

# Possibility study for utilization of solar energy in Arctic areas (SHO6261)

Stutee Tamrakar (140722)

*UiT - The arctic university of Norway in Narvik, PO Box 385, N-8505 Narvik*

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## **Abstract**

This thesis investigates a solar thermal system and a solar photovoltaic system which produces local energy by incoming solar radiation to meet the energy consumption demand of a residential building in the arctic region. An existing building block in Narvik, within the sub-arctic region, was taken as study case to analyze the potential of solar energy. For this purpose, the performance and function of both the systems were studied. This was achieved by calculation and simulation model of the solar thermal system and the solar PV system separately. Furthermore, a study on various parameters which influence design and operation of the systems were investigated. The studied parameters included orientation, inclination angle, solar irradiation, solar hours and collector area for both the systems. For the solar thermal collector, energy storage accumulator tank and the size of the tank were discussed. Similarly, for the PV system, utility grid, battery as energy storage for grid-connected PV system, solar cell technologies, plus-customers and relevant scheme for plus-customers were investigated. The simulation results showed that the solar thermal collector produced about 14314 kWh throughout a year, whereas, the PV system generated annual energy output of 18639 kWh. Thus, it can be concluded that the potential of solar utilization is considerable, however the investment cost for both the solar systems are still expensive in today's market.

Key words: solar radiation, solar thermal collector, PV system

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## **1. Introduction**

Ever-increasing energy consumption and greenhouse gas emissions from energy production have led to the need for measures that can reduce emissions. Norway has a total consumption of 122.20 billion kWh of electric energy per year with about 40% of the total energy consumption in households and buildings (Worlddata., 2018). The high-energy consumption is an increasingly discussed topic, especially in old residential building, which needs to be limited to some extent with focus on energy efficiency, building standards and increased integration of local renewable energy production.

Cumulative focus on the integration of renewable production and energy efficiency of buildings implies that an increasing number of buildings will install local power supply from a solar system. The Smart Arctic Building project which focuses on sustainability, energy and smart solutions in the arctic region encourages local production of solar energy on existing buildings with automated smart meters to control and be up to date with building energy system.

### **1.1 Thesis problem formulation**

Basically, this thesis attempts to provide a solution for the following question;

Can installation of a solar system in an existing residential building be profitable in the arctic region?

Regarding this, an existing study case building block is considered for the calculation of local energy production by incoming solar radiation through convenient solar installations, in this case, solar thermal collectors and PV modules. Various factors need to be considered for the design of the system where energy storage plays a vital role. There is a great demand for energy storage in buildings to prolong stored heat and electrical energy consumption. An accumulator tank is used for the solar thermal system, whereas, a battery bank is used for the PV system. There are several energy storage types found in the market, and their prices decrease year after year. So, preferable components for the solar system are discussed, since they affect the efficiency and cost of the system. Finally, the feasibility of both systems for the building block is analyzed to acquire the investment and payback period of the systems.

## 1.2 Research methodology

This thesis is based on a literature study, participation in a workshop about Smart Arctic Building, dialogue with experts on solar system and quantitative analysis. The quantitative method was utilized to collect and analyze data required for dimensioning of the PV system and the solar thermal collector system. Along with that, an economic analysis was carried out to understand the profitability of the investment of both systems.

Solar information about the study case building location, in Narvik was retrieved from various sources. Temperature and climate data were collected from the Norwegian Meteorological Institute, solar hours and peak sun hours were acquired from Suncurves AS and solar path and solar radiation per month were simulated using PVsyst V6.77 software. The optimal inclination angle and optimal azimuth angle for solar collector was simulated from PVGIS software. Besides, condition assessment report and drawings of the study case building were provided by OMTBBL. Simulation of energy output by solar thermal collectors were executed in the solar calculator (R. Bird and R. Hulstrom, 1981). The area of the solar collector was calculated by simple calculation techniques using the tables provided by (Zijdemans, 2012). In the case of PV system, the area of the PV modules was determined with respect to architecturally suitable area for installation of the PV modules. For further calculation of the energy output by the system, SIMIEN program was used. The existing SIMIEN file was provided by Lars Kimo Jørgensen, Enerconsult AS which follows TEK17. Finally, for the economic analysis, prices were retrieved from Catch solar and STS solar technologies Scandinavia for the solar thermal collector system and the PV system respectively. The payback period and profitability of both solar systems were calculated using the net present value formula.

## 1.3 Limitations

The limitations of this work are stated below:

- The data availability for detailed solar information required for the location of the case building is limited due to scarcity of measurements of sun hours with respect to clouds and rains in meteorological weather stations.
- There is scarcity of space to install the required number of solar collectors/panels, since the installation is limited to the case building itself.
- The battery bank is not included in the calculation of the payback period of the PV system.

## 2. Solar energy potential in The Arctic region

The arctic region is located at the northernmost part of the Earth with latitude above 66°33'47.5" N. Weather conditions and varying solar availability throughout the year in the arctic region is low compared to other regions. However, low temperatures and snow are considered beneficial for PV solar systems, as the solar cells operate efficiently at lower temperature than in higher temperatures, which as a result minimizes heat loss and wearing of the system. The standard test condition for determining efficiency of solar cells is 25°C. Hence, at lower temperatures, the efficiency of the solar cell increases by 0.2% - 0.5% per degree (Jha, 2009).

This theoretically shows that conditions in the arctic region are favorable for solar energy. The solar radiation passes through a thick atmosphere in northern latitudes and hit the surface of the earth at a low angle. For maximum utilization, the receiving surface must be installed at an optimum angle facing southwards. In Northern Norway, the solar radiation on a horizontal surface spans from 700 kWh/ m<sup>2</sup> per year to 900 kWh/ m<sup>2</sup> per year.



Figure 1. Solar irradiation on a horizontal surface in Norway for winter and summer. (Hagos, et al., 2014)

The possible utilization of solar energy in buildings is harnessed by three main types of technology: passive solar energy, solar thermal energy collector and photovoltaics (PV) system.

1. Passive solar energy: utilization of solar energy for heating purposes of building via solar heat gains through large windows and thermal walls.
2. Solar thermal collector: directly converts radiation from the sun to thermal energy or convert that thermal energy to electricity through a device.
3. PV system: directly convert photons from the sunlight into electricity using a semiconductor device.

## 2.1 Factors affecting utilization of solar radiation

The amount of solar radiation reaching the surface of the earth is dependent upon solar hours, sun peak hours, solar path, local solar irradiation and orientation of the solar collector.

### Annual solar hours

Solar hours are the number of hours with sunshine during a day which is affected by cloudy and rainy days and varies throughout the year. Table 1 below shows the approximate average monthly variation of solar hours in Narvik (Suncurves, 2019).

Table 1. Average monthly and annual number of solar hours in Narvik.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Solar Hours	0	12	217	362	444	446	454	407	285	70	0	0	2697

### Peak sun hours

Peak sun hours are the number of hours per day when solar irradiance is 1000 W/m<sup>2</sup> at average. Narvik has approximately 4.2 sun peak hours as given in table 2, which means that the energy received during total sunlight hours is equal to the energy received, that is the solar irradiance of 1000 W/m<sup>2</sup> (Suncurves, 2019).

Table 2. Total sun peak hours in Narvik.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Solar Hours	0	0.78	4.35	6.3	7.09	9.9	9.4	6.2	4.76	1.47	0.2	0	4.2

### Local solar irradiation

Values for the annual direct horizontal solar irradiation and diffuse horizontal irradiation obtained from PVSYST v.6.77 are as follows: direct horizontal solar irradiance is approximately 790 kWh/m<sup>2</sup>, whereas diffuse horizontal solar irradiance is approximately 400 kWh/m<sup>2</sup>. Figure 2 below shows the monthly global and diffuse solar irradiation per square meter during a year in Narvik.

### Sun path diagram

Sun path diagram is the position of the sun in terms of sun height ( $\gamma_s$ ) and solar azimuth ( $\alpha_s$ ) at a specific time at a given location, which is useful for considering shading on a collector surface. The sun height is the angular height of the sun in the sky measured from the ground. At sunrise, the elevation is 0° and 90° while the sun is directly overhead. Whereas, the solar azimuth angle is the angle between the projection of sun's center towards the horizontal plane and due south direction. The figure 3 below shows the sun path diagram for selected days during the year for Narvik.

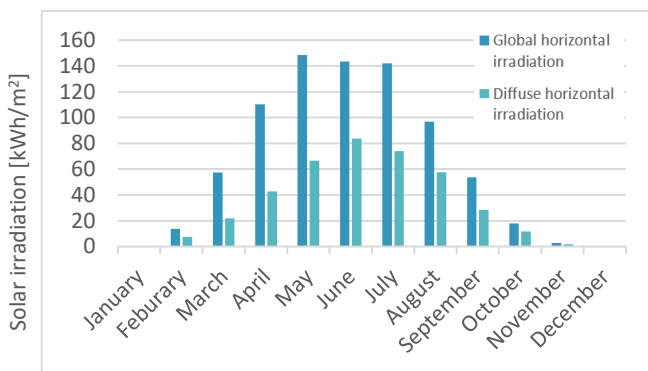


Figure 2. Monthly solar irradiation per m<sup>2</sup> surface area

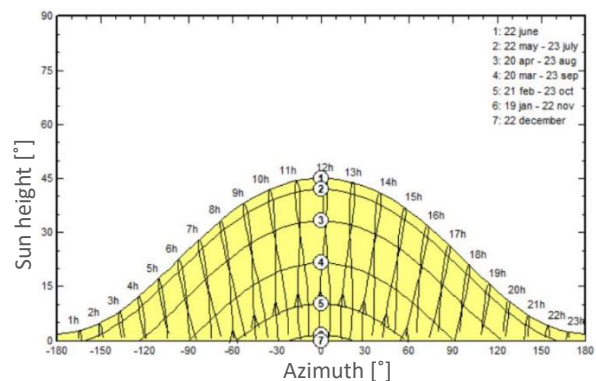


Figure 3. Sun path diagram for Narvik

### Orientation and inclination angle of the receiving surface

The orientation of the solar receiving surface should be such that it collects most of the solar radiation. With respect to the horizontal plane, the orientation refers to two angles: azimuth angle ( $\alpha$ ) and inclination angle of collector ( $\beta$ ). Whereas inclination angle is the angle between the horizontal plane and the solar panel. A receiving surface which faces the south directly is the most ideal azimuth angle of 0°. The clear sky daily radiation increases with elevation and varies according to inclination angle. The increases are maximum in winter, when the sun is at lowest angle (Page, 2012). So, in the arctic region, vertically standing solar collectors have more efficiency in producing energy. A solar collector must be tilted at an optimum angle to obtain maximum radiation yield. PVGIS software was used for calculation of average optimal angles at Narvik. The optimal inclination angle of the solar collector is 47° and optimal azimuth angle is 12°.

## 3. Literature study

### 3.1 Solar thermal system

Solar thermal heating system transforms the energy from the sun to usable heat, which can be used for heating rooms and domestic hot water. This system consists of thermal solar collectors, a distribution system, an accumulator tank for heat storage and a control system as shown in figure 4 below. The solar collector can be designed as stationary or mobile to track solar radiation, there are two types of tracking systems: single axis tracking and two-axis tracking. Only stationary collector will be considered for this project as the addition of a tracking system will incur additional cost and complexity to the planned installation. Most common types of stationary thermal solar collectors are flat solar collectors and vacuum tube collectors, among which flat solar collector will be discussed in the following paragraphs.

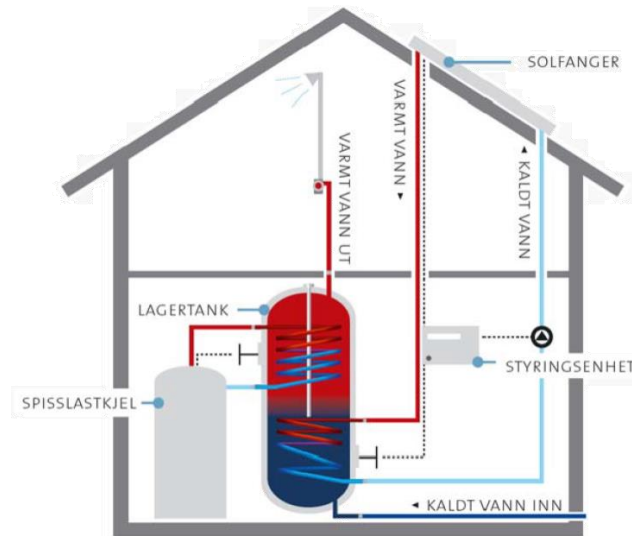


Figure 4. Principle diagram of solar thermal collector in a building. (Halvorsen, et al., 2011)

### 3.2 Flat plate collector

The flat plate collector consists of a transparent front cover, channels and the absorber. The collector can be either glazed or unglazed. Glazed collectors are sealed in a tight insulated container with a glazed front in order to prevent thermal losses by convection, while the unglazed collectors are exposed to the surrounding environment and are prone to lose thermal energy due to convection. Whereas unglazed collectors are preferable in warmer climates due to their reduced cost. According to Newton's law of cooling, heat transfer depends on the temperature gradient, so this gradient is reduced due to convection when the temperature of the absorbing medium is increased. Then, the heat losses to the surrounding increases, similarly, the heating medium circulates through the channels in a flat absorber under the absorber surface.

#### Collectors performance and efficiency

According to (Zijdemans, 2012), the efficiency of a solar collector,  $\eta_{sc}$ , can be calculated using the following equation:

$$\eta_{sc} = \eta_0 - a_1 \cdot \frac{(T_L - T_A)}{G} - a_2 \cdot \frac{(T_L - T_A)^2}{G} \quad (1)$$

Where,  $\eta_0$  is the efficiency of the collector without convection and radiation losses known as the optical efficiency,  $a_1$  is the heat loss coefficient as a result of convection and conduction [ $W/m^2K$ ],  $a_2$  is the heat loss coefficient as a result of radiation [ $W/m^2K$ ],  $G$  is the solar irradiance of the location [ $W/m^2$ ],  $T_L$  is the average liquid temperature within the solar collector [ $K$ ] and  $T_A$  is the ambient air temperature [ $K$ ].

#### Solar collector area

A simplified estimation of the required solar collector area can also be found out based on the following table 3. The area is determined by type of heating facility provided to the building by solar collector either by number of residents or the number of dwellings (Zijdemans, 2012).

Table 3. Estimation of solar collector area (Zijdemans, 2012).

	DHW heating	DHW and space heating
Per person in a multi-dwelling building	1 – 1.5 m <sup>2</sup>	1.5 – 2 m <sup>2</sup>
Per 100 m <sup>2</sup> dwelling in a multi-dwelling building	3 - 4 m <sup>2</sup>	4- 5 m <sup>2</sup>

### 3.2 Grid-connected Photovoltaic (PV) solar systems

The grid-connected PV systems are composed of various components with specific purposes such as utility grid, solar modules/ panels, inverter, battery bank and loads (Yang, et al., 2010). The principle mechanism of PV system connected to the grid is such that PV cells produce DC when they react to solar radiation. The DC-AC inverter changes the received electric current from DC to AC, where AC current can be utilized by the building load/ appliances or fed into the utility grid as shown in figure 5. This system is regulated under what is known as feed-in tariff.

During a sunny day, PV modules generate a higher amount of electricity which is utilized by the building and the excess energy is sold to the grid. The customers who sell surplus energy back to the grid, that is below 100 kW at any time, are known as plus-customers. And when there is no sun, the electricity is taken either from the utility grid or from the battery. The battery system stores electrical power which is later used when sunlight is not available to meet the energy demand of the building.

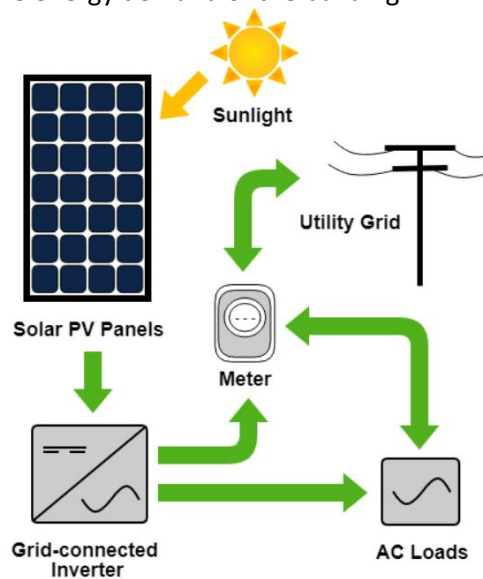


Figure 5. Standard grid-connected solar system (Humphreys, 2019).

#### Solar cell efficiency

The efficiency of the solar cell is the ratio of power emitted from the solar cell and the effect of the incident light measured under standard conditions (Jha, 2009). In terms of MPP voltage and current, the efficiency can be expressed as:

$$\eta = \frac{P_{max}}{P_{in}} = \frac{V_{mpp} \cdot I_{mpp}}{P_{in}} \quad (2)$$

The performance of a solar system can be measured by the electrical energy can be expressed as follows:

$$Total\ Energy\ [KWh] = Total\ power\ [KW] * time\ [h] \quad (3)$$

#### Battery for energy storage

Most relevant energy storage alternative in a grid-connected PV system that saves surplus electricity in a household is a battery and can be used as a backup when there is power interruption in the grid. When the price of the grid electricity is too high, the battery is used since batteries can store power output in low demand period and deliver power in high demand to the household. In a grid-connected system, charging and discharging of the battery occurs frequently and lithium-ion (Li-ion) batteries are the best option among other battery types for the grid-connected system (Dogger, et al., 2011). Li-ion batteries are light and compact battery with long cycle life, high energy density, deep recycling characteristics and safe use.

Today, Li-ion batteries are mostly used for portable electronic devices and electric vehicles (EV). Since the introduction of the first EV, the topic of battery reuse has been discussed regularly. With the enhancement in EV every year, some of the older generation or initially produced EVs are at a disposable stage but can be given a second life. These second life batteries can be an alternative to energy storage solutions which avoid installation of new systems, resulting in economically and environmentally profitable batteries.

#### Solar cell technologies today

The solar cell technologies that lead the market today are monocrystalline silicon (mono-Si), multicrystalline silicon (multi-Si) and several types of thin-film cells. The most predominant of solar cell technologies are wafer-based silicon solar cells. The production of crystalline silicon cells is either single crystal (mono-Si) or polycrystalline (multi-Si) cells. Multi-Si cells comprises of numerous crystal grains which require less energy to produce, resulting in less efficient cells. In mono-Si cells, the silicon has only one continuous crystal lattice with the least defects and impurities, thus providing comparatively high efficiencies. Due to the advanced production process, the price of mono-Si is relatively higher than other solar cells in the market.

#### 4. Case – Beisfjordveien 88, Narvik

The study case building of this thesis is Beisfjordveien 88, which is an apartment block considered for renovation and upgradation by OMTBBL in Narvik, which will follow the latest building engineering regulation standard TEK17. The incorporation of solar thermal collector and PV system in the building will be thoroughly discussed in this section.

The building block is a wooden structure which was originally erected in 1961. It has three floors among which the lower floor is basement (partly below ground). The block comprises of 10 apartments with two staircases, four apartments on each upper floor and two apartments on the basement. The basement also includes facility rooms such as hobby room, storage units for each apartment and laundry. The table 4 below shows the areas of apartments on the building along with an estimated number of residents according to the number of bedrooms available.



Figure 6. The study case building - Beisfjordveien 88



Figure 7. Roof view

Table 4. Area of apartments and estimated number of residents in the case study building.

Apartments	No. of apartments	No. of residents	Apartment area [m <sup>2</sup> ]	Total area [m <sup>2</sup> ]
A Apartments	4	16	71.9	287.6
B Apartments	4	12	58.2	232.8
Basement Apartments	2	4	46.3	92.6
<b>Total Area</b>	<b>10</b>	<b>32</b>		<b>613</b>

#### Energy demand of the building

The total energy demand and specific energy demand for the building is simulated in SIMIEN with the value of 70534 kWh and 98.8 kWh/m<sup>2</sup> respectively per year. The required DHW of the building is 21264 kWh and space heating demand is 19239 kWh.

#### 4.1 Dimensioning and simulation result of solar thermal collector

The flat collector is preferable for the building because it has good insulation property, a larger area of absorption and aesthetic appearance. However, the drawbacks could be its relatively high heat losses and a higher degree of reflection (Zijdemans, 2012). Zijdemans simplified calculation given in table 3 in section 3.2 is used for area calculation of the solar collector which provides for DHW and space heating in the building. The required daily DHW is taken 50 liters per person. The water inlet temperature and outlet temperature in the system are considered as 5°C and 50°C respectively. As shown in table 5, the total solar thermal collector area is 64 m<sup>2</sup> with respect to utilization of DHW and space heating of 2 m<sup>2</sup> for 32 residents.

Table 5. Area of solar thermal collector.

No. of residents	DHW and space heating in a multi-dwelling	Area of solar thermal system [m <sup>2</sup> ]
32	2 m <sup>2</sup>	64 m <sup>2</sup>

The solar collector is placed on the roof with an inclination of 27° facing west direction. Here, the calculation of energy output by the solar thermal system is executed by solar calculator which is based upon Bird and Hulstrom’s model, and Ryan and Stolzenbach’s model (R. Bird and R. Hulstrom, 1981).

#### 4.2 Solar thermal collector’s energy production

The figure 8 below shows the total energy production from the proposed solar collector at roof inclination of 27° facing towards west direction. Also, the total energy production of hypothetical solar collector at façade inclination of 90° facing west direction is simulated to better understand production increase with respect to placement and inclination of the building integrated solar collector. The total output produced from the solar collector is 14314 kWh on the roof. Though, according to the calculation, façade placement provides a slightly better result with total output production of 15618 kWh.

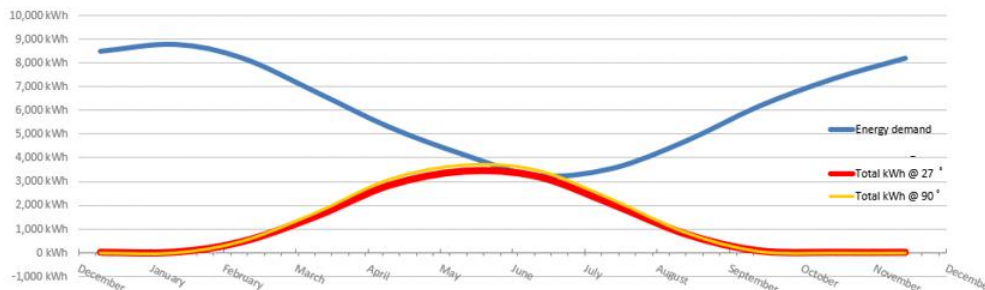


Figure 8. Solar thermal energy production with respect to energy demand of the case study building.

#### 4.3 Dimensioning and simulation result of PV system

The calculation of the PV area is done from a simplified method developed by IEA-PVPS Task 7 (Good, et al., 2016) known as the estimation of architecturally suitable areas for the solar installation with respect to the floor area of the building. According to the method, generalized utilization factors for roofs are 0.4 and facades are 0.15 per m<sup>2</sup> built-up area. The built-up area of the building is 312 m<sup>2</sup>. With respect to the architectural suitability, the total area of PV panels is 172 m<sup>2</sup>. Monocrystalline panels are recommended for the system as panels have higher efficiency for diffused radiation, which will be an advantage in the arctic region where the period of direct radiation is shorter (Fraunhofer ISE, 2019). Lithium-ion phosphate Powerwall battery bank of 13.5 kWh by Tesla is proposed for the building with a capacity of peak power up to 5 kW continuous power. The following table 6 shows the number of PV modules, nominal power and total annual energy produced by the system. The nominal power is calculated by multiplying PV area by efficiency of the Mono-Si cell. Here, the efficiency of Mono-Si is considered to be 20% (Green, et al., 2018). The module size of 1.7 m<sup>2</sup> is considered which are attached to respective building elements.



Table 6. PV system area and nominal power.

Placement	PV Area [m <sup>2</sup> ]	No. of modules	Nominal power [kWp]
Roof – west orientation	125	74	20
South facade	27	16	5.4
West facade	20	12	4
<b>Total Sum</b>	<b>172</b>	<b>102</b>	<b>34.4</b>

#### 4.4 Solar PV modules energy production

The total energy production from the PV modules at roof inclination of 27° and vertical façades of 90° were simulated from SIMIEN. The panels are oriented to west direction since there is no shading and open space is available at the western side of the building. The PV modules placed at south harness more solar radiation than in west. Proposed 102 numbers of PV modules generate the total output production of 18639 kWh, where around 65% of the production satisfies the demand of the building and rest is fed back to the grid.

A comparison of total energy production from the PV system and the total energy demand of the building is presented below in figure 9. The variation of solar radiation leads to over-production of electricity at summer time, and lack of production to satisfy the energy demand in winter time. Due to minimum hours of sunlight and accumulation of snow, in winter, the solar panels produce no energy in December and January but in November little energy is produced through the vertical PV panels. The maximum energy production is during May, June and July. As a result, there is transmission of energy back to the grid when the demand is met. It can be seen in April and August that the electricity is sent back to the grid even though the demand is not achieved. Here, an energy storage technology would play a significant role in increasing the reliability of the solar PV system and maximizing solar PV energy usage. In SIMIEN, energy storage batteries are not taken into consideration, such that electricity is fed to the grid rather than be utilized later in need.

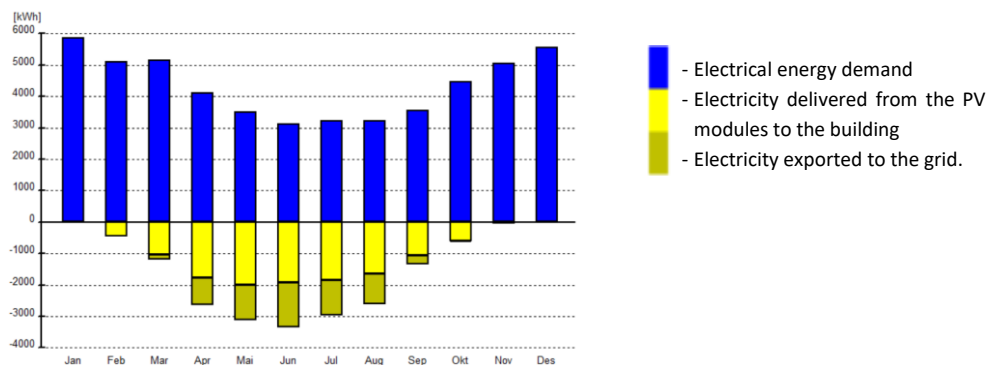


Figure 9. Energy production from PV panels drawn by SIMIEN.

#### 4.5 Economic analysis of the solar thermal collector and the PV system

The price for the solar collectors is estimated to be 1674 NOK/m<sup>2</sup>, and the current subsidy given by Enova is 15,000 NOK for the solar thermal collector. For 64 m<sup>2</sup> area coverage of the solar thermal collectors, the total sum investment cost is about 224,834 NOK. This system is profitable due to the reduction in the monthly bills with a payback period of 15 years and doubled initial investment in about 24 years.

The estimated investment price for the PV panels, with the cost of a fully assembled solar PV system presumed to be 16 NOK/Wp (p=peak), is 440,000 NOK. PV system produces own electricity of 18639 kWh which reduces the electricity bill of the household by consuming the energy of 12598 kWh generated from the PV system and gets income or deduction of 6042 kWh in monthly payment by exporting generated electricity to the grid. The total electricity price of 1.23 NOK/ kWh is presumed to be the cost which is retrieved from Statistics Norway. All the energy that is delivered to the building saves the extra cost. And, the energy cost for purchase of each kWh from the household by the grid company is assumed to be 1 NOK/kWh (Barstad, 2017), which is the maximum purchase rate by power company till date. The system will have a payback period of within 20 years.

## 5. Conclusion

The aim of this report was to assure the possible advantage of solar energy in existing residential buildings in the arctic region. To reach this aim, calculation and simulation models that take solar energy systems into account have been investigated. In both the systems, solar thermal collector and PV modules, the energy demand of the building was met during summer. The solar collector was designed such that the area of the collector was properly sized with respect to energy demand in summer to avoid wastage of energy generated. For building applied PV modules, the architectural suitability area was taken into consideration since it is unfit to install the whole building with PV panels. The structure and orientation of the study case building affect the maximum amount of possible solar utilization since minimum area is exposed to the south direction, resulting in lower energy generation than expected for the number of PV panels installed. The solar thermal collector produces 14314 kWh which satisfies around 68% of DHW demand throughout a year whereas the proposed installation of PV system size generates 18639 kWh where around 67% of the production is self-consumed. When battery storage is considered for the PV system almost 90% of the production can be utilized by the building. Storage of energy during low demand and utilization during high demand can reduce electricity bill, besides that, batteries aid in controlling energy fluctuations. Both the systems contribute to the building in self-sufficiency and less dependency on external power consumption.

## 6. Acknowledgement

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