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Faculty of Engineering Science and Technology
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Possibility study for utilization of solar energy in Arctic areas

Mulighetsstudie for bruk av solenergi i Arktiske områder

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Mulighetsstudie for bruk av solenergi i Arktiske områder

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

Bakgrunn

Smart Arctic Building er et prosjekt med fokus på bærekraft, energi og smarte løsninger i arktisk klima. Prosjektet er et samarbeid mellom Ofoten Midt-Troms Boligbyggerlag og UiT. Målet er å utvikle løsninger for boligbyggelag slik at energibruken reduseres med fornybare og smarte tiltak. Prosjektet ser på oppgradering av boligblokker i Narvik.

I dag brukes 40 % av netto sluttforbruk av energi i bygningsmassen i Norge. Ved å gjennomføre tiltak i bygningsmassen kan vi erstatte annen forurensende energi, med fornybare energikilder som bidrar til å redusere klimagassutslippene og har lavt klimafotavtrykk.

Energieffektivisering av bygg er et viktig bidrag til at Norge kan utvikle et bærekraftig energisystem som møter våre internasjonale forpliktelser med hensyn til klimagassutslipp de neste tiårene. Satsingen på innovasjon og bruk at ny energi- og klimateknologi er for mange en naturlig vei å gå.

Oppgaven går ut på å kartlegge potensialet for bruk av solen som energikilde i arktiske områder, og hvordan eldre boligblokker i prosjektet Smart Arctic Building kan nyttiggjøre seg av solens energi.

Målet vil være å se etter de mest innovative løsningene som optimaliserer produksjonen på en kostnadseffektiv måte.

Videre skal det gjøres vurdering av lønnsomheten ved utnyttelse av solenergi, utarbeide energi- og effektbudsjett, og økonomisk analyse for de ulike solenergikonseptene sett opp mot ulike bygningsmessige standarder.

Lønnsomheten vil også vurderes med bruk av ulike lagringsmuligheter for energi hvor man blant annet ser på kommersielle lagringsalternativer og skalering av disse i forhold til kostnader.

Fokuset skal være å finne løsninger for utnyttelse av solens energi i arktiske strøk som er realistiske både økonomisk for byggeier/forbruker, og at det er praktisk mulig å installere på eksisterende bygg.

Begrensning av oppgaven

Ingen spesielle.

Arbeidet skal omfatte (men ikke nødvendigvis avgrenses til):

1. Innledende arbeid/litteraturstudium med avgrensninger og definisjoner.
2. Kartlegge potensial for bruk av solenergi i arktiske områder.
3. Beskrive/utarbeide innovative løsninger for optimal utnyttelse av solenergi til boligformål.
4. Gjøre vurderinger og beskrive ulike lagringsmuligheter for solenergi.
5. Vurdere ulike konsept for utnyttelse av solenergi opp mot ulike bygningsmessige standarder.
6. Lønnsomhetsvurderinger.
7. Det skal utarbeides en vitenskapelig artikkel/paper basert på besvarelsen, maks 10 sider. (Artikkelen kan sees på som er kortversjon av hele besvarelsen.)

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Oppgaven gjennomføres i samarbeid med Ofoten Midt-Troms boligbyggerlag og Sweco AS.

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Senest 14 dager etter at oppgaveteksten er utlevert skal resultatene fra det innledende arbeid være ferdigstilt og levert i form av en forstudierapport. Forstudierapporten skal godkjennes av veileder før kandidaten har anledning til å fortsette på resten av hovedoppgaven. Det innledende arbeid skal være en naturlig forberedelse og klargjøring av det videre arbeid i hovedoppgaven og skal inneholde:

- Generell analyse av oppgavens problemstillinger.
- Definisjon i forhold til begrensinger og omfang av oppgaven.
- Klargjøring/beskrivelse av de arbeidsoppgaver som må gjennomføres for løsning av oppgaven med definisjoner av arbeidsoppgavenes innhold og omfang.
- En tidsplan for framdriften av prosjektet.

Sluttrapporten skal være vitenskapelig oppbygget med tanke på litteraturstudie, arbeidsmetodikk, kildehenvisninger etc. Alle beregninger og valgte løsninger må dokumenteres og argumenteres for. Besvarelsen redigeres som en forskningsrapport med et sammendrag både på norsk og engelsk, konklusjon, litteraturliste, referanser, innholdsfortegnelse etc. Påstander skal begrunnes ved bevis, referanser eller logisk argumentasjonsrekker. I tillegg til norsk tittel skal det være en engelsk tittel på oppgaven. Oppgaveteksten skal være en del av besvarelsen (plasseres foran Forord).

Materiell som er utviklet i forbindelse med oppgaven, så som programvare/kildekoder eller fysisk utstyr, er å betrakte som en del av besvarelsen. Dokumentasjon for korrekt bruk av dette skal så langt som mulig også vedlegges besvarelsen.

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Hvis kandidaten, mens arbeidet med oppgaven pågår, støter på vanskeligheter som ikke var forutsatt ved oppgavens utforming, og som eventuelt vil kunne kreve endringer i eller utelatelse av enkelte spørsmål fra oppgaven, skal dette umiddelbart tas opp med UiT ved veileder.

Besvarelsen leveres digitalt i WISEflow.

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UiT – Norges Arktiske Universitet
Institutt for bygg, energi og materialteknologi

Mohamad Mustafa / Raymond Riise

Faglig ansvarlig/veileder

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. The solar systems met the energy demand during summer due to availability of sun for longer hours. However, in winter, especially in December and January, the energy output production was zero due to snow accumulation and minimum sunlight. In rest of the seasons, energy output production from both the systems satisfied the energy demand only partly. 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 of 26 KW size generated annual energy output of 18639 kWh. The price for the solar thermal collector is 1674 NOK/m^2 with a payback period of 15 years. While, the price for a fully assembled PV system is 16 NOK/Wp (p=peak) which has a payback period of 22 years. 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.

Sammendrag

Denne oppgaven undersøker et solvarmeanlegg og et solcelleanlegg som produserer lokal energi ved innkommende solstråling for å møte etterspørselen etter energiforbruk i en boligbygging i den arktiske regionen. En eksisterende bygning i Narvik, innenfor den subarktiske regionen, ble tatt som casestudie for å analysere potensialet for solenergi.

For dette formål ble ytelsen og funksjonen til begge systemene studert. Dette ble oppnådd ved beregning og simuleringsmodell av solvarmesystemet og solcellesystemet separat. Solsystemene møtte energibehovet på sommeren på grunn av tilgjengeligheten av sol i lengre timer. Men om vinteren, spesielt i desember og januar, var produksjonen av energiproduksjon null på grunn av snøakkumulering og minimum sollys. I resten av årstider, energiproduksjon fra begge systemene tilfredsenergibehovet bare delvis. Videre ble det gjennomført en undersøkelse av ulike parametere som påvirker design og drift av systemene. De undersøkte parameterne inkluderer orientering, helningsvinkel, solstråling, soltimer og solfanger/ solcellemoduler arealer for begge systemene. Energilagringsakkumulatortank og tankens størrelse på solfangeren ble diskutert. På samme måte ble grid, batteri som energilagring, solcelleteknologi, pluss-kunder og relevante ordninger for pluss-kunder undersøkt.

Simuleringsresultatene viste at solfangeren produserte ca. 14314 kWh gjennom et år, mens solcelleanlegget med 26 KW-størrelse genererte årlig energiproduksjon på 18639 kWh. Prisen til solfanger er 1674 NOK / m^2 med en tilbakebetalingstid på 15 år. Prisen på et fullt montert solcelleanlegget er imidlertid 16 NOK / Wp (p = peak) som har en tilbakebetalingstid på 22 år. Dermed kan det konkluderes med at potensialet for solenergi utnyttelse er betydelig, men investeringskostnadene for begge solsystemene fortsatt er dyre i dagens marked.

Preface

This thesis is submitted to fulfill the requirements for two-year education in Master of Technology – Integrated Building Technology at the Department of Building, Energy and Material Technology, UiT - The Arctic University of Norway, Narvik campus.

This report is a part of Smart Arctic Building project, provided by Ofoten Troms- Midt Boligbyggelag (OMTBBL) in collaboration with UiT.

I am grateful to my supervisors Raymond Riise and Mohamad Mustafa for their support and guidance during this thesis. I would like to give special thanks to Sigurd Leiros from OMTBBL and Lars Kimo Jørgensen, my external supervisor from Enerconsult for providing all the necessary and helpful information about the project. Furthermore, I would like to also thank the team involved in the *Smart Arctic Building* workshop organized by OMTBBL which motivated me in additional development of the work. I am also grateful to Liudmila Veshniakova, PhD student, for the inspiration and suggestion for further work. Also, thanks to Eirik Lockertsen and Trond Øines for taking time to answer my queries and assisting with valuable information regarding solar systems.

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Stutee Tamrakar

16.05.2019

Narvik

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Acronyms

AC: Alternating current.

AM: Air mass

BAPV: Building applied photovoltaic system

BIPV: Building integrated photovoltaic system

CdTe: Cadmium Telluride

CIGS: Copper indium gallium selenide

DC: Direct Current.

DHI: Diffuse Horizontal Irradiance.

DHW: Domestic hot water

DNI: Direct Normal irradiance.

GHI: Global Horizontal irradiance.

GW_p: Gigawatt-peak.

kWh: Kilowatt hour.

kWh/m^2: Kilowatt hour per meter squared area.

kW_p: Kilowatts peak.

kV: Kilovolt

Li-ion: Lithium ion

Mono-Si: Monocrystalline cells

MPPT: Maximum power point tracking

Multi-Si: Multicrystalline cells

PV: Photovoltaics

PVGIS: Photovoltaic geographical information system (web application)

PVsyst: Photovoltaic system software

STC: Standard Test Conditions

TWh: Terawatt hour.

1 INTRODUCTION

1.1 Background

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 emissions, increasing energy efficiency and increasing the integration of renewable energy production into the power system within 2020 (EU, 2019). 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 renewable energy production. Local production of electricity through solar power is an indispensable part of a passive house or low energy house for them to be self-sufficient in electrical power. Both passive and low-energy house strategies focus on energy efficiency, comfort and affordability. Though for self-sufficiency, passive house depends upon natural ventilation, thermal mass and solar heat, whereas low energy house targets low energy consumption of heating and electricity (Audenaert, et al., 2010).

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. Most of the existing buildings in Norway have been constructed before 2010 as shown in figure 1 below, for example, in the city of Narvik in Northern Norway, a drastic increase in construction of residential buildings started around 1945 after world war II, which means that the prime locations within the core city are already occupied. This shows the need to restore existing buildings rather than demolish them. So, in this work, the possible utilization of solar energy for an existing residential building will be further investigated.

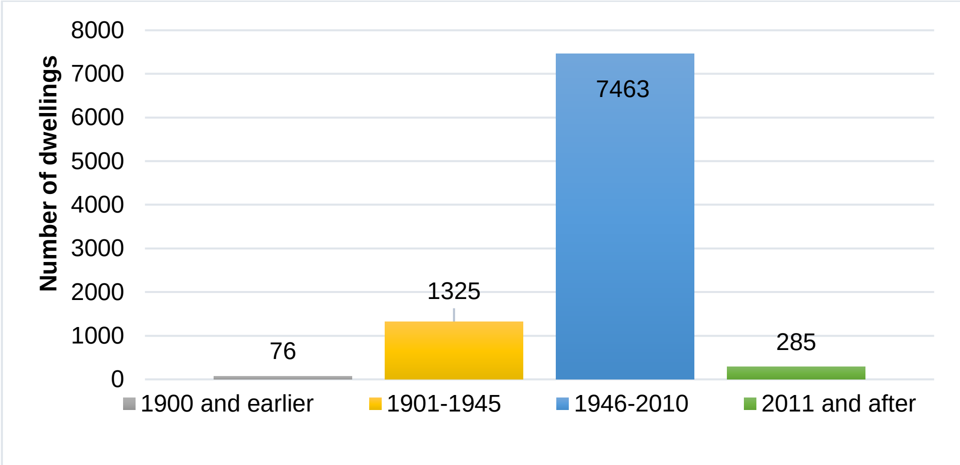

Figure 1. Number of residential units (apartment blocks, houses) in Narvik, Norway (SSB, Statistics Norway, 2019)

1.2 Solar technologies and building energy needs

In a global scenario, the exploitation of solar power and modern energy retrieving technologies have surpassed all expectations in the last decade with the increased production of solar energy. 50% more solar power was installed globally in 2016 than the year before (Teknologirådet, 2017). Whereas in Norway, hydropower is currently the most common energy source, nevertheless, the growth of solar systems is rapid regarding innovation of technology, availability and price which makes it viable for residential buildings connected to the grid.

Solar energy can deliver the energy needs of any building through space heating, cooling, electricity, lighting and domestic hot water (DHW) depending on its active or passive form as shown in the figure 2 below (Andren, 2003). An active solar system has mechanisms such as solar collector and photovoltaic cells that contribute to energy conversion by capturing, storing and then converting solar energy to heat or electricity. In contrast, a passive solar system operates by utilizing direct sunlight for heating and cooling purposes. Generally, large south facing windows and thermal mass are established so that solar radiation can be absorbed, stored and redistributed within the building (Audenaert, et al., 2010). Solar thermal collectors can produce DHW using active solar thermal collectors. Space heating can be provided by direct solar gain through windows creating a greenhouse effect or indirectly by waterborne floor heating. The floor acts as a radiator that transfers heated fluid within a closed loop and recirculates it between solar collector’s accumulator tank and floor (Andren, 2003). Photovoltaic modules provide electricity for lighting and other appliances.

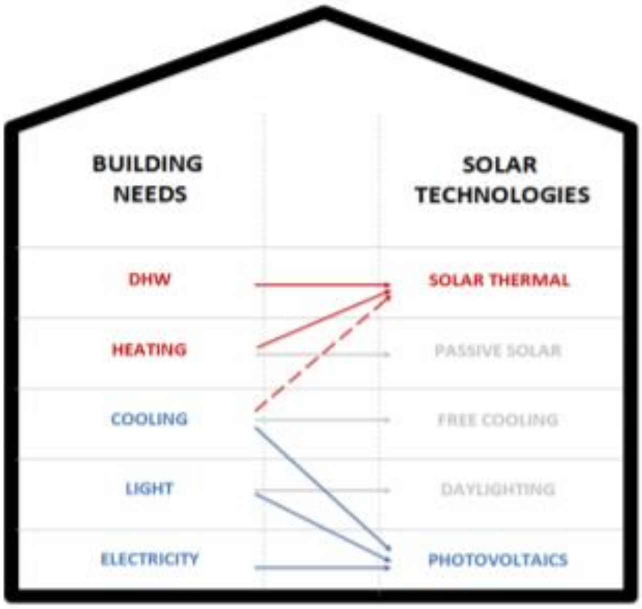

Figure 2. Solar technologies according to building needs (Fraunhofer et al., 2019).

The world needs an energy revolution that requires major investments in new solutions and infrastructure. A building with installed solar PV modules and solar thermal collector indicates innovation and environmental awareness. It helps in satisfying the requirements of energy efficiency with the following advantages (Shaikh, et al., 2017).

- Reduction in carbon emissions.
- Reduction in expenses related to electricity bill and grid rent.
- Enhancement in resilience and reliability of the electricity supply.
- Achievement of high energy class, which in turn increases the value of the property.

1.3 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, which is building block in the sub-arctic region, provided by OMTBBL, 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 decreases year after year. So, preferable components for the solar system are discussed and recommended along with energy storage alternatives, since they affect the efficiency and cost of the system. Finally, the feasibility of both systems for the building block under consideration is analyzed to acquire the investment and payback period of the systems.

1.4 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 designing and dimensioning of both solar systems: PV system and 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 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 reports and drawings of the case building – Beisfjordveien 88 were provided by OMTBBL.

Simulation of energy output by solar thermal collectors were executed in the solar calculator provided by Catch Solar which follows Bird and Hulstroms model and Ryan and Stolzenbach's model (Solar, 2019). The area of the solar collector was calculated by simple calculation techniques using the tables provided in the book Vannbaserte oppvarmings og kjølesystemer (Zijdemans, 2012), and the procedure for calculation and selection of products were recommended based on "Solenergi for varmeformål" report (NVE and KanEnergi, 2008). 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.

1.5 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.
- There is minimum production throughout the year since the elongated part of the building faces east and west, rather than south, which is the best orientation for solar collectors. Also, in winter due to snow accumulation and less availability of sunshine, the production is next to zero.
- The battery bank is not included in the calculation of the payback period of the PV system.
- The investment cost of solar systems and batteries are quite high resulting in high investment cost.

1.6 Thesis outline

This thesis comprises of 6 chapters and chapter 1 explains the necessity and advantages of solar energy in today's world, along with an overview of the types of energy demand in households and information about the existing building study case in Narvik. Furthermore, the problem and methodology of this thesis are explained. Chapter 2 presents a theoretical background about the solar energy and its potential in the arctic region. Whereas, Chapter 3 comprises a literature study of both the thermal and the PV solar systems along with their components. Plus-customer and support scheme for plus-customers is further discussed in this chapter along with price and market of solar installations and relevant Norwegian standards. Dimensioning and simulation result of a solar thermal collector system and a PV system for the case building – Beisfjordveien 88 along with economic analysis are discussed in chapter 4 and discussion, conclusion and further work of this thesis are presented in chapter 5 and 6 respectively.

2 Solar energy potential in The Arctic region

Sun is the source of pure energy which is received by our earth surface directly through solar radiation and indirectly through wind, hydro, biomass, ocean and other forms. The energy radiated by the sun is a consequence of the thermonuclear fusions taking place at the surface of the sun, where hydrogen is transformed into helium (Andren, 2003). This transformation involves a loss of mass, which is converted into energy. Earth receives 15 000 times more energy from the sun than the earth's population spends in a whole year. And the total energy that earth's atmosphere, land and sea absorb is around $3.85 * 10^{26}$ Watt per year (Mertens, et al., 2014). Only a fraction of this hits earth's surface, and only 0.4% to 13% of this fraction of raw solar energy can be utilized with respect to insulation, cloud cover and land covered by humans. Even in Norway, the sun provides 1500 times more energy than the population can utilize. Depending on the location of the earth, the solar energy potential differs from 700 to over 2500 kWh/m^2 per year (Halvorsen, et al., 2011).

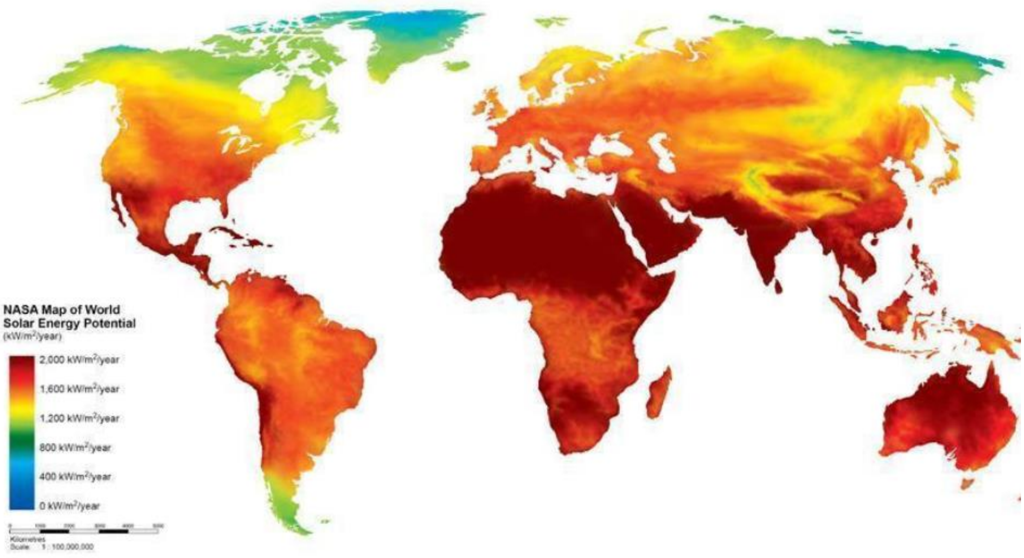

Figure 3. World map of solar energy potential (NASA, 2016).

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. Besides that, the reflection of the solar radiation due to snow contributes to the production of energy through high ground reflected radiation. Due to high albedo, which is the ability of surfaces to reflect light, snow reflects about 90% of the incoming shortwave radiation (Kahl, et al., 2019).

2.1 Solar irradiance

Solar irradiance (SI) is the intensity of incoming solar radiation (insolation) per unit area. SI outside earth has an average power of around 1366 W/m^2, which is measured by satellites and known as the solar constant (Andren, 2003). When solar radiation reaches earth's surface, either the energy is reflected or absorbed by water vapor, ozone and carbon dioxide in the atmosphere. Therefore, there are two types of solar radiation that reach the surface of the earth: Direct radiation and diffuse radiation. Direct radiation is the radiation that travels on a straight line from the sun down to the ground whereas diffuse radiation is the sunlight that has been scattered by molecules and particles in the atmosphere.

Figure 4. Solar irradiation on a horizontal surface in Norway for winter and summer. (Hagos, et al., 2014)

The potential for solar radiation utilization for production of usable energy is lower in the arctic region and varies with latitude, clouds, humidity, day and season. 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^2 per year to 900 kWh/ m^2 per year. On a clear day in summer, direct radiation is about 85% of the total insolation striking the surface and diffuse radiation is only about 15%. Though, when the sun is at a lower angle (e.g. 10˚) especially in winter, the diffuse radiation increases to about 40%. In the context of the northern parts of Norway that lie above the arctic circle, global horizontal irradiation (*GHI*) varies from 1460 kWh/ m^2 per year to 1640 kWh/ m^2 per year in summer and ≤ 20 kWh/ m^2 per year in winter (Hagos, et al., 2014).

In comparison, a new building that follows TEK17 has an energy requirement of 95 - 225 kWh/m^2 of heated utility area per year. This suggests that a normally shade-free Norwegian building receives far more energy in the form of solar radiation than the building uses for a whole year. 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.

2.2 Factors affecting utilization of solar radiation

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

2.2.1 Annual solar hours

Solar hours are the number of hours with sunshine during a day which varies throughout the year. The solar hours are affected by cloudy and rainy days. 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

2.2.2 Peak sun hours

Peak sun hours are the number of hours per day when solar irradiance is 1000 W/m^2 at average. Narvik has approximately 4.2 sun peak hours 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^2 (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

2.2.3 Local solar irradiation

The total solar irradiation from the sun, also known as global horizontal irradiance (*GHI*) for a given surface can be measured by the summation of direct horizontal solar irradiance (*DHI*) and diffuse horizontal solar irradiation (*DNI*) at angle of inclination (β).

$$GHI = \mathrm{DHI} + DNI \ \cdot \cos \beta \tag{1}$$

Values for the annual direct horizontal solar irradiation and diffuse horizontal irradiation have been obtained using PVSYST v.6.77 as follows: DHI is approximately 790 kWh/m^2, whereas DNI is approximately 400 kWh/m^2. Figure 5 below shows the monthly global and diffuse solar irradiation per square meter during a year in Narvik.

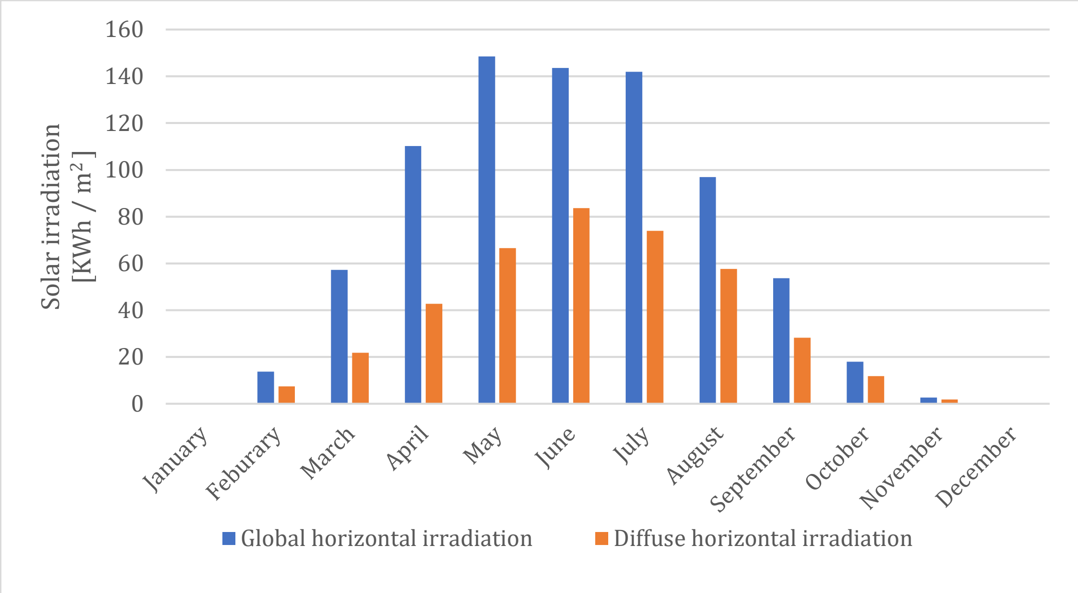

Figure 5. Monthly solar irradiation per m^2 surface area, directed towards south (PYSYST v.6.77).

2.2.4 Sun path diagram

Sun path diagram is the position of the sun in terms of sun height (γ_s) and solar azimuth (α_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. The solar azimuth angle is the angle between the projection of suns center towards the horizontal plane and due south direction. The figure 6 below shows the sun path diagram for selected days during the year for Narvik.

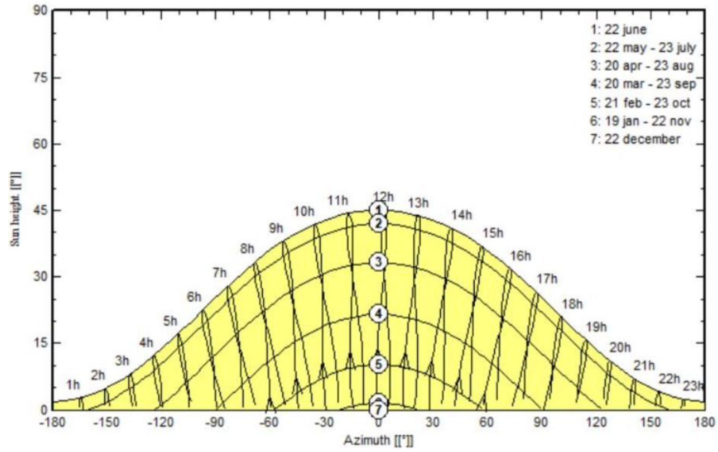

Figure 6. Sun path diagram for Narvik drawn by PVSYST v6.77.

2.2.5 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 (α) and inclination angle of collector (β), as shown in figure 7 below. 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˚.

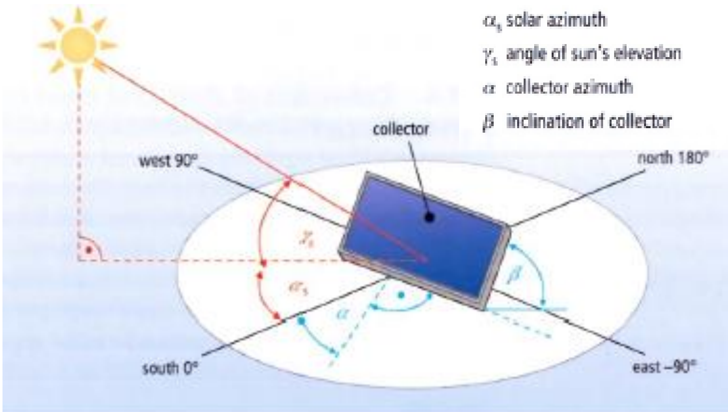

Figure 7 . Angles used in solar technology. (Jha, 2009)

3 Literature study

The possible utilization of solar energy in buildings is harnessed by two main types of technology: solar thermal system and PV system.

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 8 below. Basically, there are two types of solar collectors: concentrating and non-concentrating. A concentrating collector has a concave reflecting surface which captures and focuses the solar radiation to a smaller receiving area. On the contrary, a non-concentrating collector has the same definite area for absorbing and capturing solar radiation. They 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 (Kalogirou, et al., 2004). 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, which will be discussed further in the following paragraphs.

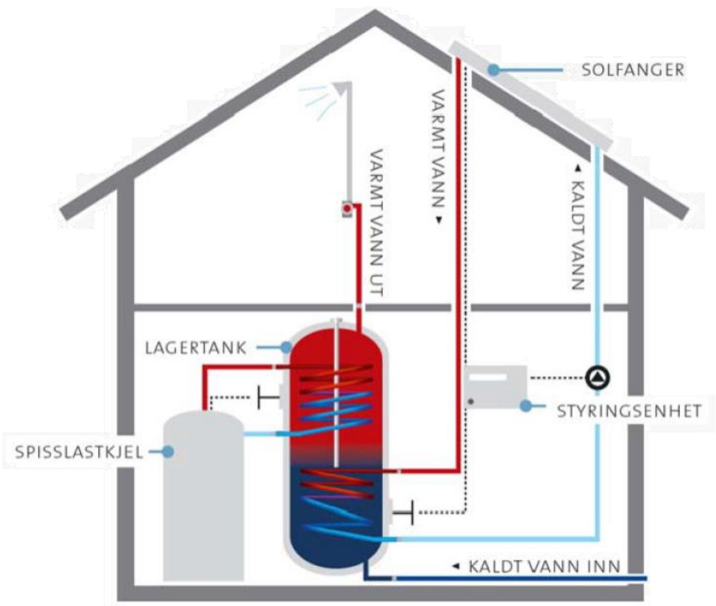

Figure 8. Principle diagram of solar thermal collector in a building. (Halvorsen, et al., 2011)

3.1.1 Flat plate collector

The flat plate collector consists of a transparent front cover, channels and the absorber as shown in figure 9 below. 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 (Kalogirou, et al., 2004). The absorber can be made of copper or aluminium. Whereas unglazed collectors are made of plastic polymers and preferable in warmer climates due to their reduced cost. According to Newtons 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.

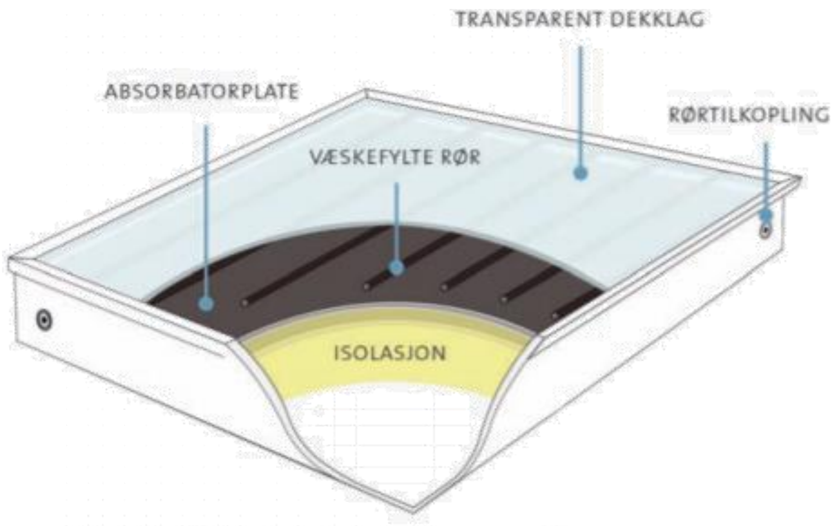

Figure 9. Flat plate collector (Halvorsen, et al., 2011)

3.1.2 Evacuated tube collector

In the case of evacuated tube collector, the absorber is placed within a vacuum-sealed glass tube, as in figure 10 below, so that heat loss from the absorber through convection and conduction is reduced than in flat plate collector. The working mechanism is similar to the heat transfer as explained in the section 3.1.1. In this case, a small quantity of liquid which has a very low boiling point in a copper pipe is heated up by the sun. This liquid then begins to evaporate, and the vapor rises to the top which is cooled down by the manifold, where the cold solar circuit liquid circulates. Then, the vapor condenses and flows back to the bottom of the pipe. As vapor needs more space than liquid, the pressure within the pipes increase, resulting in the phase change from gas into liquid. This process keeps on circulating in a loop. The evacuated tube collectors should be mounted at an inclination angle, particularly from 20˚ to 70˚ for the internal heating medium to maintain circulation (Zijdemans, 2012).

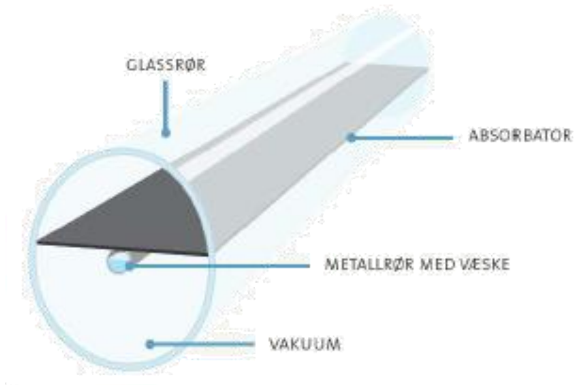

Figure 10. Section through a direct flow vacuum tube solar collector. (Halvorsen, et al., 2011)

3.1.3 Collectors performance and efficiency

The solar collector's efficiency is defined as the ratio of usable heat production, Q from the collector to the amount of solar radiation, I received by the collector (Rabl, 1985).

$$\eta_{sc} = \frac{Q}{I} \tag{2}$$

In other words, the solar collector's efficiency is the ability of the solar collector to utilize incoming radiation. According to (Zijdemans, 2012), the efficiency of a solar collector, η_{Sc}, can be calculated using the following equation:

$$\eta_{sc} = \eta_0 - a_1 \cdot \frac{(T_L - T_A)}{G} - a_2 \cdot \frac{(T_L - T_A)^2}{G} \tag{3}$$

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 measured in W/m^2K, a_2 is the heat loss coefficient as a result of radiation measured in 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].

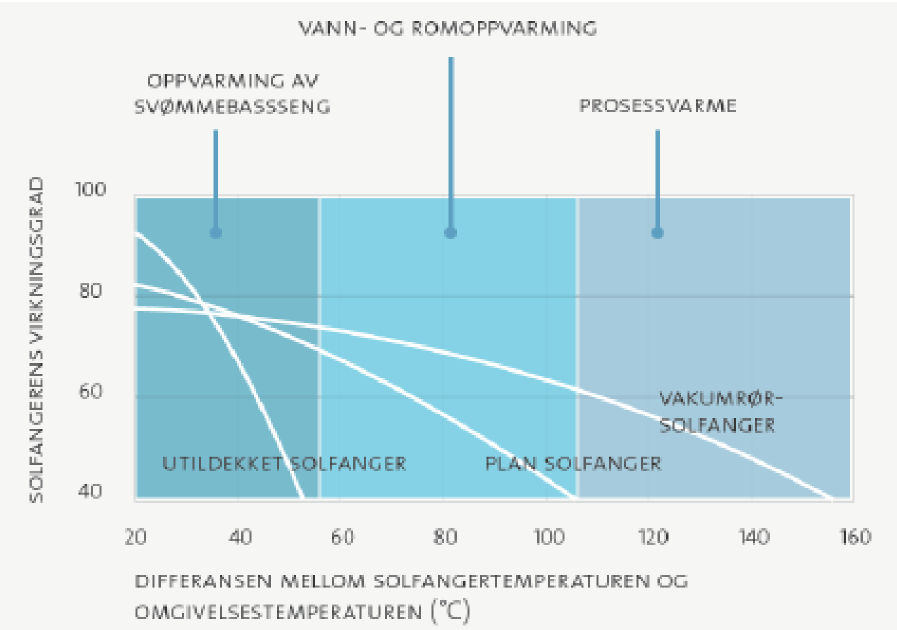

Figure 11. Typical efficiency characteristic curves for different solar collectors. (Halvorsen, et al., 2011)

Typical efficiency characteristic curves and temperature level of different application area for evacuated tube collector, flat plate collector and low-temperature collector are shown in the figure 11 above. For the flat solar collector, the temperature of water needs to be about 30 – 80 ˚C, whereas, for vacuum tube, the water temperature needs to be about 50 – 150 ˚C (Halvorsen, et al., 2011).

In Norway, a proper system for residential buildings can produce up to 300 – 700 kWh/ m^2 (Halvorsen, et al., 2011). This assumes that all heat energy produced in summer can be utilized. The solar system should be sized appropriately such that all the solar radiation received during summer is fully utilized. This helps in adequate energy production per m^2 and low heat loss in the accumulator tank.

3.1.4 Solar collector area

According to (Zijdemans, 2012), a simple calculation method for estimation of the required solar collector area is given by following equation 4.

$$A_{abs} = \frac{Q_{demand} \cdot SF}{Q} \qquad [m^2] \tag{4}$$

Where, A_{abs} is the absorber area dependent upon total heat demand (Q_{demand}), desired solar fraction (SF) and collector yield (Q).

However, 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^2	1.5 – 2 m^2
Per 100 m^2 dwelling in a multi-dwelling building	3 - 4 m^2	4- 5 m^2

3.1.5 Accumulator tank for heat storage

The storage of heat is necessary for the solar collector system since the amount of energy generated does not match the heat demand of the building and varies according to season and weather condition. There are different types of heat storage available, however, the most common means to store heat is liquid. In a household, the types of heat storage systems used are short-term and long-term systems. The short-term heat storage system is required to store heat in hot accumulator tanks with heat exchanger linked to the solar collector over a period of few days. Whereas the long-term heat storage systems can compensate with seasonal fluctuations for storing heat until use. Such systems are usually relevant for large solar heating system with connection to district heating. A high and slim accumulator tank will be beneficial for the system under consideration, as it has good insulation layer in the tank. The size of the tank can be determined by heat demand, type of collector and heating requirement of the building. The following table 4 provides a simplified estimation for the size of storage tank volume in a solar thermal heating system for multi-family dwelling (Zijdemans, 2012).

Table 4. Storage tank volume (Zijdemans, 2012).

Storage tank volume	**DHW heating**	**DHW and space heating**
Per dwelling in a multi-dwelling-building	200 – 300 liters	300 – 500 liters
Per 100 m^2 dwelling in a multi-dwelling-building	600 – 500 liters	600 – 800 liters

3.2 Photovoltaic (PV) solar systems

The photovoltaic (PV) system converts solar energy to electricity by means photovoltaics, where photo means light and voltaic means voltage. This system consists of several components 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 (Andrews, et al., 2013).

PV systems range from small building-integrated systems to large-scale power stations. There are generally two types of solar PV system preferable for dwellings: Stand-alone PV system and grid-connected PV system. Stand-alone systems are often used in places without access to the electrical grid, for example, cabins in Norway, remote areas or rural areas in developing countries for basic household electrical usage. In such systems, there must be a battery for energy storage to provide stored power at the time of necessity. In the case of grid-connected systems, these are commonly used in residential units. Though only about 1.5% of the solar panels are connected to the grid in Norway (Yang, et al., 2010). There are two types of grid-connected PV systems available, one with battery storage and the other without battery storage facility. In this thesis, 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.

3.2.1 Grid-Connected solar PV 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 (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. 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 are further discussed in section 3.4. 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.

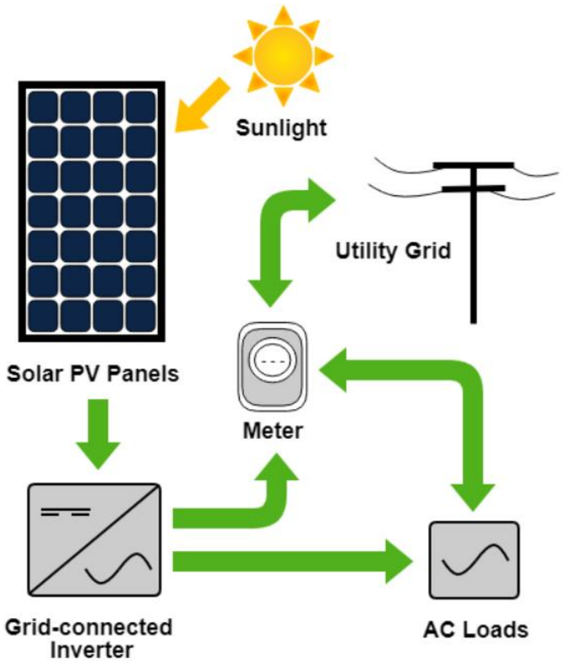

Figure 12. Standard grid-connected solar system (Humphreys, 2019).

3.2.2 Utility grid

A utility grid is a combined network of distribution systems that transmits electric power to the consumers. Today's power system has large production facilities and transmission of electricity over long distances to the consumers. In Norway, the transmission grid is divided into three voltage levels: main grid, regional grid and distribution network. The main grid has a voltage level of 132 – 420 kV that transports electricity from large-scale power production to the regional network. The regional grid is a link between the main grid and the distribution network with a voltage level of 33 – 132 kV. The distribution network distributes electricity to customers such as households, businesses and smaller industries and has a voltage level of 0.23 to 22 kV (OED., Kraftnett, 2019).

3.2.3 PV panel

The PV panel includes one or more PV modules that are assembled, and these PV modules consist of PV cell circuits sealed in a protective laminate. These photovoltaic cells, also known as solar cells, convert solar radiation to electricity. A p-n junction fabricated in a layer of a semiconductor forms a photovoltaic cell as shown in figure 13 below. When an incoming photon has energy equal or larger than the band gap of the solar cell material, the photon may be absorbed in the material. This generates an electron-hole-pair, where the electron signify as a negative charge and hole signifies a positive charge. Then the electron flows through the external circuit by connecting an external circuit to the cell and combine with the hole on the p-side creating an electric current (Jha, 2009).

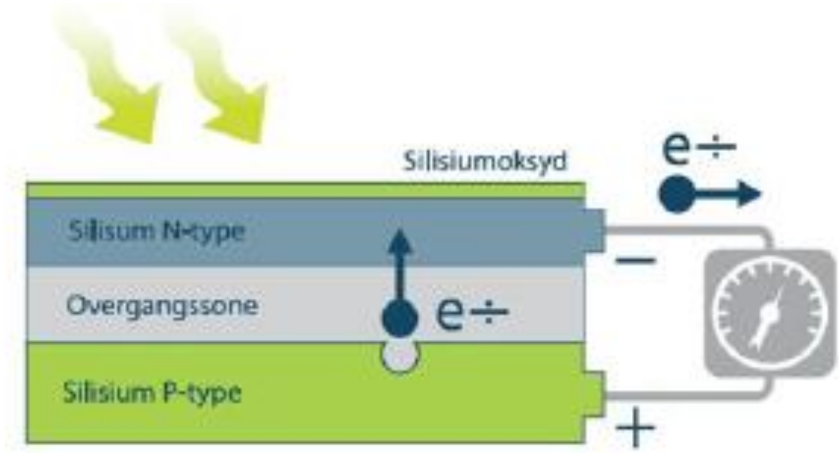

Figure 13. Generation of electric current in a solar cell (Halvorsen, et al., 2011).

Usually, solar modules have several solar cells interconnected in series or parallel, to meet the demand requirements in terms of power output, current and voltage. A single solar cell can generate an electric voltage in the range of 0.3 to 0.6 volts. By connecting solar cells serially in a solar module, voltage contributions from each solar cell are summed to a higher voltage, whereas in parallel connection, the current output of the module increases and in both cases the power output of the solar module increases. The power output and current output against module voltage of a solar module which demonstrates possible maximum power output (P_{MPP}), as a function of current and voltage, and indicates how current and voltage are changed by variation in solar radiation.

The current and voltage are reduced by reduced solar radiation, which means that possible power production is also reduced. The values in figure 14 are based on a temperature of 25ºC, where the higher temperature will reduce the maximum effect (Jha, 2009).

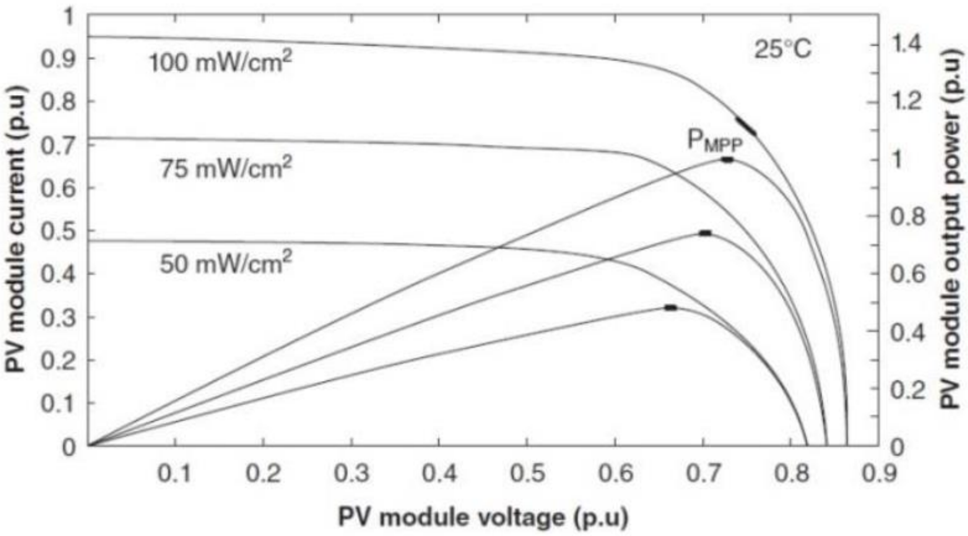

Figure 14. Power curves and characteristics of solar cell (Jha, 2009).

The point maximum power point (P_{MPP}) specifies the point where the possible power output is highest. The possible power generation depends on solar radiation, temperature, latitude, and maximum power generation. The standard test conditions (STC) indicates the efficiency of solar cell modules and are specified by irradiation of 1000 W/m^2, an air mass (AM) 1.5 spectrum and cell temperature of 25˚C. Watt peak (Wp) or nominal power is the most used term to rate the performance of solar cells and is the maximum power output produced by the PV module under STC. 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:

$$\eta = \frac{P_{max}}{P_{in}} = \frac{V_{mpp} \cdot I_{mpp}}{P_{in}} \tag{5}$$

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

$$Total\ Energy\ [KWh] = Total\ power\ [KW] * time\ [h] \quad (6)$$

3.2.4 The inverter

The main purpose of the inverter is to convert DC power produced by the solar PV to AC current, in order to match the power requirements of the load such that electricity is utilized by appliances within the building or fed into the grid. Other benefits of an inverter are adjusting the frequency of the output AC power, performing maximum power point tracking (M_{PPT}) to take full advantage of the energy generation from the PV system and controlling the effective value of the output voltage. Most common types of inverters are string inverter, central inverter, microinverter and battery-based inverter. String inverters are connected to a couple of strings of PV modules and ensures minimum risk to the PV system. This is because when one inverter disconnects or stops, the PV system can still supply power from the rest of the string inverters. A string inverter is preferable for residential or small commercial buildings since they have capacities that range from 1 kW to 8 kW. This inverter operates approximately at the MPP of the PV system, and the efficiencies vary from 90% to 96% at full load. For the size of the inverters, the efficiency and the ability to withstand the overload condition must be considered.

Net metering

Net metering, also known as net billing, refers to both purchase and sale of electricity according to electricity usage and production from the solar system. Installation of a smart power meter is necessary which can show hour by hour energy consumption along with peak power usage. This aids in getting actual data about electrical production and demand. The customer must pay only for the consumption. When excess electricity is sold back to the grid by a plus-customer, either there may be positive payment or reduction in monthly electricity bill, but this may vary according to suppliers.

3.2.5 Battery for energy storage

Most relevant energy storage alternative in a grid-connected PV system to save surplus electricity in a household is a battery and can be used as a backup when there is power interruption in the utility 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. The battery energy storage depends upon various factors such as depth of discharge (DoD), efficiency, capacity and power which determines the effectiveness of the battery. And in a grid-connected system, charging and discharging of the battery occurs frequently and rechargeable lithium-ion (Li-ion) batteries are the best option among other battery types for the grid-connected system (Dogger, et al., 2011).

Apart from Li-ion batteries there are lead-acid batteries and saltwater batteries which are popular in the market today. Lead acid batteries are mostly used in stand-alone systems since the battery has lower DoD, a shorter life span and are least expensive than other battery types. Whereas, the saltwater battery is new energy storage which does not contain heavy metals but depends on saltwater electrolytes. These batteries can be easily recycled and are safe for the environment because of their non-toxic, non-corrosive and non-flammable qualities. However, saltwater batteries have been used in only a few projects in Norway (Røine, 2019).

Li-ion battery, on the other hand, is light and compact rechargeable battery with long cycle life, high energy density, deep recycling characteristics, higher efficiency and safe use (Dogger, et al., 2011). 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 (Marinez-Laserna, et al., 2016). When the capacity of an EV battery reduces to below 80% of the rated capacity, the battery reaches end-of-life and can be recycled and reutilized as a solar PV energy storage. The research on second-life battery pack of 10 kWh for a household with grid-connected PV system of 2.16 kW size was executed in 2017, and the result showed the battery system was able to accomplish 64% to 100% decrease of grid consumption. (Tong, et al., 2017).

Manufacturers of EV such as Nissan and Tesla have introduced battery banks as energy storage systems. Tesla Powerwall battery bank has a capacity of 6.4 kWh and 13.5 kWh whereas, Xstorage of Nissan has three models of lower capacity: 4.2 kWh, 6 kWh and 10.8 kWh. These recycled batteries aid households by storing electricity in the battery when the power is cheap, balancing energy consumption peaks and delivering a uniform load to the utility grid.

In the case of plus-customers, the payment is done for excess energy per kW per hour either as fixed price or spot price. Though the challenge is that battery banks are expensive and, in the future, if the prices decrease along with tariffs, the possibility of storing energy is beneficial for plus-customers.

3.2.6 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. In 2017 the global production of PV production was 97.5 GWp where about 32.2 GWp of these were mono-Si cells, 60.8 GWp were multi-Si cells and about 4.5 GWp were thin- film cells as shown in figure 15 below. (Fraunhofer ISE, 2019). 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 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.

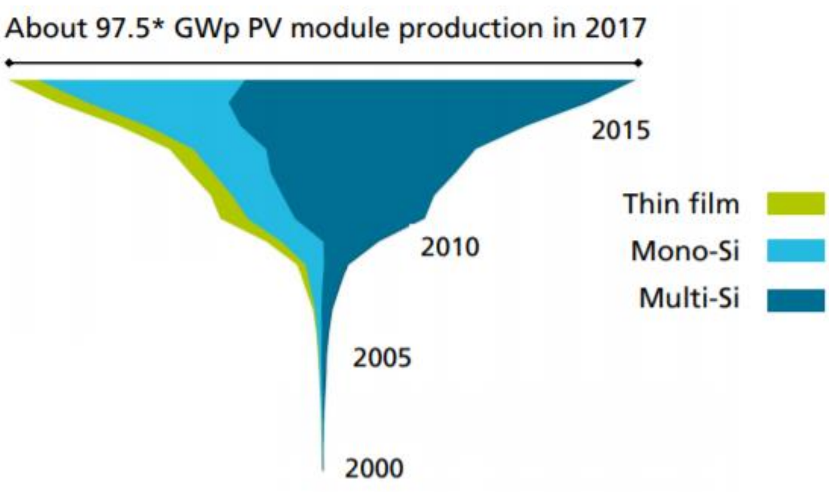

Figure 15. Annual PV production in 2017. (Fraunhofer ISE, 2019)

Minimal use of thin layers of photovoltaic materials are used in thin-film cells. The thickness of these films is about 1 µm, so much less material than of silicon wafers of 200 – 400 µm thickness. There are numerous types of thin film cells in the market today: gallium arsenide (GaAs), copper indium gallium selenide (CIGS), cadmium telluride (CdTe) and amorphous silicon (a-Si). Thin film cells are less efficient and hence use more roof space, but they perform better in low light conditions. Though only small area GaAs cells have been made since it is expensive, resulting in use in space applications (Green, at el., 2018).

Emerging solar cells include perovskite cells, solar PV glass and dye-sensitized cells and organic cells. Although the production process has given a variable result, due to low production costs and increasing cell efficiencies, these solar cells have a bright future. Extensive research has been conducted to improve the conversion efficiency of solar cells. However, it should be considered that the conversion efficiency of a solar cell is usually higher than the efficiency of the solar panel. Table 5 below shows the solar cell efficiencies in the laboratory.

Table 5. Solar cell efficiencies. (Green, at el., 2018)

Solar Cells	**Record of lab cell efficiency**	**Module efficiency**
Mono-Si	25%	22.7%
Multi-Si	22.3%	16.5%
CIS/CIGS	22.9%	14%
CdTe	21%	10%

3.3 Factors affecting the solar system on the building

3.3.1 Shading

The risk of shading must be considered while planning a system that utilizes solar energy. Shadow from the horizon affects only direct radiation whereas shadow from the objects nearby has great influence, especially shadow casted by nearby modules can make a huge difference in the output from the system (Andren, 2003).

3.3.2 Ventilation

Ventilation gap between the building and the panels must be considered for improving the efficiency of the panel. There may be condensation or some water at the back of the module in the future, hence a small gap between roof and PV installation will be appropriate (Andren, 2003).

3.3.3 Derating due to snow and dirt

The output of the PV module can be reduced because of dirt and snow on the surface of the module. The actual value of derating is dependent upon location. There are several new solutions provided each year for improvement in removing snow and dirt over the panels. In case of vertical facades, the snow will not accumulate on the modules, however on inclined roofs, snow may either fall off or must be removed as it can damage the system (Andren, 2003).

3.3.4 Format of solar modules

Standard solar modules are approximately 1 x 1.7 m^2 which will not fit properly in between window openings. Customization of the solar modules can be done but only similar modules can be connected electrically, resulting in the placement of solar modules unpleasing visually.

3.3.5 BAPV

Building applied photovoltaic system (BAPV) are regular solar PV system that is installed on a completed existing building whereas building Integrated photovoltaic (BIPV) system are solar modules integrated into the building elements such as roof tiles, glass facades, sun shading, atriums, etc. In the case building, BAPV system will be utilized for assembly of a complete solar PV system with PV modules laid to minimize cable lengths and electrical losses. BAPV should be introduced earlier in the planning process with experts for assuring good and optimum integration.

3.4 Plus-costumer scheme

Norwegian Water Resources and Energy Directorate (NVE) defines "a plus customer as an end user with consumption and production behind the connection point, where the input power at the connection point does not exceed at any time beyond 100 kW." A plus customer can always have maximum input of 100 kW in the network. Grid companies check the input power through measurement data to verify whether the limit is not exceeded. The customer will no longer be a plus customer if the input fed to the grid is over 100 kW, and then must pay tariffs for feed (NVE., Pluskunder, 2019).

NVE have introduced plus-customer scheme so that plus-customers are excused from the regulations for power producing units. The scheme needs plus-customers to have an agreement with grid company to sell their surplus production, where plus-customer agreement is between grid company and consumption consumer, who have installed a production source (solar system installations). The grid company purchases the power fed into the grid hour by hour, which can compensate for the losses in the network. Besides that, the plus-customer is required to have smart feeding system or smart power meter that handles input and output measurements, so that power company only charges the customer for power fed into the network, and only the tariffs for the power that plus-customers deduct from the grid line (NVE., Pluskunder, 2019). Here it is worth noting that NVE has stated that it will introduce requirements for power tariffs. This means in practice that the plus customers will have to expect to get a network rental tariff for withdrawals from the network that can vary over the year and over the day. The factors that will promote the development towards a smarter network and own electricity production are given below.

3.4.1 Smart power meters (AMS)

Smart power meters will contribute to more accurate settlement of power consumption for private customers, as plus-customers will be charged for their actual electricity consumption. AMS will give the customers exact information about their consumption and ensures that cheap local energy can be used when prices of purchased energy are at their highest. Smart electricity meters will be installed in all Norwegian households within 2019 (AMS, 2019).

3.4.2 Elhub

Elhub is a national data hub that contains all measurement data of electricity consumption per consumer in Norway, and has access to consumers, network companies and power companies. Elhub is being developed by Statnett with the aim of ensuring efficient exchange of measurement values. The registered electricity consumption in the smart meter is transferred to Elhub which will be available for monitoring to the grid company and consumer in all Norwegian households by 2019 (NVE., 2018). Until Elhub is fully in operation, grid companies will purchase surplus power. When the Elhub is in operation, same power supplier must be chosen for both purchase of electricity and sale of the excess production.

3.4.3 Plus-customer support scheme

Today, there are two support schemes relevant for plus-customers who produce renewable solar energy: investment support scheme from Enova and electricity certificate scheme.

Enova supports customers who produce their own electrical and thermal renewable energy. The owner of a local production unit can receive grants for the installation of solar systems. In case of thermal collectors, a consumer can receive support of 15,000 NOK plus 5000 NOK if the accumulator tank is also installed. Also, 10,000 NOK is granted when waterborne floor heating is introduced to the building. Besides that, installation of PV modules for production of electricity can receive grants up to a maximum of 28,750 NOK for consumers who produce their own energy (ENOVA, 2016). Enova's support scheme may vary between individual consumers and real-estate companies as such businesses are covered under electricity certificate scheme. However, such support scheme is a motivation to increase the number of buildings with their own energy production.

The electricity certificate scheme is a collaboration on a Norwegian-Swedish support scheme where NVE administrates the Norwegian portion of the scheme. Solar power with entire production of every MWh produced by preapproved power system receives an electricity certificate. A registration fee of 15,000 NOK for systems that produce below 100 kW is required to participate in this scheme. This scheme is feasible for companies rather than small individual plus-customers (OED, 2014).

3.5 Price and market of solar installations

The price for electricity plays a vital role in profitability of the system. The average price of electricity for Norwegian households in 2019, excluding taxes and grid rent is 54.8 øre per kWh. The overall average price of electricity including grid rent and taxes amounted to 123.4 øre per kWh (SSB, Statistics Norway, 2019). However, the prices largely vary depending upon the grid company and location of the building. Household customers in Northern Norway are exempted from VAT, while companies and companies need to pay the VAT. In case of prices for surplus electricity fed back to the grid, power companies, such as Smart Energi and Otovo have offered 75 øre/ kWh and 1 NOK/ kWh for surplus flow respectively (Barstad, 2017). However, prices could more less rely upon the company that the customers have chosen and, also on network losses due to power production increment or reduction.

The prices of a fully installed solar system vary widely. STS solar technologies Scandinavia has made an estimation of 14 – 18 NOK/ Wp (p= peak) for a small scaled solar system. Whereas the price provided by Catch solar for solar collector is NOK 1674 per m^2. Though according to NVE, the cost of solar cell installation is 1.7 NOK/ kWh and solar collector is about 0.55 NOK/kWh (Sidelnikova, et al., 2015). Nevertheless, the cost of the PV modules continues to decline year after year. And within 2025, the costs of the PV modules are expected to reduce up to 20-35% (Thorud, et al., 2015).

In order to calculate the feasibility of investing in solar thermal collectors or PV systems, it is imperative to estimate the pay-pack period, on the basis of the net present value. The net present value method, as the name indicates, is used for calculating the profitability of the installations based on the present value of future discounted cash flows (SINTEF et al., 2018). The discount rate is individual, determined mainly by the investor and depends on the projects risk and the investors expectation of financial dividend. The formula for present value is as follows.

$$NPV = -I + \sum_{t=1}^{n} \left(\frac{FV}{(1+r)^t} \right) \tag{6}$$

Where, I = Investment cost, FV = Future value, r = rate of return, t = number of years.

3.6 Norwegian Standards

3.6.1 NS3031:2014

The Norwegian standard NS3031:2014 is the standard for calculating energy requirements in buildings. The *net energy demand* is defined as the total energy demand for all the energy services, such as lighting, DHW, space heating, ventilation fans, water pumps and cooling in a building. The average energy use in households was 47.6 TWh in 2016, with the largest portion of the overall energy consumption used in DHW as shown in table 6 below. Electricity generates 70 – 80% of the energy used to heat buildings, depending on various factors including prices (OED., Energifakta Norge, 2019).

Table 6. Standard values for annual demand from NS3031:2014.

Building Category	**Lighting**		**Household appliances**		**Hot water**	
	W/m^2	kWh/ (m^2 year)	W/m^2	kWh/(m^{2}year)	W/m^2	kWh/(m^{2}year)
Building block	1.95	11.4	3	17.5	5.1	29.8

3.6.2 TEK 17 energy requirements

TEK 17 is the building engineering regulations that specify the minimum requirements for construction works. The energy requirements in TEK 17 is relevant for the use of solar energy states as follows. In the second paragraph of § 14 -4: Requirements for solutions for energy supply, it is stated that building with over 100 m^2 heated usable floor area should have energy-flexible heating systems and be improved for use of low temperature heating solutions. This can be a good solution for smaller buildings to utilize low temperature renewable heating solutions.

3.6.3 NEK 400 for building installations

NEK 400: 2018 is the standard for design and execution of electrical low voltage installations. In the normative supplement 712C, the impact of the solar installations installed on the roof are stated. Roof area where placement of solar modules are considered, the PV modules should be mounted at a distance of ≥ 1.0 m from the outer edge of the roof and ≥ 1.25 m from the fire separator protruding above the roof surface.

3.6.4 Energy labeling of buildings

Energy labeling schemes are based on regulations on energy labeling of buildings and energy assessment of technical facilities. The scheme consists of energy and heating character and provides a good indication of energy standard of a home which describes what type of energy and how much energy is delivered to the building (Energimerkeordningen, 2015). The energy rating is dependent upon energy delivered for the household. A good character is achieved at low energy requirements and installation of energy systems that contribute to higher efficiency, such as PV panels. The heating grade is affected by the source of heat produced. Households that use fossil fuels or electrical energy for heating have a low character. Installation of solar thermal collector can improve the heating grade and the best grade is achieved when a maximum of 70% is covered by renewable energy.

4 Case – Beisfjordveien 88, Narvik

4.1 Characteristics of the building

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.

Figure 16. The case study building - Beisfjordveien 88

The building is located at Øra on the outskirts of Narvik and was originally erected in 1961 (Leiros, 2018). It is a wooden structure except the basement which is casted in concrete. Three out of four walls are cladded with steel plates while the remaining wall is cladded with eternite plates. There are two types of windows with two-layered glass and PVC frame, and doors are made of aluminum. It has three floors among which the lower floor is basement (partly below ground) and upper floors are above 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 built-up area of the building is 312 m^2. The table 7 shows the areas of apartments on the building along with an estimated number of residents according to the number of bedrooms available.

Table 7. Area of apartments and estimated number of residents in the case study building. (Leiros, 2018)

Apartments	**Number of apartments**	**Number of residents**	**Primary apartment area [m²]**	**Total area [m²]**
A Apartments	4	16	71.9	287.6
B Apartments	4	12	58.2	232.8
Basement Apartments	2	4	46.3	92.6
Total Area	**10**	**32**		**613**

4.1.1 Placement of the solar collectors

The narrow side of the building faces north and south direction, with only possibility to place the system to 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 at the west direction, and maximum solar radiation is received at west facades due to low angle of the sun as discussed in section 2.2.4 (Page, 2012). 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.

Figure 17. Roof view

4.2 Energy demand of the building

According to measurement data provided for the case building by OMTBBL, the energy demand of the building is 216 kWh/ m^2 year. Though this value is for the building before it has satisfied the building standard TEK17.

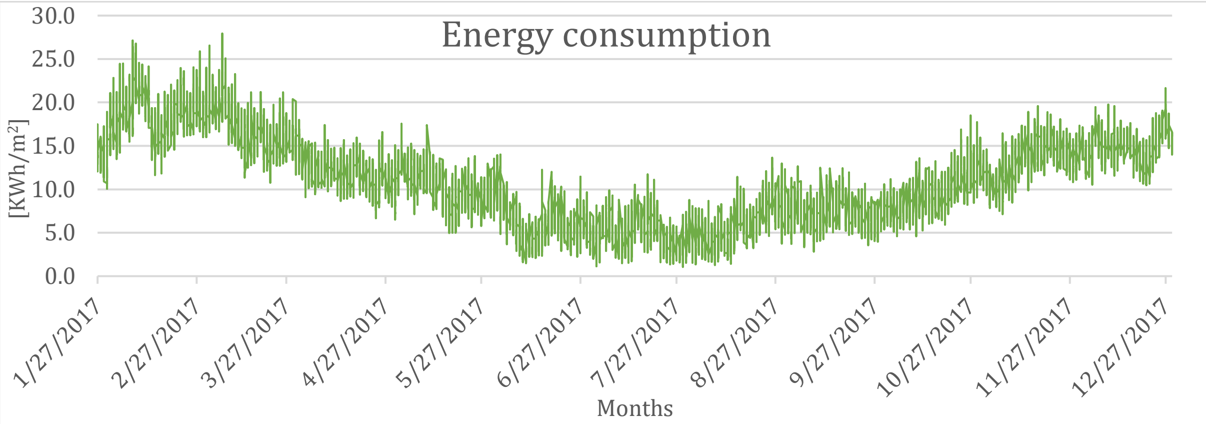

Figure 18. Result of electricity load data for Beisfjordveien 88. (Leiros, 2018)

The following table 8 shows the energy simulation, total energy demand and specific energy demand per year in SIMIEN, which follows TEK 17. The total net energy demand of building is 98.8 kWh/ m^2 year.

Table 8. Energy budget of the building simulated in SIMIEN.

Energy budget real values		
Energy post	**Energy needs (kWh)**	**Specific energy needs (kWh/m^2)**
1a Room heating	19239	26.9
1b Ventilation heat	5394	7.6
2 Hot water (Tap water)	21264	29.8
3a Ventilators	2769	3.9
3b Pumps	601	0.8
4 Lighting	8758	12.3
5 Technical equipment	12509	17.5
Total net energy needs sum 1-5	**70534**	**98.8**

4.3 Solar thermal system

4.3.1 Dimensioning and simulation result of solar thermal collector

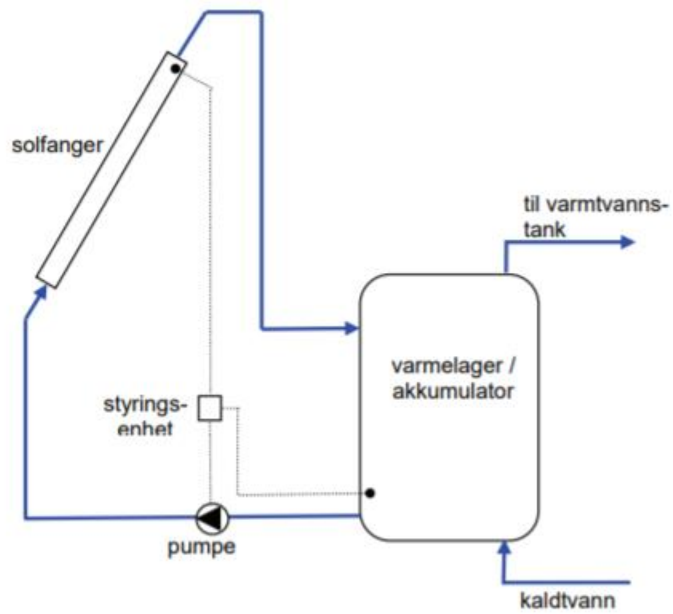

Figure 19. Working mechanism of thermal solar collector. (Andresen, 2008)

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 3.1.4 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 9, the total solar thermal collector area is 64 m^2 with respect to utilization of DHW and space heating of 2 m^2 for 32 residents.

Table 9. Area of solar thermal collector.

No. of residents	DHW and space heating in a multi-dwelling	Area of solar thermal system [m^2]
32	2 m^2	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. The absorber area, orientation and angle of solar collector also affects the degree of coverage of energy demand.

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). The required DHW of the building is 21264 kWh and space heating demand is 19239 kWh as shown in table 8.

4.3.2 Solar thermal collector's energy production

The table 10 and figure 20 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.

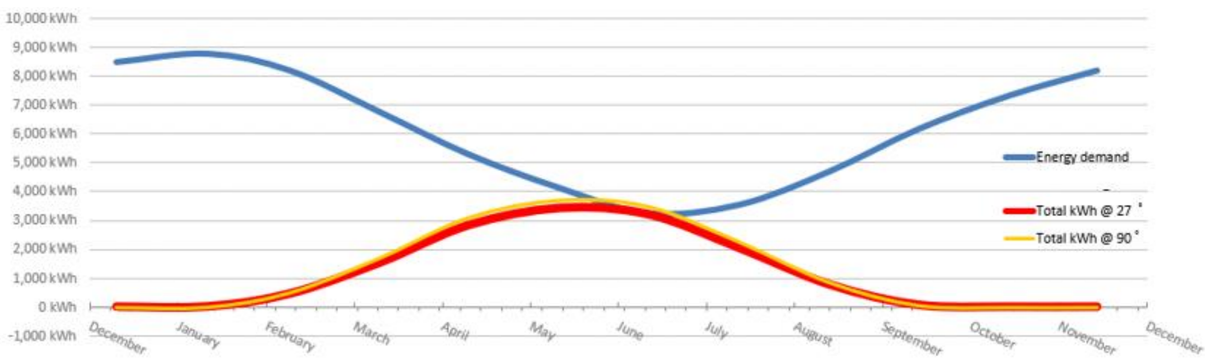

Figure 20. Solar thermal energy production with respect to energy demand of the case study building.

The accumulator tank size normally increases with respect to the solar collector area. A size of 1.5-day heat consumption is used for sizing of heat accumulator tank. According to Zijdemans simplified calculation of storage tank volume in table 4, section 3.1.5, DHW and space heating of 500 liters per dwelling in building block is recommended, which is about 5000 liters.

The solar system should be properly sized with respect to energy demand in summer to avoid wastage of energy generated. Therefore, the area of the solar thermal collector is dimensioned such that it satisfies energy demand in summer as shown in figure 20 above, resulting in no wastage in energy generation and reduced investment cost.

Table 10. Total solar thermal system production output at an inclination of 27˚ and 90˚.

Solar collector's energy production					
Month	**Solar hours**	**Average kWh/m^2 Ø @ 27˚**	**Average kWh/m^2 Ø @ 90˚**	**Total kWh @ 27˚**	**Total kWh @ 90˚**
Jan	0	0	0	0	0
Feb	12	16	17	7	8
Mar	217	54	60	451	503
Apr	362	111	123	1540	1712
May	444	166	181	2827	3082
Jun	446	200	215	3418	3679
Jul	454	184	199	3203	3463
Aug	407	130	144	2039	2252
Sept	285	70	78	764	851
Oct	70	24	25	64	68
Nov	0	2	2	0	0
Dec	0	0	0	0	0
Annual	**2697**	**373**	407	**14314**	15618

4.3.3 Economic analysis of the solar thermal collector

The typical costs for the solar thermal system were retrieved from Catch solar. Table 11 below consists of a total estimated price for components of the thermal system along with labor cost where the hourly rate is around NOK 800 and price for solar collectors are estimated to be 1674 NOK/m^2 (R. Bird and R. Hulstrom, 1981). The current subsidy given by Enova is 15,000 NOK for the solar thermal collector.

Table 11. Total investment cost for solar collector.

Types	**Area [m^2]**	**Price [NOK]**	**Quantity [liter]**	**Cost [NOK]**
Solar collectors	64	1,674		107,136
Heat storage			5,000	22,917
Circulation pumps				1,333
Vacuum system				4,347
System Controller				934
Pipes and fittings				3,200
Labor				50,000
VAT 25%				34,967
Total Investment Sum				**224,834**
Enova grant				-15,000
Total Sum				**209,834**

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. After investing in the solar thermal collector, it is desirable to determine payback period. The net present value (NPV) method was used to perform the economic analysis.

The economic analysis is presented in figure 21 below, where the total sum investment for the solar thermal collector is 224,834 NOK. The investment is paid at an interest rate of 2% per year. The conventional energy is the output heat production from the solar collector, which is retrieved from table 10. The energy cost is considered to be 1 NOK/kWh (Solar, 2019), which increases at an interest rate of 4% per year. The net gain is the amount of cost saved with thermal energy production per year in the building. 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.

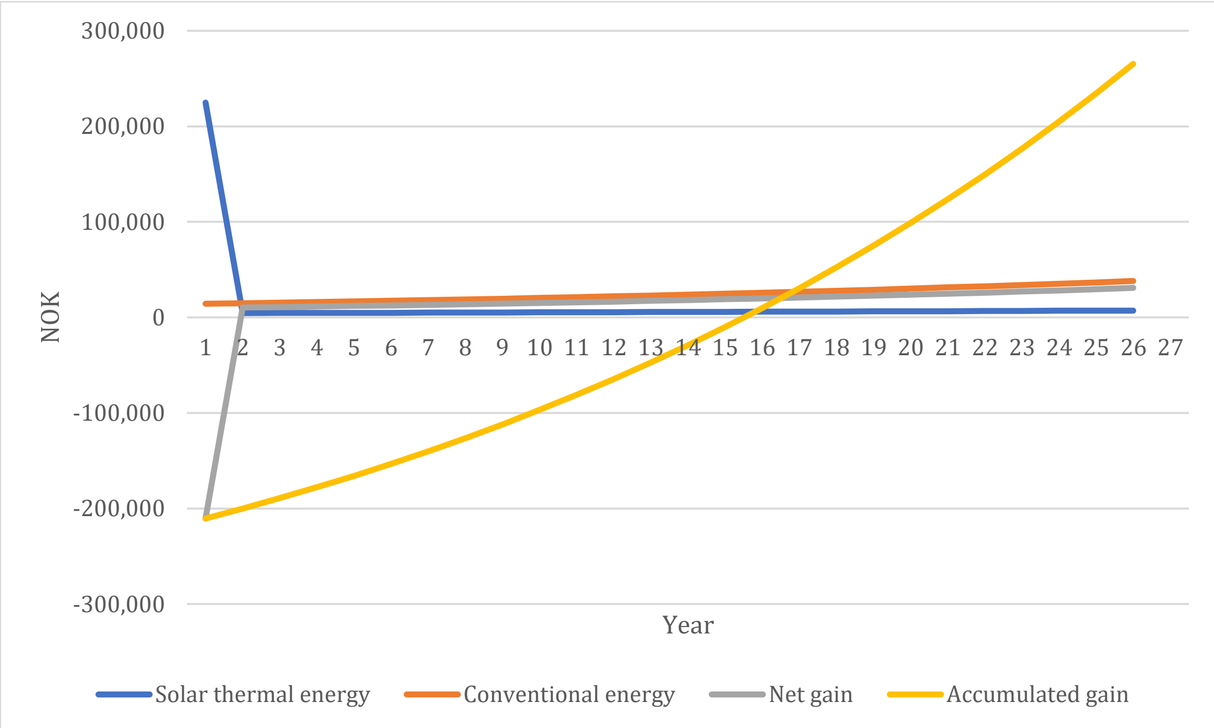

Figure 21.Graphical representation of payback period of solar thermal collector investment.

4.4 PV system

4.4.1 Dimensioning and simulation result of PV system

The calculation of the PV system is executed for the study case building with an area of 613 m^2 for 10 apartments. The total energy demand of the building is 98.8 kWh/m^2/year, which was retrieved from SIMIEN as presented in table 8. As shown in table 12 below, a solar system size of 4 kW per apartment is calculated with respect to the total energy demand and peak sun hours (Andren, 2003). The nominal power of the system is 51.6 kWp. The number of solar panels is determined by solar system size along with 86 % efficiency (14% loss) consideration and solar crystalline module with nominal nameplate power of 300 Watt. 152 numbers of solar panels are required for the building, resulting in a solar system area of 258.4 m^2, where area of the panel is 1.7 m^2.

Table 12. Calculation of solar system size and number of panels.

Energy demand [kWh/m^2/year]	Peak sun hours	Solar system size [kW]	No. of solar panels	Area of PV panels [m^2]	Nominal power [kWp]
98.8	4.2	40	152	258.4	51.6

However, architectural suitability must be taken into consideration since is affected by limitations in construction, shading and historical conditions of the building. Estimation of architecturally suitable areas for the solar installation is taken with respect to the floor area of the building which is retrieved from a simplified method developed by IEA-PVPS Task 7 (Good, et al., 2016). According to the method, generalized utilization factors for roofs are 0.4 and facades are 0.15 per m^2 built-up area. So, the area relevant through architectural suitability is considered for the case building. With respect to the architectural suitability, table 13 below shows that the total area of PV panels are172 m^2.

Table 13. Estimated area for solar installations in the building.

	Built-up area [m^2]	Suitable roof area [m^2]	Suitable facade area [m^2]	Total suitable area [m^2]
Building block	312	125	47	**172**

For the planning of the PV system in a building, first and foremost the type of solar cell must be determined. Both polycrystalline and monocrystalline cells are preferable to the building according to the characteristics of the cells. However, monocrystalline panels are recommended 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). Monocrystalline panels often have a STC value of 200-320 W_p. String inverters are recommended for the PV system since they have capacities that range from 1 kW to 8 kW and efficiency above 90%.

The following table 14 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, at el., 2018). The module size of 1.7 m^2 is considered which are attached to respective building elements.

Table 14. 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**

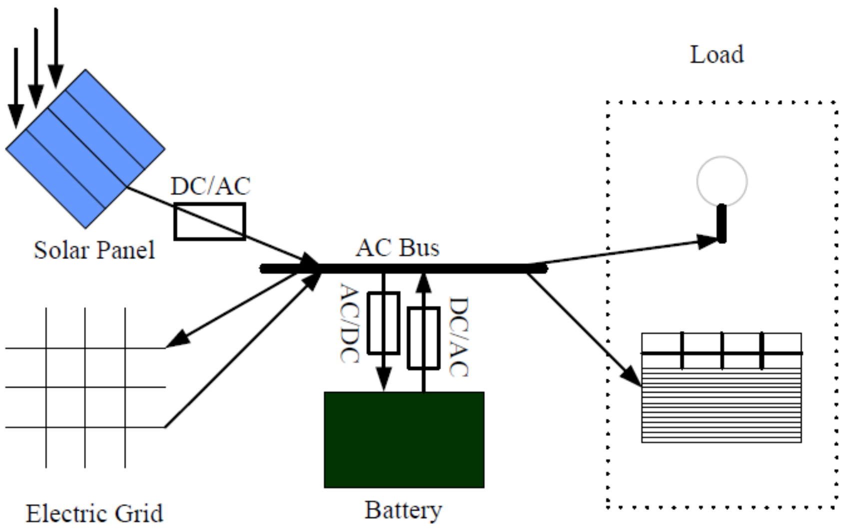

Figure 22. Working mechanism of grid-connected PV system. (Martinez, et al., 2013)

4.4.2 Solar PV modules energy production

The total energy production from the PV modules at roof inclination of 27° and vertical façades of 90°, which was simulated from SIMIEN and presented below in table 15. 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.

Table 15. Total solar PV system production output at an inclination of 27˚ and 90˚.

Solar modules energy production						
Month	**kWh @ 27˚ roof**	**kWh @ 90˚ - west facade**	**kWh @ 90˚ - south facade**	**kWh Sum Produced**	**kWh Utilized by the building**	**kWh Exported to the grid**
Jan	0	0	0	0	0	0
Feb	354	20	106	480	466	15
Mar	958	74	194	1227	1065	162
Apr	2155	180	350	2685	1797	889
May	2597	233	322	3152	2021	1128
Jun	2803	242	327	3373	1939	1434
Jul	2481	216	296	2993	1870	1123
Aug	2164	179	306	2649	1672	977
Sep	1095	87	193	1376	1095	281
Oct	504	31	114	649	615	34
Nov	43	2	11	55	55	0
Dec	0	0	0	0	0	0
Annual	**15155**	**1265**	**2219**	**18639**	**12598**	**6042**

A comparison of total energy production from the PV system and the total energy demand of the building is presented below in figure 23. 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.

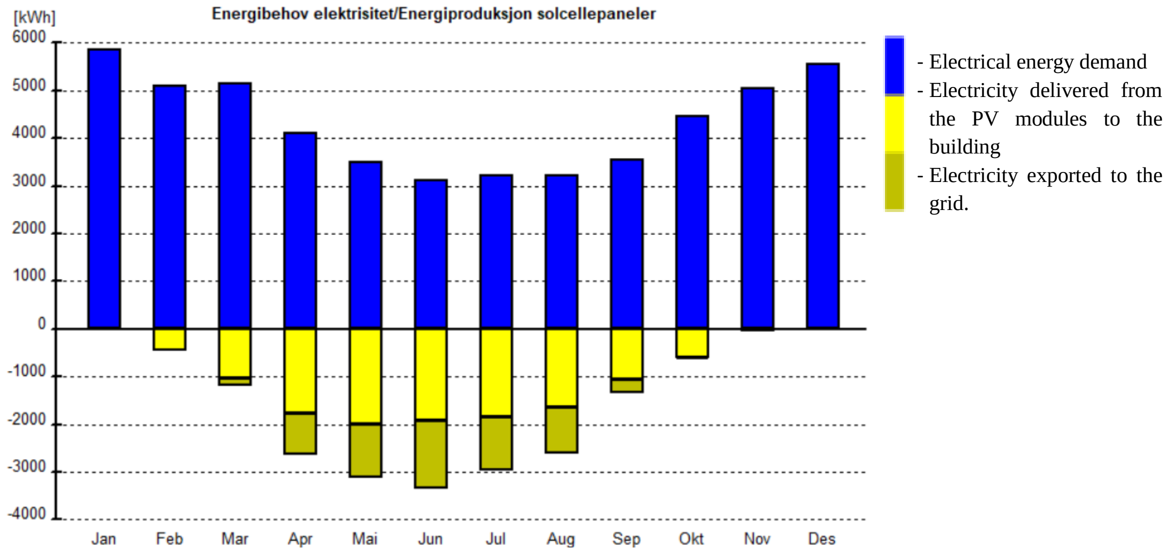

Figure 23. Energy production from PV panels drawn by SIMIEN.

Careful planning and dimensioning of the batteries are required to determine the right size and configuration for the building. Lithium-ion phosphate rechargeable Powerwall battery bank of 13.5 kWh by Tesla is proposed for the building with a capacity of peak power up to 7 kW and 5 kW continuous power. For the number of Powerwall batteries, a rough calculation was done for the case building. The average of the energy demand of the case building is 70534 kWh/ year, from table 8, which is around 194 kWh/ day and the battery can deliver 13.5 kWh of capacity, which means the case building will approximately require 14 Powerwall batteries.

4.4.3 Economic analysis of the PV system

PV panels have a lifetime warranty of 20 years which will generate at least 80% of the rated power after 20 years of utilization since each year the panels degrade about 1%. The electricity companies use various tariff schemes for delivering electricity, which may vary for summer, winter and peak power usage. The table 16 below shows the estimated investment price for PV panels with the cost of a fully assembled solar PV system presumed to be 16 NOK/Wp (p=peak) as provided by STS solar technologies Scandinavia.

Table 16. Investment cost per watt peak.

Placement	**PV Area [m^2]**	**Watt peak [kWp]**	**Cost [NOK/Wp]**	**Cost [NOK]**
Roof	125	20	16	320,000
South facade	27	4.3	16	68,800
West facade	20	3.2	16	51,200
Total Sum		**27.5**		**440,000**

The following table 17 presents the investment cost of one 13.5 kWh Tesla Powerwall battery (Tesla, 2019). As explained in section 4.4.2, 14 Powerwall battery banks will be required for the case study building. The investment cost for 14 battery banks can reach up to 1,269,800 NOK.

Table 17. Cost estimation for one 13.5kWh Powerwall from Tesla (Tesla, 2019).

Battery	**Quantity**	**Cost [NOK]**
13.5 kWh Powerwall battery	1	69,000
Supporting hardware		7,200
Deposit for Powerwall		4100
Installation cost		10,400
Total sum		**90,700**

An overview of economic analysis is presented in figure 24, where the total sum investment for the solar PV modules is 440,000 NOK. The investment is paid at an interest rate of 2% per year. 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 (SSB, Statistics Norway, 2019). 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. About 6042 kWh is exported to the grid in this case. The net gain is the amount of cost reduced with own electrical energy production per year. The payback period of the investment cost will be around 20 years.

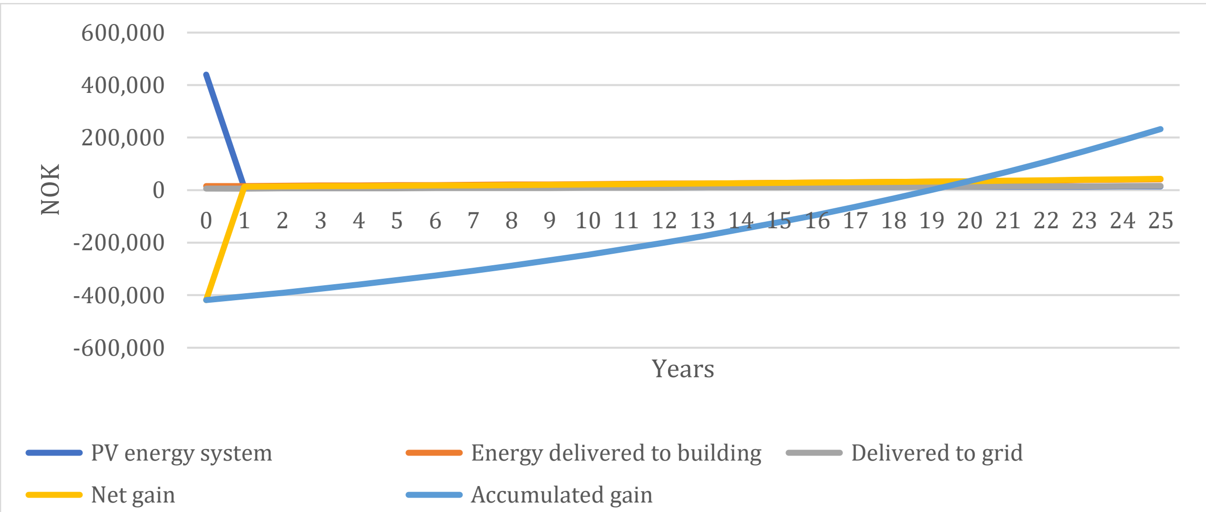

Figure 24. Graphical representation of payback period of solar PV system investment.

4.5 Recommended PV cells and solar collector

The table 18 below shows the characteristics of monocrystalline solar cell and flat plate collector that are recommended for the case study building.

Table 18. Characteristics of recommended solar thermal collector and PV system.

Characteristics	**Photovoltaics (Monocrystalline cells)**	**Solar collector (Flat plate collector)**
Module size	1.7 m^2	3 m^2
Placement	Roof – east, south façade, west facade	Roof - west facing
Receiving area	172 m^2	64 m^2
No. of modules	101	21
Annual Energy production	West direction: Roof ~122 kWh/ m^2	West direction: Roof ~335 kWh/m^2
Total annual Energy production	~ 109 kWh/ m^2	~335 kWh/m^2
Shape/ Size flexibility	High flexibility	Low flexibility
Thickness	0.4 cm	4 to 10 cm
Weight	19kg/m^2	20kg/m^2
Module structure	Laminated modules	Sandwich modules
Materials	Glass/ silicon cells/ Tedlar-Mylar or glass	Glass/ air / metal absorber/ hydraulic system/ insulation
Surface textures	External glass: smooth/ acid etched/ structured Silicon cells: variable patterns, possible transparency	External glass: smooth/ acid etched/ structured Absorber: slightly corrugated, opaque metal sheet
Colors	Black/ blue mainly	Black/ dark blue mainly
Energy medium	Electricity	Hot water
Energy transport	Flexible cabling (0.8-1.5 cm diameter). Low energy losses	Rigid insulated piping system (3-8 cm diameter). High energy losses
Energy storage	Lithium battery storage/ into the grid	Accumulator tank
Working temperature	Lower temperature preferable (back ventilation required)	Higher temperature preferable (back insulation required)
Shadows impact	Reduction in performances Risks of permanent damage to panel.	Reduction of performances proportional to shadow size, no damage to the panel.
Cost estimation	16 NOK/ Wp	1647 NOK/m^2

5 Discussion

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, which were retrieved from (Suncurves, 2019), 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 case of the PV system, SIMIEN model of the study case building was used, which was provided by Lars Kimo Jørgensen from 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 or not was not cross-checked. For detailed simulation of the energy production, programs such as POLYSUN for the solar thermal collector and PVSYST, IDAICE, Energy Plus or Matlab for the PV system could be used. These software's can be used to design the collectors that provide accurate simulation with respect to actual module size and types found in the market.

Regarding the cost of the systems, they were retrieved from various sources. The costs for the PV system provided by various companies ranged from 10 NOK/ Wp to 30 NOK/Wp for a complete setup of PV system. Finally, the price provided by STS solar technologies Scandinavia was chosen. Also, the price 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 (Sidelnikova, et al., 2015). Nevertheless, the cost of the PV modules continues to decline year after year. And within 2025, the costs of the PV modules are expected to reduce up to 20-35% (Thorud, et al., 2015).

The payback period used in this work is a simple calculation which fails to factor in several important factors in estimation such as the lifetime of the system, operation and maintenance costs. These parameters are taken into account in lifecycle costing (LCC), which is the cost of using a PV system during its lifetime. The LCC includes capital cost, operation and maintenance costs and replacement costs.

6 Conclusion

6.1 Summary

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. This resulted in enough energy produced per m^2 in summer and low heat loss in the accumulator tank. When the vertical solar thermal collectors are compared to roof collectors at 27˚, the vertical collectors generate approximately 1300 kWh more energy than the collectors on the roof as shown in table 10. 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 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. However, the requirement for the building to completely satisfy the energy demand would require 51.6 kWp nominal power as shown in table 12, but due to limitation in the area for installation, nominal power of 34.4 kWp was chosen as presented in table 14.The characteristics of the recommended solar thermal system and PV system are presented in section 4.5 in table 18 where the output energy production from the solar thermal system is quite high than in the PV system.

The price for a solar thermal collector system is estimated to be 1674 NOK/m^2 resulting in total investment cost of 209,834 NOK which has a payback period of 15 years. Whereas for the PV system, the price of a fully assembled solar PV system is considered to be 16 NOK/Wp which results in total invest of 440,000 NOK. The system, however, does not consist of battery investment and has a payback period of 20 years. A Tesla Powerwall battery bank investment cost is provided in table 17 but the cost is very high for the number of batteries required by the building. Second life batteries of an older version of EV are a better option for the PV system which can be stacked and purchased as secondhand. The loft area would be a good placement for battery storage.

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.

6.2 Further work

The solar potential for power production by solar technologies in Norway is sought after by all solar enthusiasts and experts. Though the meteorological stations for observations of solar irradiation throughout Norway are limited. More such stations should be introduced, and the accurate measurements ought to be available publicly.

The capacity of the frame of the modules for both solar systems may or may not withstand the pressure of snow accumulated during winter. Modules are generally rated by horizontal pressure, but the modules are mounted at an angle or vertically. The tilt of the module should be either high so that the snow falls off easily or low so that the frame is not affected by snow load. Clearance of snow during winter is a must to utilize solar radiation and not damage the frame of the module. More detailed research is required for such situations in Northern Norway.

Today, there are varieties of BIPV materials available in the market which can replace existing roof or windows. If the building must be renovated, then such solutions also can be implemented which can reduce both costs for installation of solar modules and building material cost. For instance, Tesla has introduced solar PV roof tiles which replace conventional roof tiles. However, these solutions are still relatively new, and case-studies should be done on this topic.

Installation of the solar systems in households to be self-sufficient should be encouraged by the government and NVE which in return will economize the cost for a fully assembled solar system. Other than that, many individuals should invest in a solar system for the benefits of own energy consumption and contribution to the environment by no usage of fossil fuels.

7 References

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8 Appendix

8.1. Optimal inclination angle and azimuth angle at Narvik from PVGIS.

8.2 Sun path diagram from PVSYST.

8.3 Weather and solar information at Narvik from Suncurve

8.4 Solar thermal system production and investment analysis.

8.5 PV system simulation in SIMIEN.

8.6 PV system investment analysis