel, therefore the final formula is:

$$Rate = Number\ of\ modules/Total\ Energy$$

2.3. Power/energy consumption

Power consumption is the required amount of input energy for electrical appliances/equipment to operate (futura-sciences, 2018). Power consumption is measured in watts (W) or in kilowatts (KW). It is important to mention that the amount of energy for equipment is more than the energy that is really needed. This is due to the efficiency of equipment since there is no equipment with %100 efficiency. For example, light bulbs do not only convert the energy into lights, there is also a waste of energy which is released by heat (PennState-university, 2018). There are several calculators which can measure energy consumption for different appliances. Energy consumption can be estimated by the number of electrical equipment i.e. computers, lighting, ventilation and etc. which are in each office in the commercial buildings in order to measure the total energy consumption rate. In fact, power calculation can help us to understand the dynamic behavior of energy consumption rate for energy decisions and/or energy management.

2.4. System dynamics (SD)

The implication of system thinking is about helping to understand how complex systems can behave and it was introduced in 1950. It is a tool to consider entire system for problem solving rather than considering each single section of the system (Russell, 2010).

System dynamics (SD) has been defined as a methodology according to system thinking (Forrester, 1969). SD can analyze problems to determine dynamic changes, delays and etc. by using different factors to control the system such as feedback loops. System dynamic models is suitable for decision makers regarding the fact that it helps them to understand complex behavior and dynamic trend of the system over time (Caponio, Massaro, Mossa, & Mummolo, 2015).

System dynamics has been used in different areas including environment, politics, healthcare and construction. SD modeling explores and demonstrates feedback processes and nonlinearities using stock and flow diagram (Sterman, 2000).

It assists to simulate mathematical solutions and simulation can help us to make difficult decisions in complex conditions plus in the case of various variables and different goals, simulation can concentrate on specific variables and outputs in order to find the source of problem behavior (Ghaffarzadegan, Lyneis, & Richardson, 2011).

A central idea in system dynamics originates in stocks and flows. Stocks and flows comprise conceptual and mathematical definitions. "Stocks are accumulations. They characterize the state of the system and generate the information upon which decisions and actions are based. Stocks give systems inertia and provide them with memory. Stock creates delays by accumulating the difference between the inflow to a process and its outflows. By decoupling rates of flow, stocks are the source of disequilibrium dynamics in systems"(Sterman, 2000).

Stock and flows have diagram notation in system dynamics:

- Stocks have been represented by rectangles.
- Inflows have been represented by "a pipe (arrow) pointing into (adding to) the stock".
- Outflows have been represented by "pipes pointing out of (subtracting from) the stock".
- Valves have been used to control the flows.
- Clouds shows the source and sinks for the flows. "a source indicates that the stock from which a flow origination outside the boundary of the model arises. Sinks shows the stocks into which flows leaving the model boundary drain. Sources and sinks are

assumed to have infinite capacity and can never constrain the flows they support”(Sterman, 2000).

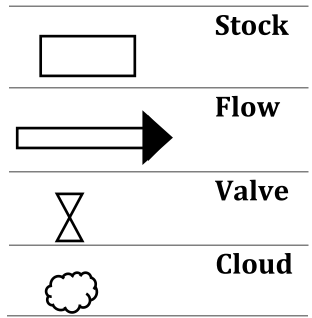
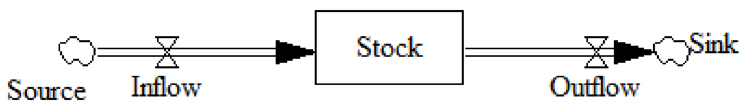


Table 2: System dynamics signs

Figure 6: stock-flow diagram (Sterman, 2000)



2.4.1 System dynamics for energy building

There are several studies which consider system dynamics for energy buildings and they are helpful to increase the understanding of system dynamics for energy buildings. Following tables show the five studies.

Methodology	• A system dynamics model has been developed in order to analyze and estimate the energy consumption, demand, production and carbon dioxide emission • Simulation of several production and demand scenarios have been done to estimate the energy demand for future (20 years) • Using a causal structure to illustrate the effect of subsidy[1] reform on energy consumption during the long term Three corrective policies have been considered including (a)production of blended cement, (b)using alternative fuel from waste materials for production, c)recovery of wasted heat for generating electricity
Results	Simulation results indicate that "complete removal of energy subsidy" plus applying corrective scenarios can lead to : • 29% reduction in natural gas • 21% reduction in electricity consumption 22% reduction in carbon dioxide emission
Future research	• To consider some socio-economical factors such as monetary policies To add several encouraging policies to produce blended cement and to generate electricity from waste materials plus recovery of wasted heat

Table 3 : Literature review of system dynamics for energy buildings :Case Study 1-Iranian cement industry (Ansari & Seifi, 2013)

Methodology	• Developing a system dynamics model (from 2005 to 2030) based computer simulation ("Beijing-STELLA Model") to estimate and predict the energy demand and carbon dioxide emissions
	• It consists of six sub-models including "socioeconomic, agricultural, industrial, service, residential, and transport".
	• Five scenarios have been considered named:
	  • "Reference scenario"
	  • "+25% population growth rate"
	  • "+25% GDP growth rate"
	  • "−25% GDP growth rate"
	"90% share of the service sector by 2030"

Results	• Beijing will face heavy energy consumption and carbon emission in future. • Largest sectors for energy consumption are industrial sector and transportation Sensitive analysis shows that the remarkable effects of the population and economic growth on changing energy consumption
Future research	• Not to describe internal dynamics in details Merely macroeconomic factors have been taken into account in sensitivity analysis.

Table 4: Literature review of system dynamics for energy buildings: Case Study 2-Beijing (capital city of China) (Feng, Chen, & Zhang, 2013)

Methodology	• Analyzing variables about energy consumption • Using system dynamics for simulation • Considering "what-if" scenarios • Analyzing the result of implementation of energy policies
Results	• 400,000 tons reduction in CO_2 • Increasing cost to 65,000,000€, however the raft of benefit-cost is in the best value The population is approximately constant
Future research	• To set further energy policies such as changing outdated devices with energy efficient appliances

Table 5: Literature review of system dynamics for energy buildings: Case Study 3:-Bari (a city in the Southeast of Italy) (Caponio et al., 2015)

Methodology	Presenting SD model to change household appliances with more efficient ones
Results	Analyzing several alternatives about technology in electricity consumption and the influence of pricing policies on different energy consumption
Future research	Applying same scenarios and alternatives in an office building

Table 6: Literature review of system dynamics for energy buildings: Case Study 4- A residential building (Dyner, Smith, & Peña, 1995)

Methodology	• Using key performance indicators (KPIs) to measure the performance of office building financially and functionally • Using system dynamics (SD) to quantify the interrelationship of key performance indicators (KPIs) in order to estimate future results Monitoring how the energy consumption have an effect on overall expenses
Results	Balancing the maintenance expenses and energy consumption since both of them have influences on the performance of the building
Future research	• To quantify variables • To consider other aspects such as Health, Safety and Environment • To use this research for other type of buildings

Table 7: Literature review of system dynamics for energy buildings: Case Study 5-Facility Maintenance company in Egypt, (Marzouk & Seleem, 2018)

2.5 Systemic risk analysis

The words systemic and systematic have different meanings. Systemic means something occurs throughout a whole system. This means something which works together or can influence the system as a whole (DifferenceBetween.net, 2018). Conversely, systematic means something conducts step-by-step or organized manner into systems (DifferenceBetween.net, 2018; grammarist.com, 2018). Therefore, the systemic risk analysis describes risk that happens or exists to the entire system and it can affect the whole system e.g. there are several factors in solar energy production and energy consumption which are associated with risk and uncertainty. Therefore, they have the capability to influence the entire system since both energy production and energy consumption create the systemic energy building profile to evaluate the possibility for achievement of the net zero energy building.

2.6 Solar system payback period

The solar system payback estimates the time will take to earn the solar energy investment. Thy typical solar payback time varies between 6 and 8 years (energysage.com, 2017). Payback time is dependent on several factors including PV efficiency, energy price, solar energy production, PV panel price and solar system efficiency. The following formula shows payback time formula (Smestad, 2008):

$$Payback\ time = \frac{Cost\ of\ solar\ system\ \$/m^2}{\eta * Yearly\ energy\ production\ kW * electricity\ price\ \$/kWh}$$

Where η is solar system efficiency.

Recent research has shown that solar system payback time is becoming short due to more efficient solar panels which can produce more solar energy production (cleantechnica.com, 2018).

2.7 Expected net present value

Risk analysis conducts to support decision-making in situations with high uncertainties such as investment and design. It is significant how to use analysis in decision making process. Cost-effectiveness and cost-benefit analysis are two examples on how analysis can be applied for decision making process. Cost-benefit analysis is a method to evaluate the costs and benefits of the project. Currency of the country is a common scale for measurement of benefits and costs in a project. In order to estimate the cost-benefit of a project, we need to transform all the attributes to monetary values to calculate the net present value [NPV] and "when the NPV are uncertain", it is normally represented by expected net present value E[NPV] (Aven, 2015). If the computed E[NPV] is greater than zero, the project is considered economically beneficial, otherwise, it is not recommended to implement the project. However, these types of analysis are based on expected value which doesn't see all aspects of risk and uncertainties. The output could be different from expected value, as extreme outputs can occur. Hence, it is needed to see beyond expected values which can be carried out by uncertainty assessment.

2.8 Risk management and uncertainty assessment

Risk management is about balancing between opportunities in one hand and avoiding accidents, and losses on the other hand. Risk includes two major dimensions: consequences and uncertainties. Uncertainties can be covered in the background knowledge (models, data, information and assumption). Risk analysis predicts consequences and assesses the uncertainties (Aven, 2015). Uncertainty assessment starts with determining the uncertain factors in the model and it carries out based on four steps which include (1) degree of uncertainty (2) sensitivity analysis and degree of sensitivity (3) degree of importance (4) Importance factor and the results show which uncertain factor need to be considered for more treatment, if time and budget allows (Selvik, Lohne, & Aven, 2012).

2.8.1 Degree of uncertainty

As mentioned, the first stage for uncertainty assessment is to determine uncertain factors which are given rank based on degree of uncertainty that is determined according to the Aven- Flage category (Flage & Aven, 2009). Table 8 describes different degree of uncertainty i.e. high, medium and low.

Degree of uncertainty	Explanation
High	There is a high uncertainty (weak knowledge) when one, more or all the following conditions have been met: - Models are not completely understood and it yields low accuracy predictions - The assumptions have been used in the model indicate clear simplifications and they are not reasonable - The data have been used in the model are unavailable and unreliable - There is not consensus between experts
Medium	cases between high and low uncertainty
Low	There is a low uncertainty (strong knowledge) when all the following conditions have been met: - Models are completely understood and it yields high accuracy for predictions - The assumptions have been used in the model are strong and they are reasonable - The data have been used in the model are available and reliable - There is strong consensus between experts

Table 8: Explanation of different degree of uncertainty (Flage & Aven, 2009)

2.8.2 Sensitivity analysis and degree of sensitivity

Sensitivity analysis is a technique to evaluate how potential changes on independent case base values impact dependent variables and conclusion (Saltelli, 2002). Sensitivity analysis is used as a basis for uncertainty assessment and it can determine the degree of sensitivity for the uncertain factors. Table 9 defines degree of uncertainty:

Degree of sensitivity	Explanation
High	Adequately small changing in base case values give acceptable output
Medium	Adequately large changing in base case values give acceptable output
Low	Unrealistically big changing in base case values give acceptable output

Table 9: Explanation of degree of sensitivity (Flage & Aven, 2009)

2.8.3 Degree of importance and importance score

A degree of importance is combination of degree of uncertainty and degree of sensitivity. For instance, if the degree of uncertainty is Low and the degree of sensitivity is High, the degree of importance is Medium. In addition, factors are given score based on degree of importance which called importance score. Therefore, uncertain factors have been ranked according to importance scores in order to distinguish the most important uncertain factors (Selvik et al., 2012).

3. The case study and data collection

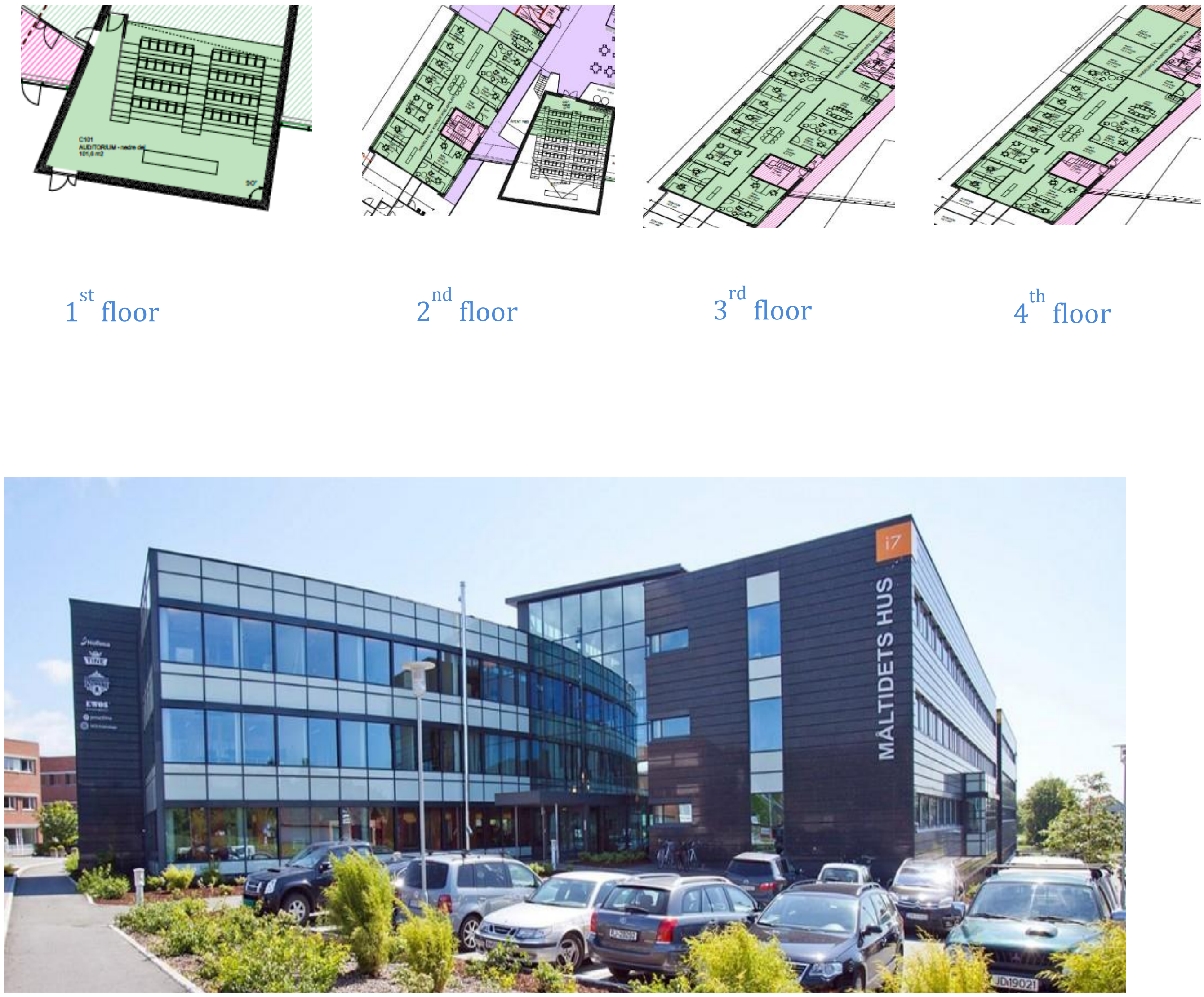
3.1. The case study: Måltidets hus

In this chapter, all related data related has been collected from Måltidets hus. Måltidets hus is located in Ipark, Stavanger, Norway. This building is an office building with working hours starting at approximately 8 AM and finishes around 17 during weekdays. The area of this system is 1150m^2 (50m length and 23m width) and the height of this building is 16m. This building consists of four floors and each floor has been divided into different sections (section A, section B and section C). Only the first floor includes section C and the other three floors contains section A and section B while each section has different parts. The canteen located in part B (B2.01) of the second floor, has had the highest of power consumptions according to the energy measurements done in March of 2018 compared to the other parts. In addition, there is a lab located in the part A (A1.02) of the first floor which uses the second highest amount of energy in comparison to the other parts. Furthermore, the heating system is excluded as it has been distributed in the building by another source. Table 10 and figure 7 give some information to us about NZEOB architecture:

NZEOB	Office building
Working hours	8-17
Area	1150m^2
Height	16m
Number of floors	4
1st floor	Section A,B,C
2nd,3rd & 4th floors	Section A,B
Canteen	Part B2.01
Lab	Part A1.02
offices	33
Meeting rooms	3
Amphitheater	2

Table 10: Måltidhuset (NZEOB) architecture data

Figure 7. Måltidets hus architecture maps and image (nofima.no, 2018)



4. Data analysis, modelling, and simulation

4.1. Systems analysis of the selected building and potential solar energy designs

As mentioned in delimitations, solar energy is the only green energy source in this study. HelioScope is a solar energy calculator which has been used to eastimate solar energy production. Therefore, different solar design factors have been considered which include different tilt angles i.e. 10°, 30°, 45°, 90°, azimuth i.e. 180°, different pitches from 0 to 50m, two different types of racking i.e. fixed tilt racking or East-West racking and we also consider total shad losses by entering an only condition of Bergen weather since it is the closest weather condition to Stavanger. The results include solar energy production rate, the number of PV panels, and the shading losses. Table 10 shows the alternatives:

Alternatives	Tilt	Azimuth	Racking	Pitch	Condition
Alternative 1	Tilt 10°	180°	Fixed or East-west racking	[0,50]	Bergen weather
Alternative 2	Tilt 30°	180°	Fixed or East-west racking	[0,43]	Bergen weather
Alternative 3	Tilt 45°	180°	Fixed or East-west racking	[0,44]	Bergen weather
Alternative 4	Tilt 89°	180°	Fixed or East-west racking	[0,46]	Bergen weather

Table 10: Different alternatives for solar energy production

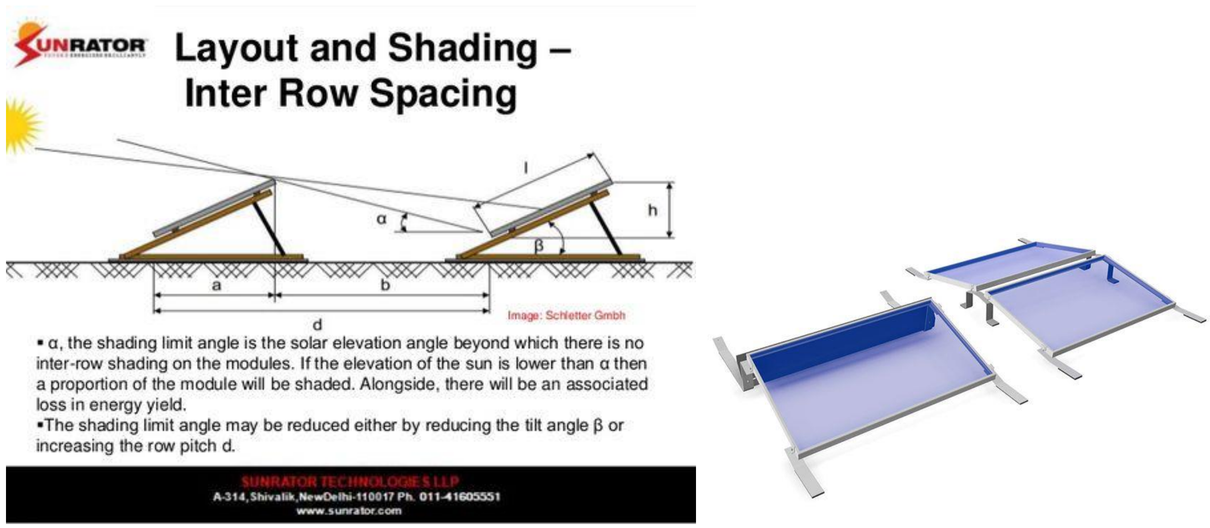
Table 11 schematizes the inputs, alternatives and outputs of HelioScope:

Inputs	Alternatives	Outputs
Location	Ipark, Stavanger	1. Number of required solar PV panels 2.Produced energy 3.Shade losses
Selected installation area	1150 m^2	
Tilt angle	10°, 30°, 45°,89°	
Pitch (horizontal spacing)	0, 0.1, 0.2-10m (16 options)	
Racking type	Fixed, East/west	
Azimuth	180°	
Weather site condition	Bergen weather	

Table 11: Inputs and outputs of HelioScope software

Figure 8 defines and visualizes shading losses which happens because of inter row spacing:

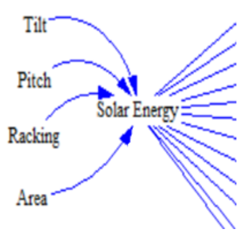
Figure 8. PV panels & Layout and shading inter row spacing (Sunrator)



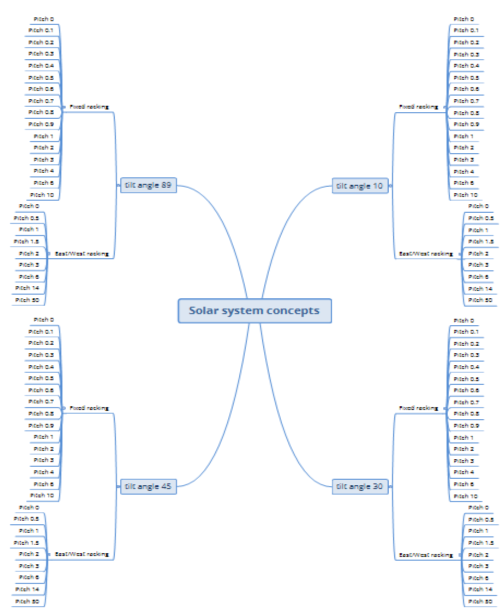
4.2 Determine optimal design concept for solar energy system

147 solar designs have been considered to find the optimal alternative. Figure 9 shows these 147 solar design:

Figure 9: Solar designs alternatives



Inputs	Alternatives
Location	Ipark
Selected installation area	1150
Tilt angle	10, 30, 45,89
Pitch (horizontal spacing)	0, 0.1, 0.2-10m (16 options)
Racking type	Fixed, East/west
Azimuth	
Weather site condition	Bergen weather



4.2.1 Evaluation of tilt 10°

Table 12 shows the different options for tilt 10° based on different pitch and two types of racking. There are several reasons to find the best option:

First, we cannot choose zero row spacing as we need to consider space for maintenance (option 1 & option 17 have not taken into consideration).

Second, the next options (option 2 & option 3) have been compared according to the amount of yearly energy production, number of PV panels/modules and total shade losses. In fixed tilt racking with 0.1m and 0.2m row spacing, the level of yearly produced energy is relatively close to each other (90.2MW and 86.1MW respectively) but the number of PV panels decreases from 418 to 374 while the total shade losses for option 3 is almost nothing.

Third, we compare option 3 with option 18 (East-West racking), there is no significant reduction in number of PV panels and the level of yearly produced energy is less than option 3. Thus, option 3 has been chosen as the best option in evaluation for tilt 10°.

Option	Tilt	Pitch (Row Spacing (m))	Fixed Tilt Racking	East-West Racking	PV panels	Yearly energy(MW)	Total shade losses
1	10	0			462	91.4	14.6%
2	10	0.1			418	90.2	6.8%
3	10	0.2			374	89.49	3.4%
4	10	0.3			352	79.6	2.3%
5	10	0.4			330	75.1	1.6%
6	10	0.5			308	70.4	1.2%
7	10	0.6			286	65.5	1.0%
8	10	0.7			264	60.6	0.9%
9	10	0.8			242	55.6	0.8%
10	10	0.9			242	55.6	0.7%
11	10	1			220	50.6	0.6%
12	10	2			154	35.5	0.3%
13	10	3			110	25.4	0.2%
14	10	4			88	20.3	0.2%
15	10	6			44	10.2	0.1%
16	10	10			22	5.08	0.0%
17	10	0			460	99.2	0.0%

18	10	0.5			360	77.6	0.0%
19	10	1			300	64.7	0.0%
20	10	1.5			260	56.1	0.0%
21	10	2			240	51.7	0.0%
22	10	3			180	38.8	0.0%
23	10	6			120	25.9	0.0%
24	10	14			60	12.9	0.0%
25	10	50			20	4.31	0.0%

Table 12: Inputs and outputs for tilt 10°

4.2.2 Evaluation of Tilt 30°

Table 13 shows the different options for tilt 30° based on different pitch and two types of racking. There are several reasons to find the best option:

First, we cannot choose zero row spacing as we need to consider space for maintenance (option 1 & option 18 have not taken into consideration).

Second, the next options (option 2 & option 3) have been compared according to the amount of total yearly energy, number of PV panels and total shade losses. In fixed tilt racking with 0.1m and 0.2m row spacing, the level of yearly produced energy is really close together (89.4MW & 86.5MW). The difference between total shade losses for both option is not considerable (27.8% and 23.3% respectively) but there is a notable difference between the number of PV panels (46 PV panels). Therefore, option 3 outweighs option 2.

Third, option 3 and option 19 (East-West racking) have taken into consideration. Although there is no remarkable change in the amount of yearly energy (86.5MW & 81.6MW respectively), the number of PV panels and total shade losses have changed significantly (number of PV panels from 460 to 400 and total shade losses from 23.3% to 0.0%). Thus, option 19 has been selected as the best one.

Option	Tilt	Pitch (Row Spacing (m))	Fixed Tilt Racking	East-West Racking	PV panels	Yearly energy(MW)	Total shade losses
1	30	0			552	89.6	33.5%
2	30	0.1			506	89.4	27.8%
3	30	0.2			460	86.5	23.3%
4	30	0.3			414	83.8	17.4%

5	30	0.4			391	83.2	13.1%
6	30	0.5			345	75.4	10.7%
7	30	0.6			322	71.7	9.1%
8	30	0.7			299	67.4	8.0%
9	30	0.8			299	68	7.2%
10	30	0.9			276	63.3	6.5%
11	30	1			253	58.4	5.9%
12	30	1.5			207	48.8	3.9%
13	30	3			138	33.1	2.2%
14	30	4			115	27.7	1.8%
15	30	6			69	16.7	1.3%
16	30	10			46	11.2	0.8%
17	30	20			23	5.63	0.0%
18	30	0			520	106.1	0.0%
19	30	0.5			400	81.6	0.0%
20	30	1			340	69.4	0.0%
21	30	1.5			280	57.1	0.0%
22	30	2			240	49	0.0%
23	30	3			200	40.8	0.0%
24	30	4			160	32.7	0.0%
25	30	6			120	24.5	0.0%
26	30	8			100	20.4	0.0%
27	30	12			80	16.3	0.0%
28	30	20			60	12.2	0.0%
29	30	22			40	8.16	0.0%
30	30	43			20	4.08	0.0%

Table 13: Inputs and outputs for tilt 30°

4.2.3 Evaluation of Tilt 45°

Table 14 shows different options for tilt 45° based on different pitch and different racking. There are several reasons to find the best option:

First, we cannot choose zero row spacing as we need to consider space for maintenance (option 1 & option 20 have not taken into consideration).

Second,, the maximum yearly energy after option 20 (is not acceptable due to 0 row spacing) is produced by option 21 (East-west racking, 91.5MW) with no total shade losses and reasonable number of solar panels (480 PV panels). There is no need to do more comparison with other options as in fixed tilt racking, there are a large amount of total shade losses in most options with lower amount of yearly energy and further number of PV panels. Thus, option 21 is the best option.

Option	Tilt	Pitch (Row Spacing)	Pitch (Row Spacing (m))	East-West Racking	PV panels	Yearly energy(MW)	Total shade losses
1	45	0			690	81.8	50.2%
2	45	0.1			598	82.2	42.5%
3	45	0.2			529	81.4	36.0%
4	45	0.3			483	79.4	31.7%
5	45	0.4			437	77.2	26.8%
6	45	0.5			391	73.7	21.9%
7	45	0.6			368	72.2	18.6%
8	45	0.7			345	69.5	16.5%
9	45	0.8			322	66.3	14.8%
10	45	0.9			299	62.6	13.4%
11	45	1			276	58.6	12.2%
12	45	1.5			230	50.8	8.8%
13	45	2.5			161	36.8	5.6%
14	45	3.5			115	26.7	4.2%
15	45	4.5			92	21.5	3.5%
16	45	5.5			92	21.6	3.2%
17	45	6.5			69	16.3	2.6%
18	45	9.5			46	10.9	1.8%
19	45	20			23	5.57	0.00%
20	45	0			640	122	0.0%
21	45	0.5			480	91.5	0.0%
22	45	1			380	72.4	0.0%
23	45	1.5			320	61	0.0%
24	45	2			280	53.4	0.0%
25	45	3			220	41.9	0.0%
26	45	3.5			200	38.1	0.0%

27	45	4.5			160	30.5	0.0%
28	45	6.5			120	22.9	0.0%
29	45	9.5			100	19.1	0.0%
30	45	12.5			80	15.2	0.0%
31	45	13.5			60	11.4	0.0%
32	45	21			40	7.62	0.0%
33	45	44			20	3.81	0.0%

Table 14: Inputs and outputs for tilt 45°

4.2.4 Evaluation of Tilt 89°

Table 15 shows different options for tilt 89° according to different pitch, different racking. There are several reasons to find the best option:

First, we cannot choose zero row spacing as we need to consider space for maintenance (option 1 & option 20 have not taken into consideration).

Second, options 2, 3, 4, 5, 6, 7, 8, 9, 10, 21, 22, 23, 24 have not been selected due to the existing large number of PV panels. Amongst all options, option 25 has the best yearly solar energy production with no total shade losses and reasonable number of PV panels.

Option	Tilt	Pitch (Row Spacing (m))	Fixed Tilt Racking	East-West Racking	PV panels	Yearly energy	Total shade losses
1	89	0			28,014	16.6 MW	98.5%
2	89	0.1			4,140	31.0 MW	93.2%
3	89	0.2			2,254	51.9 MW	83.8%
4	89	0.3			1,541	56.1 MW	76.1%
5	89	0.4			1,173	56.8 MW	69.3%
6	89	0.5			943	57.8 MW	62.1%
7	89	0.6			805	57.6 MW	56.4%
8	89	0.7			690	56.4 MW	50.7%
9	89	0.8			598	54.2 MW	45.7%
10	89	0.9			529	51.4 MW	42.2%
11	89	1			483	49.2 MW	39.5%
12	89	2			253	32.5 MW	25%
13	89	3			161	22.6 MW	18.7%
14	89	5			115	17.1 MW	14.1%
15	89	7			92	14.1 MW	11.9%

16	89	10			69	10.8 MW	9.8%
17	89	11			46	7.41 MW	7.3%
18	89	20			46	7.45 MW	6.7%
19	89	22			23	4 MW	0.0%
20	89	0			26,540	3.48 GW	0.0%
21	89	0.1			6,840	897.4 MW	0.0%
22	89	0.5			1,720	225.7 MW	0.0%
23	89	1			900	118.1 MW	0.0%
24	89	1.5			600	78.7 MW	0.0%
25	89	2			460	60.4 MW	0.0%
26	89	3			320	42.0 MW	0.0%
27	89	4			240	31.5 MW	0.0%
28	89	6			160	21.0 MW	0.0%
29	89	8			120	15.7 MW	0.0%
30	89	10			100	13.1 MW	0.0%
31	89	12			80	10.5 MW	0.0%
32	89	16			60	7.87 MW	0.0%
33	89	23			40	5.25 MW	0.0%
34	89	46			20	2.62 MW	0.0%

Table 15: Inputs and outputs for tilt 89°

4.2.5 Optimal solar design

Four selected options have been given rank to find the optimal alternative based on following formula:

$$Rate = Number\ of\ modules/Total\ Energy$$

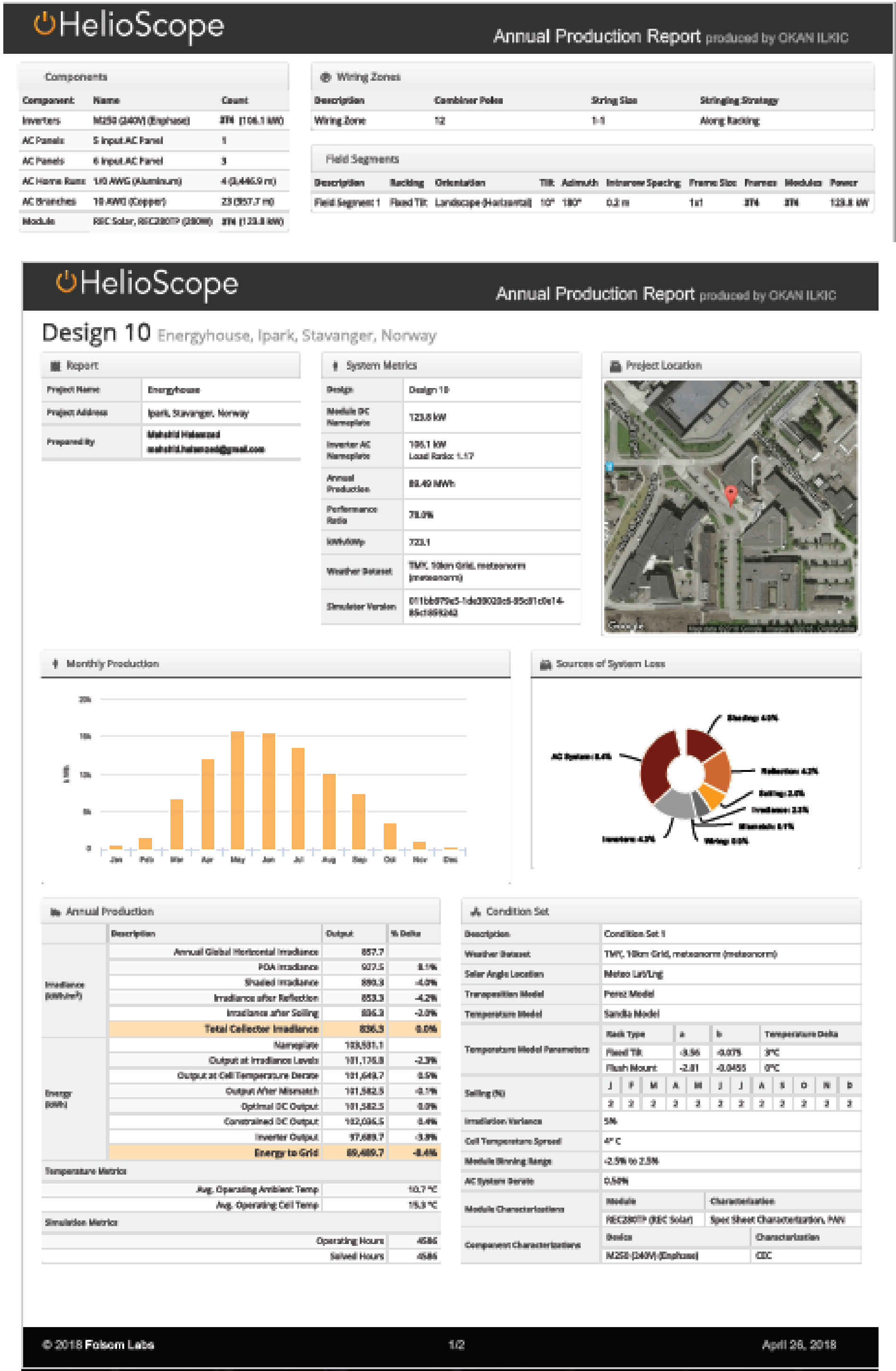
It means dividing number of PV panels/modules into energy, and the minimum rate shows the optimal option or dividing amount of energy into number of PV panels and the maximum rate is the optimal option. Table 16 shows the result:

Alternative	Tilt	Pitch (m)	Racking	Total Shade losses	PV panels	Yearly energy (MW)	Energy/Module	Score
A	10°	0.2	Fixed tilt	3.4%	374	89.49	0.23	1
B	30°	0.5	East-West	0.0%	400	81.6	0.204	2
C	45°	0.5	East-West	0.0%	480	91.5	0.191	3
D	89°	2	East-West	0.0%	460	60.4	0.131	4

Table 16: Selecting the best alternative

The maximum energy level is belonging to an alternative C, however, the minimum number of module belongs to an alternative A, and the highest rank has been given to an alternative A according to rate formula. Therefore, alternative A. is the optimal design. Figure 10 shows HelioScope outputs for selected alternative.

Figure 10: HelioScope outputs



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Components

Component	Name	Count
Inverters	M250 (240V) (Enphase)	374 (106.1 kW)
AC Panels	5 input AC Panel	1
AC Panels	6 input AC Panel	3
AC Home Runs	1/0 AWG (Aluminum)	4 (3,446.9 m)
AC Branches	10 AWG (Copper)	23 (957.7 m)
Module	REC Solar, REC280TP (280W)	374 (123.8 kW)

Wiring Zones

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

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Landscape (Horizontal)	10°	180°	0.2 m	1x1	374	374	123.8 kW

HelioScope — Annual Production Report produced by OKAN ILKIC

Design 10 Energyhouse, Ipark, Stavanger, Norway

Report

Project Name	Energyhouse
Project Address	Ipark, Stavanger, Norway
Prepared By	Mahshid Hatamzad mahshid.hatamzad@gmail.com

System Metrics

Design	Design 10
Module DC Nameplate	123.8 kW
Inverter AC Nameplate	106.1 kW Load Ratio: 1.17
Annual Production	89.49 MWh
Performance Ratio	78.0%
kWh/kWp	723.1
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Simulator Version	011bb079e5-1de39020c6-85c81c0e14-85c1859242

Project Location

Monthly Production

Sources of System Loss

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	857.7	
	POA Irradiance	927.5	8.1%
	Shaded Irradiance	890.3	-4.0%
	Irradiance after Reflection	853.3	-4.2%
	Irradiance after Soiling	836.3	-2.0%
	Total Collector Irradiance	**836.3**	**0.0%**
Energy (kWh)	Nameplate	103,531.1	
	Output at Irradiance Levels	101,176.8	-2.3%
	Output at Cell Temperature Derate	101,649.7	0.5%
	Output After Mismatch	101,582.5	-0.1%
	Optimal DC Output	101,582.5	0.0%
	Constrained DC Output	102,036.5	0.4%
	Inverter Output	97,689.7	-3.9%
	Energy to Grid	**89,489.7**	**-8.4%**
Temperature Metrics			
	Avg. Operating Ambient Temp		10.7 °C
	Avg. Operating Cell Temp		15.3 °C
Simulation Metrics			
		Operating Hours	4586
		Solved Hours	4586

Condition Set

Description	Condition Set 1
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Solar Angle Location	Meteo Lat/Lng
Transposition Model	Perez Model
Temperature Model	Sandia Model

Temperature Model Parameters

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

Soiling (%)

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

Irradiation Variance	5%
Cell Temperature Spread	4° C
Module Binning Range	-2.5% to 2.5%
AC System Derate	0.50%

Module Characterizations

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

Component Characterizations

Device	Characterization
M250 (240V) (Enphase)	CEC

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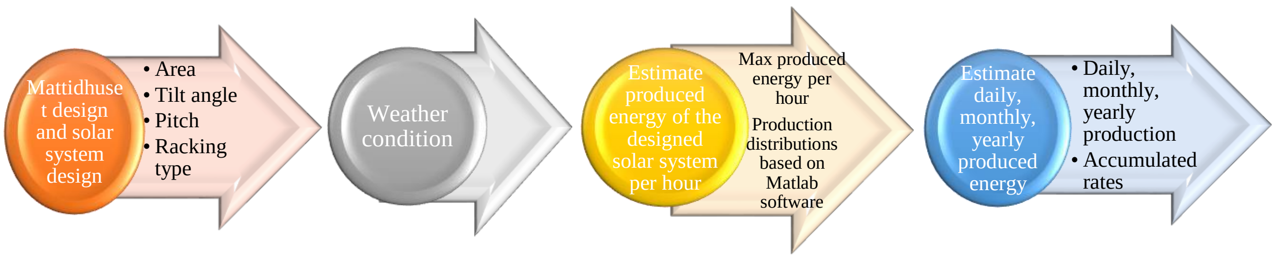
4.3 Modelling solar production using Vensim

Optimal solar energy design includes following factors:

Tilt: 10, Pitch :0.2 (m), Racking: Fixed

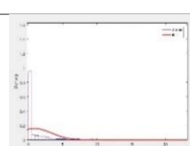
In addition, the outputs are number of PV panels/modules, total shade losses and energy production rate in different time units. HelioScope outputs use as inputs for Vensim software to simulate the solar energy production per hour for the entire year based on monthly solar energy production distributions which have been calculated by Matlab software. Simulation model of solar energy production increases our understanding for the dynamic behavior of solar energy production within a day and over the weeks. Figure 11 shows the summary of each step to simulate solar energy production:

Figure 11: Steps for simulation of solar energy production



4.3.1 The historical solar data analysis

Solar energy production has been modeled based on monthly distributions according which have been computed by Matlab software. Table 17 shows the Matlab results. Solar energy production distributions are selected as the best fit for solar energy production data. It is clear that the distributions cannot cover the first intervals which are mostly zero energy production and they do not have a considerable impact on the accumulated/cumulative monthly solar energy production rate. April, May and June have the best fit distributions due to less noise in the solar energy production data. Therefore, we expect to have more accurate estimation over these months than other months.

Months	Graph	Distribution characteristics
January		Distribution: Normal Domain: -Inf < y < Inf Mean: 0.878989 Variance: 6.26946

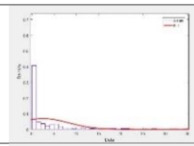
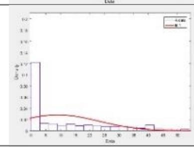
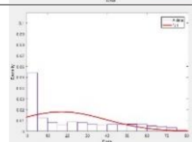
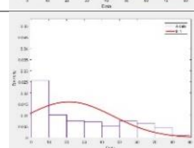
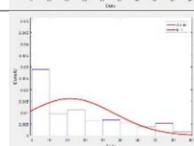
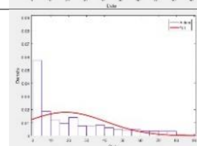
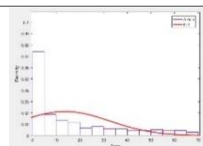
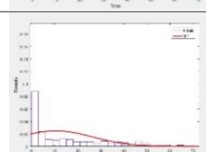
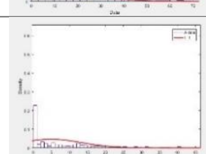
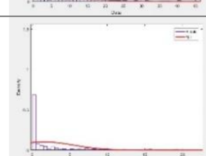
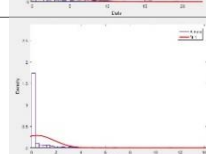
February		Distribution: Normal Domain: -Inf < y < Inf Mean: 2.52429 Variance: 34.0472
March		Distribution: Normal Domain: -Inf < y < Inf Mean: 9.14257 Variance: 195.198
April		Distribution: Normal Domain: -Inf < y < Inf Mean: 17.0344 Variance: 496
May		Distribution: Normal Domain: -Inf < y < In f Mean: 21.3279 Variance: 620.914
June		Distribution: Normal Domain: -Inf < y < Inf Mean: 21.7557 Variance: 610.031
July		Distribution: Normal Domain: -Inf < y < Inf Mean: 18.4106 Variance: 497.269
August		Distribution: Normal Domain: -Inf < y < Inf Mean: 13.7325 Variance: 354.726
September		Distribution: Normal Domain: -Inf < y < Inf Mean: 10.474 Variance: 256.997
October		Distribution: Normal Domain: -Inf < y < Inf Mean: 4.84464 Variance: 74.7035
November		Distribution: Normal Domain: -Inf < y < Inf Mean: 1.58124 Variance: 15.6806
December		Distribution: Normal Domain: -Inf < y < Inf Mean: 0.432319 Variance: 1.90305

Table 17: Production profile in office building (Monthly distributions of energy production)

4.3.2 Estimate/simulate the daily, weekly and yearly energy production of the optimal solar design

Figure 12 illustrates all the steps that have been taken to simulate solar energy production. First, HelioScope outputs have been used as inputs for Vensim software. Second, the monthly solar energy production distributions and time limitation have been applied to simulate the hourly solar energy production for the entire year. Third, monthly solar energy production has been simulated based on hourly rate. Fourth, the stocks in the model shows accumulated energy production in each month and accumulated total energy production in the year.

Figure 12. Simulation of solar energy production in Vensim software

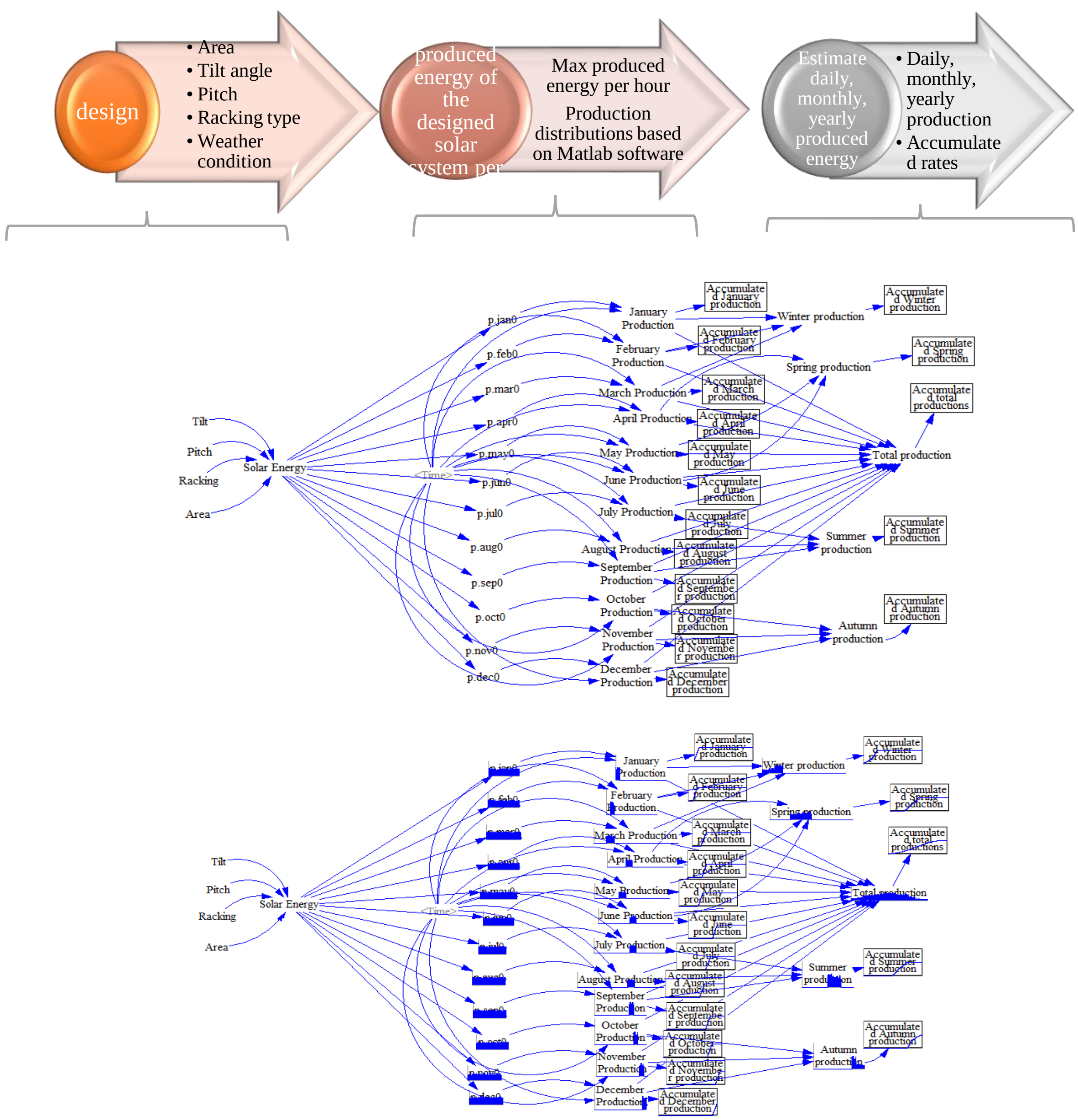


Table 18 shows the highest and lowest solar energy production rate per hour and monthly time span. It is obvious that there is an increasing trend in level of hourly energy production rate from January to May and there is a reduction in hourly energy production rate from June to December. The maximum solar energy production rate is 87 KWh in May and the minimum solar energy production rate is 14 KWh in December.

Month	Minimum solar energy production (KWh)	Maximum solar energy production (KWh)	Time (Hour)
January	0	23	Time<=744hours
February	0	35	Time>744:AND:Time<=1344
March	0	54	Time>1344:AND:Time<=2160
April	0	79	Time>2160:AND:Time<=2880
May	0	87	Time>2880:AND:Time<=3624
June	0	84	Time>3624:AND:Time<=4344
July	0	85	Time>4344:AND:Time<=5088
August	0	70	Time>5088:AND:Time<=5832
September	0	69	Time>5832:AND:Time<=6552
October	0	46	Time>6552:AND:Time<=7296
November	0	23	Time>7296:AND:Time<=8016
December	0	14	Time>8016:AND:Time<=8760

Table 18: Max & min solar energy production rate per hour and monthly time span

4.3.2.1 Comparison solar energy production at daily base

Table 19 illustrates the dynamic behaviour of solar energy production rate in first day of each month. Vertical axis shows solar energy production rate in KW and horizontal axis demonstrates time in hour. It is visible in the charts, there is no solar energy production over the night. Additionally, the solar energy production rate is increased from January to May and it is decreased from June to December. The highest solar energy production rate is in May and the lowest level is in December.

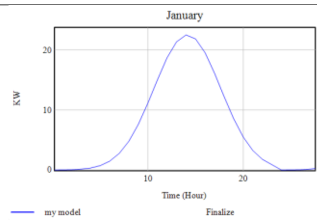
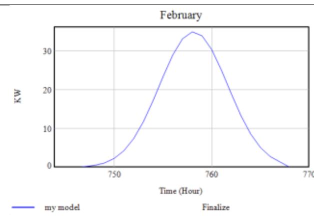
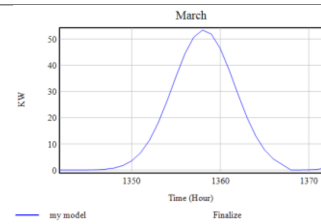
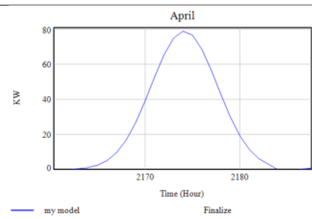
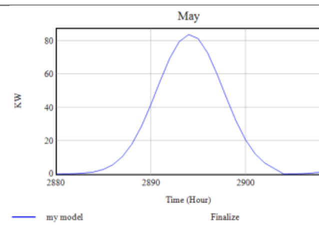
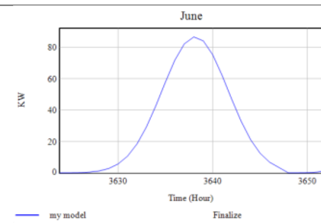
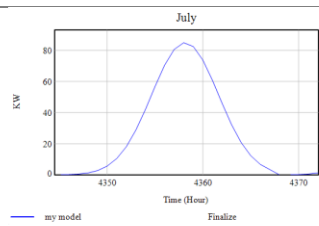
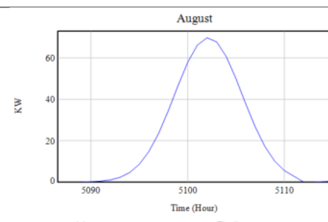
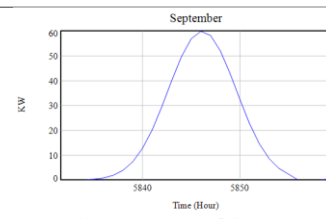
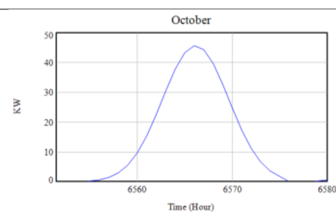
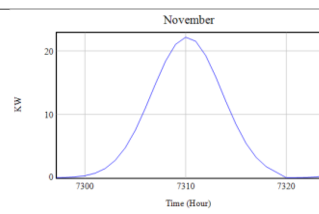
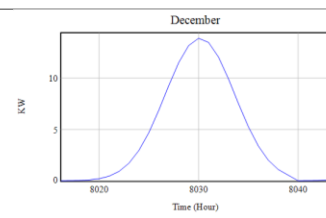
Season	Daily grah		
Winter			
Spring			
Summer			
Autumn			

Table 19: Daily solar energy production graphs in different months

4.3.2.2 Comparison solar energy production at weekly base

Table 20 represents the dynamic behaviour of solar energy production rate in first week of every month. Vertical axis shows solar energy production rate in KW and horizontal axis shows the time in hour. The graphs indicate the fluctuations of solar energy production in seven days i.e. there is no energy production at night, however, production will reach to its maximum value in the middle of the day and after that decreases to reach zero production.

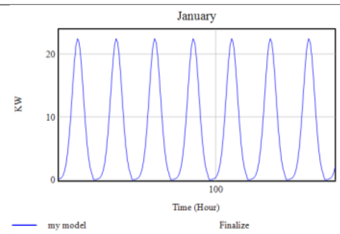
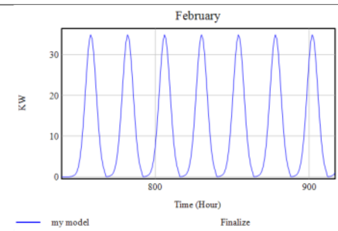
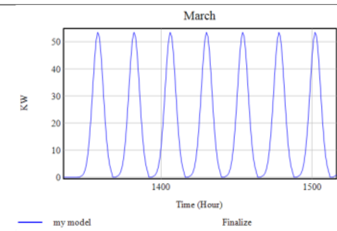
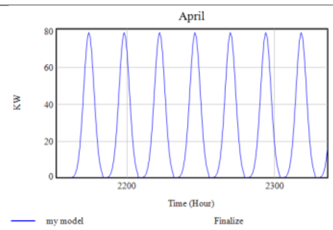
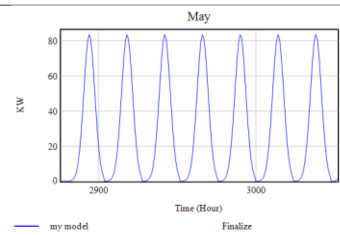
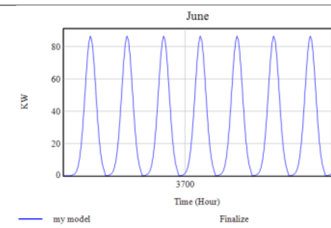
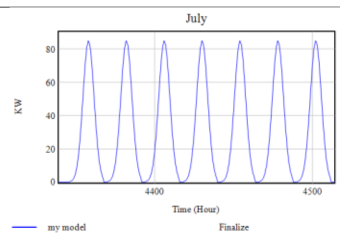
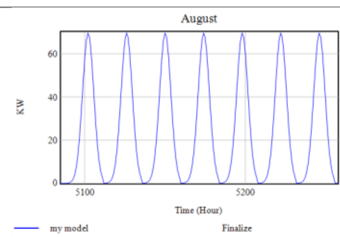
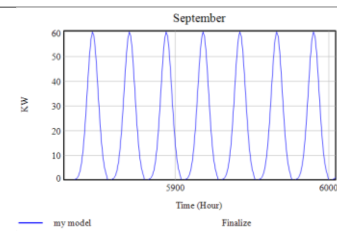
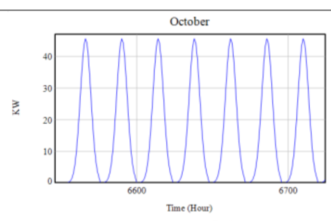
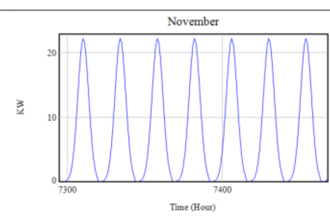
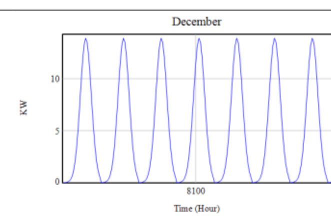
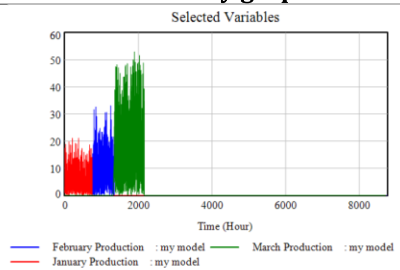
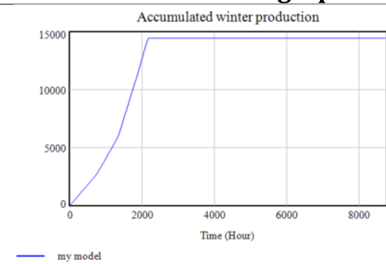
Season	Weekly graph		
Winter			
Spring			
Summer			
Autumn			

Table 20: Weekly solar energy production graphs in different months

4.3.2.3 Hourly solar energy production graphs and seasonally accumulated charts

Table 21 shows hourly solar energy production graphs and accumulated charts for in each season and total yearly solar energy production per hour. Vertical axis demonstrates solar energy production rate in KW and horizontal axis shows the time in hour. Each color visualizes hourly solar energy production for each month.

<table>
<tr><th>Season</th><th>Hourly graphs</th><th>Accumulated graph</th></tr>
<tr><td>Winter</td><td>
</td><td>
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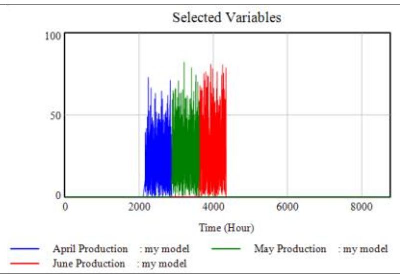
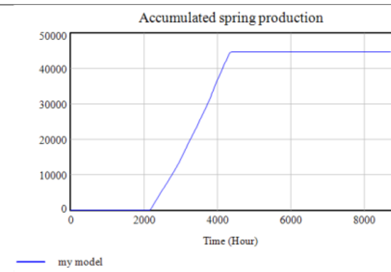
<tr><td>Spring</td><td>
</td><td>
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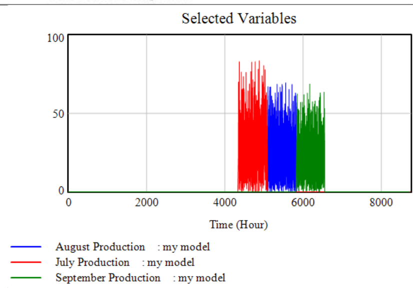
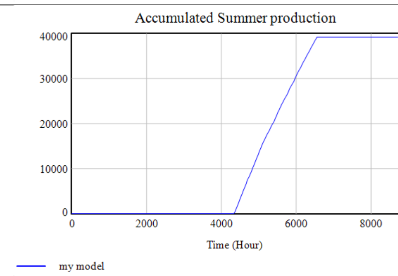
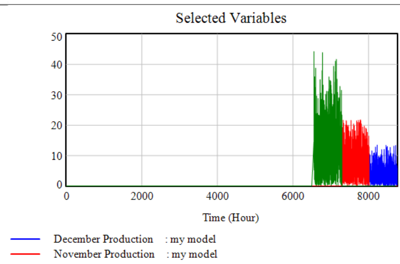
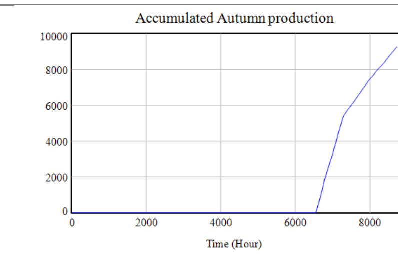
<tr><td>Summer</td><td>
</td><td>
</td></tr>
<tr><td>Autumn</td><td>
</td><td>
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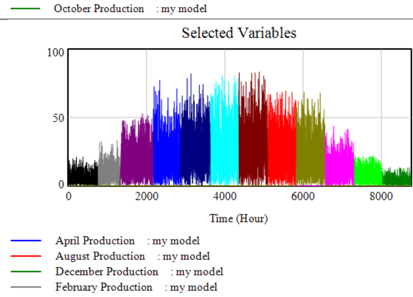
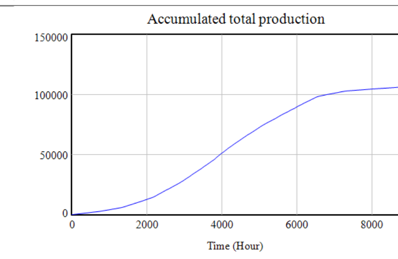
<tr><td>Total</td><td>
</td><td>
</td></tr>
</table>

Table 21: Hourly solar energy production graphs & seasonally accumulated energy production graphs

4.3.3 Comparison between the estimated solar energy production provided by Vensim and the real/estimated production provided by HelioScope

Figure 13, table 22, and figure 14 shows the monthly Comparison between the estimated solar energy production provided by Vensim and the real/estimated production provided by HelioScope. It is clear in the table 15, there is no significant gap between HelioScope results and Vensim estimation. However, the illustrated gaps are due to some noise in solar energy production data. The accuracy of solar energy production model is about 83% which is a good prediction result.

	January	February	March	April	May	June	July	August	September	October	November	December
HelioScope (KW)	654	1696.3	6802	12264	15888	15664	13697	10217	7541.2	3604.4	1138.5	321.6
Vensim (KW)	2296.5	3126	9052	12534	16216	15990	16291	12794	10161	4824	2376	1550

Table 22: Comparing HelioScope results & Vensim estimation for solar energy production

Figure 13. HelioScope results vs. Vensim estimation for solar energy production

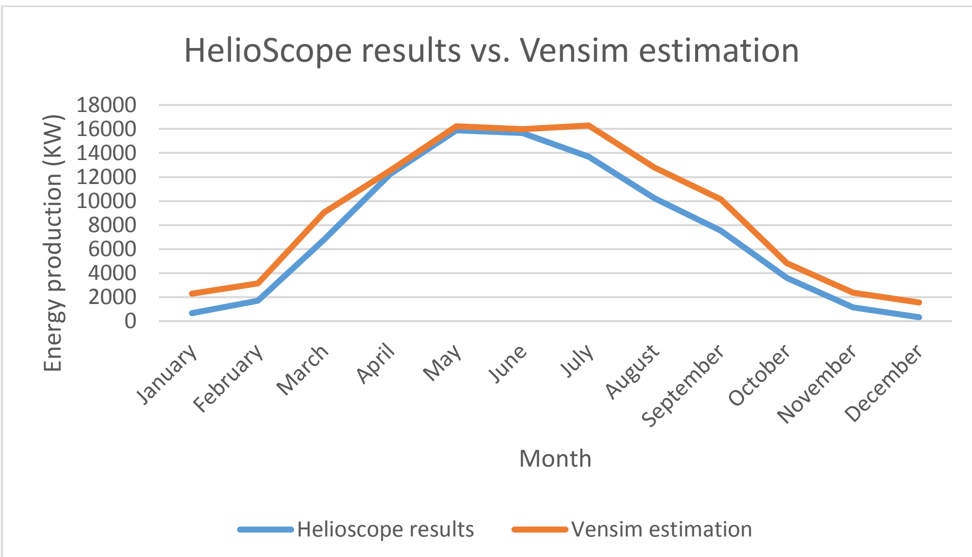
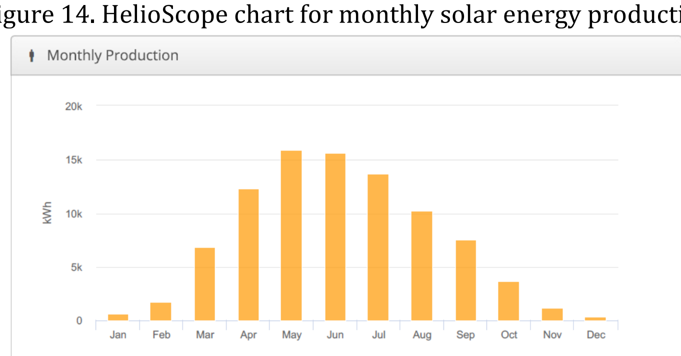


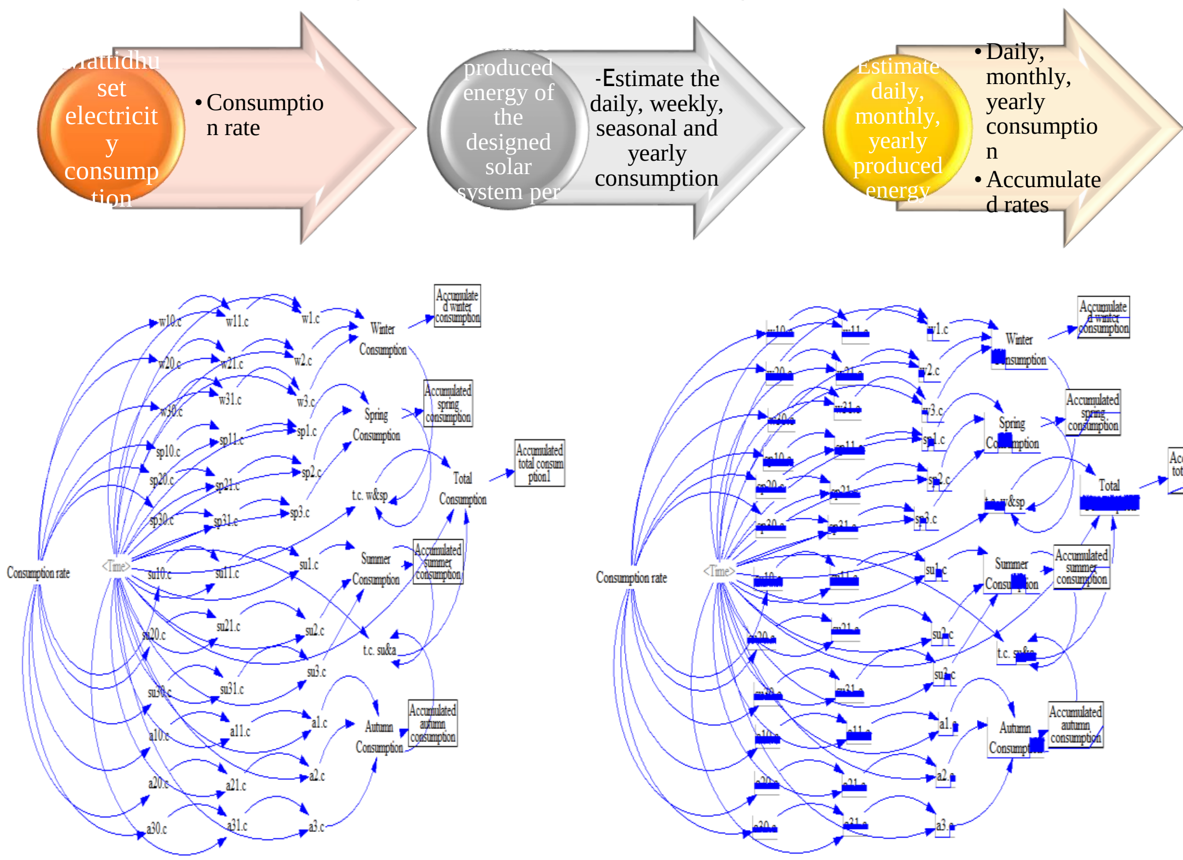
Figure 14. HelioScope chart for monthly solar energy production



4.4 Modelling Maltidhuset's consumption using Vensim

The hourly energy consumption has been simulated based on a few stages in Vensim. First, energy consumption distributions are calculated by Matlab software. Second, energy consumption rate is calculated based on electrical equipment in the office building. In addition, if any changes are adopted in the building such as reducing the number of offices, the change rate can enter to the simulation model to estimate the altered output. Third, the energy consumption distributions have been applied to the model fourth, imposing a few conditions which include: (1) Weekdays, active hours: it needs to happen after every 14 passive hours with the duration of 10 hours. (2) Weekdays, passive hours: it should happen after 10 active hours with the duration of 14 hours. (3) Weekends: it should happen every 120 hours with the duration of 48 hours. (4) Holidays which include Easter holiday, Summer holiday and Christmas holiday. Fourth, adopting the time span for each season. Figure 15 shows the process for simulation model of energy consumption.

Figure 15. Simulation model of energy consumption



4.4.1 the historical energy consumption data

Hourly energy consumption data is divided into three categories in each season since level of energy demand is similar in each category. Following are the categories:

1. **Weekdays, active hours**: it describes Monday to Friday between 8:00 to 17:00 when energy demand increases since staffs come to office for work.
2. **Weekdays, passive hours**: it describes Monday to Friday between 18:00 to 6:00 when the energy demand reduces due to the turning off the equipment and no staff works over these hours.
3. **Weekends and holidays**: it describes Saturdays, Sundays and holidays in 24 hours since the energy consumption rate is similar over the weekends and holidays.

Seasonally energy consumption distributions in each category have been computed by Matlab software. Energy consumption data excludes from heating system and it includes lighting, equipment e.g. computers and ventilation. Following tables show energy consumption distributions:

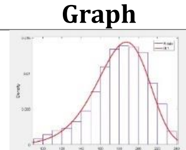
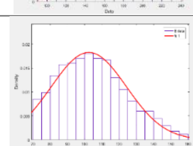
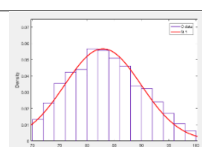
Winter	Graph	Distribution characteristics
Winter, weekdays, active hours		Distribution: Normal Domain: -Inf < y < Inf Mean: 179.17 Variance: 815.121
Winter, weekdays, passive hours		Distribution: Normal Domain: -Inf < y < Inf Mean: 102.441 Variance: 477.747
Winter, weekends		Distribution: Normal Domain: -Inf < y < Inf Mean: 82.928 Variance: 49.5435

Table 23: Consumption profile in office building (Winter distributions of energy consumption)

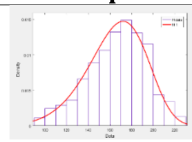
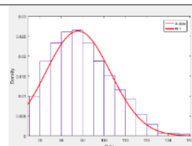
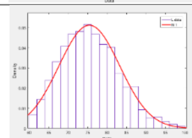
Spring	Graph	Distribution characteristics
Spring, weekdays, active hours		Distribution: Weibull Domain: 0 < y < Inf Mean: 164.54 Variance: 770.804 A 175.938, B 6.96824
Spring, weekdays, passive hours		Distribution: Normal Domain: -Inf < y < Inf Mean: 87.8122 Variance: 229.809
Spring, weekends & Easter holidays		Distribution: Normal Domain: -Inf < y < Inf Mean: 75.4382 Variance: 60.848

Table 24: Consumption profile in office building (Spring distributions of energy consumption)

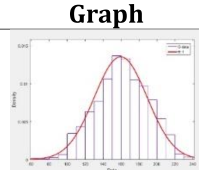
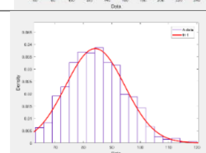
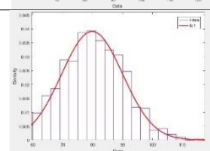
Summer	Graph	Distribution characteristics
Summer, weekdays, active hours		Distribution: Normal Domain: -Inf < y < Inf Mean: 159.585 Variance: 867.701
Summer, weekdays, passive hours		Distribution: Normal Domain: -Inf < y < Inf Mean: 84.111 Variance: 108.748
Summer, weekends & summer holiday		Distribution: Normal Domain: -Inf < y < Inf Mean: 79.8056 Variance: 104.5

Table 25: Consumption profile in office building (Summer distributions of energy consumption)

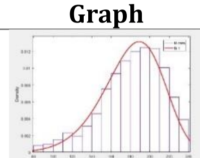
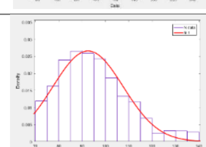
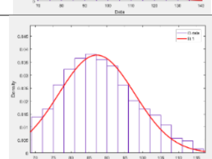
Autumn	Graph	Distribution characteristics
Autumn, weekdays, active hours		Distribution: Weibull Domain: 0 < y < Inf Mean: 180.699 Variance: 962.702 A 193.407, B 6.83821
Autumn, weekdays, passive hours		Distribution: Normal Domain: -Inf < y < Inf Mean: 92.5319 Variance: 226.48
Autumn, weekends & Christmas holiday		Distribution: Normal Domain: -Inf < y < Inf Mean: 87.142 Variance: 112.039

Table 26: Consumption profile in office building (Autumn distributions of energy consumption)

4.4.2 Estimate/simulate the daily, weekly and yearly energy consumption of case building

Table 27 shows the highest and lowest energy consumption in each month. It is clear the lowest energy demand is 60 KWh in April and the highest energy consumption is 245 KWh in December.

Months	Minimum energy consumption (KWh)	Maximum energy consumption (KWh)	Time
January	70	235	Time<=744hours
February	70	235	Time>744:AND:Time<=1344
March	70	235	Time>1344:AND:Time<=2160
April	60	225	Time>2160:AND:Time<=2880
May	65	220	Time>2880:AND:Time<=3624
June	65	225	Time>3624:AND:Time<=4344
July	65	230	Time>4344:AND:Time<=5088
August	65	235	Time>5088:AND:Time<=5832
September	65	230	Time>5832:AND:Time<=6552
October	70	235	Time>6552:AND:Time<=7296
November	70	240	Time>7296:AND:Time<=8016
December	75	245	Time>8016:AND:Time<=8760

Table 27: Minimum & maximum monthly energy consumption

4.4.2.1 Comparison energy consumption at daily base

Table 28 shows energy consumption in the first day of each month (24 hours). Vertical axis is energy consumption in KW and horizontal axis is time in hour. It is clear in the charts that there is no considerable gap between minimum energy consumption in different month and there is no significant difference between maximum energy consumption in every month.

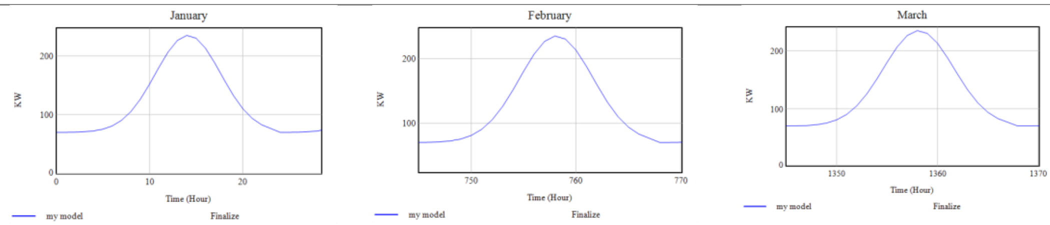
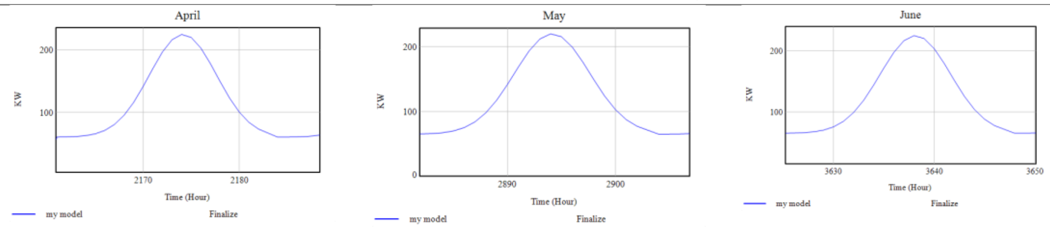
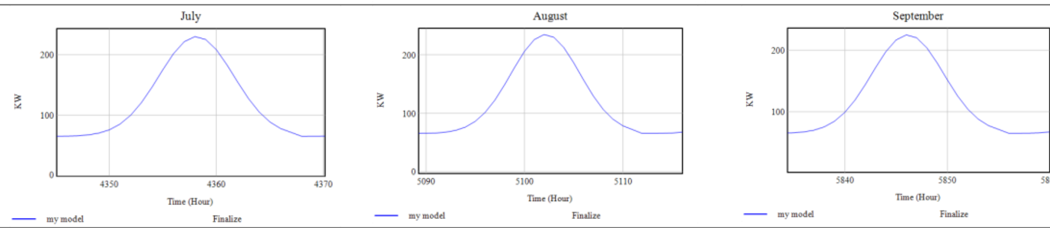
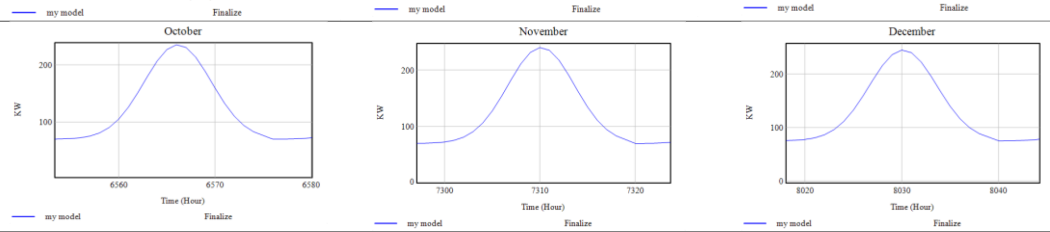
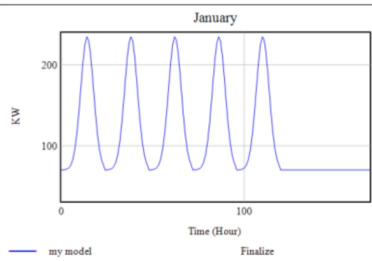
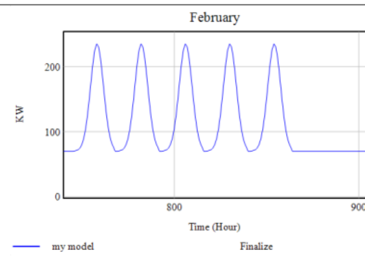
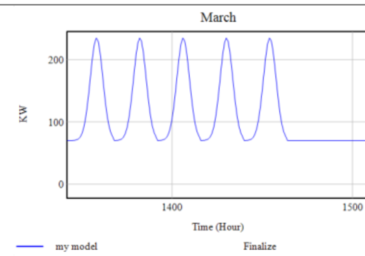
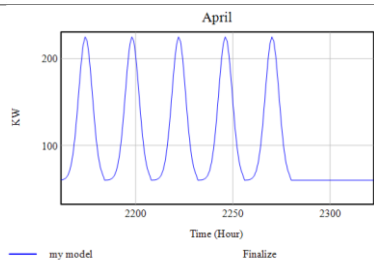
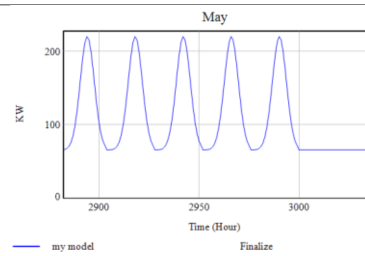
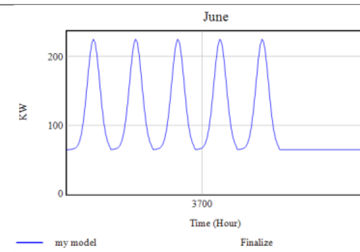
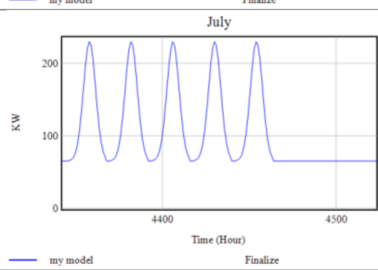
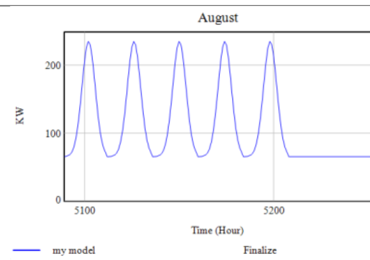
Season	Daily graph
Winter	
Spring	
Summer	
Autumn	

Table 28: daily energy consumption

4.4.2.2 Comparison energy consumption at weekly base

Table 29 represents first week of energy consumption in each month. Vertical axis is energy consumption in KW and horizontal axis is time in hour. It is obvious that that there are five days fluctuations (Monday to Friday i.e. 120 hours) and it reaches its lowest level over the weekends (Saturday and Sunday i.e. 48 hours).

<table>
<tr><th>Season</th><th colspan="3">Weekly graph</th></tr>
<tr><td>Winter</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
<tr><td>Spring</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
<tr><td>Summer</td>
<td>
</td>
<td>
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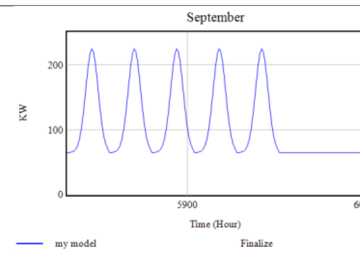
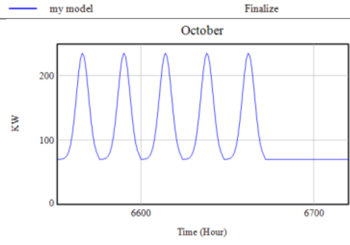
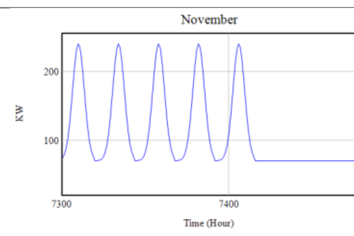
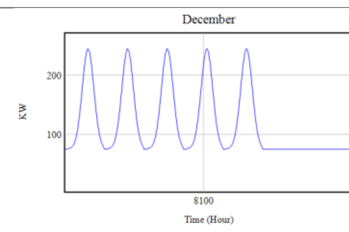
<td>
</td></tr>
<tr><td>Autumn</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
</table>

Table 29: Weekly energy consumption graphs

4.4.2.3 Hourly solar energy production graphs and seasonally accumulated charts

Table 30 represents hourly energy consumption graphs and accumulated energy consumption charts in each season. Vertical axis demonstrates energy consumption in KW and horizontal axis shows the time in hour and each color shows energy consumption in each individual season in hourly total energy consumption graph.

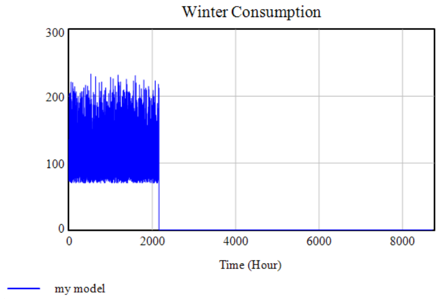
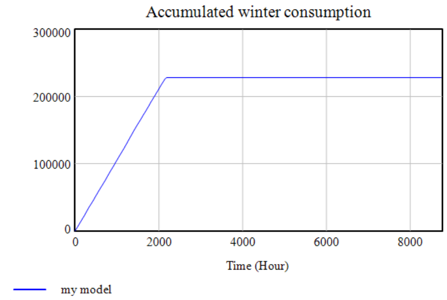
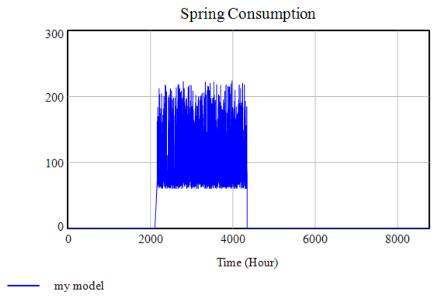
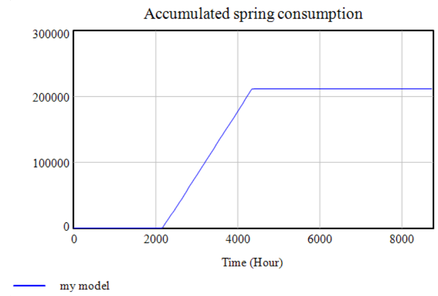
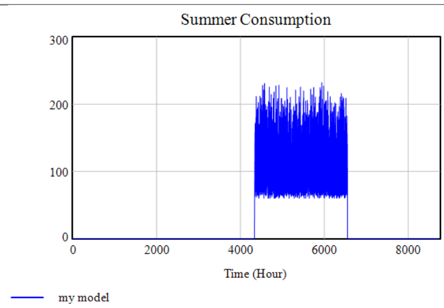
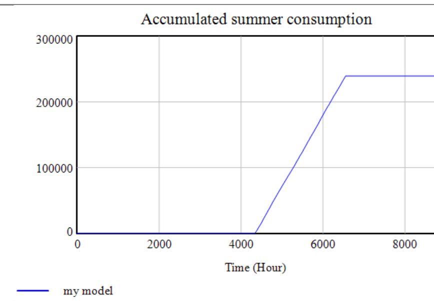
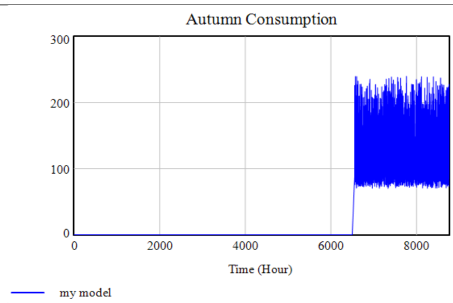
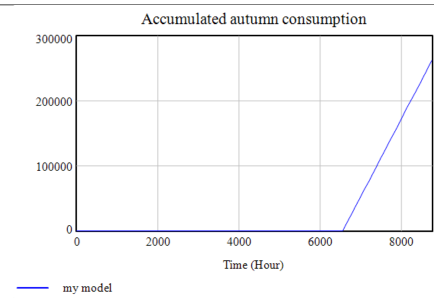
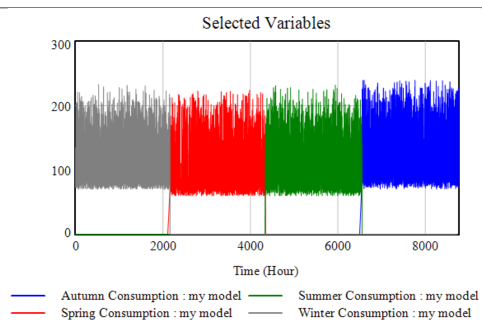
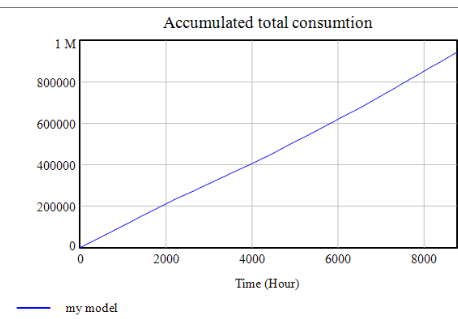
<table>
<tr><th>Season</th><th>Hourly consumption graph</th><th>Accumulated consumption graph</th></tr>
<tr><td>Winter</td><td>
</td><td>
</td></tr>
<tr><td>Spring</td><td>
</td><td>
</td></tr>
<tr><td>Summer</td><td>
</td><td>
</td></tr>
<tr><td>Autumn</td><td>
</td><td>
</td></tr>
<tr><td>Total</td><td>
</td><td>
</td></tr>
</table>

Table 30: Hourly energy consumption graphs & seasonally accumulated energy consumption graphs

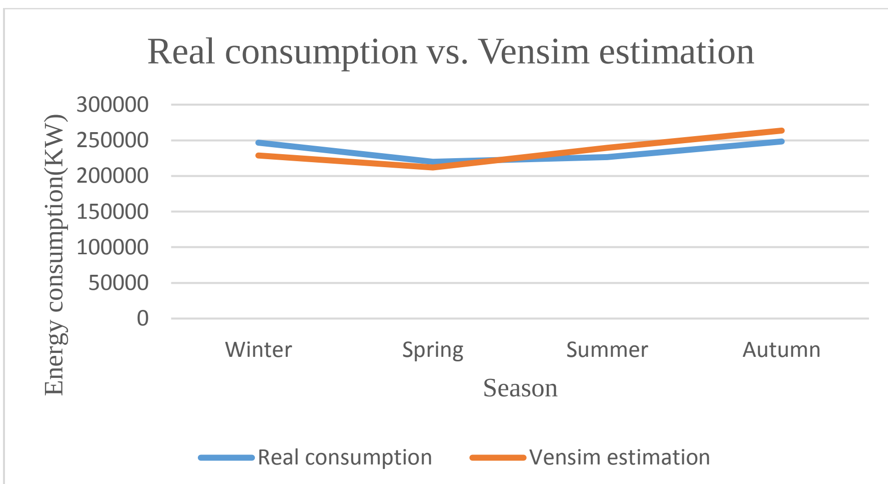
4.4.3 Comparing the estimated consumption by Vensim with the real consumption measurements

Table 31 and figure 16 shows seasonally real energy consumption estimated by Vensim. It is obvious that the accuracy of energy consumption model is high (approximately 99%) because there is no considerable noise in energy consumption data (it is also clear in consumption distributions).

	Winter	Spring	Summer	Autumn	Sum
Real energy consumption (KW)	246520	219880	226215	248320	940935
Vensim estimation (KW)	228472	211842	239634	263615.5	943563.5

Table 31: comparison between real energy consumption and Vensim estimation

Figure 16. Real energy consumption vs. Vensim estimation



4.5 Systemic picture: energy production and energy consumption

Figures 17 shows the simulation model of systemic energy profile which indicates when the energy consumption rate is more than energy production rate, the rest of the energy should be purchased from the grid and when energy production rate is more than energy consumption rate, the excess of produced energy can be stored to use it at another time or sell it to another places. Average energy price has been considered 0.27 (Data, 2017) to evaluate the cost of purchased energy from the grid and benefit of stored energy.

Figure 17. Simulation model of systemic energy picture

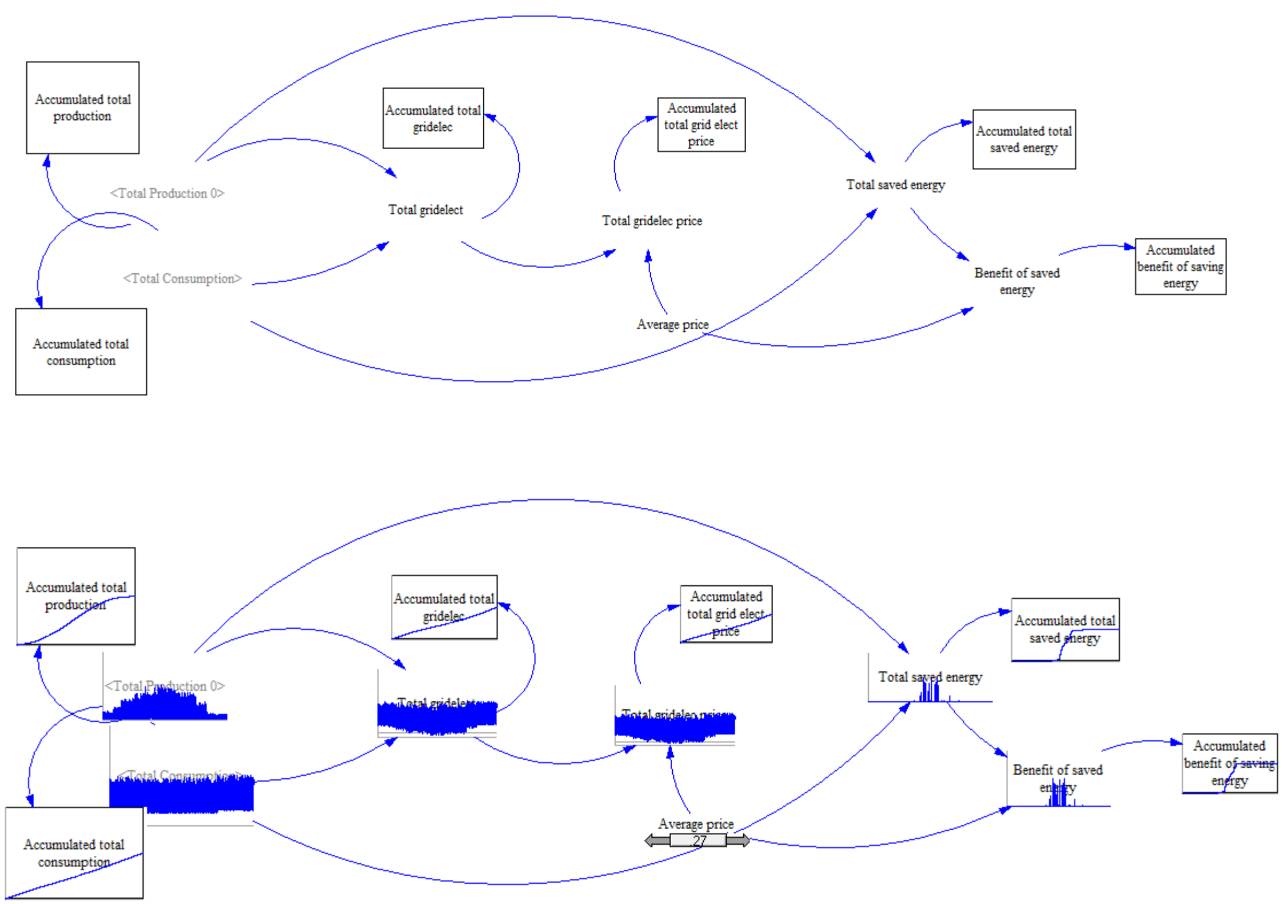


Table 32 represents systemic energy profile i.e. the utilized energy profile, stored and/or purchased energy from grid which demonstrate that if the minimal consumption profile over the day exceeds the maximum solar production rate, then either the design should be revised, or the consumption should be minimized.

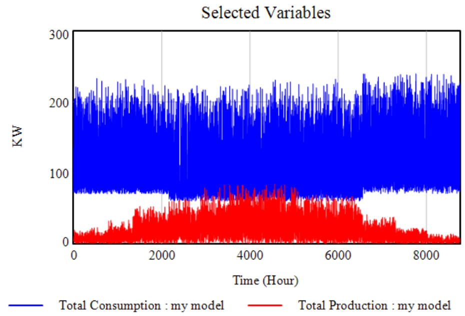
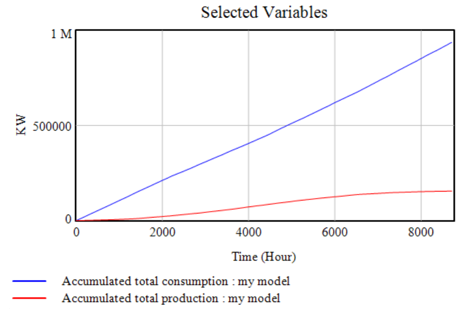
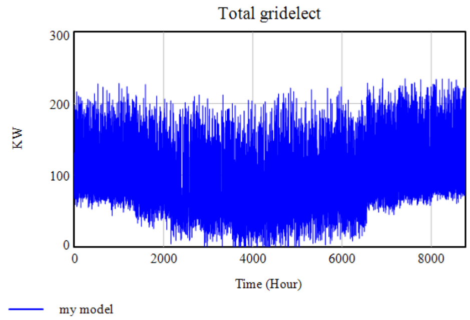
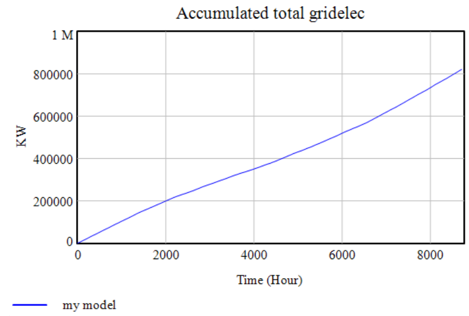
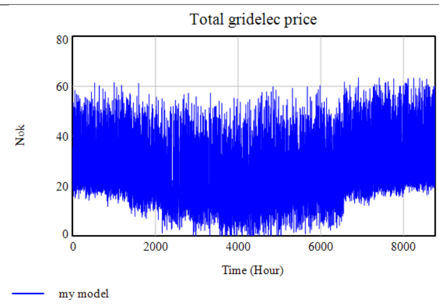
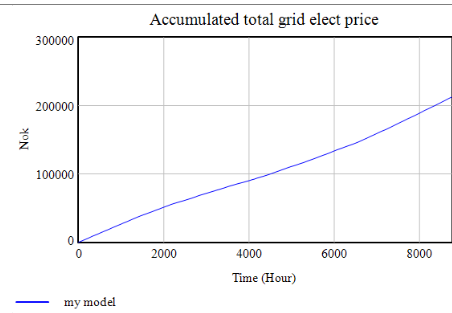
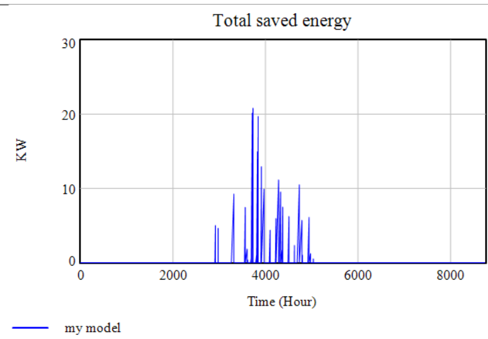
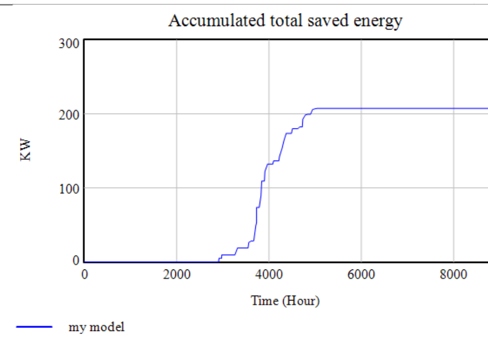
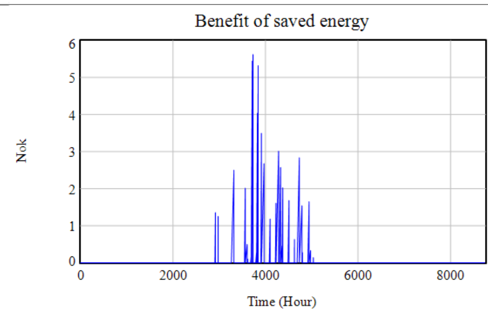
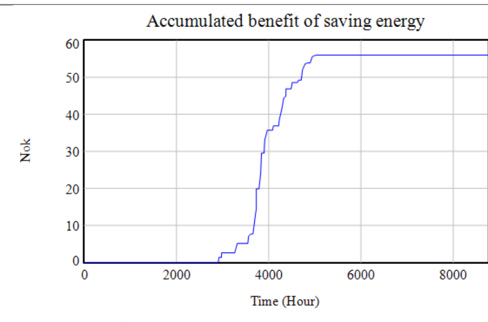
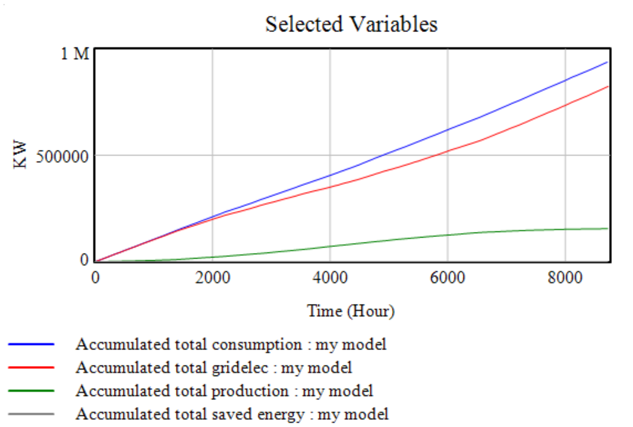
<table>
<tr><th>Criteria</th><th>Hourly graphs</th><th>Accumulated graphs</th></tr>
<tr><td>energy consumption vs. energy production</td><td>
</td><td>
</td></tr>
<tr><td>Purchased energy from the grid</td><td>
</td><td>
</td></tr>
<tr><td>Cost of purchased energy from the grid</td><td>
</td><td>
</td></tr>
<tr><td>stored energy</td><td>
</td><td>
</td></tr>
<tr><td>Benefit of stored energy</td><td>
</td><td>
</td></tr>
</table>

Table 32: systemic energy profile

4.5.1 Provide the big picture (overall energy supply system) of Måltidhuset and how much it complies with NZEB

Figure 18 and table 33 show that the utilization rate is quite high in the office building and it becomes clear that high demand building (high building with limited roof area) will not achieve net zero energy mission and it will keep depending in grid supply.

Figure 18. Utilized energy profile graphs



Outputs	Results	Units
Total solar energy production	107178.1	KW
Total energy consumption	943563.5	KW
Total purchased energy from the grid	836385.4	KW
Total stored energy	151.233	KW

Table 33: Utilized energy profile values

The developed simulator provides a simple and effective tool for the use to estimate what is the expected production, consumption, storage, and grid dependences in terms of money (table 34).

Outputs	results	Unit
Solar energy production in terms of money	28938.1	NOK
Solar energy consumption in terms of money	254762.2	NOK
Purchased energy from the grid in terms of money	225824	NOK
Stored energy in terms of money	40.8	NOK

Table 34. Accumulated systemic energy profile in terms of money

4.6 Systemic risk analysis and uncertainty assessment

4.6.1 Payback time

The solar system payback estimates the time will take to earn the solar energy investment. Following steps show how to calculate the payback time.

- Step 1: PV is mostly sold based on $\frac{cost(\$)}{W_p}$. Following formula shows how to covert $\frac{cost(\$)}{W_p}$ to $\frac{cost\ (\$)}{m^2}$ (Smestad, 2008):

  $$\frac{\$}{W_p} = \frac{\$/m^2}{\eta * 1000W_p/m^2}$$

- Step 2: after converting cost per peak watt to cost per square meter. payback time is calculated according to following equation (Smestad, 2008):

  $$Payback\ time = \frac{Cost\ \$/m^2}{\eta * Yearly\ energy\ production\ kW * electricity\ \$/KWh}$$

  Where η is solar system efficiency

- Step 3:

  \$/W: \$0.5/W

  Average electricity price in Norway: 0.27 NOK/KWh (Data, 2017)

- Step 4: Consequently, payback time is calculated based on following formula for the net zero energy building:

  $\$0.5/\text{W} = \frac{\$/m^2}{0.12*1000}$

  \$60/m2 = 483NOK/m^2

  Payback Time = $\frac{483*374}{0.85*89.49*1000*0.27}$ = 8.8 years

4.6.2 Expected net present value

Analysis has been done by system dynamics approach based on hourly simulation of solar energy production and energy consumption. The final output is to inform Decision Makers whether it is economically beneficial to invest on launching NZEOB or not. Different methods exist to investigate whether a project is economically beneficial amongst which is to calculate expected net present value, E(NPV). To calculate E(NPV), all attributes should be converted to monetary value; and the E(NPV) is computed as: E(benefit)- E(cost). A project is considered economically beneficial if E(NPV)>0. We use this method as the basis for economical evaluation of the study here.

As production can bring us profit, this factor has been seen as a benefit and since consumption is an expense, this factor has been considered as a cost. When energy consumption is higher than energy production, the required energy should be purchased from the grid and when level of energy production is higher than energy demand, this production not only can meet the energy demand but also it can be stored or sold to supply the energy for other places. To calculate the expected values for benefits and costs we need to have their distributions. Since the distributions are Normal and Weibull (close to Normal), there is no problem with calculation of the mean values. However, as mentioned in previous chapter, each seasonal consumption has been modeled based on different activity hours as:

- ✓ Weekdays, active hours
- ✓ Weekdays, passive hours
- ✓ Weekends & holidays

Therefore, activity hours are considered to compute the expected value of final output. Expected value has been given weight based on following formula:

$$Consumption\ weight = \frac{Total\ hours\ in\ each\ category\ for\ every\ season}{Total\ hours\ in\ mentioned\ season}$$

Therefore, we have following table:

Consumption category	Mean Value(kWh)	Weighted mean value	Average grid energy price(NOK/kWh)
Winter, weekdays, active hours	179.2	53.93	0.276
Winter, weekdays, passive hours	102.4	43.14	0.276
Winter, weekends & holiday	82.9	23.03	0.276
Spring, weekdays, active hours	164.5	46.98	0.253
Spring, weekdays, passive hours	87.8	34.89	0.253
Spring, weekends & holidays	75.4	24.03	0.253
Summer, weekdays, active hours	159.6	46.98	0.258
Summer, weekdays, passive hours	84.11	34.66	0.258
Summer, weekends & holidays	79.8	23.42	0.258
Autumn, weekdays, active hours	180.7	53.2	0.288
Autumn, weekdays, passive hours	92.5	38.12	0.288
Autumn, weekends & holidays	87.14	25.57	0.288

Table 35: Mean value, weight and seasonally price for calculation of expected cost

Expected cost has been computed based on average seasonally price (Data, 2017) and weighted mean value.

$$E[Cost] = 120.7 \ {}^{Nok}/_{Hour}$$

Expected value of energy production distributions have been given weight based on following formula:

$$Production\ weight = \frac{Total\ hours\ in\ each\ month}{Total\ hours\ in\ its\ season}$$

Therefore, we have following table:

Production category	Mean Value (KW)	Weighted mean Value	Average grid energy price (NOK/kWh)
January	0.9	0.31	0.276
February	2.5	0.78	0.276
March	9.1	3.13	0.276
April	17	5.6	0.253
May	21.4	7.3	0.253
June	21.8	7.2	0.253
July	18.4	6.2	0.258
August	13.7	4.62	0.258
September	10.5	3.42	0.258
October	4.8	1.62	0.288
November	1.6	0.52	0.288
December	0.4	0.13	0.288

Table 36: Mean value, weight and seasonally price for calculation of expected benefit

Expected benefit has been computed based on average seasonally price and weighted mean value.

$$E(Benefit) = 10.6\ {}^{Nok}/_{Hour}$$

Next, expected net present value is calculated according to expected benefit and expected cost.

$$E(NPV) = E(benefit) - E(cost) = 10.6 - 120.7 = -110.1\,{}^{Nok}/_{Hour} < 0$$

The E[NPV] is negative. However, the calculation of E(NPV) is based on expected values, and expected values do not see all aspects of risk and uncertainty and we need to see beyond expected values. Hence, in the following, we provide uncertainty assessment.

4.6.3 Uncertainty Assessment

The uncertainty that we talk here is epistemic uncertainty which comes from background knowledge. The assumptions that have been made can hide some uncertainties. For example, since the HelioScope simulator has been calculated solar energy production, we needed to have some assumptions (area, tilt, pitch and racking). In addition, in energy consumption data (ventilation, lighting, equipment or number of offices) we also made some assumptions. However, this building is going to rebuild and there is a probability to apply some changes in the number of offices, removing the lab and amphitheaters plus using smart lighting and smart technology in the building. Therefore, it would be a reduction in the energy demand.

Hence, we implemented a semi quantitative uncertainty assessment based on (Aven, 2011), in which "knowledge-based assumptions are used to analyze our system quantitatively" .

Four steps have been considered for uncertainty assessment based on Selvik, Lohne et al. 2012 to find the most crucial factors affecting outputs in our system. These steps are:

1. Degree of uncertainty
2. Degree of sensitivity
3. Degree of importance
4. Importance score

4.6.3.1 Degree of uncertainty

Simulation of solar energy production has been conducted by hourly solar energy data which is output of HelioScope software. HelioScope results are based on some assumptions which have been made according to background knowledge (subjective or judgmental). In particular, only four tilt angles have been examined which include 10, 30, 45 and 89. Maybe, there is an angle between them that is able to produce more solar energy in a cost-effective manner. In addition, one azimuth (180) has been considered for the case. Moreover, only flat roof mounting has been considered. However, tilted roof/ sloped roof can lead to better outputs. Therefore, amongst all these uncertain factors, tilt angle is the most uncertain attribute and we have decided to evaluate uncertainty assessment on this factor. As mentioned before, the assumptions for this angle are based on qualitative comparisons and semi-quantitative formula. Therefore, these assumptions are neither strong nor weak and data is neither unreliable nor reliable. Thus, the degree of uncertainty for this factor has been considered *Medium.*

Simulation of energy consumption has been done by hourly energy demand in an office building. The data have been computed based on number of offices which have electrical equipment such as computers, light bulbs and ventilation. As mentioned before, there is a probability to change number of offices. Therefore, number of offices is the uncertain factor, because there is a probability of adopting renewable energy for two floors. As a matter of fact, the assumption shows strong simplification and data are not reliable. Thus, degree of uncertainty for this factor has been considered *High.*

Thus, we have following table:

	Degree of uncertainty
Tilt angle	Medium (M)
Number of offices	High (H)

Table 37: Degree of uncertainty

4.6.3.2 Degree of sensitivity

Sensitivity analysis has been carried out to show that how the outcome is dependent on different conditions and assumptions. Sensitivity analysis often starts with the conclusion and "go backwards" in the analysis to find which uncertain factors can have a considerable impact on the result. It is important to mention that sensitivity analysis cannot analyze the uncertainties, however, it can create a basis for uncertainty assessment (Aven, 2015). Sensitivity analysis can determine the degree of sensitivity for uncertain factors.

In order to see how sensitive the output is to uncertain factors, we consider the following scenarios:

1. We have decided to consider 3rd and 4th floors of this building for calculating energy consumption. Therefore, we have less offices and almost half of area to consume energy compare to overall area. Therefore, the impact of this change on expected values of energy consumption distributions has been evaluated. Hence, we have following table:

Consumption category	Mean Value(kWh)	Weighted mean value	Average grid energy price(NOK/kWh)
Winter, weekdays, active hours	102.14	30.74	0.276
Winter, weekdays, passive hours	59.39	25.02	0.276
Winter, weekends & holiday	48.91	13.59	0.276
Spring, weekdays, active hours	108.57	30.82	0.253
Spring, weekdays, passive hours	58.83	23.38	0.253
Spring, weekends & holidays	51.27	16.34	0.253
Summer, weekdays, active hours	103.74	30.54	0.258
Summer, weekdays, passive hours	53.83	22.18	0.258
Summer, weekends & holidays	50.27	14.75	0.258
Autumn, weekdays, active hours	95.77	28.19	0.288
Autumn, weekdays, passive hours	47.17	19.44	0.288
Autumn, weekends & holidays	45.31	13.3	0.288

Table 38: Weighted mean values after changing the area of energy consumption

E(cost)= 71.94 $^{Nok}/_{Hour}$

E(NPV)= 10.6-71.94= -61.34 $^{Nok}/_{Hour}$<0

It is clear in the calculation, E(NPV) remains negative after changing the uncertain factor. We also test %75 reduction (reduction more than %75 is unrealistic) in expected values of energy consumption to evaluate whether it is possible to have a positive E(NPV) or not.

$$E(Cost) = 30.175\, {}^{Nok}/_{Hour}$$

$$E(NPV) = E(Benefit) - E(Cost) = 10.6 - 30.175 = -19.6\, {}^{Nok}/_{Hour} < 0$$

E(NPV) is still negative.

2. We have decided to change the tilt angle to 40° and the impact of this changing on expected values of energy production distributions have been evaluated. Hence, we have following table:

Production category	Mean Value(KW)	Weighted mean Value	Average grid energy price (Nok/kWh)
January	1.01	0.35	0.276
February	2.83	0.9	0.276
March	10.4	3.6	0.276
April	21.25	7.01	0.253
May	27.178	9.3	0.253
June	27.5	9.1	0.253
July	21.5	7.3	0.258
August	16.3	5.5	0.258
September	12.2	3.4	0.258
October	5.33	1.8	0.288
November	1.73	0.6	0.288
December	0.44	0.15	0.288

Table 39: Weighted mean values after changing the tilt angle

E(benefit)= 11.74 ${}^{Nok}/_{Hour}$

E(NPV)= 11.74-120.7=-108.96 ${}^{Nok}/_{Hour}$

E(NPV) is less than zero. In addition, we also test %75 growth (growth more than %75 is unrealistic) in expected values of energy production to evaluate whether it is possible to have a positive E(NPV) or not.

$$E(Benefit) = 18.55\, {}^{Nok}/_{Hour}$$

$$E(NPV) = E(benefit) - E(cost) = 18.55 - 120.7 = -102.15\, {}^{Nok}/_{Hour} < 0$$

E[NPV] is still less than zero.

However energy consumption is more sensitive than energy production, because it is able to have significant impact on output. Therefore, the degree of sensitivity for number of offices is *Low* $^{+}$ and for tilt angle is *Low*$^{-}$.

Hence, we have following table:

Scenario	Degree of sensitivity
Tilt angle	Low^{-} (L^{-})
Number of offices	Low $^{+}$ (L^{+})

Table 40: Degree of sensitivity

4.6.3.3 Degree of Importance and importance score

A degree of importance is combination of degree of uncertainty and degree of sensitivity. For instance, if the degree of uncertainty is Low and the degree of sensitivity is High, the degree of importance is Medium. According to importance scores, uncertain factors have been ranked in order to distinguish the most important uncertain factors (Selvik et al., 2012). Table 41 shows the degree of importance and importance factor in for uncertain factors:

Factors	Degree of uncertainty	Degree of sensitivity	Degree of importance	Importance score
Tilt angle	M	L^{-}	M/L^{-}	2
Number of offices	H	L^{+}	H/ L^{+}: M^{+}	1

Table 41: Degree of importance & importance score

Degree of uncertainty and sensitivity for *tilt angle* is respectively *Medium* and *Low*$^{-}$. Therefore, the degree of importance for this factor has been considered *Medium/ Low*$^{-}$. In addition, degree of uncertainty and sensitivity for *number of offices* is *High* and *Low* $^{+}$. Hence, the degree of importance for this factor is *Medium*$^{+}$.

These two uncertainty factors have been given rank according to the degree of importance. Importance score shows the number of offices needs to be considered for more treatment and evaluation, if time, budget and resources permits.

6. Conclusion and recommendations

6.1. Conclusion

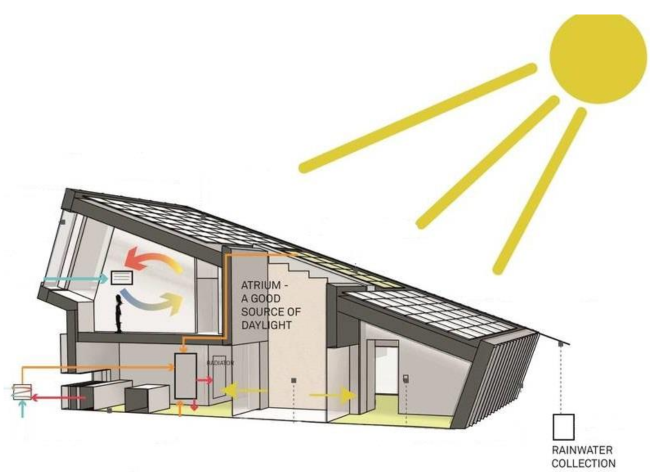
We are proposing a model to develop the systemic energy system in the office building in a cost-effective and low risk manner in seven phases: (1) Solar energy production is dependent on several solar design factors which includes tilt angle for PV panels, spacing between PV panels i.e. pitch, racking type and geographical site conditions. Results from the HelioScope software has shown that the most important design factor is tilt angle for PV panels and the best alternative design is one which can produce the more energy with less number of PV panels. (2) Historical solar energy production data and probability distributions represent that there is a high noise in hourly energy production data. However most of these noises are related to the first intervals of probability distributions which have no considerable influence on cumulative solar energy production rate regarding the fact that the first intervals mostly consist of zero energy production rate. (3) The simulation model of solar energy production illustrates that hourly energy production rate is considerably fluctuating over the month. However, there are no big gaps between accumulated rate and monthly energy production. In addition, the highest level of energy production is in May and the lowest level of energy production is in December. (4) The simulation model of energy consumption indicates that there is no considerable fluctuation in hourly energy consumption over the season. Furthermore, the maximum level of hourly energy consumption rate in December and the minimum level of hourly energy consumption is in May. However, there is no significant difference between minimum energy consumption over the year as well as no major difference between maximum energy consumption in the whole year. (5) The systemic energy building profile represents that the building will be dependent on grid supply since the consumption rate is quite high in the office building and solar energy production is not sufficient to meet the energy demands. (6) The calculation of payback time shows that PV price, energy price and solar system efficiency play crucial roles to reduce payback time i.e. increasing the trend of using solar energy can cause an increase in the energy price, decrease the PV price and increase the solar system efficiency in future which can lead to a reduction in payback time. Additionally, sensitive solar design factors are also very important because they can improve the solar energy production rate which can lead to achieve the better payback time. (7) Systemic risk analysis is the risk that exist or happen in the entire system. Uncertainty assessment is conducted to determine uncertain factors in simulation model which influence expected net present value. The most uncertain factor is number of offices in the building which can first change the energy consumption and then change the expected net present value. It is important to mention that the uncertainty assessment is different from traditional risk. Traditional risk analysis describes risk is expected value and probability. However, uncertainty assessment highlights that risk is more than probability and expected value. Therefore, the calculation of expected net present value that has been done in the first step, is exactly what traditional risk does define. It means that traditional risk only consider expected value/mean value and probability/weight. Thus, the traditional risk is considered as a basis for uncertainty assessment to specify the most uncertain factors for more treatment.

6.2. Recommendations for future work

This section provides some recommendations to achieve the target as NZEB system.

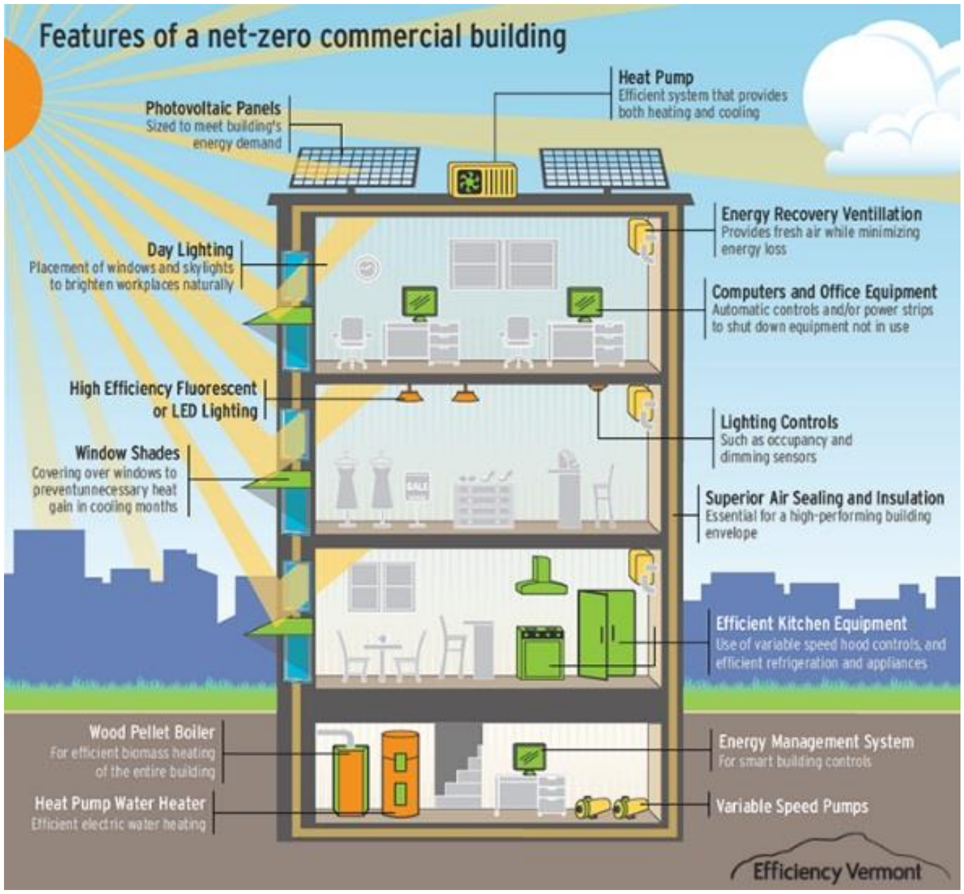
- Utilise the rainfall/electricity generator and wind energy to improve the energy production
- Consider the sloped/tilted roof to increase solar energy production
- Use more accurate solar energy production simulator to reduce the fluctuations in data
- Increase the solar energy area as it is shown in figure 19

Figure 19. Increasing the area which in the effect of sun radiation(Google.images)



- Several disruptive technologies can be applied in the future which has shown in figure 20:

Figure 20. Features of a net-zero commercial building (Google.image)

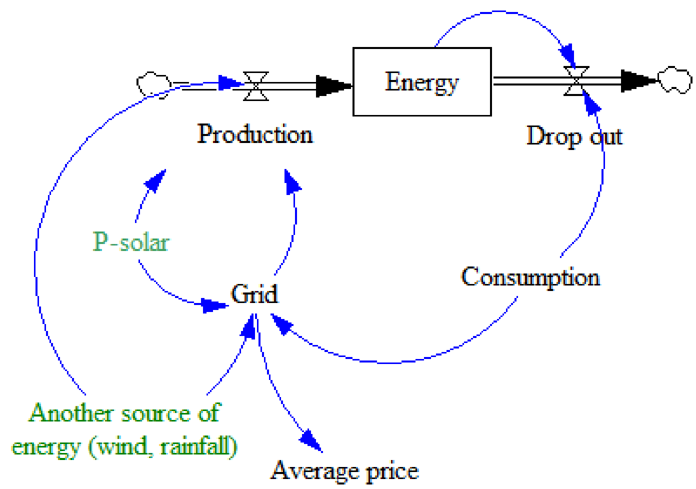


- Need to reduce the daily consumption profile using smart lighting system (sensors based on natural lighting)
- Calculate energy consumption in details for simulation model which means that to simulate the lighting consumption, ventilation consumption and equipment consumption because they can help us on understanding the dynamic behavior of each energy consumer in details
- System dynamics includes some assumptions and functions which can be changed e.g. change the constant factors inside of functions to equations to have wider view for dynamic behavior of each variable

- Reduce payback time by selecting the solar design with high efficiency and improving the solar energy production rate
- Consider the most uncertain factors i.e. tilt angle of PV panels and number of offices for more treatment
- Conduct uncertainty assessment for all uncertain factors
- Consider whole Ipark instead of one building to evaluate the achievement of net zero energy building in a broader vision
- Use Vensim PLE plus which can provide users with all options e.g. sensitivity simulations, export/import external data and discreet event functions which are unavailable in Vensim PLE/student license.
- The figure 21 shows the concept of system dynamics and it indicates behavior of different variables in our system. In addition, it can help us to find some optimal solutions for different problems in future. It is clear in the following figure, we have one stock (Energy), one inflow (Production), one outflow (Drop out) and different variables are including consumption, grid supply, p-solar (solar production), average energy price and another source of green energy such as wind or rainfall.

  In system dynamics, stock is considered as a variable that can be charged and discharged by inflow and outflow. In this model, the energy can be filled by solar production, grid and another source of clean energy. In addition, it can be emptied by consumption rate. Moreover, when the solar energy and another source cannot satisfy the energy consumption, we need to purchase the rest of energy from the grid. Therefore, the energy is supported by solar energy production, another source of green energy and grid. Furthermore, average hourly energy price is considered to estimate the cost of purchased energy from the grid and benefit of clean energy production. The following system dynamics model is a base model to simulate optimization problems for future such as next 20 years in order to find optimal solutions. We could not run this model due to limitation of Vensim PLE (student license).

Figure 21. Stock-flow diagram for future research



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