Techno-Economic Feasibility Analysis of Integrated Heat Pump and Solar Cell Systems for Commercial Buildings

-A cost effective analysis towards 2040

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Abstract

As economic feasibility is one of the utmost tonality in every single thing exclusively in energy disciplines, it is consequential assesing the techno-economic feasibility of integrated heat pump and solar cell systems for commercial buildings. This thesis investigates the techno-economic feasibility of heat pump and solar system for the i4Health building at UiA considering performance evaluation, cost-effectiveness, and environmental impact and a potential analysis of cost effectiveness towards 2040. In the beginning, Coefficient of Performance (COP) has been evaluated for the Ground Source Heat Pumps (GSHPs) to analyze the performance and Solar System's (SS) performance has been analyzed on the basis of Performance Ratio (PR) and Solar Ratio (SR). Secondly, Annual cost savings from GSHPs and SS as well as the contribution of GSHPs and SS to the building's economy along with the Payback Periods (PPs) indicate cost-effectiveness. An estimation model is developed presenting cost effectiveness towards 2040. Lastly, reduction of CO2 gas by GSHPs and SS of i4Health building has been estimated for analyzing environmental impact. Performance evaluation, cost-effectiveness, and environmental impact estimations are conducted using Python Programming and the model presenting a future scenario of cost effectiveness of GSHPs and SS for i4Health building has been developed by Multiple Variable Linear Regression Model (MVLRM) using Jupyter Notebook.

The findings present that COP varies around 4.98-5.7 per week in cold weather and around 3.26-4.43 per week in warm weather. PR of solar system is 96% in 2022 whereas 89% in 2023. Solar system has highest SR in week 23 of 2023. Heat pump saves costing at 1.899 NOK/kwh in 2022 with a highest value in week 50 and 1 NOK/kwh in 2023 with a highest value in week 48. Solar system saves costing NOK 355121.69 in 2022 with a highest value in week 35 and NOK 122414.82 in 2023 with a highest value in week 24. From the cost savings model, NOK 398233.09, NOK 1474462.2, NOK 2902506.45 and NOK 3976269.33 is saved for the year 2025, 2030, 2035 and 2040 chronologically by heat pump and, at the same time NOK 293277.4, NOK 1612463.33, NOK 3370724.8 and NOK 4686860.5 is saved by solar system. The contribution of heat pump is 54.4% and 65.3% for the year 2022 and 2023 whereas the contribution of solar system is 60.27% and 56.59% at the same time. Payback period for heat pump is 16.33 years, and 30.63 years for solar system. This research also finds that heat pump and solar system reduce 32.28 ton and 36.05 ton CO2 in 2022 and, 35.66 ton and 33.69 ton in 2023. The thesis creates significant futute work opportunities.

Sammendrag

Ettersom økonomisk gjennomførbarhet er en av de ytterste tonalitetene i hver eneste ting utelukkende innen energidisipliner, er det en konsekvensvurdering av den teknisk-økonomiske gjennomførbarheten av integrerte varmepumpe- og solcellesystemer for næringsbygg. Denne oppgaven undersøker den teknoøkonomiske gjennomførbarheten av varmepumpe og solcelleanlegg for i4Health-bygget ved UiA med tanke på ytelsesevaluering, kostnadseffektivitet og miljøpåvirkning og en potensiell analyse av kostnadseffektivitet mot 2040. I begynnelsen, Coefficient of Performance (COP)) har blitt evaluert for Ground Source Heat Pumps (GSHPs) for å analysere ytelsen og solsystemets (SS) ytelse er analysert på grunnlag av Performance Ratio (PR) og Solar Ratio (SR). For det andre indikerer årlige kostnadsbesparelser fra GSHP og SS samt bidraget fra GSHP og SS til bygningens økonomi sammen med tilbakebetalingsperioder (PPs) kostnadseffektivitet. En estimeringsmodell er utviklet som presenterer kostnadseffektivitet frem mot 2040. Til slutt er reduksjon av CO2-gass med GSHP og SS fra i4Health-bygg blitt estimert for å analysere miljøpåvirkning. Ytelsesevaluering, kostnadseffektivitet og miljøpåvirkningsestimater er utført ved hjelp av Python-programmering, og modellen som presenterer et fremtidig scenario for kostnadseffektivitet for GSHP-er og SS for i4Health-bygging er utviklet av Multiple Variable Linear Regression Model (MVLRM) ved bruk av Jupyter Notebook.

Funnene viser at COP varierer rundt 4,98-5,7 per uke i kaldt vær og rundt 3,26-4,43 per uke i varmt vær. PR av solcelleanlegg er 96 % i 2022, mens 89 % i 2023. Solcelleanlegg har høyest SR i uke 23 i 2023. Varmepumpe sparer kostnad på 1 899 NOK/kwh i 2022 med høyeste verdi i uke 50 og 1 NOK/kwh i 2023 med høyest verdi i uke 48. Solcelleanlegg sparer koster 355121,69 kroner i 2022 med høyeste verdi i uke 35 og 122414,82 kroner i 2023 med høyest verdi i uke 24. Fra kostnadsbesparelsesmodellen 398232,4746 kroner 2902506,45 og kr 3976269,33 spares for år 2025, 2030, 2035 og 2040 kronologisk med varmepumpe og samtidig kr 293277,4, kr 1612463,33, kr 4,086 er spart 4,086 kr anlegg 4,086 kr. Bidraget til varmepumpen er 54,4 % og 65,3 % for året 2022 og 2023, mens bidraget fra solsystemet er 60,27 % og 56,59 % på samme tid. Tilbakebetalingstid for varmepumpe er 16,33 år, og 30,63 år for solcelleanlegg. Denne forskningen finner også at varmepumpe og solcelleanlegg reduserer 32,28 tonn og 36,05 tonn CO2 i 2022 og 35,66 tonn og 33,69 tonn i 2023. Oppgaven skaper betydelige fremtidige arbeidsmuligheter.

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List of Abbreviations

CARE	Collaborative Action for Improving Educational Capacities in Renewable Energy to Mitigate Climate Crisis
GSHPs	Ground Source Heat Pumps
SS	Solar System
COP	Coefficient of Performance
PR	Performance Ratio
SR	Solar Ratio
HP	Heat Pump
HP IK01	Heat Pump IK01
HP IK02	Heat Pump IK02
HP IK03	Heat Pump IK03
HP IK01/02	Heat Pump IK01/02

Chapter 1

Introduction

Fossil fuel consumption for electricity in the public, commercial, and residential sectors is a preeminent contributor to climate change, which poses a serious warning to our environment[6]. The European Union (EU) wants to cut its greenhouse gas emissions from 1990 levels by 80–95% by the year 2050. This lofty objective requires the energy industry to decarbonize significantly [7],[8]. The goal of Norway is to diminish emissions by 55% by 2030 and 90–95% by 2050. But, according to projections, there will be a 27% decrease by 2030 and an 80% decline by 2050 when compared to 1990[9]. The substitution of renewable energy sources for fossil fuels is a practical and effective way that must significantly cut energy-induced greenhouse gas emissions so as to meet climate commitments [10].

Power may be produced from healthy, renewable sources of energy including wind, solar, biomass, and heat pumps without contributing to air pollution or upsetting vast tracts of land or water [5]. Due to their many benefits versus electricity, heat pumps (HPs) have grown more and more prevalent in residential applications[11]and among the heat pumps ground source heat pumps are a tested renewable energy innovation that can cut the production of greenhouse gases by at least 66%[5] when used for indoor heating and cooling. The alluring benefits of high energy and environmental performances have led to the widespread usage of ground-source heat pump (GSHP) systems in both residential and commercial buildings worldwide. Likewise, among the most essential and reasonably priced technological solutions for the building industry to meet its decarbonization targets is the renewable electricity produced on residential buildings' rooftops PV arrangements [7] at It’s growing installation rate including 60% on buildings[12]. One can potentially reduce fuel costs and significantly improve the well-being of later generations by implementing each of the green energy solutions [5].

Considering the i4Health Building of University of Agder (UiA), a detailed picture of ground source heat pump has been analyzed on basis of performance efficiency, economic efficiency and environmental impact as well as the builds rooftop solar cell energy source. Energy from heat pump and solar cell being used for the building’s space heating and for other allowances, a cost-effective contribution of heat pump as well as solar cell to the building’s total power consumption has been determined along with the payback periods. Based on the analysis, a model regarding the cost-effective contribution has been developed towards 2040. Along with the performance efficiency and economic efficiency, green contribution to reduce CO_2 emissions with the buildings ground source heat pump and rooftop solar cell has been developed.

1.1 Research Project

The research project carried out by the thesis author in autumn 2023 as a requirement for the University of Agder's Master's program in Renewable Energy is being continued with this study under the Collaborative Action for Improving Educational Capacities in Renewable Energy to Mitigate Climate Crisis (CARE) project between UiA and CUET. In the pre-study period, a detailed of renewable energy in Norway has been studied emphasizing ground source heat pump and solar cells with describing the market price of electricity to evaluate the cost effectiveness of ground source heat pump and rooftop solar cells of i4health buidling of UiA. Previous research regarding the contribution of renewable energy to improve economic feasibility as well as to reduce Green House Gas (GHG) emissions is also the objectives of the pre-study. An in-depth analysis of ground source heat pumps has been conducted based on performance, economic, and environmental efficiency with a cost effectiveness forcasting for the i4Health building; in addition, a rooftop solar cell energy contribution to economic feasibility and to help reaching the climate commitments.

1.2 Research Outline

This thesis paper is presented as the following seven chapters: Chapter 1 represents the introductory section, after the introduction chapter 2 presents a literature review to display a comprehensive overview of renewable energy scenario and the electricity market price in Norway, with the previous related research on economic feasibility and environmental impact of renewable energy. Chapter 3 presents the objectives of the study. Thereafter chapter 4 displays the relevant theoretical background. Chapter 5 provides the methodical approach that is used to conduct the evaluation of the objectives. The results and discussions are then presented in chapter 6. Lastly, chapter 7 concludes with the most important findings, answering the research questions and future work recommendations.

Chapter 2

Objectives of the Study

This chapter consists of describing the objectives of this thesis in details. Possible research questions have been developed that will be investigated in this thesis and lastly this chapter consists of the limitations of this study.

2.1 Objectives

With regard to the techno-economic feasibility analysis of the i4Health building of UiA, this master's thesis basically accomplishes three objectives. The first objective is analyzing the performance of GSHP and solar system working in i4Health building. Secondly, evaluation of cost effectiveness of these systems and finally analyzing the environmental impact of GSHP and solar system for the building.

Installing ground source heat pump and rooftop solar cell systems are popular and inevitable for replacing fossil fuel consumption with renewable energy in a facile way for commercial buildings. In this paper, an economic feasibility is evaluated along with performance efficiency considering i4Health building of University of Agder (UiA) as a sample owing to the fact that the building has ground source heat pump installation and rooftop solar cell system.

For the year 2022 and 2023 based on weekly database, power production from GSHP as well as from solar system are analyzed with the production variation with outside temperature and building's energy demand.

The performance efficiency is evaluated depending on the Coefficient of Performance (COP) for the ground source heat pump and, Performance Ratio (PR) and Solar Ratio (SR) for solar cell system of i4Health Building. Variation of COP with outside temperature and demand, variation of SR with outside temperature are also analyzed.

For evaluating cost effectiveness, cost savings from the ground source heat pump (GSHP) and contribution of GSHP to the building's total cost of total energy consumption are estimated, so for the rooftop solar cell system. Based on the results, a predictive model for the building regarding cost effectiveness has been developed towards 2040. Payback periods for the heat pump and solar cell also been evaluated in this thesis.

Lastly, for analyzing the environmental impact of heat pump and solar cell system working in the i4Health building, contributions to reduce greenhouse gas emissions also exploited in this research.

2.2 Research Questions

The following research questions will be looked into in this master's thesis:

RQ1: How energy production from GSHP and solar system varies with outside temperature, set temperature and the building's energy demand?

RQ2: How COP of ground source heat pump of i4health building varies with outside temperature and the building's energy demand?

RQ3: What is cost savings from GSHP and solar system of i4Health building?

RQ4: What is the contribution of GSHP and solar system to the building's energy economy?

RQ5: What are the payback periods of heat pump and rooftop solar cell system with respect to installation costs?

RQ6: What is the environmental impact of GSHP and solar system working in i4Health building?

2.3 Limitations

Several predominant limitations of this study are listed below:

- The dominant limitation of this master's thesis is that, for the evaluation, the data are considered for the year 2022 and 2023 whereas data from wider time period is needed to achieve more relevant results.
- Ground Source Heat Pump (GSHP) system and solar system of i4Health building is taken as sample for analyzing techno-economic feasibility at this time, but what about other buildings?
- For the evaluation and analyzation of the target objectives, weekly data is considered but not the hourly or daily data.
- The cost savings model is not developed based on enough trained data

These limitations of this research creates further opportunity to work with.

Chapter 3

Literature Review

There are four sub-sections in this literature review chapter. In the beginning, the renewable energy condition in Norway has been described. In the second section, an overview of ups and downs of electricity market price has been pictured. The third section reviews the previous research works related to the performance analysis, cost effectiveness and environmental impact of heat pump and solar cell used in commercial buildings. In conclusion of this chapter, contribution of this master's thesis has been presented.

3.1 Renewable Energy Overview

There is no doubt that renewable energy is dominating in Norway on basis of hydropower primarily[13], wind power, offshore wind power, thermal power, solar power are also working as renewable energy sources[14]. The country had 1,769 hydroelectric facilities in Norway as of the starting of 2023, with a total installed capacity of 33 691 MW[15]. The annual output of Norway's hydropower plants amounts to 136.49 TWh, or almost 88% which is 0.8% greater than 2021[3] of the country's total generation of electricity. Whereas there were 65 wind farms with a combined installed capacity of 5073 MW at the start of 2023[15]. This is equivalent to 16.9 TWh and 11% to the Norwegian production capacity[15] which is 0.4% greater than 2021 of the country's total generation of electricity[3]. Wind power plant output varies depending on the weather[15]. There were 373.025 MW of solar power installed totally among which over 90% installed capacity was linked to the electrical grid and the majority of solar energy is installed on residential and commercial rooftops in 2023 in Norway[15].

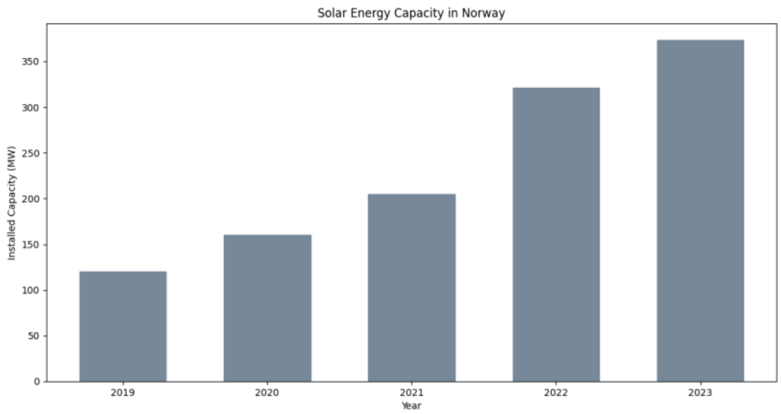

Fig. 3.1 Solar energy installed capacity in Norway [1], [2]

Fig 3.1 shows the solar energy installed capacity for last five years in Norway. The amount of installed capacity is 120 MW in 2019, after that the capacity is increasing every year. In 2020, the installed capacity is 160 MW which turns to 205 MW in 2021. The installed capacity has increased 253.05 MW in last five years and it becomes 373.05 MW in 2023[2].

In Norway, the most common application of geothermal energy is through the use of ground source heat pumps. In line with Norway's energy policy of utilizing more renewable energy sources, the government is planning to increase its usage of geothermal energy. In 2020, the geothermal heat pump capacity was 1862 kW[16] and Norway has installed 60 heat pumps for every 100 households by this year[17].

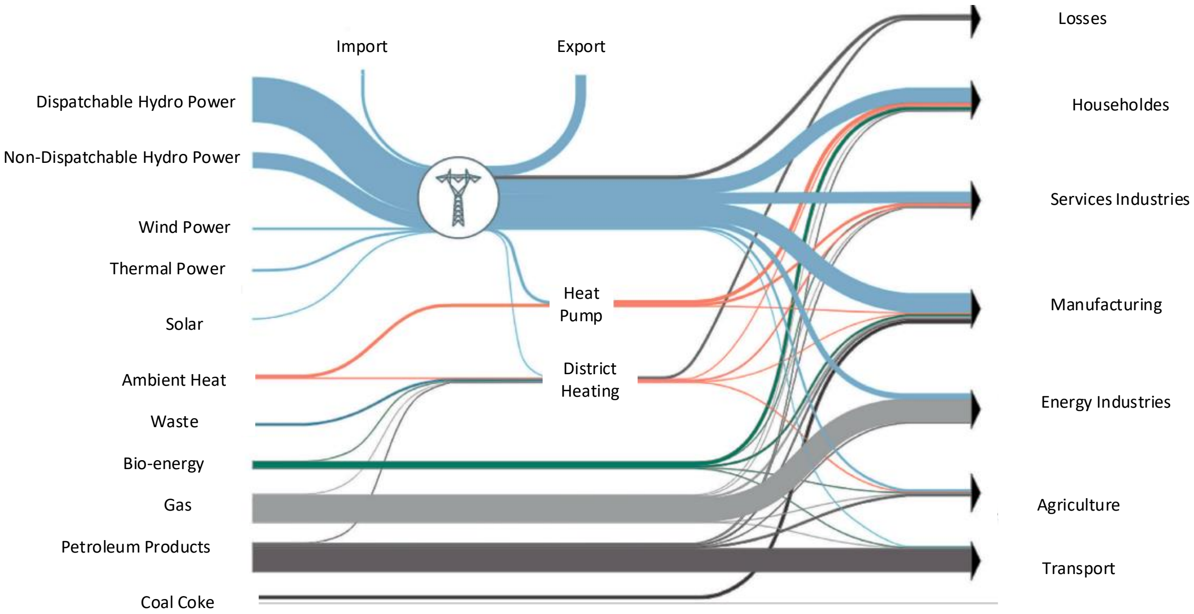

Fig. 3.2 present status of energy [3]

The sankey diagram in Fig. 3.2 presents current of energy with respect to the application field. Thermal power from heat pump is used for householdes, services, manufacturing etc.
In Norway, the building stock accounts for around 40% of total energy consumption, with the residential sector accounting for 22% and the non-residential sector for 18% [18].

3.2 Variation of Power Price for last five years

Price of power can be varied with different variables such as weather temperature, power consumption, power production, imports power etc. Lower weather temperature causes higher power consumption and rising of power price. Lower consumption and higher production causes to fall the price [19], [4].

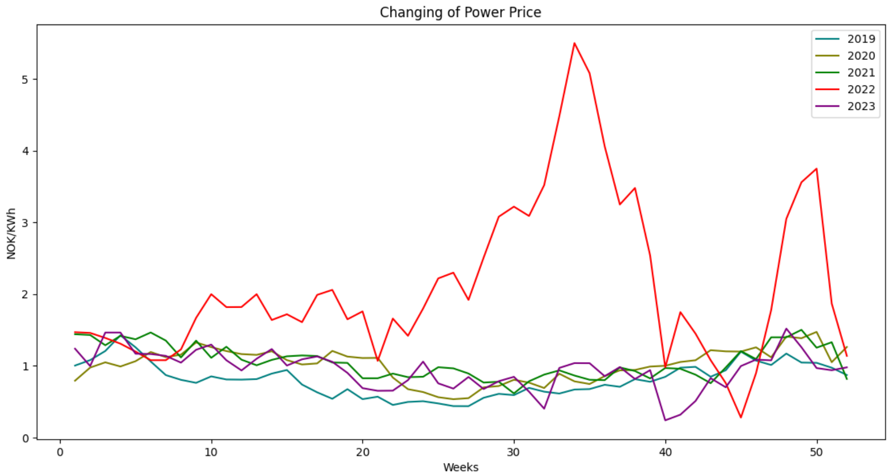

Fig. 3.3 Price overview of NO2 [4]

From analyzation of the last five years, power price is increasing. Power price is increased from the year 2019 to 2021 but the deviation is not much. Average annual power price is 0.81 NOK/kwh, 1.01 NOK/kwh and 1.06 NOK/kwh in the years 2019, 2020 and 2021 respectively. In 2022, price of power is increased more than double of 2021 for the Russia-Ukraine war. There is the highest price 5.5 NOK/kwh in week 34 of 2022. The price falls again in 2023 and comes back close to the price before 2022. The annual average price in 2023 is 1.11 NOK/kwh [4].

3.3 Related Previous Work

Based on the major energy source for each type of building, a parametric solar photovoltaic (PV) size study is carried out, and the total life cycle cost, renewable fraction, and greenhouse gas (GHG) emissions are computed in this paper. The result shows that GHG emissions from residential buildings can be instantly reduced by up to 50% when PV is combined with heat pumps. If renewable energy targets are satisfied, this effect will increase with time and result in a decrease in building emissions of nearly 90% [20].

By integrating the heat pump with a solar system, thermal storage , and an intelligent rule-based system of controls that enables focused heat pump operation with on-site PV electricity, this paper examined the prospect of reducing grid electricity use. Two refurbishment scenarios involving space heating and domestic hot water preparation in a Zurich single-family home were simulated using TRNSYS. The results show that 5 kW of PV can reach the shortest payback period of 17.1 years. The system reduced grind electricity 29% [21].

In order to assess the viability of PV+HP systems in the northern regions of North America, this research employs economic analysis and numerical simulations. The findings demonstrate that homeowners in North America may now affordably build residential PV+HP systems to meet all of their heating and electricity needs. In the United States, these systems can yield returns of up to 1.9%, and in Canada, up to 2.7%. PV-only systems have better returns—up to 4.3%—but have less than half the PV capacity[22].

This study examines the power production and energy efficiency of a PV-integrated variable refrigerant flow (VRF) heat pump unit in a five-story residential structure in Cyprus. In the chosen areas, the annual horizontally radiation intensity varies between 1,784 and 1,882 kWh/m2. VRF power usage varies from

14005 to 18,710 kWh per year, and a 13kW photovoltaic array may provide 23,200 to 23,650 kWh per year. According to the economic feasibility analysis, installing PV for this application in all areas under investigation is financially advantageous. Over the course of a 20-year investment period, the project's net present value would range from $4,843 to $13,355[23].

This research investigates a parametric techno-economic analysis of integrated solar and heat pump systems in order to pinpoint the crucial economic factors influencing profitability based on a case study in Vienna and using black box efficiency models and Building Model Generator with hourly data. The result shows that GSHP with PV is profitable. Subsidies and capital expenses have a significant impact on the benefit-to-cost ratio (BCR), but natural gas prices have the biggest impact. For both HP and PV, a 0.01 €/kWh, or 17%, increase in natural gas costs will suffice to replace all other intricate subsidies. This might lead to a 45%–60% decrease in the release of CO_2 in multi-family homes, or an equivalent carbon footprint price of 33 €/ton [24].

3.4 Contribution to the Field

The main contribution to the field is assessing the feasibility of GSHP and solar system with the point of view performance efficiency, cost efficiency and environmental pros at the same time. The analysis of performance can lead the project of finding more energy saving process. Evaluation of cost savings can make the GSHP and solar system more reliable. Installation of GSHP and Solar system mitigates the fossil fuel consumption and hence the greenhouse gas reduction. This thesis contributes to analyzation of reduction of CO_2 emission by using GSHP and solar system of i4Health building that proves again the significance of installing renewable energy sources to the households and commercial buildings.

Chapter 4

Relevant Theory

Heating and cooling both can be conducted parallelly in almost any kind of climate by heat pump on the basis of reverse Carnot thermodynamic cycle which means it takes drive energy as input and provides thermal energy as output[25].

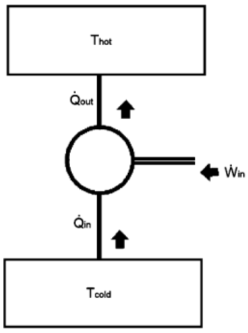

Fig. 4.1 working principle of heat pump[5]

There are mainly two types of heat pumps which are air source heat pump and ground source heat pump. Heat is transferred between indoor and outdoor air in an Air Source Heat Pump (ASHP) whereas Ground Source Heat Pump (GSHP) works depending on air and ground temperature difference as the ground temperature remains higher than air temperature in winter and lower in summer. Because of these variations in temperatures, heat energy can be transferred to meet building thermal needs during every season [14]. Because of its reliable, throughout the year performance, ground source heat pump (GSHP) systems are becoming more and more popular[26] for replacing the gas radiators and air conditioner to meet building's space heating and cooling [14].

Ground source heat pump is classified basically in three types presented in Fig. 4.2 named as open system, closed system and the heat pump which can't be categorized within opened or closed system either, it is classified as others [27].

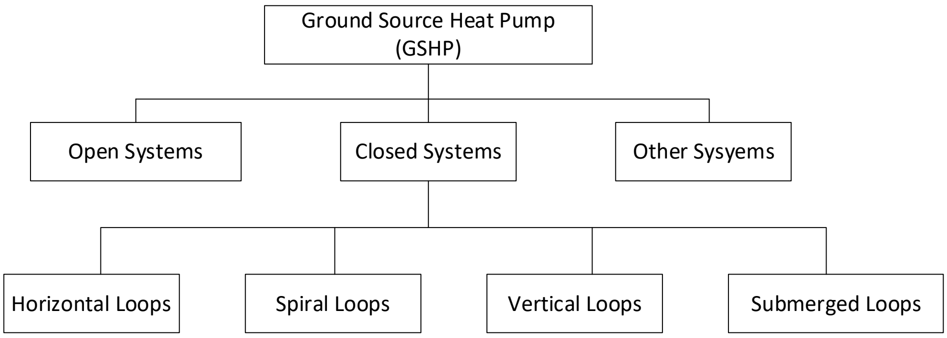

Fig. 4.2 Classification of Ground Source Heat Pump[27]

Heat pump uses groundwater directly as heat transporter without using any heat exchanger in open system ground source heat pump whereas, heat exchanger is used in closed systems making a barrier between ground water and heat transporter fluid which is flowed within the heat exchanger. If there isn't a real barrier but has a discernible difference between ground water and heat transporter fluid, then the heat pump can be categorized as other systems ground source heat pump [28].

Heat exchanger is installed horizontally which requires large ground area to the ground in horizonal closed loop system. The horizontal systems primarily rely on solar energy reaching the outermost layer of the earth for their primary thermal recharging [29].

In spiral loop system, pipe is laid out in trenches in a spiral pattern, with the horizontal or vertical arrangement and circular loops among them. It reduces installation costs [30],[31].

Vertical loop systems work through vertical heat exchanger or borehole heat exchanger installed in a certain depth of ground. In the vertical borehole, the closed-loop pipes are placed. With closed-loop systems, it takes a minimal amount of pumping energy and area of surface [32].

When closed loop exchanger system is submerged in a pond or lake, then the pump system can be referred as submerged loop system or pond ground source heat pump system. This system needs a substantial body of water[33].

How well a heat pump operates can be described on the basis of coefficient of performance (COP) which is the ratio of produced thermal energy by required driving energy to produce that thermal energy by the heat pump[25].

$$COP = \frac{\text{Produced Thermal Energy}}{\text{Required Driving Energy}} \quad (1)$$

COP can be referred as seasonal coefficient of performance when it is measured for a year of a system.

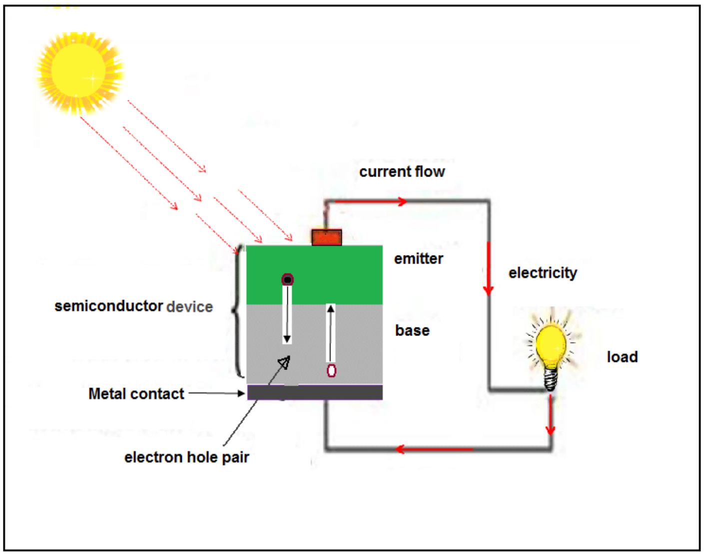

Fig. 4.3 Solar cell working principle[34]

Performance of solar system in a building can be described based on various parameters such as performance ratio (PR), solar ratio (SR), self-consumption (SC) and, solar fraction (SF) [11].

Performance ratio (PR) is percentage of the ratio between actual power output and expected theoretical power output of a solar system [35],[36].

$$\text{PR} = \frac{\text{Actual Output}}{\text{Theoritical Output}} \times 100\ \% \qquad (2)$$

Solar ratio (SR) is the percentage of the ratio between total power generation from solar system and the total power demand of the building [24].

$$\text{SR} = \frac{\text{Total Generation}}{\text{Total Demand}} \times 100\ \% \qquad (3)$$

$$\text{SF} = \frac{\text{SC}}{\text{Total Demand}} \times 100\ \% \qquad (4)$$

Equation (4) indicates the solar fraction (SF) as a percentage of the ratio of self-consumption (SC) to the total energy demand of the building whereas self-consumption (SC) can be defined as the amount of solar power that is used in the building directly[24].

$$\text{Payback Period} = \frac{\text{Yearly Benefit}}{\text{Investment Cost}}\ \text{Years} \qquad (5)$$

Payback period indicates the time needed for retrieving the investment cost[37].

Chapter 5

Methodology

This chapter describes the research methodology in details through the following sections: section 5.1 talks about the basic knowledge of i4Health building's GHSP and solar system installation. Section 5.2 describes the GSHP's heat distribution to the building and the total energy flow. Data collection procedure is presented in section 5.3 and lastly section 5.4 concludes the chapter with presenting the evaluation method and model development information.

5.1 Energy Boreholes and Solar Cell working in i4Health Building

The construction of Ground Source Heat Pump and rooftop solar cell system of i4Helse building started in March, 2018 by the client JBU and the architect and the project completion are estimated for August 2019. Considering to look at the measures for energy and the environment, the project group has come up with two different measures that can be implemented.

For the ground source heat pump systems, there are 21 energy boreholes consisting total of 5300 meter within which one of the energy boreholes used for teaching and research purposes, and able to have limited production. These have an assumed annual production of 383,250 kwh. This is planned in collaboration with the professional community. And, the rest energy boreholes are for pure energy production. The boreholes have an almost infinite lifespan.

542 Solar cells having total 887 m^2 area are placed in the rooftop of i4Helse building. the panels have a lifespan of between 40 and 50 years. The solar system has an assumed annual production of 157,942 kwh.

5.2 Heat Distribution System from the Borehole to the Building

There is total 21 energy boreholes addressing as "a" in the Fig. 5.1 diagram for the pure production 20 boreholes and "a′" for the teaching and research purpose borehole which are hidden under the floor of the parking basement and not visible to the public.

The water with antifreeze flows towards the cooling battery, IT cooling and usability lab mentioned as "d", "e" and "f" respectively from the boreholes after gaining heat from the ground. IT equipment and usability lab need to maintain a steady lower temperature as high temperature can harm them. Cooling battery helps the water mixture coming from borehole flowing steadily by storing during the cooling process. This cooling process makes the proper utilization of the heat produced from the IT equipment and usability lab making the water warmer that reduces the heat pump power input and makes the system more efficient. An additional cooling from the cooling production existing building exchanges heat with the water line coming from boreholes to main the desired temperature. The violet lines are showing the flow from borehole to cooling battery with IT cooling and usability lab and, the blue lines are showing the returned flow after cooling entering to the heat pumps.

Three heat pumps named IK01, IK02 and IK03 are working in this system to generate thermal energy using electricity as input. Heat pumps IK01 and IK02 are the predominant producer and heat pump

IK03 works as filler energy producer to supply total energy in a desired range. Hot water flows from the three heat pumps addressing with the red lines get mixed in the storage tank (ST).

Heat pump IK01 works together with IK02, and alternates between being in operation. Heat pump IK03 works independently with the same set point as IK01 and IK02. It is programmed to kick in slightly before IK01 and IK02.

Depending on the outside temperature, a temperature is set called set temperature at which the heat flows through the ventilation system. Additional heat from the heating production existing building exchanges heat with the hot water line coming from the storage tank and adds more heat. Heat flows to the floor heating unit and heat battery which stores the heat and makes the heat flow steady. The returned low temperature flows coming from the heat battery and floor heating unit are presented by blue lines which return back to the boreholes through heat pumps to repeat the process.

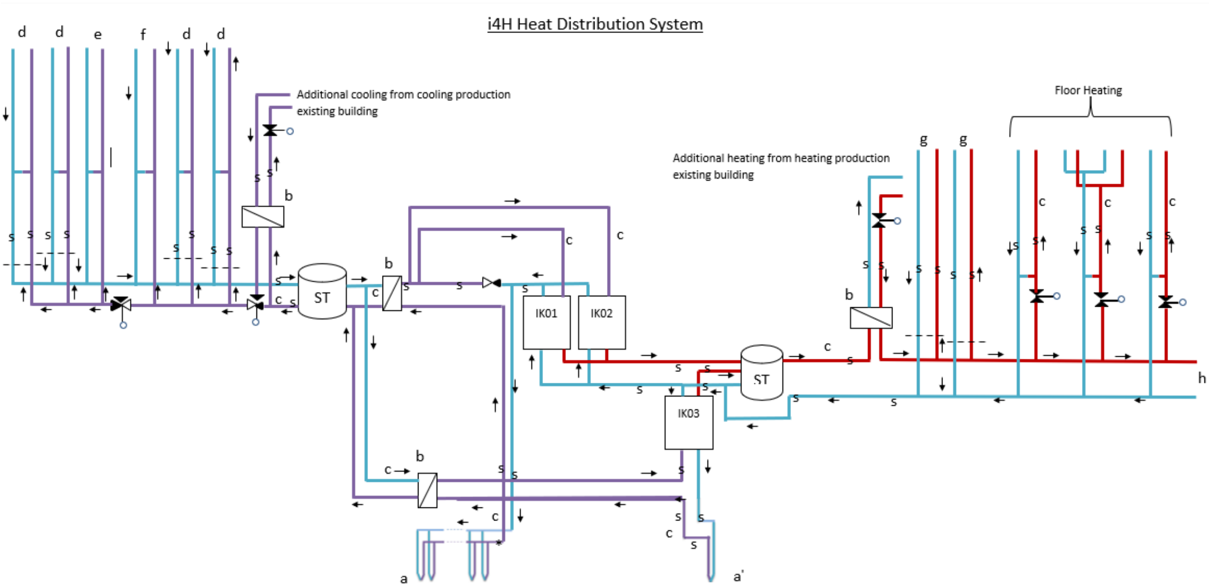

Fig. 5.1 Heat distribution system from GSHP of i4Health building

The meanings of the alphabet used in this diagram are listed below -

a: borehole
b: Heat Exchanger
c: water pumps
d: cooling battery
e: usability lab
f: IT cooling
g: heating battery
h: Varmekurs bygg 320.141
s: sensors

The high temperature heating line is continuous with the Varmekurs bygg 320.141 which is addressed as "h" in the diagram.

A pathway direction of energy flows from borehole to the heat pump and later to the building is shown in Fig. 5.2 presenting that borehole transfers the heat after extracting from ground to the cooling battery, IT cooling and usability lab before entering heat pump.

Thermal energy produced from heat pump flows to the building for space heating using heat exchanger from the storage tank. Heating battery assures a uniform thermal flow for space heating and floor heating according to the requirement. Varmekurs bygg 320.141 is attached with the main heat flow line coming from the storage.

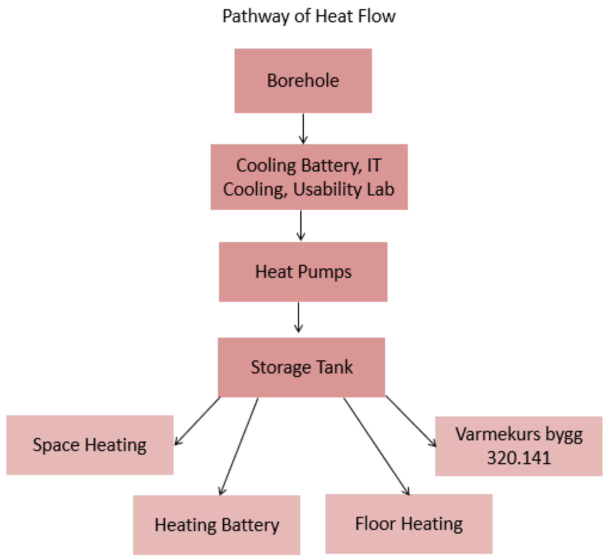

Fig. 5.2 Pathway of Energy Flow

5.3 Energy Flow Analysis

Heat pump, solar cell and the grid together meet the i4Helse building's total demand including the demand for space heating and power needed for other allowances. Fig. 5.2 presents the total usable power of the building for the year 2022.

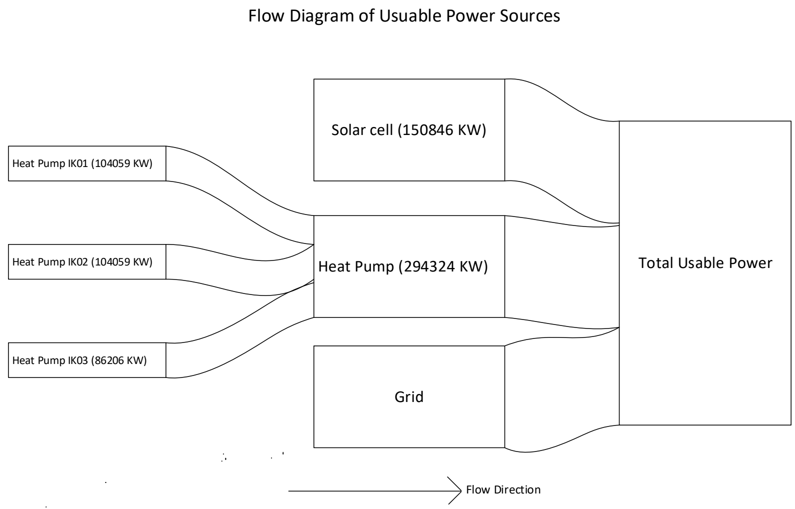

Fig. 5.3 Usable power sources in i4Health building

Total energy demand of i4Health is fulfilled by three energy sources, from grid, from the GSHP and from the solar system. Three heat pumps produce thermal energy to meet the demand for space heating and floor heating. Energy from grid as well as solar system is used to meet the building's demand.

5.4 Data Collection

For the evaluation and model development to meet the objectives, necessary data such as building's demand, power production from renewable sources, driving power is being provided from https://www.ens-portalen.no/ as well as from the authority of i4Health building's energy system for the year 2022 and 2023 on the basis of 52 weeks for each year.

Some preliminary data is also developed for meeting the target objectives by predicting through linear regression machine learning approach.

5.5 Evaluation and Model Development

All the evaluations are conducted using Python Programming which are added in the appendix. Energy effectiveness of GSHP as well solar, variation of productions with outside temperature and demand, variation of COP with outside temperature and building's demand, annual cost savings, contribution of renewable energy to the building's total demand, payback periods are evaluated.

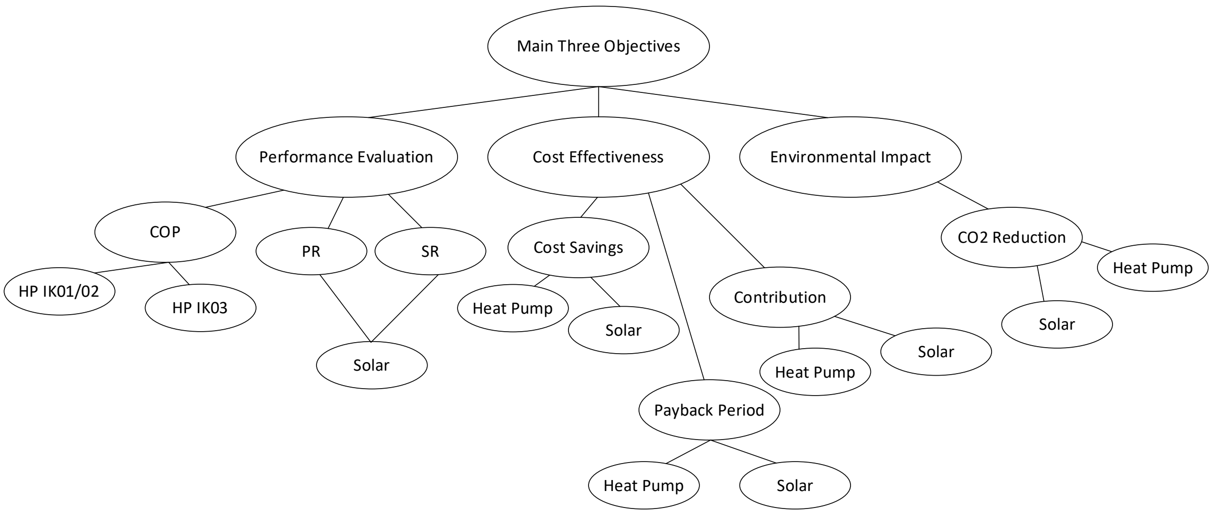

Fig. 5.4: Process of evaluation to meet the objectives

Performance evaluation is undergone by three parameters; COP for heat pump's performance, PR and SR for solar systems performance.
COP of heat pump HP IK01/02 and HP IK03 is evaluated from the ratio of heat pump power generation to the amount of driving power from grid needed to generate the power for analyzing the heat pump performance for the year 2022 and 2023 based on weekly values. Performance of solar system is estimated through performance ratio (PR) which indicates how efficiently a solar system can produce power actually with respect to the power assumed to be produced theoretically. For the buildings, solar ratio is evaluated from the solar power divided by building's total demand.

Secondly, for cost effectiveness analyzation, there are three parameters considered: in the beginning, cost savings from heat pump and solar system which means how much cost can be saved for supplying power from those renewable sources instead of from grid. Then, contribution of heat pump and solar system which means how percentage of cost can be saved with respect to the building's total energy consumption cost. Contribution is evaluated from the value of cost savings with respect to total energy consumption cost. Lastly, payback period indicates how many years are needed to retrieve the system's investment for installing. Payback period is estimated dividing the investment cost by the annual cash flow using eq (5), here cost savings for a year is considered as annual cash flow.

Thirdly, the environmental impact by using GSHP and solar system in i4Health building is analyzed through measuring the reduction of CO2 gas emission using GSHP and solar system with respect to grid energy. CO2 emission factor is considered to measure the amount of emission reduction. CO2 emission factor for GSHP is 0.15 kg/kwh [38],[25], 0.041 kg/kwh for solar system [39] and 0.28 kg/kwh for grid electricity [24] is considered to measure reduction of CO2 by using GSHP and solar system avoiding grid electricity.

A cost savings model is developed by Multiple Variable Linear Regression Model towards 2040.

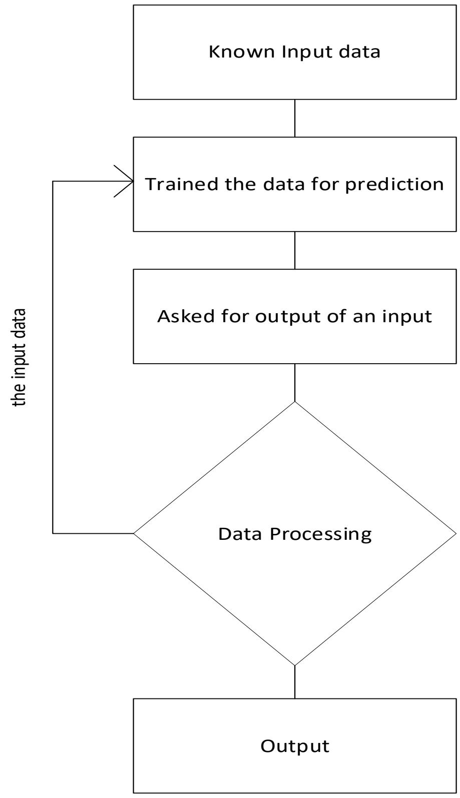

Fig. 5.5: working process of linear regression model

In multiple variable linear regression showing in Fig. 5.5, multiple types of variable data are being trained on the basis of know relationship between them where the needed/ to be predicted data is dependent variable and others are independent. After getting trained, output is asked for being predicted on the basis of previous training and independent variables work as the input with respect to which the output will be predicted.

For prediction cost savings from heat pump as well as solar system, three independent variables are considered that are: year, electricity price and demand at an increasing rate. 2025, 2030, 2035 and 2040 is used where electricity price is considered 1.18, 1.61, 1.94 and 2.27 for the respective years and the prices are assumed on the basis of the change of electricity price for previous five years. Demand is assumed at the increasing rate 2%, 5%, 7% and 10% of the demand 2023 for the respective years chronologically.

For the evaluation and model development, there are some assumptions have been considered:

- Total power production from solar system is using for meeting the building's demand ignoring the selling of additional power to the grid
- Driving power from solar to heat pump is ignored
- Demand is considered at an increasing rate 2%, 5%, 7% and 10% of the demand of 2023 for the prediction of cost savings from year 2025, 2030, 2035 and 2040.

Chapter 6

Results and Discussions

This chapter consists of seven sections displaying the achieved results chronologically targeting to meet the objectives. For evaluating the performance of the heat pumps and solar system, section 6.1 presents the annual power production from heat pump and solar cell. Then section 6.2 gives an overview that how the power production varies with the buildings outside temperature and demand. Thirdly section 6.3 presents the different parameters to assess the performances. Section 6.4 starts the economic evaluation presenting the amount of cost savings using GSHP and solar system developing a model towards 2040 in section 6.5, the contribution of GSHP and solar to building's total cost savings is exhibited in section 6.6. Payback period is ascertained in 6.7 section and lastly section 6.8 concludes this chapter presenting the amount of GHG gas emission reduction to analyze the environmental impact of using GSHP and solar system.

6.1 Annual Production from Heat Pump and Solar System

This section divided into two sub-sections referring as annual production from heat pump as sub-section 6.1.1 and sub-section 6.1.2 presents the annual production from solar system.

6.1.1 Annual Production from Heat Pump

As the heat pump IK01 works together with IK02, and alternates between being in operation, that's why the Fig. 6.1 represents the power production of IK01 and IK02 together referring as HP IK01/02 and the independent heat pump IK03 production by HP IK03.

In the year of 2022, production from HP IK01/02 has the highest value in week 1 among 52 weeks that is 13176 kwh for the building having higher energy demand at that time and starts decreasing from week 1 to 16 with a lower production value 2173 kwh in week 16.

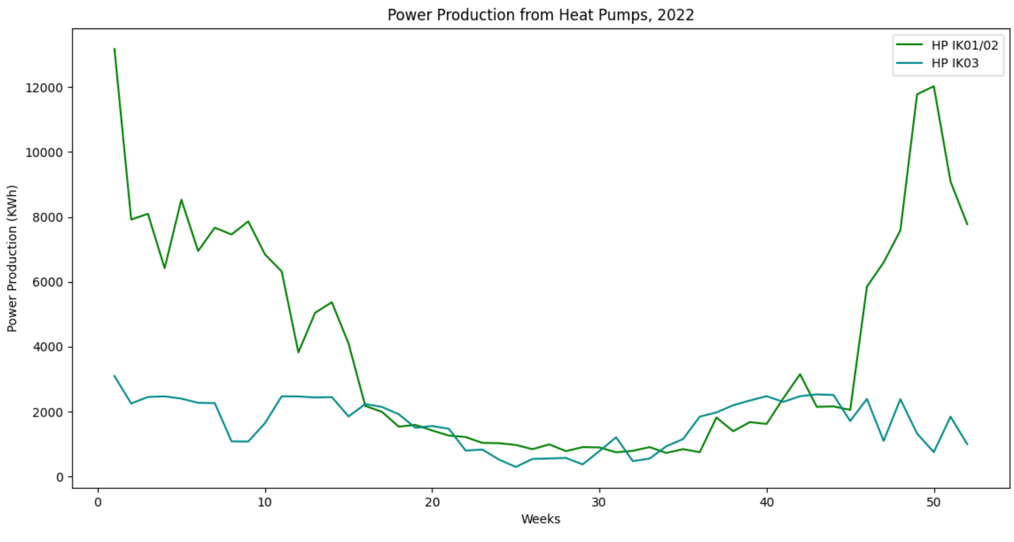

Fig. 6.1 Power production from heat pumps, 2022

For lower power demand the HP IK01/02 power production remains in a lower range between 725-2173 from week 16 to 36 having the lowest power production in week 34. In accordance with the rise of demand, power production started to rise gradually from week 34 and the rising rate became high from week 45 to 50 having a high production value of 12028 in week 50. Production became fallen for week 51 and 52 but still having high production value. HP IK01/02 produced total 208118 kwh annually in 2022 for a total building demand 378832.8 kwh.

Heat pump IK03 supports and kicks in slightly before heat pump IK01/02. It also helps to maintain the overall COP value in a balanced range and keeps the heat pumps performance balanced. The power production from HP IK03 has in a continuous lower range as it is the secondary heat pump. HP IK03 produced power in a range of 294-3096 kwh with the highest power generation in week 1 and the lowest power generation in week 25 with a total annual production 86203 kwh for 2022.

The varying power production from heat pump IK01/02 and IK03 for 52 weeks in 2023 has been shown in Fig. 6.2 As described of the causes of variation in power production for 2022, production from HP IK01/02 having highest value 11390 in week 48 and lowest value 26 in week 52 varied with the building's power demand. The total annual production from HP IK01/02 is 239229.8 kwh for a total annual demand 395459.7 kwh in 2023.

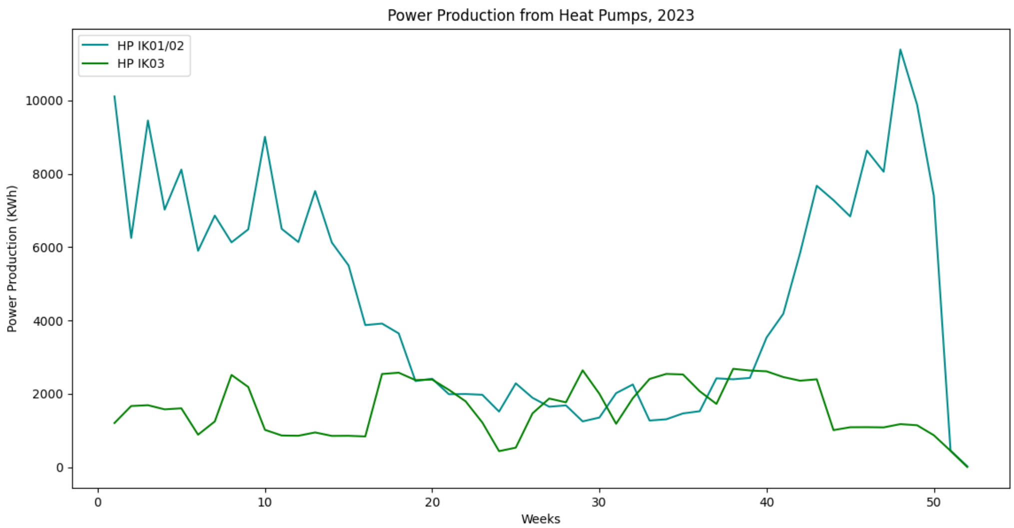

Fig. 6.2 Power production from heat pumps, 2023

Heat pump IK03 has a total annual power production 83979 kwh with low production range of 6-2683 kwh with the highest power generation in week 38 and the lowest power generation in week 52 in 2023.

Fig. 6.3 makes the analysis of HP IK01/02 power production between 2022 and 2023. The i4Helse building's annual demand was higher in 2023 than 2022 as well as the annual power production from HP IK01/02.

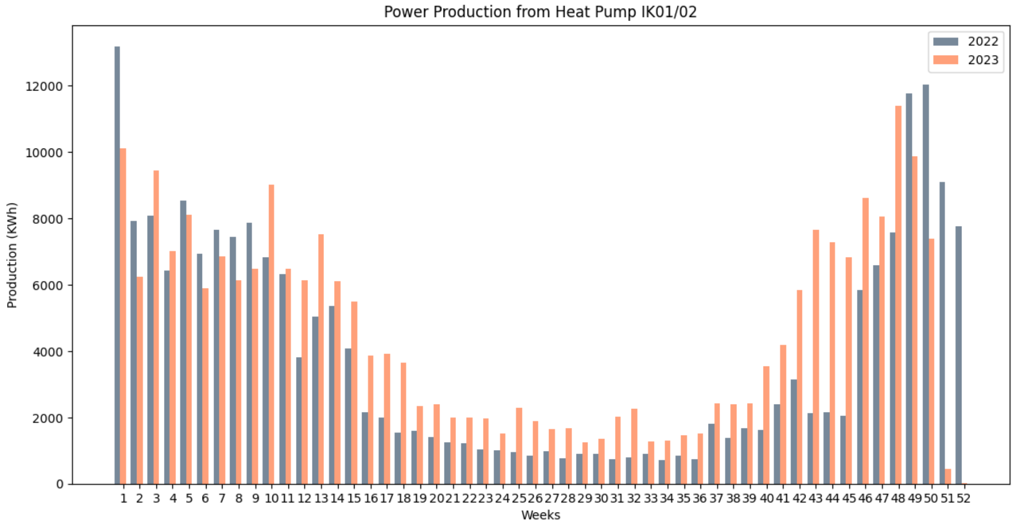

Fig. 6.3 Power production comparison of HP IK01/02 between 2022 and 2023

Rising of annual demand 1.75% from 2022 to 2023 has risen the annual production from HP Ik01/02 14.95%.

Table 6.1: Summary of the power production comparison of HP IK01/02 between 2022 and 2023

HP IK01/02					
Year	Demand (kwh)	Production (kwh)	Rising of Demand	Rising of Production	Weeks having higher production in 2022
2022	378832.8	208118	1.75 %	14.95 %	1,2,5,6,7,8,9,49,50,51,52
2023	385459.7	239229.8			

Weekly power production was higher in most of the weeks of 2023 except some weeks in winter mentioned in Table 6.1

Likewise, an analysis of the power production of supporting heat pump HP IK03 has been shown in Fig. 6.4 between 2022 and 2023.

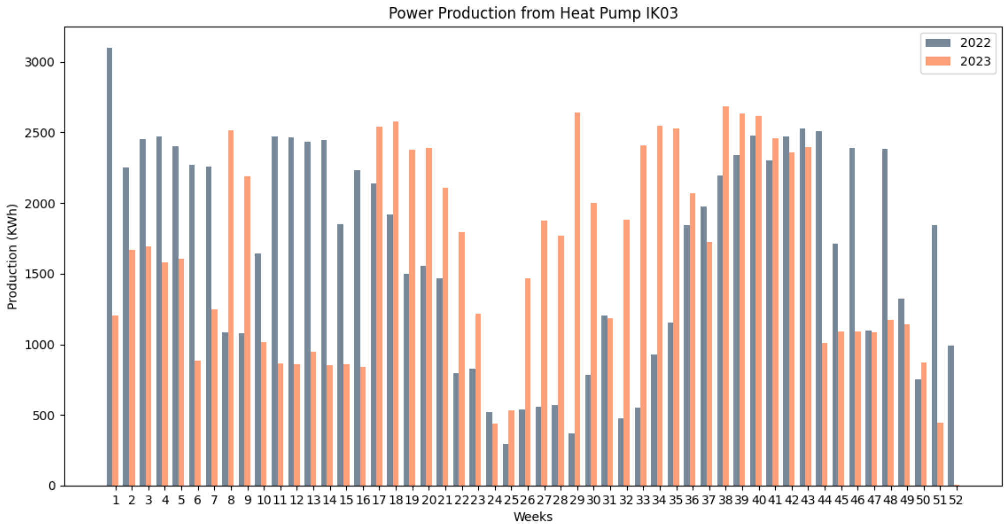

Fig. 6.4 Power production comparison of HP IK03 between 2022 and 2023

In that case, the production was higher in 2022 than 2023 creating 2.58 % falling in 2023 with respect to 2022. Most the weeks from last of spring to last of autumn have higher production in 2023 and the rest weeks have higher from in 2022.

Table 6.2: Summary of the power production comparison of HP IK03 between 2022 and 2023

HP IK03					
Year	Demand (kwh)	Production (kwh)	Rising of Demand	Rising of Production	Weeks having higher production in 2022
2022	378832.8	86203	1.75 %	-2.58 %	1-7,10-16,24,31,37,42-49,51,52
2023	385459.7	83978			

As the Heat pump IK03 supports and balances heat pump IK01/02, when the production of IK01/02 falls down, IK03 helps to be balanced.

6.1.2 Annual Production from Solar System

The annual power production from solar cell of i4Helse building has been presented in the Fig. 6.1.5 for 2022 and Fig. 6.1.6 for 2023 on the basis of 52 weeks

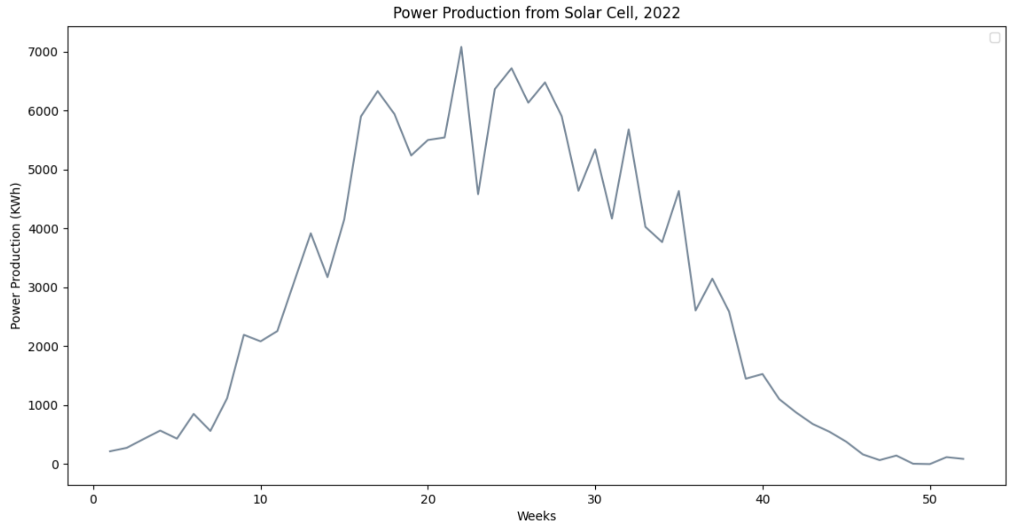

Fig. 6.5: Power production from solar system, 2022

The production rises with the rising of outside temperature and falls when there isn't enough direct or indirect sunlight for power production. In 2022, power production rises gradually from week 1 to 22 having the highest production 7090 kwh in the week 22. At the week 23, production falls to 4590 kwh for the falling of temperature. After 23, solar production starts to rise till week 25 and then falls gradually from week 25 to 52 having the lowest 0 kwh in week 50 and a total annual production 150846 kwh in 2022.

In 2023, power production rises gradually from week 1 to 23 having the highest production 7560 kwh in the week 23 and then falls gradually from week 23 to 52 having the lowest 4 kwh in week 49. Solar system has a total annual production 140972.1 kwh in 2023.

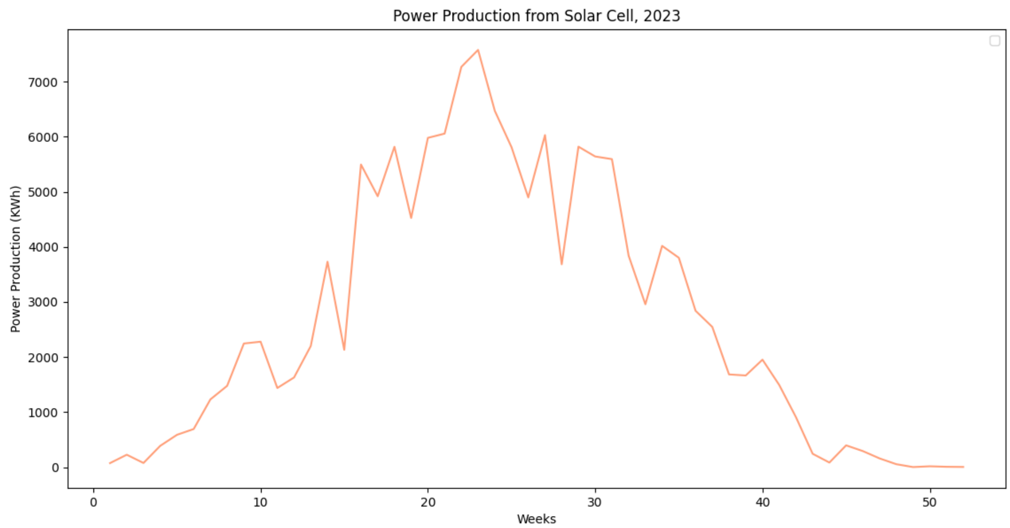

Fig. 6.6: Power production from solar system, 2023

Fig. 6.7 makes the analysis of power production from solar cell between 2022 and 2023. The annual power production of 2022 is higher than 2023.

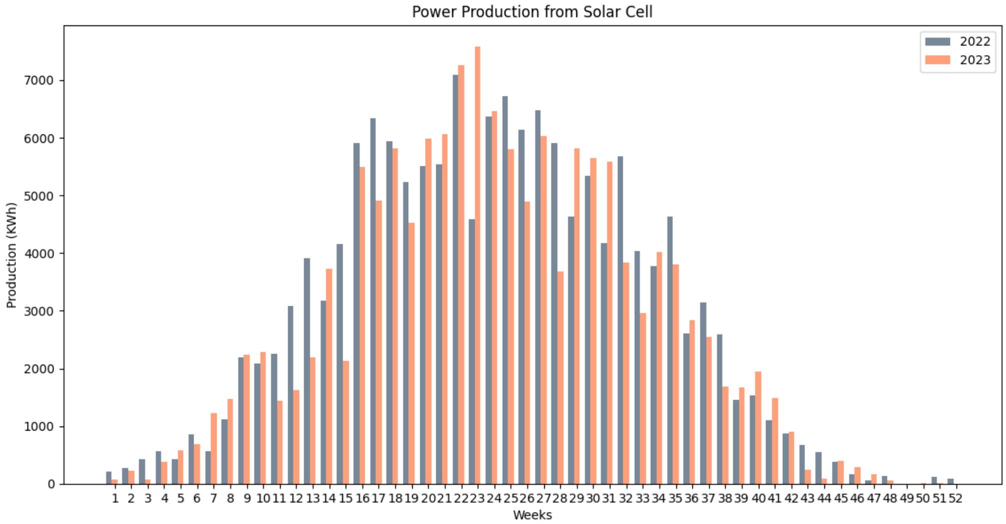

Fig. 6.7 Power production comparison from solar system between 2022 and 2023

Though the highest production was in week 23 of 2023, most of the weeks in 2022 have higher power production than 2023.

6.2 Production Variation with Temperature and Demand

Power production from heat pump varies with the demand of the building and the outside temperature. From the Fig 6.8, the production has highest value in week 1 and starts decreasing from week 1 to 16 with the increasing of outside temperature and the decreasing of demand. Outside temperature continued rising and have a highest temperature of 19.8 °C in week 29.

The heat pump produced power at a lower range from week 16 to 36 in accordance with the higher outside temperature and lower building's energy demand.

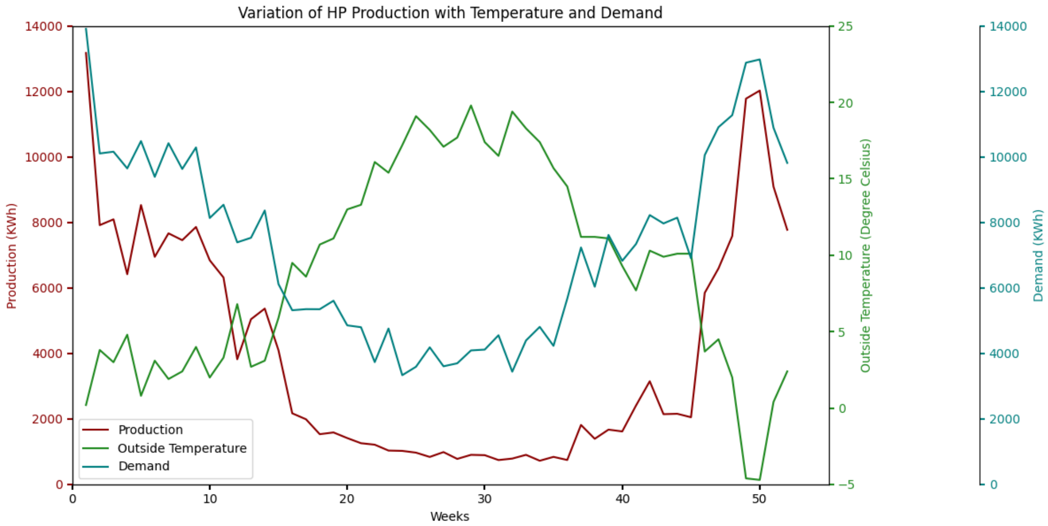

Fig. 6.8 Production variation from HP with temperature and demand

After week 36, the production started rising again with the reducing of outside temperature and the rising of building's energy demand till week 49. In the rest of the weeks, production fell for the rising outside temperature and falling the building demand. Thereupon, the production of heat pump rises when the outside temperature falls and when the building's energy demand rises.

The power production from solar cell depends on the directly or indirectly sunlight presents. Fig. 6.9 shows the variation of annual power production with outside temperature based on 52 weeks of 2022.

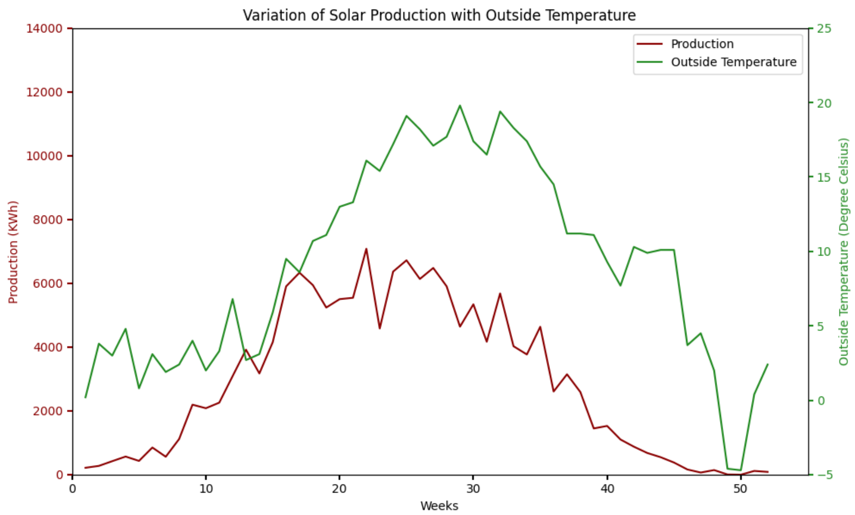

Fig. 6.9 Production variation from Solar with temperature and demand

Rising of outside temperature is also rising the solar power production from week 1 to 22 having a pick production value of 7084 kwh at the temperature of 16.1 Degree Celsius in the week 22. The production has started to fall with the falling of outside temperature having the lowest production value 0 kwh at the temperature -4.7 Degree Celsius in the week 50.

6.3 Performance Evaluation

This section is divided into two sub-sections. In the beginning, performance evaluation of heat pump has been established and the performance of solar cell has been evaluated in the second sub-section.

6.3.1 Performance of Ground Source Heat Pump

The coefficient of performance (COP) of heat pump IK01/02 varying throughout the year of 2022 is presented in the Fig. 6.10 Heat Pump IK01/02 has higher COP value from week 1 to 16 with a varying COP range from 4.98 to 5.54 as power production is high in those weeks to fulfill the required energy demand for space heating. The weeks are between mid-winter to mid-spring season.

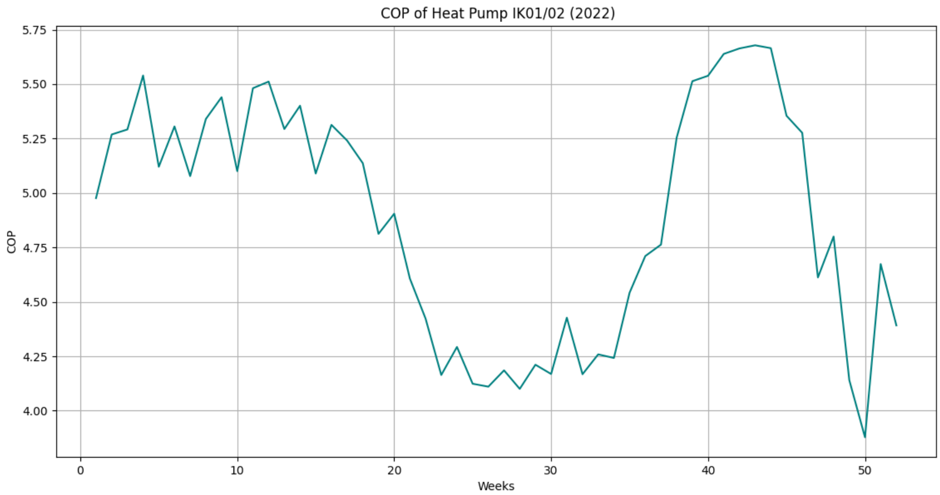

Fig. 6.10: COP of Heat Pump IK01/02 (2022)

After the week 16, COP has started to decrease from week 16 to 23 according to the decreasing thermal energy demand as well as power production from last of spring to starting of the Summer. The value remains in the range from 4.1 to 4.43 in the week 23 to 31 during the time of whole summer. From the last of Summer to the whole Autumn, COP has started to increase again till week 43 at a highest value of 5.7. For the variation of demand, COP value has fell down till the week 50. The starting of winter starts to increase the demand so as the COP.

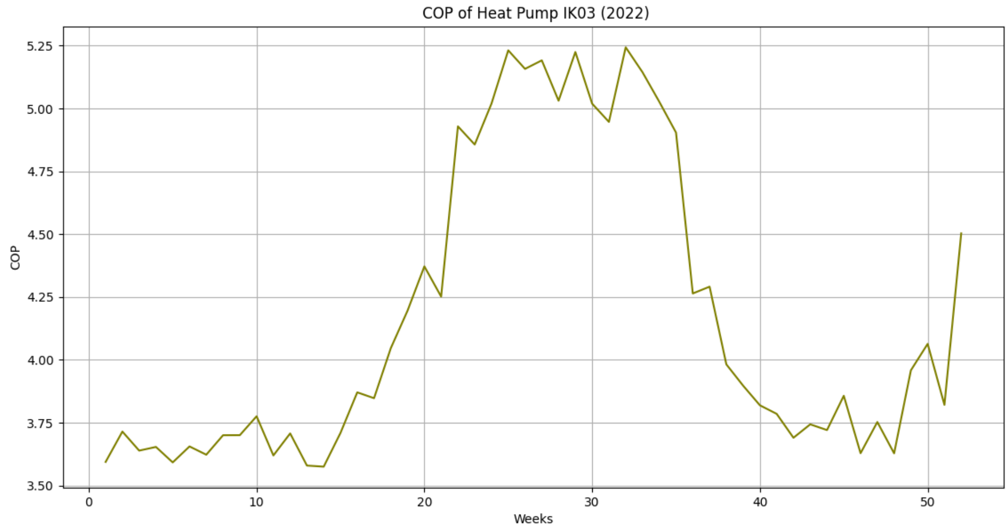

Fig. 6.11: COP of Heat Pump IK03 (2022)

Fig. 6.11 presents weekly COP of heat pump IK03 throughout the year 2022. Week 1 to 14 has lower COP value between 3.59 to 3.78. The performance coefficient starts to rise gradually after week 14 to 25 having a high COP value 5.23 in week 25. COP value remains at range 4.95 to 5.24 from week 25 to 32 and then, starts to fall gradually to 3.69 in week 42. After week 42, the value remains at a lower range and it starts rising again from week 51.

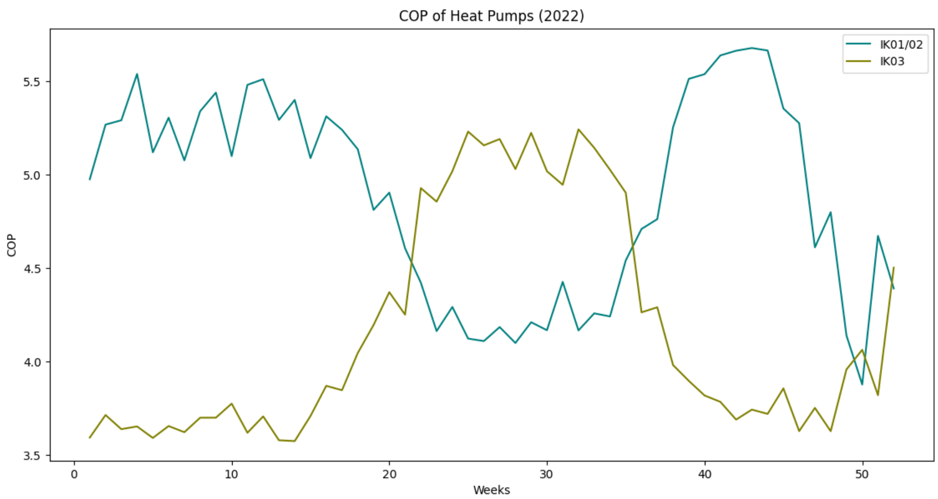

Fig. 6.12 COP of Heat pumps

It is eye-catching that the COP graph of HP IK03 seems quite opposite of COP graph of HP IK01/02. The reason behind this is, HP IK03 is an auxiliary and supporting heat pump for HP IK01/02. When HP IK01/02 has higher performance, the performance of HP IK03 becomes lower and vice-versa showing by Fig. 6.12 for keeping a balance performance to overall heat pump system.

Performance of heat pump that means COP varies with the buildings outside temperature and the energy demand of the building presented by Fig. 6.13

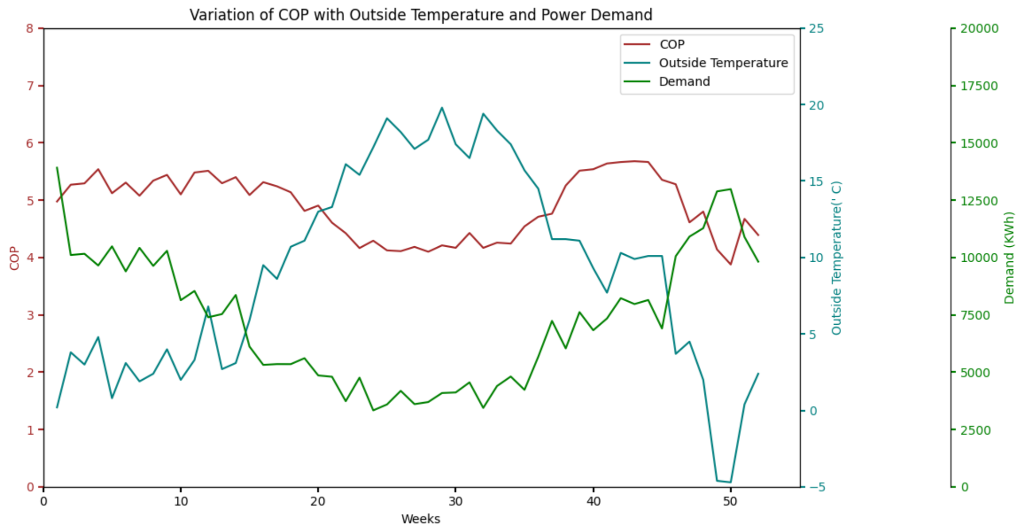

Fig. 6.13: Variation of COP with outside temperature and demand

When the outside temperature becomes lower, the energy demand remains higher and so, the COP becomes higher to meet the required energy demand showing in the above figure from week 1 to 14. With the rising of outside temperature, the thermal energy demand becomes lower causing the COP value lower from week 14 to 32. The outside temperature starts to fall again from week 32 causing the rise of demand as well as the COP.

6.3.2 Performance of Ground Source Heat Pump

Performance of solar cell power production can be assessed through various parameters. For the solar system of i4Helse building, the production performance has been evaluated by Solar Performance Ratio and Solar Ratio.

Fig. 6.14 represents the Performance Ratio (PR) of i4Helse building's solar system for the year 2022 and 2023.

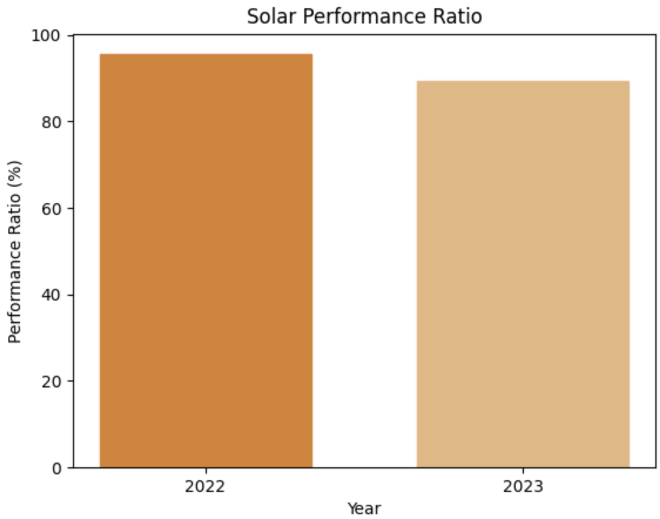

Fig. 6.14: Solar performance ratio

In 2022, Performance Ratio (PR) is 96 % that means the solar system has produced actual power 96 % of the expected power and, the PR has higher value in 2022 than 2023. Solar system has produced actual power 89% of the expected generation in 2023. The PR value of the solar system indicates high performance solar system working in i4helse building of UiA.

Solar Ratio (SR) indicates the total power production from solar system that can be used for the building's total demand including the electrical appliances and energy for heat pump operation. SR greater than 1 means there is addition power available after meeting the building's demand and the addition power can be stored or supplied to the grid. SR increases with the increase of production and can vary with the total demand.

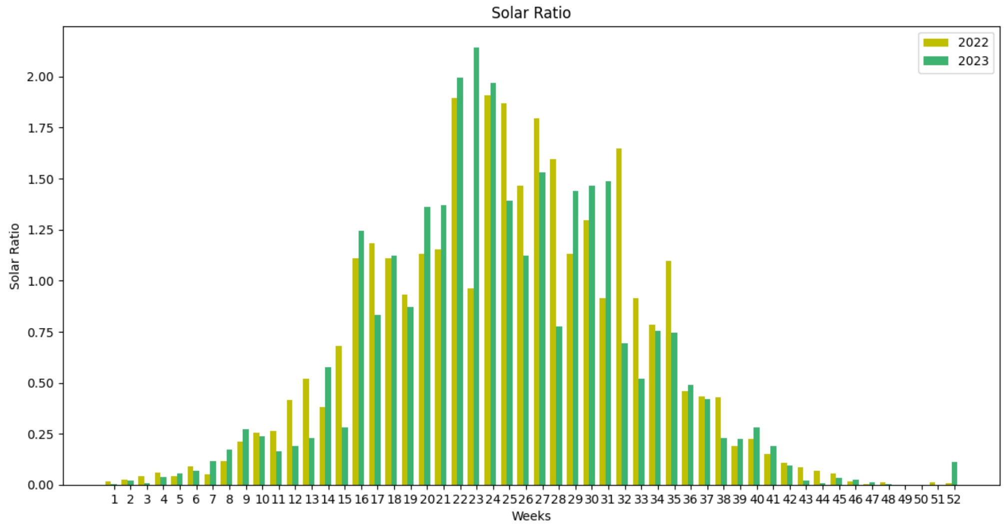

Fig. 6.15 Solar Ratio of solar system for 2022 and 2023

Among 2022 and 2023 shown in the above Fig. 6.15, there is SR greater than 1 almost after week 15 to 33 in 2022 and week 15 to 31 in 2023 when the temperature was high as well as the solar power generation. In those weeks, additional power can be sold to the grid or can be stored. SR has a pick value 1.922 in week 24 of 2022 and 2.136 in week 23 of 2023. This additional production contributes to the buildings energy economy directly by selling power.

6.4 Cost Savings from GSHP and Solar System

Cost saving means the amount of cost can be saved using power from GSHP as well as solar system instead of grid. Depending on the weekly price of grid power, cost savings are evaluated for the year 2022 and 2023 showing in the Fig. 6.16 for heat pump and Fig. 6.17 for solar system.

In 2022, amount of cost savings from heat pump is in a range of NOK 822.164-18761.463 between the week 1 to 45 on the basis of variation of power price and power production from heat pump. Savings is very high in week 49 and 50, almost NOK 35325.88 and NOK 35596.88 respectively for higher power price and higher power production in those weeks. A total amount of NOK 436336.16 is saved in 2022 and the savings is 1.899 NOK/KWh.

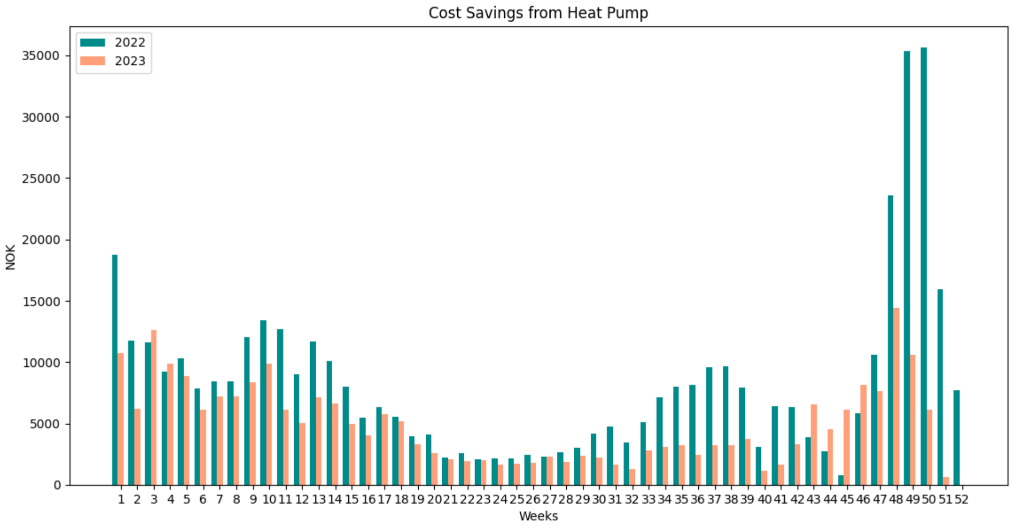

Fig. 6.16 Cost savings from GSHP

In 2023, amount of cost savings from heat pump is lower than 2022 because power price was high in 2022 for Russia-Ukraine war. Savings is almost constant around NOK 2000 in the weeks 20 to 42. Week 48 has the pick value of savings NOK 14440 in 2023. A total amount of NOK 253682.11 is saved in 2023 at a savings rate is 1 NOK/KWh.

Fig. 6.4.2 shows the cost savings from solar system throughout the year 2022 and 2023. Cost savings is increased highly in 2022 with a pick value NOK 23580. Total annual savings in 2022 is NOK 355121.69 at the rate 2.35 NOK/KWh.

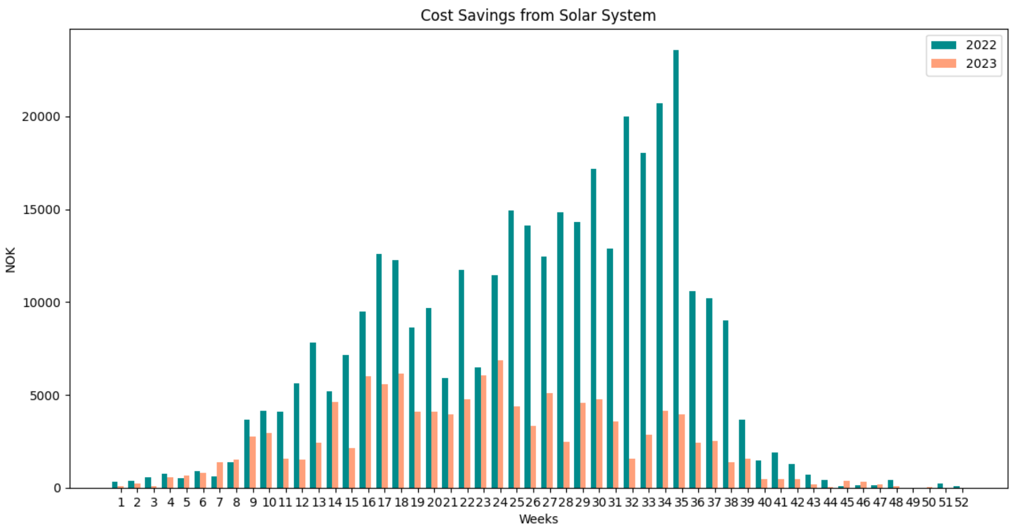

Fig. 6.17 Cost savings from solar system

Cost savings is lower in 2023 almost every week than 2022. The total annual savings is 122414.82 at a rate 0.87 NOK/KWh with the highest value is NOK 6840 in week 24.

6.5 Cost Savings Model Towards 2040

For the prediction process, multivariable linear regression model is used where year, power price and building's total demand act as variables depending upon which the cost savings towards the year 2040 has been developed. Increase of power price and demand increases the cost savings and vice-versa. Considering demand will change at an increasing rate 2%, 5%, 7% and 10 % of the demand 2023 for the year 2025, 2030, 2035 and 2040 chronologically. Power prices for these years are assumed based on the changing of last five years power price for both the prediction of heat pump and solar cell.

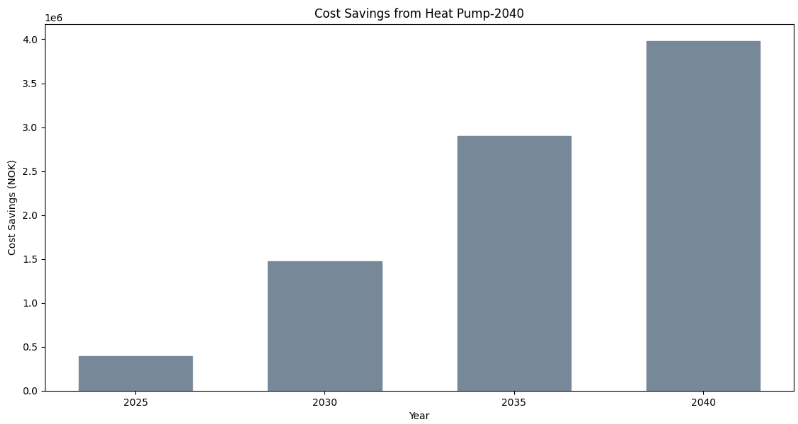

Fig. 6.18 Cost savings from GSHP towards 2040

Above Fig. 6.18 presents the result of the model showing that cost can be saved in a significant way till 2040 with the increase of grid power price and building's power demand. There is a possibility of falling power price after 2040. At 2025 and with a power price 1.18 NOK/kwh, the cost savings can be 398233.09 NOK whereas 1474462.2 NOK cost savings achieved in 2030 at a power price 1.61 NOK/kwh. There are cost savings amounts for 2035 and 2040 are NOK 2902506.45 and NOK 3976269.33 respectively. Cost savings can be estimated by this model for anytime by knowing the power price and building's power demand.

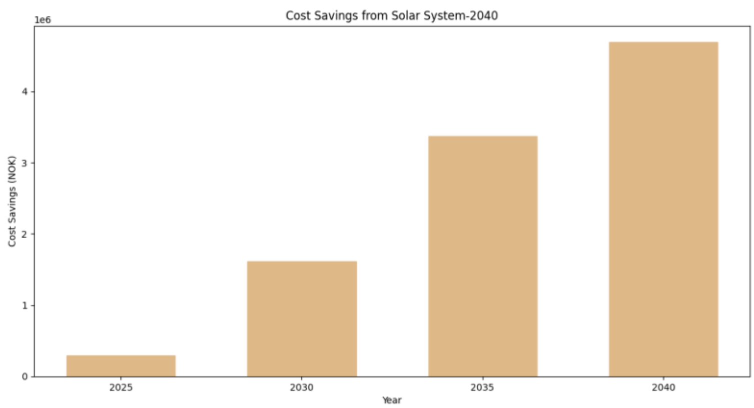

Fig. 6.19 Cost savings from solar system towards 2040

Uses of power from solar system contributes to increase cost savings compared to using grid power. Solar system of i4Health building saves NOK 293277.4 in the year 2025 and NOK 1612463.33 in 2030 shown in Fig. 6.19 With the rising of grid power price and buildings demand, cost savings also increased significantly in the year 2035 and 2040 with the amount NOK 3370724.8 and NOK 4686860.5 that is huge amount of cost savings.

6.6 Contribution of GSHP and Solar System

GSHP and Solar system contribute to the building's total cost for total consumption of power. Contribution is the percentage of ratio of the cost savings from heat pump or solar system to the total cost for the building's total power consumption. From Fig. 6.20, it has been analyzed that heat pump contributes averagely 54.4% at 2022 and 65.3% at 2023 to the building's total cost for total power consumption having a pick value 95% in week 18 of 2022. Heat pump contributes higher in 2023 than 2022.

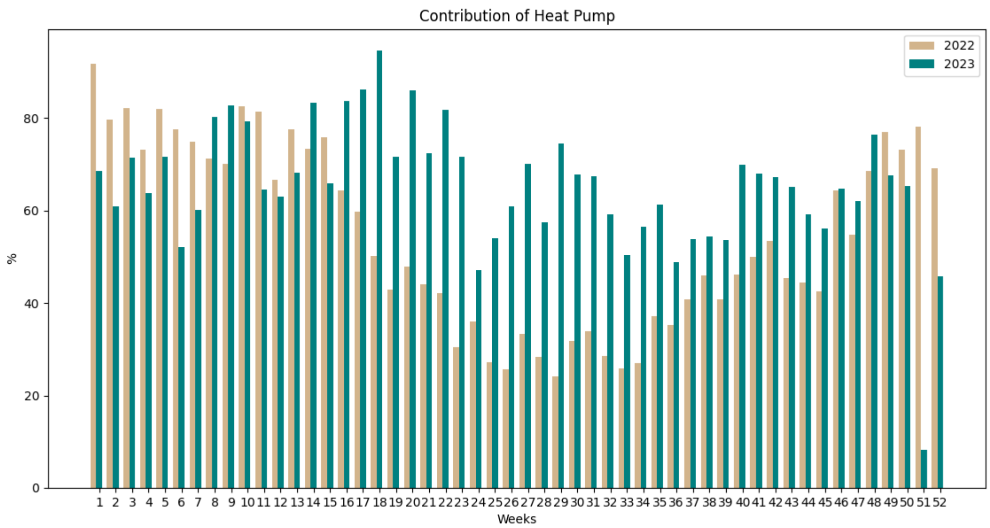

Fig. 6.20 Contribution of heat pump

Contribution depends on power production as well as total power consumption. Solar system contributes 60.27% in 2022 and 56.59% in 2023. Percentage of contribution becomes greater than 100 for a week when the production becomes higher than the consumption in that week. The additional produced power can be supplied to the grid or can be stored.

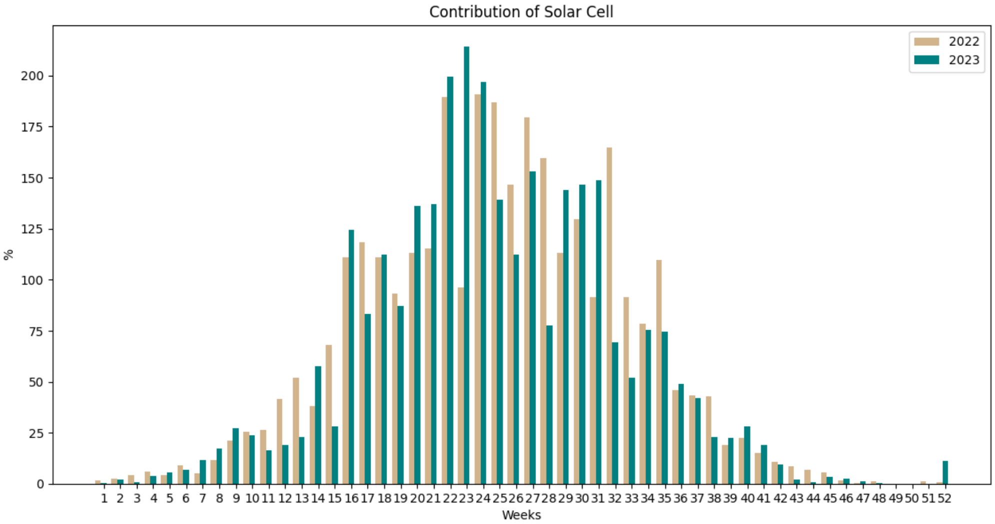

Fig. 6.21 Contribution of Solar system

6.7 Payback Period

Payback period is the indicator of how many years need to retrieve the installation costs of the project. In the basis of cost savings from GSHP and solar system of the year 2022 and 2023, payback period has been evaluated considering total investment cost with VAT.

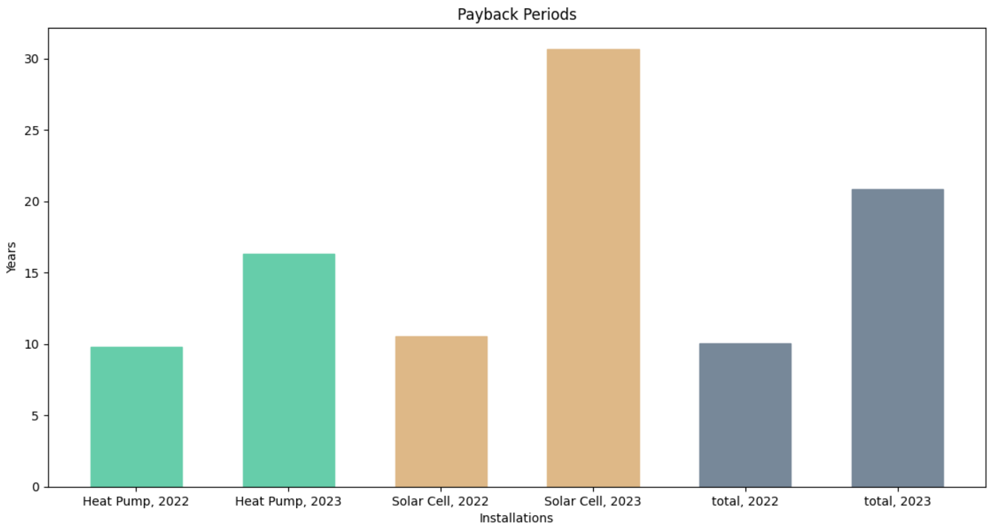

Fig. 6.22 Payback periods of GSHP and solar system

Heat pump need around 9.78 years based on 2022 cost savings and 16.33 years based on 2023 cost savings whereas solar system needs 10.56 years and 30.63 years according to 2022 and 2023 respective cost savings. Payback period for the total integrated system is 10.07 years and 20.83 years with respect to 2022 and 2023.

The power price was incredibly high in 2022 for the Russia-Ukraine war, so it is preferable to consider the payback periods resulted from cost savings data of 2023. The project completion is estimated for August 2019. Therefore, heat pump need around 12.33 years and solar system needs around 26.63 years more from now to meet the payback period.

6.8 Environmental impact of GSHP and Solar System

There has been widespread agreement on objectives and plans for lowering greenhouse gas (GHG) emissions and energy consumption in order to address the problems posed by climate change and resource scarcity. Power production from fossil fuels is the major causes of increasing Green House Gases (GHGs). Installation of GSHP and solar system can reduce the GHG emission in a significant way. For i4Health building, Fig. 6.8 shows the amount of CO2 reduction for the year 2022 and 2023.

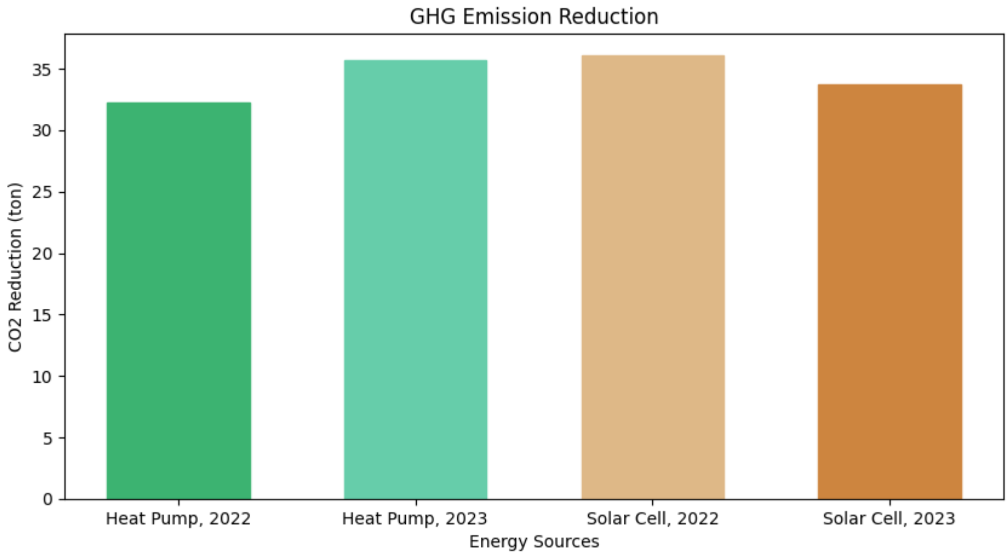

Fig. 6.23 CO2 emission reduction

Heat pump reduces 32.28 ton of CO2 than from grid in 2022 and 35.66 ton in 2023 whereas solar system reduces 36.05 ton in 2022 and 33.69 ton in 2023. The reduction of CO2 gas emissions contributes to the zero-emission goal and makes the place of GSHP and solar system more sustainable.

This section concludes the result and discussion chapter.

Chapter 7

Conclusions and Further Research

Mainly three objectives are achieved for analyzing the techno-economic feasibility of i4Health building of UiA in this Master's thesis. The first objective is analyzing the performance of GSHP and solar system working in i4Health building. Secondly, evaluation of cost effectiveness of these systems and finally analyzing the environmental impact of GSHP and solar system for the building.

7.1 Conclusions

From the thesis evaluations, modeling and analyzations, following conclusions are found to meet the research questions:

RQ1: How energy production from GSHP and solar system varies with outside temperature set temperature and the building's energy demand?

Production from GSHP depends on outside temperature and the building's energy demand. Lower outside temperature sets the set temperature higher and increases the building's energy demand. When set temperature becomes high and energy demand increases, the production from heat pump also increases. And, higher outside temperature sets the set temperature lower and when outside temperature is higher, the building's energy demand decreases that led the production decreased. There are three heat pumps are working in i4health building's GSHP system. Heat pump IK01 and heat pump IK02 works together alternatively with the basic relation of outside temperature, set temperature and the building's energy demand whereas the auxiliary heat pump IK03 produces high energy when the main two heat pump produces lower and vice-versa to support the main two heat pumps and to continue a balanced energy supply.

The production from solar system varies with the sunlight directly or indirectly thus, with the outside temperature. In summer, outside temperature becomes high that causes high power generation from solar system. Winter makes the output from solar system lower.

RQ2: How COP of GSHP of i4health building varies with outside temperature and the building's energy demand?

High outside temperature makes the building's energy demand lower and in this time COP of GSHP also becomes lower. Likewise, when the outside temperature remains at low temperature, COP of GSHP becomes higher to meet the required energy demand. In cold weather, COP of heat pump IK01 and IK02 remains around 4.98 to 5.7 per week and in warm weather it remains around 3.26 to 4.43 per week. Heat pump IK03 perforce kind of opposite of heat pump IK01 and heat pump IK02.

RQ3: What is cost savings from GSHP and solar system of i4Health building?

Cost savings varies here with the grid power price and production from GSHP and solar sysyem. In 2022, amount of cost savings from heat pump is in a range of NOK 822.164-18761.463 between the week 1 to 45 on the basis of variation of power price and power production from heat pump. Savings is very high in week 49 and 50, almost NOK 35325.88 and NOK 35596.88 respectively for higher power price and higher power production in those weeks. A total amount of NOK 436336.16 is saved in 2022 and the savings is 1.899 NOK/KWh. In 2023, amount of cost savings from heat pump is lower than

2022 because power price was high in 2022 for Russia-Ukraine war. Savings is almost constant around NOK 2000 in the weeks 20 to 42. Week 48 has the pick value of savings NOK 14440 in 2023. A total amount of NOK 253682.11 is saved in 2023 at a savings rate is 1 NOK/KWh.

Savings from solar system is increased highly in 2022 with a pick value NOK 23580. Total annual savings in 2022 is NOK 355121.69 at the rate 2.35 NOK/kwh. Cost savings is lower in 2023 almost every week than 2022. The total annual savings is 122414.82 at a rate 0.87 NOK/kwh with the highest value is NOK 6840 in week 24.

RQ4: What is the contribution of GSHP and solar system to the i4Health building's energy economy?

Contribution is the percentage of ratio of the cost savings from heat pump or solar system to the total cost for the building's total power consumption. It has been analyzed that heat pump contributes averagely 54.4% at 2022 and 65.3% at 2023 to the building's total cost for total power consumption having a pick value 95% in week 18 of 2022. Heat pump contributes higher in 2023 than 2022. Solar system contributes 60.27% in 2022 and 56.59% in 2023.

RQ5: What are the payback periods of heat pump and rooftop solar cell system of i4Health building with respect to installation costs?

Heat pump need around 9.78 years based on 2022 cost savings and 16.33 years based on 2023 cost savings whereas solar system needs 10.56 years and 30.63 years according to 2022 and 2023 respective cost savings. Payback period for the total integrated system is 10.07 years and 20.83 years with respect to 2022 and 2023. The power price was incredibly high in 2022 for the Russia-Ukraine war, so it is preferable to consider the payback periods resulted from cost savings data of 2023. The project completion is estimated for August 2019. Therefore, heat pump need around 12.33 years and solar system needs around 26.63 years more from now to meet the payback period.

RQ6: What is the environmental impact of GSHP and solar system working in i4Health building?

GSHP and solar system can reduce the GHG emission in a significant way. Heat pump reduces 32.28 ton of CO_2 than from grid in 2022 and 35.66 ton in 2023 whereas solar system reduces 36.05 ton in 2022 and 33.69 ton in 2023. The reduction of CO_2 gas emissions contributes to the zero-emission goal and makes the place of GSHP and solar system more sustainable.

This Master's thesis meets the main objectives about GSHP and solar system of i4Health building including performance evaluation, cost effectiveness and environmental impact. The research should be conducted before doing investment for GSHP and solar system for knowing the overall idea for making a proper plan. But, doing the research now contributes to get an overall idea from here to imply it for other commercial buildings before doing investment.

7.2 Future Research

Results and analysis from the Master's thesis of techno-economic analysis of integrated ground source heat pump and solar system opens various further research opportunities.
For future research and development, the following recommendations are proposed:

- The solar system of i4Health building is traditional, the further research can be conducted based on the techno-economic feasibility of updated rooftop solar systems such as PV system attached with the rooftop or window glasses for the building.

- This thesis is conduction depends on limited data resources; further research needs to be worked with wide data.

- Techno-economic feasibility of integrated heat pump and solar system analyzing is also applicable for other commercial buildings instead of only i4Health building.

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Appendices

The Python coding is used for acheving the objectives are given here:

For power production evaluation from Heat Pump, same for solar

```
from matplotlib import pyplot as plt
import numpy as np
t=np.linspace(1,52,52)
total_power_consumption=np.array([13911.7,10108,10161.4,9650.8,10485.8,9393
.8,10421,9634,10292.3,8137.4,8541.8,7394,7533.2,8366.3,6117.9,5320.4,5354,5
351.9,5610.9,4859,4802.1,3736.1,4762.1,3337,3594.7,4187.6,3609.1,3700.3,409
3.2,4118.7,4556.6,3444.5,4396.8,4812,4232.3,5671.7,7237.4,6037.6,7619.2,682
8.8,7342.5,8226.1,7970.7,8147.2,6906.1,10057.6,10911.2,11277.4,12879.8,1297
8.8,10892.8,9819.2])
power_production_HPIk12=np.array([13176,7918.9,8096,6420,8533,6951,7669,746
0,7863,6846,6320,3824,5046,5370,4097,2173,1991,1535.9,1589,1417,1260,1215,1
036,1026,972,841,989,781.1,905,895,746,791,905,725,843,748,1818,1395,1675,1
620,2410,3152,2147,2159,2053,5852,6598,7586,11781,12028,9094,7776.1]);
power_production_HPIk3=np.array([3096,2249,2451,2470,2400,2271,2260,1082,10
78,1644,2471,2467,2436,2447,1850,2232,2142,1919,1501,1556,1469,798,830,520,
294,540,556,571,372,782,1207,474,552,930,1152,1843,1974,2195,2342,2475,2300
,2474,2530,2512,1710,2391,1097,2382,1321,751,1844,993]);
power_used_HPIk1=np.array([1321.4,786.5,737.3,586.1,841.9,645.1,750,862.7,8
96.1,753.8,627.9,345.3,439.9,480.3,442.4,218,184.4,146.7,170.1,138.9,143.7,
142.6,125.7,115.8,118,99.4,122.9,89.4,107.8,109.7,82.8,85.8,106.8,83.8,87.4
,80.2,194.2,135.3,152.9,144.5,229.7,275.7,183.8,193.9,197.1,542.5,611.6,921
.2,1576.5,1206.3,733.1,782.4]);
power_used_HPIk2=np.array([1326.3,716.5,792.6,572.8,824.6,665,760.4,848.6,9
42.7,693.4,525.1,348.5,513.3,514,362.6,191,195.5,152.3,160.1,150,129.8,132.
1,123.1,123.2,117.7,105.2,113.4,101.1,107.1,105,85.7,104,105.7,87.1,98.2,78
.6,187.5,130.2,150.9,148,197.7,280.8,194.3,187.2,186.3,566.6,819,507.1,1268
.8,1895.4,1212.7,988.2]);
power_used_HPIk3=np.array([861.4,605.4,673.5,676,668.1,621.2,623.8,241.5,23
7,419.4,682.6,665.4,680.5,684.4,498.7,576.6,556.7,474.2,357.7,355.9,345.5,1
61.9,170.9,103.6,56.2,104.7,107.1,113.5,71.2,155.8,244,90.4,107.3,185,234.9
,432.2,460,551.2,600.9,648,607.6,670.4,675.8,675.1,443.3,658.9,292.3,656.5,
333.7,184.8,482.6,220.5]);
power_production_HPIk12_23=np.array([10110,6251,9453,7023,8115,5900,6860,61
31,6485,9009.9,6499,6139,7530,6125,5502,3875,3917,3648,2350,2412,1990,1996,
1975,1517,2286.9,1893,1650,1686,1250,1354,2019,2256,1273,1307,1467,1527,242
4,2398,2435,3538,4185,5835,7673,7281,6838,8632,8056,11390,9885,7399,453,26]
);
power_production_HPIk3_23=np.array([1205,1669,1691,1578,1606,887,1248,2516,
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3,1468,1873,1769,2642,2002,1184,1882,2406,2544,2529,2071,1726,2683,2637,261
4,2458,2359,2397,1012,1090,1092,1086,1175,1144,872,448,6]);
power_production_solar=np.array([217,276,424,569,432,852,563,1118,2195,2084
,2258,3091,3919,3174,4154,5904,6333,5943,5240,5503,5546,7084,4583,6367,6721
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,6136,6481,5906,4641,5342,4168,5683,4028,3769,4637,2608,3148,2590,1450,1529
,1103,878,681,549,381,164,67,145,6,0,118,88])
power_production_solar_23=np.array([76,228,78,389,589,694,1232,1478,2246,22
79,1439,1630,2201,3731,2132,5494,4918,5816,4524,5978,6055,7266,7574,6468,58
08,4897,6029,3684,5818,5640,5592,3839,2958,4018,3802,2840,2547,1685,1666,19
53,1494,910,245,86,398,294,161,56,4,18,9,6.1])
week=([1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26
,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51
,52])
#production 2022
print('IK01/02,2022',power_production_HPIk12)
print('IK03,2022',power_production_HPIk3)
plt.plot(t,power_production_HPIk12, label = "HP IK01/02",
color='lightslategrey')
plt.plot(t, power_production_HPIk3, label = "HP IK03",color='lightsalmon')
plt.title('Power Production from Heat Pumps, 2022')
plt.xlabel('Weeks')
plt.ylabel('Power Production (KWh)')
plt.legend()
plt.show()
#production 2023
plt.plot(t,power_production_HPIk12_23, label = "HP IK01/02",
color='lightsalmon')
plt.plot(t, power_production_HPIk3_23, label = "HP
IK03",color='lightslategrey')
plt.title('Power Production from Heat Pumps, 2023')
plt.xlabel('Weeks')
plt.ylabel('Power Production (KWh)')
plt.legend()
plt.show()
#production solar,22,23
print('IK01/02,2023',power_production_HPIk12_23)
print('IK01/02,2023',power_production_HPIk3_23)
plt.plot(t,power_production_solar, color='lightslategrey')
plt.title('Power Production from Solar Cell, 2022')
plt.xlabel('Weeks')
plt.ylabel('Power Production (KWh)')
plt.legend()
plt.show()
plt.plot(t,power_production_solar_23,color='lightsalmon')
plt.title('Power Production from Solar Cell, 2023')
plt.xlabel('Weeks')
plt.ylabel('Power Production (KWh)')
plt.legend()
plt.show()
#barIK01/02,22,23
N= 52
ind = np.arange(N)
```

```
width = 0.35

xvals = power_production_HPIk12
bar1 = plt.bar(ind, xvals, width, color = 'lightslategrey')

yvals = power_production_HPIk12_23
bar2 = plt.bar(ind+width, yvals, width, color='lightsalmon')


plt.xlabel("Weeks")
plt.ylabel('Production (KWh)')
plt.title("Power Production from Heat Pump IK01/02")

plt.xticks(ind+width,['1','2','3','4','5','6','7','8','9','10','11','12','1
3','14','15','16','17','18','19','20','21','22','23','24','25','26','27','2
8','29','30','31','32','33','34','35','36','37','38','39','40','41','42','4
3','44','45','46','47','48','49','50','51','52'])
plt.legend( (bar1, bar2), ('2022', '2023') )
plt.show()
#barIK03,22,23
N= 52
ind = np.arange(N)
width = 0.35

xvals = power_production_HPIk3
bar1 = plt.bar(ind, xvals, width, color = 'lightslategrey')

yvals = power_production_HPIk3_23
bar2 = plt.bar(ind+width, yvals, width, color='lightsalmon')


plt.xlabel("Weeks")
plt.ylabel('Production (KWh)')
plt.title("Power Production from Heat Pump IK03")

plt.xticks(ind+width,['1','2','3','4','5','6','7','8','9','10','11','12','1
3','14','15','16','17','18','19','20','21','22','23','24','25','26','27','2
8','29','30','31','32','33','34','35','36','37','38','39','40','41','42','4
3','44','45','46','47','48','49','50','51','52'])
plt.legend( (bar1, bar2), ('2022', '2023') )
plt.show()
#bar power production solar,22,23
N= 52
ind = np.arange(N)
width = 0.35

xvals = power_production_solar
bar1 = plt.bar(ind, xvals, width, color = 'lightslategrey')
```

```
yvals = power_production_solar_23
bar2 = plt.bar(ind+width, yvals, width, color='lightsalmon')


plt.xlabel("Weeks")
plt.ylabel('Production (KWh)')
plt.title("Power Production from Solar Cell")

plt.xticks(ind+width,['1','2','3','4','5','6','7','8','9','10','11','12','1
3','14','15','16','17','18','19','20','21','22','23','24','25','26','27','2
8','29','30','31','32','33','34','35','36','37','38','39','40','41','42','4
3','44','45','46','47','48','49','50','51','52'])
plt.legend( (bar1, bar2), ('2022', '2023') )
plt.show()
```

#For COP of heat pump

```
from matplotlib import pyplot as plt
import numpy as np
t=np.linspace(1,52,52)
total_power_consumption=np.array([13911.7,10108,10161.4,9650.8,10485.8,9393
.8,10421,9634,10292.3,8137.4,8541.8,7394,7533.2,8366.3,6117.9,5320.4,5354,5
351.9,5610.9,4859,4802.1,3736.1,4762.1,3337,3594.7,4187.6,3609.1,3700.3,409
3.2,4118.7,4556.6,3444.5,4396.8,4812,4232.3,5671.7,7237.4,6037.6,7619.2,682
8.8,7342.5,8226.1,7970.7,8147.2,6906.1,10057.6,10911.2,11277.4,12879.8,1297
8.8,10892.8,9819.2])
power_production_HPIk12=np.array([13176,7918.9,8096,6420,8533,6951,7669,746
0,7863,6846,6320,3824,5046,5370,4097,2173,1991,1535.9,1589,1417,1260,1215,1
036,1026,972,841,989,781.1,905,895,746,791,905,725,843,748,1818,1395,1675,1
620,2410,3152,2147,2159,2053,5852,6598,7586,11781,12028,9094,7776.1]);
power_production_HPIk3=np.array([3096,2249,2451,2470,2400,2271,2260,1082,10
78,1644,2471,2467,2436,2447,1850,2232,2142,1919,1501,1556,1469,798,830,520,
294,540,556,571,372,782,1207,474,552,930,1152,1843,1974,2195,2342,2475,2300
,2474,2530,2512,1710,2391,1097,2382,1321,751,1844,993]);
power_used_HPIk1=np.array([1321.4,786.5,737.3,586.1,841.9,645.1,750,862.7,8
96.1,753.8,627.9,345.3,439.9,480.3,442.4,218,184.4,146.7,170.1,138.9,143.7,
142.6,125.7,115.8,118,99.4,122.9,89.4,107.8,109.7,82.8,85.8,106.8,83.8,87.4
,80.2,194.2,135.3,152.9,144.5,229.7,275.7,183.8,193.9,197.1,542.5,611.6,921
.2,1576.5,1206.3,733.1,782.4]);
power_used_HPIk2=np.array([1326.3,716.5,792.6,572.8,824.6,665,760.4,534.3,5
49.3,588.5,525.1,348.5,513.3,514,362.6,191,195.5,152.3,160.1,150,129.8,132.
1,123.1,123.2,117.7,105.2,113.4,101.1,107.1,105,85.7,104,105.7,87.1,98.2,78
.6,187.5,130.2,150.9,148,197.7,280.8,194.3,187.2,186.3,566.6,819,659.2,1268
.8,1895.4,1212.7,988.2]);
power_used_HPIk3=np.array([861.4,605.4,673.5,676,668.1,621.2,623.8,292.4,29
1.3,435.4,682.6,665.4,680.5,684.4,498.7,576.6,556.7,474.2,357.7,355.9,345.5
,161.9,170.9,103.6,56.2,104.7,107.1,113.5,71.2,155.8,244,90.4,107.3,185,234
```

```
.9,432.2,460,551.2,600.9,648,607.6,670.4,675.8,675.1,443.3,658.9,292.3,656.
5,333.7,184.8,482.6,220.5]);
total_power_production_HP=power_production_HPIk12+power_production_HPIk3
total_power_used_HP=power_used_HPIk1+power_used_HPIk2+power_used_HPIk3
power_used_HPIK0102=power_used_HPIk1+power_used_HPIk2
COP_IK0102_22=power_production_HPIk12/power_used_HPIK0102
COP_IK03_22=power_production_HPIk3/power_used_HPIk3
print("COP of Heat Pump IK03 - 2022",COP_IK03_22)
plt.plot(t,COP_IK03_22,color='olive')
plt.title(' COP of Heat Pump IK03 (2022)')
plt.xlabel('Weeks')
plt.ylabel('COP')
plt.grid('True')
plt.show()
```

#For Performance Ratio of Solar

```
# library
import matplotlib.pyplot as plt

# create dataset
height = [95.5, 89.2]
bars = ('2022', '2023')

# Choose the position of each barplots on the x-axis (space=1,4,3,1)
x_pos = [0,0.3]

# Create bars
barw=plt.bar(x_pos, height,width=0.2)
barw[0].set_color('peru')
barw[1].set_color('burlywood')
# Create names on the x-axis
plt.xticks(x_pos, bars)
plt.xlabel("Year")
plt.ylabel("Performance Ratio (%)")
plt.title("Solar Performance Ratio")
# Show graphic
plt.show()
```

#For Solar Ratio of Solar

```
from matplotlib import pyplot as plt
import numpy as np
t=np.linspace(1,52,52)
total_power_consumption=np.array([13911.7,10108,10161.4,9650.8,10485.8,9393
.8,10421,9634,10292.3,8137.4,8541.8,7394,7533.2,8366.3,6117.9,5320.4,5354,5
351.9,5610.9,4859,4802.1,3736.1,4762.1,3337,3594.7,4187.6,3609.1,3700.3,409
3.2,4118.7,4556.6,3444.5,4396.8,4812,4232.3,5671.7,7237.4,6037.6,7619.2,682
8.8,7342.5,8226.1,7970.7,8147.2,6906.1,10057.6,10911.2,11277.4,12879.8,1297
8.8,10892.8,9819.2])
```

```
power_production_solar_23=np.array([76,228,78,389,589,694,1232,1478,2246,22
79,1439,1630,2201,3731,2132,5494,4918,5816,4524,5978,6055,7266,7574,6468,58
08,4897,6029,3684,5818,5640,5592,3839,2958,4018,3802,2840,2547,1685,1666,19
53,1494,910,245,86,398,294,161,56,4,18,9,6.1])
total_power_consumption_23=np.array([12676.5,10236.5,12060.1,10552,10552.6,
10109.5,10493,8546.2,8247.6,9570.6,8782.6,8571.6,9521.4,6458.5,7516.7,4414.
3,5909,5177.8,5185,4395.2,4422.7,3645,3538.8,3286.7,4177.2,4358,3942.8,4742
.8,4047.4,3846.8,3757,5523.5,5707,5313.2,5084.8,5821.3,6086.8,7344.6,7451.8
,6982.5,7757.3,9678.8,12185.2,10889.6,10989,11566.6,11405.9,12414.6,12485.9
,9692.6,8283,53.8])
power_production_solar=np.array([217,276,424,569,432,852,563,1118,2195,2084
,2258,3091,3919,3174,4154,5904,6333,5943,5240,5503,5546,7084,4583,6367,6721
,6136,6481,5906,4641,5342,4168,5683,4028,3769,4637,2608,3148,2590,1450,1529
,1103,878,681,549,381,164,67,145,6,0,118,88])
solar_ratio_22=(power_production_solar/total_power_consumption)
solar_ratio_23=(power_production_solar_23/total_power_consumption_23)
print('solar ratio_22',solar_ratio_22)
print('solar ratio_23',solar_ratio_23)
#2022
plt.plot(t,solar_ratio_22, color='teal')
plt.title('Solar Ratio (2022)')
plt.xlabel('Weeks')
plt.ylabel('Solar ratio')
plt.legend()
plt.show()
#23
plt.plot(t,solar_ratio_23,color='olive')
plt.title('Solar Ratio (2023)')
plt.xlabel('Weeks')
plt.ylabel('Solar ratio')
plt.legend()
plt.show()
```

Cost Savings from solar

```
from matplotlib import pyplot as plt
import numpy as np
t=np.linspace(1,52,52)
total_power_consumption=np.array([13911.7,10108,10161.4,9650.8,10485.8,9393
.8,10421,9634,10292.3,8137.4,8541.8,7394,7533.2,8366.3,6117.9,5320.4,5354,5
351.9,5610.9,4859,4802.1,3736.1,4762.1,3337,3594.7,4187.6,3609.1,3700.3,409
3.2,4118.7,4556.6,3444.5,4396.8,4812,4232.3,5671.7,7237.4,6037.6,7619.2,682
8.8,7342.5,8226.1,7970.7,8147.2,6906.1,10057.6,10911.2,11277.4,12879.8,1297
8.8,10892.8,9819.2])
total_power_consumption_23=np.array([12676.5,10236.5,12060.1,10552,10552.6,
10109.5,10493,8546.2,8247.6,9570.6,8782.6,8571.6,9521.4,6458.5,7516.7,4414.
3,5909,5177.8,5185,4395.2,4422.7,3645,3538.8,3286.7,4177.2,4358,3942.8,4742
.8,4047.4,3846.8,3757,5523.5,5707,5313.2,5084.8,5821.3,6086.8,7344.6,7451.8
```

```
,6982.5,7757.3,9678.8,12185.2,10889.6,10989,11566.6,11405.9,12414.6,12485.9
,9692.6,8283,53.8])
power_production_solar=np.array([217,276,424,569,432,852,563,1118,2195,2084
,2258,3091,3919,3174,4154,5904,6333,5943,5240,5503,5546,7084,4583,6367,6721
,6136,6481,5906,4641,5342,4168,5683,4028,3769,4637,2608,3148,2590,1450,1529
,1103,878,681,549,381,164,67,145,6,0,118,88])
power_production_solar_23=np.array([76,228,78,389,589,694,1232,1478,2246,22
79,1439,1630,2201,3731,2132,5494,4918,5816,4524,5978,6055,7266,7574,6468,58
08,4897,6029,3684,5818,5640,5592,3839,2958,4018,3802,2840,2547,1685,1666,19
53,1494,910,245,86,398,294,161,56,4,18,9,6.1])
elec_price=np.array([1.47,1.46,1.39,1.31,1.2,1.08,1.08,1.23,1.67,2,1.82,1.8
21,2,1.64,1.72,1.61,1.99,2.06,1.65,1.76,1.07,1.66,1.42,1.8,2.22,2.3,1.92,2.
51,3.08,3.22,3.09,3.52,4.48,5.5,5.08,4.06,3.25,3.48,2.54,0.98,1.75,1.45,1.0
8,0.76,0.28,0.9,1.78,3.05,3.56,3.75,1.87,1.14])
elec_price_23=np.array([1.24,0.998,1.465,1.465,1.17,1.166,1.14,1.046,1.225,
1.297,1.079,0.937,1.1,1.235,1.005,1.092,1.132,1.0573,0.903,0.6901,0.6532,0.
6553,0.802,1.06,0.757,0.684,0.846,0.678,0.787,0.848,0.641,0.404,0.972,1.039
,1.038,0.857,0.984,0.818,0.941,0.2415,0.3203,0.511,0.829,0.702,0.998,1.088,
1.078,1.52,1.257,0.97,0.94,0.98])
cost_savingsfrom_SC=power_production_solar*elec_price
cost_savingsfrom_SC_23=power_production_solar_23*elec_price_23
print('SC cost savings,22',cost_savingsfrom_SC)
print('SC cost savings,23',cost_savingsfrom_SC_23)
total_22SC=sum(cost_savingsfrom_SC)
print('total_22SC',total_22SC)
total_23SC=sum(cost_savingsfrom_SC_23)
print('total_23SC',total_23SC)
plt.plot(t,cost_savingsfrom_SC, color='darkcyan')
plt.title('Cost Savings from Solar System (2022)')
plt.xlabel('Weeks')
plt.ylabel('NOK')
plt.legend()
plt.show()
plt.plot(t,cost_savingsfrom_SC_23, color='lightsalmon')
plt.title('Cost Savings from Solar System (2023)')
plt.xlabel('Weeks')
plt.ylabel('NOK')
plt.legend()
plt.show()
```

#Contribution from solar

```
Contribution
total_cost_for_i4health=total_power_consumption*elec_price
total_cost_for_i4health_23=total_power_consumption_23*elec_price_23
SC_contribution_22=(cost_savingsfrom_SC/total_cost_for_i4health)*100
SC_contribution_23=(cost_savingsfrom_SC_23/total_cost_for_i4health_23)*100
print('contribution-22',SC_contribution_22)
print('contribution-23',SC_contribution_23)
```

```
total_22SC=sum(SC_contribution_22)
print('totalcon_22SC',total_22SC)
total_23SC=sum(SC_contribution_23)
print('totalcon_23SC',total_23SC)
plt.plot(t,SC_contribution_22, color='tan')
plt.title('Contribution of Solar System (2022)')
plt.xlabel('Weeks')
plt.ylabel('%')
plt.legend()
plt.show()
plt.plot(t,SC_contribution_23, color='teal')
```

Payback Period

```
import numpy as np
import matplotlib.pyplot as plt


# creating the dataset
data = {'Heat Pump, 2022':9.78, 'Heat Pump, 2023':16.33, 'Solar Cell, 
2022':10.56,
        'Solar Cell, 2023':30.63,'total, 2022':10.07,'total, 2023':20.83}
courses = list(data.keys())
values = list(data.values())

fig = plt.figure(figsize = (10, 5))

# creating the bar plot
bar=plt.bar(courses, values,
        width = 0.6)
bar[0].set_color('lightslategrey')
bar[1].set_color('lightslategrey')
bar[2].set_color('burlywood')
bar[3].set_color('burlywood')
bar[4].set_color('lightslategrey')
bar[5].set_color('lightslategrey')
plt.xlabel("Installations")
plt.ylabel("Years")
plt.title("Payback Periods")
plt.show()
```

#CO2 Emission Reduction

```
 library
import matplotlib.pyplot as plt

# create dataset
height = [95.5, 89.2]
bars = ('2022', '2023')

# Choose the position of each barplots on the x-axis (space=1,4,3,1)
```

```
x_pos = [0,0.3]

# Create bars
barw=plt.bar(x_pos, height,width=0.2)
barw[0].set_color('peru')
barw[1].set_color('burlywood')
# Create names on the x-axis
plt.xticks(x_pos, bars)
plt.xlabel("Year")
plt.ylabel("Performance Ratio (%)")
plt.title("Solar Performance Ratio")
# Show graphic
plt.show()
```

Cost Savings Model

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from sklearn import linear_model
df=pd.read_csv("costsc.csv")
df
reg=linear_model.LinearRegression()
reg.fit(df[['year','price','demand']], df.savings)
reg.predict([[2025,1.18,393168.894]])
```

array([293277.3994993])