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Feasibility study for utilization of solar energy in the arctic areas

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Abstract. This research 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. The study on the use of the solar systems in the arctic areas is rare and often doubted. So, to analyze the potential of solar energy, a study case of an existing building block in Narvik, Norway was selected. The performance and function of both the systems were studied and achieved by calculation and simulation models of the thermal system and the PV system separately. The solar systems met the energy demand of *DHW and space heating* during summer due to the availability of the sun for long hours. However, in winter, especially in December and January, the energy production was zero due to snow accumulation and minimum sunlight. The results showed that the solar thermal collector produced about 14315 kWh throughout a year, whereas, the PV system generated an annual energy output of 18640 kWh. Thus, the results suggest considerable potential for solar utilization, however in the current context cost can be a limitation.

1. Introduction

Ever-increasing energy consumption and greenhouse gas emissions from energy production have led to the need for measures that can reduce emissions. The Renewable Energy Directive is a measure of the European Union (EU), with goals for reducing greenhouse gas emissions, increasing renewable energy and improving energy efficiency within 2020 [1]. Norway has a total energy consumption of about 80 TWh in a year with about 40% of the total energy consumption in households and buildings [2]. The high energy consumption is an increasingly discussed topic, especially in old residential buildings, which need 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 the local power supply. Solar energy is a renewable energy source that can be utilized for such a local power supply.

The study on utilization of solar energy in the cold far north is rare and often doubted due to the climatic challenges and varying solar availability. However, the solar radiation in the arctic areas is abundant when the radiation of the whole year is measured. So, this study strives to prove the feasibility of solar energy in the arctic region.

This paper focuses on the possibility of utilization of solar energy for an existing residential building based on calculation and simulation results for the solar thermal system and the solar photovoltaic (PV)

system respectively. Various parameters that influence the design and operation of the systems such as orientation, inclination angle, solar irradiation, solar hours and collector area for both the systems are considered in the study.

2. Literature review

The Arctic region is located at the northernmost part of the Earth with several definitions according to AMAP [3]. The first definition states that the arctic circle runs above the latitude of 66°33′ N, the second is defined as the area north of the region which has an average temperature of 10°C in July. The third definition is based on vegetation boundaries where arctic is further categorized into high arctic, subarctic and low arctic. With reference to the definitions, Narvik is located in Northern Norway, just above the arctic circle and within the subarctic region.

Weather conditions and varying solar availability throughout the year in the subarctic region is low compared to other regions. However, low temperatures and snow are considered beneficial for photovoltaic solar systems, as the solar cells operate efficiently at a lower temperature than in higher temperatures, which as a result minimizes heat loss and the wearing of the system. The standard test condition for determining the 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 [4]. This shows that conditions in the arctic region are favorable for solar energy.

The solar radiation passes through a thick atmosphere in northern latitudes and hits 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^2 per year to 900 kWh/ m^2 per year [5]. Whereas in southern Norway, the maximum solar radiation on a horizontal surface spans upto 1100 kWh/ m^2 per year [5].


Figure 1. Solar irradiation on a horizontal surface in Norway for winter and summer *[5]*.

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

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

2.1. Solar thermal system

The solar thermal heating system transforms the energy from the sun to usable heat, which can be used for space heating and domestic hot water (DHW). This system consists of thermal solar collectors, a distribution system, an accumulator tank for heat storage and a control system as shown in figure 2. 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 the stationary collector is considered for this study as the addition of a tracking system will incur additional cost and complexity to the planned installation. The 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.
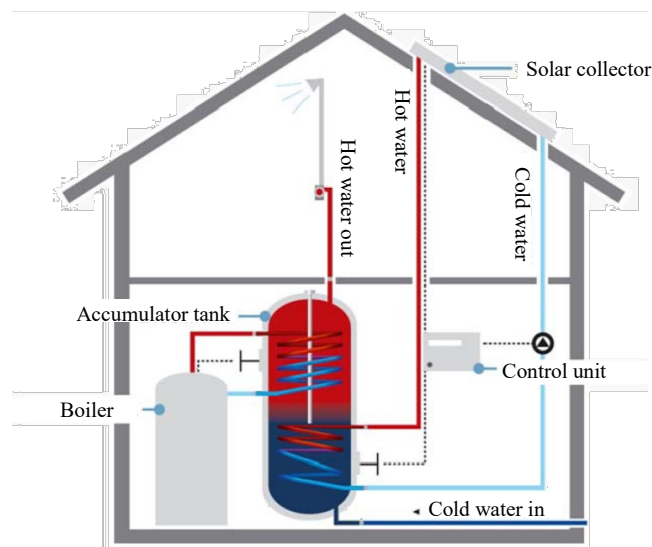
Figure 2. Principle diagram of a solar thermal collector in a building *[6]*.

2.1.1. Flat plate collector. The flat plate collector consists of a transparent front cover, channels and 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. In Norway, a proper system for residential buildings can produce up to 300 – 700 kWh/ m² *[6]*.

2.1.2. Collector's performance and efficiency. According to Zijdemans *[7]*, the efficiency of a solar collector, η_{Sc}, can be calculated using the following equation:

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

Where, η_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/m²K], a_2 is the heat loss coefficient as a result of radiation [W/m²K], G is the solar irradiance of the location [W/m²], T_L is the average liquid temperature within the solar collector [K] and T_A is the ambient air temperature [K].

2.1.3. Solar collector area. Table 1 illustrates the simplified estimation of the required solar collector area.

Table 1. Estimation of solar collector area.

	DHW heating	DHW and space heating
Per person in a multi-dwelling building	$1 - 1.5$ m^2	$1.5 - 2$ m^2
Per 100 m^2 dwelling in a multi-dwelling building	3 - 4 m^2	4- 5 m^2

2.2. Solar photovoltaic (PV) solar system

The solar photovoltaic system converts solar energy to electricity by means of photovoltaics, where photo means light and voltaic means voltage. The system consists of several componensts including PV array and balance of system components. PV array is an ensemble of PV modules that operate as a single electricity generating component. Whereas balance of system signifies all the components except for the PV modules, such as solar inverter, mounting, wiring, instrumentation and control systems to assemble a functioning system [8].

PV systems range from small building-integrated systems to large-scale power stations. There are generally two types of solar PV system preferable for residential buildings: Stand-alone PV system and grid-connected PV system. In this study, only the grid-connected PV system is considered as these are commonly used in residential units. Though only about 1.5% of the solar panels are connected to the grid in Norway [9]. There are two types of grid-connected PV systems available, one with battery storage and the other without battery storage facility. In this paper, a PV system with batteries as energy storage will be focused since the battery stabilizes the electrical fluctuations that occur in a household and improves the overall performance of the solar system.

2.2.1. Grid-connected photovoltaic (PV) solar system

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 [9]. The principle mechanism of the 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 3. This system is regulated under what is known as a 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 (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.

2.2.2. Solar cell efficiency. The efficiency of the solar cell (η) is the ratio of power emitted (P_{max}) from the solar cell and the effect of the incident light (P_{in}) measured under standard conditions *[4]*. In terms of MPP voltage (V) and current (I), the efficiency can be expressed as:

$$\eta = \frac{P_{max}}{P_{in}} = \frac{V_{mpp} \cdot I_{mpp}}{P_{in}} \tag{2}$$

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

$$Total\ Energy\ [kWh] = Total\ power\ [kW] * time\ [h] \tag{3}$$
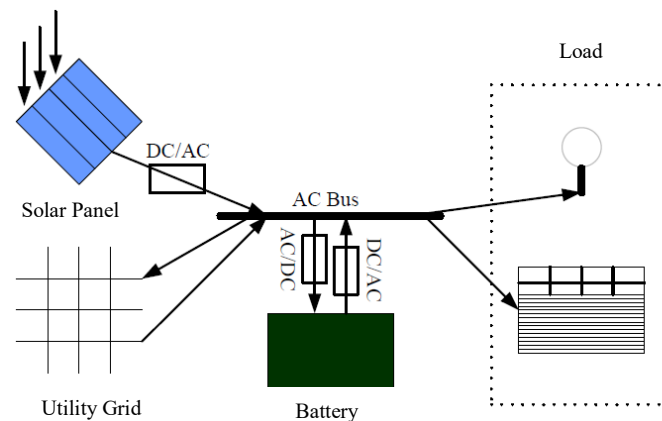
Figure 3. Standard grid-connected solar system *[10]*.

2.2.3. Battery for energy storage. The 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 a 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 [11]. Li-ion batteries are light and compact battery with long cycle life, high energy density, deep recycling characteristics and safe use.

2.2.4. Solar cell technologies today. The solar cell technologies that lead the market today are monocrystalline silicon (mono-Si), multi-crystalline 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. The multi-Si cell comprises of numerous crystal gains 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.

2.3. Obtaining data
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. The accuracy of these parameters plays a vital role in both calculation and simulation. 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 collectors were simulated from PVGIS software. The technical software SIMIEN was used for simulation of PV system which simulates energy use, ventilation and indoor climate in buildings.

3. Research method
The main motive of this study is to analyze whether the installation of a solar system in an existing building will be economically viable in the arctic region. The selected building is considered for the calculation of local energy production through convenient solar installations, in this case, solar thermal collectors and PV modules. The building is a three-story apartment block to be renovated and upgraded that follows the latest Norwegian building engineering regulation standard – TEK17 [12].

Simulation of energy output by solar thermal collectors was executed in the solar calculator which is based upon Bird and Hulstrom's model [13], and Ryan and Stolzenbach's model [14]. The flat collector was selected for the building because it has good insulation property, a larger area of absorption and an aesthetic appearance. However, the drawbacks could be its relatively high heat losses and a higher degree of reflection. The area of the solar collector was calculated by simple calculation techniques using table 1 in section 2.1.3 provided by Zijdemans [7].

In the case of the PV system, the area of the PV modules was determined from a simplified method developed by IEA-PVPS Task 7 [15] known as the estimation of architecturally suitable areas for the solar installation with respect to the floor area of the building. The SIMIEN model of the building that follows TEK17 was modelled by Enerconsult AS, and the model was used for further simulation of the energy output by the PV system. Finally, for the economic analysis, costs 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.

4. The case study building
The characteristics, energy demand and placement of the solar collectors/ modules in the building are studied and analyzed as it affects the overall energy production from both the solar systems.

4.1. Characteristics of the building
The building is a three-story apartment block with a built-up area of 312 m^2. The block comprises of 10 apartments with two staircases and four apartments on each upper floor and two on the basement. The basement also includes storage units for each apartment and laundry. The basement is casted in concrete whereas the upper floors has wooden structure. The walls are cladded with steel plates and the windows are two-layered glass with PVC frame [16].

4.2. Placement of the solar collectors/ modules
The narrow side of the building faces north and south direction, with only possibility to place the system to the east and west sides of the roof which is 27˚ inclined. Regarding façade of the building, south and west facades are considered for PV installations. West façade is selected since there is an open space in the west direction, and maximum solar radiation is received at west facades due to low angle of the sun [17]. The building is not shaded by any nearby building or hill but the shadow from nearby collectors and chimney shafts can make a difference in the output from the system.

4.3. Energy demand of the case study 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^2 respectively per year. The required DHW of the building is 21264 kWh and space heating demand is 19239 kWh.

**Figure 4.** The case study building.

5. Result

5.1. Solar thermal collector system

To determine the feasibility of the system, the area of the solar collector was calculated, 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. Depending upon the number and size of apartments, 32 people are assumed to reside within the building. According to Zijdemans [7] estimation of solar area collector as shown in table 1, the utilization area of DHW and space heating for each person is 2 m^2, resulting in the total solar thermal collector area to be 64 m^2. The amount of energy demand that solar heat can cover depends upon the temperature level on the transport medium. Waterborne floor heating and low-temperature radiators provide better utilization of solar energy than traditional radiator systems.

Table 2. Area of the solar thermal collector.

No. of residents	DHW and space heating in a multi-dwelling	Area of solar thermal system
32	2 m^2	64 m^2

Figure 5 illustrates the total energy production from the proposed solar collector at the roof inclination of 27° facing towards west direction. Also, the total energy production of hypothetical solar collectors 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 14315 kWh on the roof. Though, according to the calculation, façade placement provides a marginally better result with total output production of 15620 kWh.
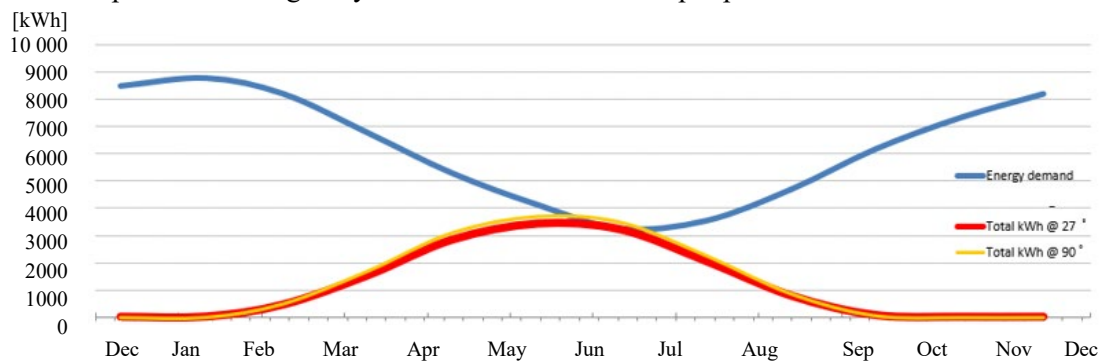
Figure 5. Solar thermal energy production with respect to the energy demand of the building.

5.2. PV system

The viability of the system was first analyzed by the area of the PV modules with respect to a simplified method developed by IEA-PVPS Task 7 [15], where generalized utilization factors for roofs are 0.4 and facades are 0.15 per m^2 built-up area. The built-up area of the building is 312 m^2. With respect to the architectural suitability, the total area of PV panels is 172 m^2. 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 [18]. 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. Table 3 shows the number of PV modules, nominal power (Wp = watt peak) and total annual energy produced by the system. The nominal power is calculated by multiplying the PV area by the efficiency of the Mono-Si cell. Here, the efficiency of Mono-Si is considered to be 20% [19]. The module size of 1.7 m^2 is considered and attached to respective building elements.

Table 3. PV system area and nominal power.

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

The total energy production from the PV modules at roof inclination of 27˚ and vertical façades of 90˚ was 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 the south façade harness more solar radiation than in the west facade. 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.

Figure 6 illustrates a comparison of total energy production from the PV system and the total electricity demand of the building. The variation of solar radiation leads to the over-production of electricity in summertime, and a lack of production to satisfy the energy demand in wintertime. 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 a 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, 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.
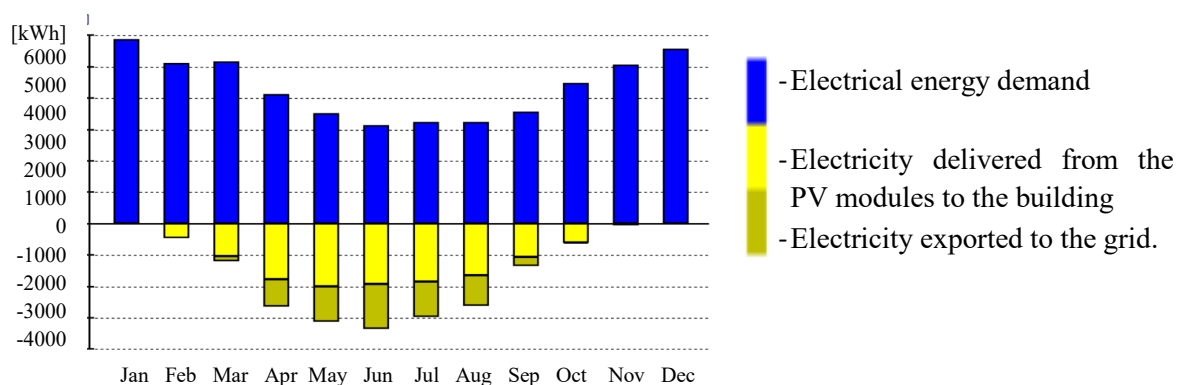
Figure 6. Energy production from PV panels drawn by SIMIEN.

5.3. Economic analysis of the solar systems

The price for the solar collectors is estimated to be 1674 NOK/m^2 [20], and the current subsidy given by Enova SF is 15,000 NOK for the solar thermal collector. The heat production from the solar collector is the amount of the cost saved and utilized by the building. For 64 m^2 area coverage of the solar thermal collectors, the total sum investment cost is about 225,000 NOK. The loan is paid at an interest rate of 2% per year. The expected lifetime of the solar thermal systems is 20 years, while supplementary equipment, such as pumps, steering and tanks can have a lifetime of around 10-20 years. This system is profitable with a payback period of 15 years and can double the 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. The installed PV systems produce electricity

of 18640 kWh which reduces the electricity bill of the household by consuming the energy of 12600 kWh generated from the PV system and gets earnings of 6040 kWh monthly by exporting generated electricity to the grid. According to Statistics Norway [21], the total electricity cost is 1.23 NOK/ kWh. 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 [22], which is the maximum purchase rate by power company till date. At an interest rate of 2%, the system will have a payback period of within 20 years.

6. Discussion
During the process of calculation, simulation and economic analysis some aspects affecting the discrepancies were identified and are as follows:

- Simple calculations and simulation models have been used for determining the size and energy output production of both the systems. The data of solar hours and peak sun hours were entered for the calculation of both the systems. However, the data are not guaranteed. Data from meteorological institute would have been more accurate, but the meteorological institutes have limited stations installed in Norway.
- In the case of the PV system, the SIMIEN model of the case study building was used, which was provided by Enerconsult that followed TEK17. The solar PV system inputs were done based on area calculations, PV cell efficiency, orientation and inclination of the building. But whether the building satisfied the standard TEK17 was not validated.
- Regarding the cost of the systems, they varied depending upon the companies. The costs ranged from 10 NOK/ Wp to 30 NOK/Wp for a complete setup of the PV system. Finally, the price provided by STS solar technologies Scandinavia was chosen.
- The prices provided by different companies had different units, for example, NVE stated that the cost for solar cell installation is 1.7 NOK/ kWh for 15 kWp system [23]. Nevertheless, the cost of the PV modules continues to decline year after year.
- The payback period used in this study is a simple calculation with a defined interest rate that can vary with future years. The payback period also fails to feature several important factors in estimation such as the lifetime of the system, operation and maintenance costs. These parameters are considered in lifecycle costing (LCC), which is the cost of using a PV system during its lifetime.

7. Conclusion
This study aimed to suggest 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 generated energy. 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 case study building affect the maximum amount of possible solar utilization since the 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 14315 kWh which satisfies around 68% of DHW demand throughout a year whereas the proposed installation of PV system size generates 18640 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.

With respect to both the solar systems, the solar thermal system is relatively cheaper and produces more output energy production of 335 kWh/m^2 than PV system with 109 kWh/m^2, even though the size of PV panels is more than double the size of the solar thermal system. The cost of PV panels and even batteries decline year after year providing increasing motivation for the installation of solar systems. Enova supports both the solar systems for individual customers who invest in renewable energy, though when a building is owned by real-estate companies or other companies PV system is not subsidized. Nevertheless, solar technologies create a positive impact on residential buildings by meeting the energy demand of the building and is profitable in the long run.

Acknowledgement

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