

# Techno-economic comparative assessment of solutions for residential heating PV and direct electrification vs district heating

MJ2438 – Modelling of energy systems



Group 12

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Building energy model, Solar irradiation and Demand computations, District Heating and PVs computations, Economic and KPI analysis, Sensitivity Analysis, Report writing

## Nomenclature

BAU	Business As Usual
BRF	Bostadsrättsförening (Housing Cooperative)
CAPEX	Capital expenditure
KPI	Key Performance Indicator
OPEX	Operating Expenditure
PBP	Payback Period
PV	Photovoltaic
PVEB	Photovoltaic And Electric Boiler
PVHP	Photovoltaic And Heat Pump
RES	Renewable Energy Share
SAM	System Advisor Model
STC	Standard Temperature Condition
STCTES	Solar Thermal Collector with Thermal Energy Storage
TES	Thermal Energy Storage

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# INTRODUCTION

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## 1.1. Background

In Nordic countries like Sweden, district heating plays a major role in fulfilling the heating requirements such as space heating and tap hot water in residential buildings. However due to larger differences in weather conditions, the demand also fluctuates according to the season. The summer is usually a period of very low heating demand making it economically unattractive and expensive for those buildings which are completely dependent on district heating. Similar is the case with BRF Årstaterrassen.

### 1.1.1. Overview of BRF Årstaterrassen

BRF Årstaterrassen is a cooperative housing association located in Stockholm, comprising 33 buildings and a total of 423 apartments, making it one of the largest associations in Sweden. The apartments range in size from one to four rooms, with an average area of 47 square meters. Specifically, the complex includes 269 one-room apartments, 142 two-room apartments, 11 three-room apartments, and a single four-room apartment. The buildings are arranged in a semicircular pattern, with the majority of them consisting of three stories [1].

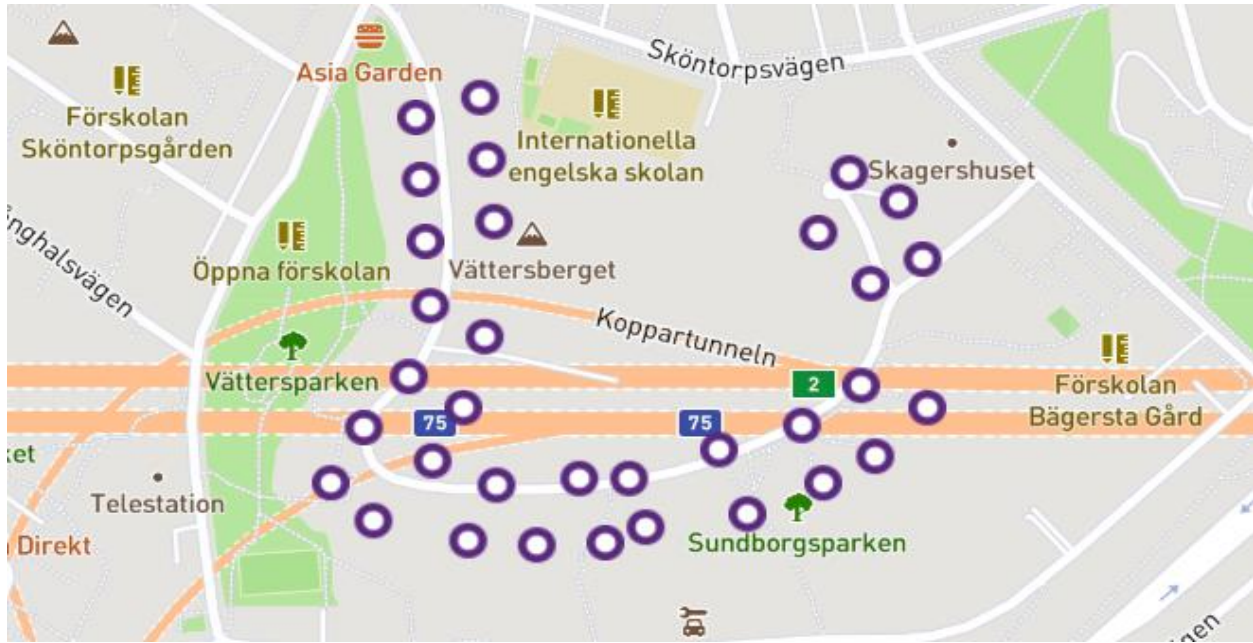


Figure 1: Årstaterrassen area layout

### 1.1.2. District heating in Stockholm

District heating represents the primary source of heat for the city of Stockholm, accounting for up to 75% of Sweden's overall heating demand [2]. In Stockholm, Stockholm Exergi has achieved a noteworthy milestone by delivering district heating with 98% renewable and recycled energy. The country has set a target to attain zero emissions by 2030. While many cities globally have substantial district heating networks, these systems often rely predominantly on fossil fuels such as coal, oil, and gas [3]. District heating systems can offer greater energy efficiency compared to individual heating solutions, as the heat is produced at a central plant and then distributed through a network of insulated pipes. This centralized approach tends to be more efficient than generating heat at each individual building [4]. However, due to the large piping network, district heating is prone to considerable heat losses. In modern systems, these losses can amount to between 15% and 20% of total heat supply [5].

The Årstaterrassen housing has relied entirely on district heating provided by Stockholm Exergi to cover its heating demand. During the summer period, specifically from May to September, district heating primarily serves the purpose of producing hot water for domestic use. However, due to the significant heat losses incurred through the piping network, Stockholm Exergi is

contemplating replacing district heating with alternative residential heating solutions, including photovoltaic (PV) solar panels, solar thermal collectors, and direct electrification.

## 1.2. Objective

The objective of this project is to assess whether the district heating system can be entirely deactivated during the five summer months, with solar thermal panels and thermal energy storage, solar PV and boiler, solar PV and heat pumps serving as alternative technologies for hot water production.

The following research questions have to be addressed:

- 1) Is it feasible for the alternative technologies to meet the entire demand for hot water during this period?
- 2) Which technology is more efficient?
- 3) Are these alternatives more cost-effective compared to the district heating system?
- 4) What potential can they have to winter contribution?

### 2.1. Modelling process

The methodology for this project follows a structured flow to determine the optimal heating solution for Årstaterrassen by evaluating four distinct scenarios. Each scenario incorporates different technologies to meet the predefined key performance indicators (KPIs) as defined in section 2.2. The scenarios are: District Heating System, PV Panels with Electric Boilers, PV Panels with Heat Pumps, and Solar Thermal Panels and are described in detail in section 2.3 and 2.4. The process is divided into four main stages: Preprocessing, Data Collection, Modeling, and Post Processing, as outlined in the flowchart in Figure 2.

#### 2.1.1. Preprocessing

The first step is the literature review and involves a comprehensive review of existing literature to gather insights and data on the project's heating technologies, economic modeling, and key performance indicators. This helps in understanding the current state of research and identifying projects and scenarios system boundaries. Based on the literature review, key performance indicators relevant to the project are defined. Then the different scenarios and system configurations are mapped out to understand the potential variations in performance and economic outcomes. This includes defining different operational conditions and geographical location.

#### 2.1.2. Data Collection

The data collection involves the systematic collection of data necessary for modeling. This includes technical data like specifications of the heating technologies such as efficiency, capacity, and lifespan. The economic data like CAPEX, OPEX and replacement of the technologies as well

as the cost for the current district heating supply. Furthermore geographical data on the area of Årstaterrassen like number and area of buildings as well as the potential solar irradiance is collected. The data is collected through official reports from the International Renewable Energy Agency (IRENA) and Global Solar Atlas.

### 2.1.3. Modeling

The modeling starts with the heating demand calculation of Årstaterrassen using Excell and the collected input data. This helps in understanding the load requirements and sizing the system appropriately. The various scenarios are calculated by assessing the required electricity demand to meet the heating demand and then calculating the numbers of solar panels needed. Simultaneously the performance and economics of each heating solution is assessed. The calculations of the first three scenarios were conducted to Excell and Google sheets because of their easiness in use and the familiarization of all the members with it, while for the calculations for the fourth scenario was used the SAM software because it is well designed for solar thermal collectors.

### 2.1.4. Post Processing

Here the results from the modeling phase are analyzed to understand the performance and economic outcomes of each heating solution across different scenarios. This includes a comparison of the Energy yield, Demand fulfilled, payback period and renewable energy share for each scenario. Then the sensitivity analysis is conducted to evaluate how changes in key parameters CAPEX affect the economic viability of each heating solution and identifies the most critical factor influencing the project. Lastly, conclusions based on the analysis are drawn.

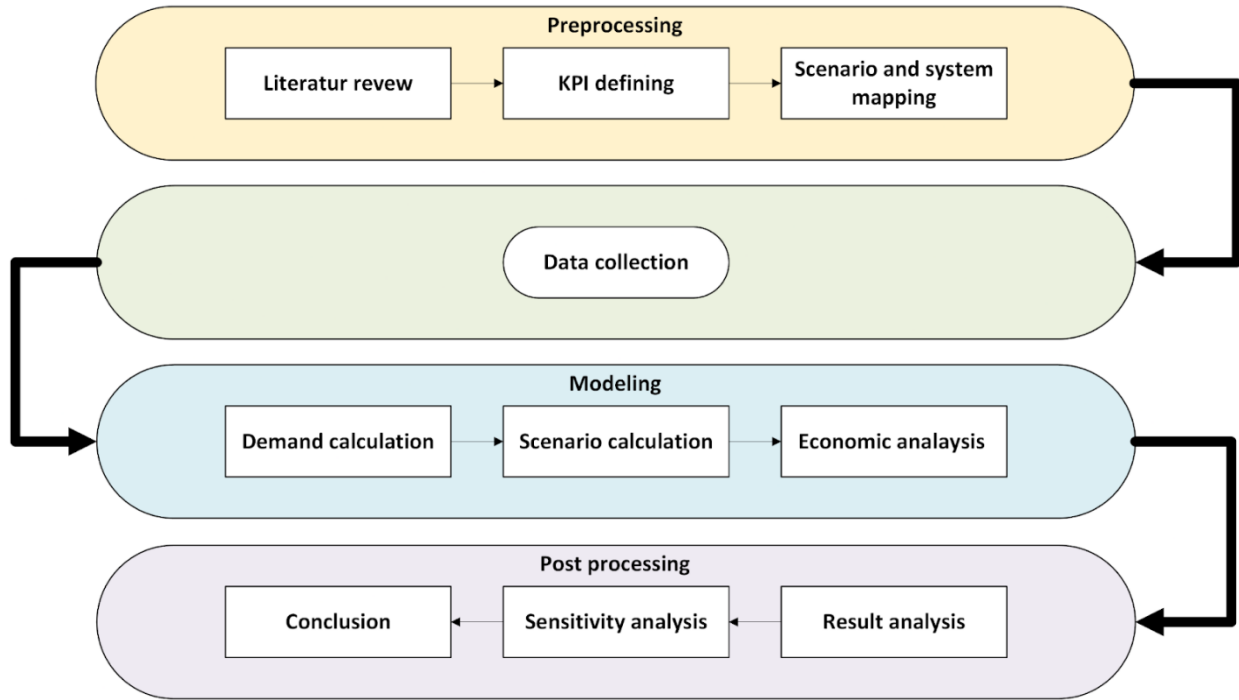


Figure 2: Methodology roadmap

## 2.2. Key Performance Indicators

Certain key performance indicators (KPIs) are selected to reply to the research questions and assess the results of the system. These KPIs concern technical, economic and environmental aspects, and are defined as followed:

### 2.2.1. Technical KPIs

#### Energy Yield (GWh)

$$AEY = \sum_{t=1}^{24} E_{NET}(t)$$

where  $E_{NET}$  is the energy production by the system in one day

#### Demand fulfillment (%)

$$Demand\ fulfillment = \frac{\sum_{t=1}^{24} E_{NET}(t)}{\sum_{t=1}^{24} E_{DEM}(t)}$$

where  $E_{DEM}$  is the energy demand of the system in one day

## 2.2.2. Economic KPIs

### **CAPEX (USD)**

The capital expenditure sums up all the component costs

### **OPEX (USD/year)**

The operational expenditure is the cost of operation and maintenance of the components

### **LCoE (USD/kWh)**

The levelized cost of electricity is a measure of the average net present cost of electricity generation over its lifetime.

$$LCOE = \frac{\sum_{n=0}^{lifetime,i} \frac{(CAPEX_{i,n} + OPEX_{i,n})}{(1+r)^n}}{\sum_{n=0}^{lifetime,i} \frac{E_{NET\ i,n}}{(1+r)^n}}$$

where  $CAPEX_{i,n}$  is the capital cost of the technology  $i$  in year  $n$  and similarly for OPEX and  $E_{NET}$ . The discount rate was set to 7% according to recommendations for renewable energy projects. [6]

### **PBP (years)**

$$PBP = \frac{CAPEX}{\sum_{h=1}^{8760} E_{net,h} \cdot p_h - OPEX}$$

The Payback Period is the number of years that it takes to even out the investment of the technology and compares therefore revenues and investment costs.

## 2.3. Scenarios

To determine the optimal heating solution of Årstaterrassen, four distinct scenarios were developed. Each scenario incorporates different technologies intended to meet the KPIs. These scenarios, named after the primary technologies employed, are:

- ❖ District heating system
- ❖ PV panels with electric boilers
- ❖ PV panels with heat pumps
- ❖ Solar thermal panels

For all the scenarios, it is assumed that all apartments are fully occupied. The total available roof area was found equal to 3460 m<sup>2</sup> [7]. However, it is assumed that only the 60% can be used for the allocation of PV panels and Solar Thermal Collectors. It is further assumed that during the summer months, from June to August, district heating is exclusively utilized for hot water production, with this level of consumption remaining steady throughout the rest months of the year.

## 2.4. System overview

A system layout has been designed for each scenario, and a techno-economic analysis has been conducted to compute the KPIs.

### 2.4.1. District heating system

In the DH scenario only district heating is considered as the energy source for supplying hot water to the apartments as the current situation is described in the project description. In this scenario the hot water demand during the summer months is supplied directly by the district heating that comes from Stockholm Exergis power plant and is distributed to Årstaterrassen and all the apartments.

### 2.4.2. PV and electric boiler

The PVEB scenario explores the potential heating supply from a solar PV system with batteries combined with an electric boiler. The system consists of PV panels that via a DC/AC inverter supplies electricity to an electric boiler that heats up water which is then supplied to the apartments like illustrated in in Figure 3.

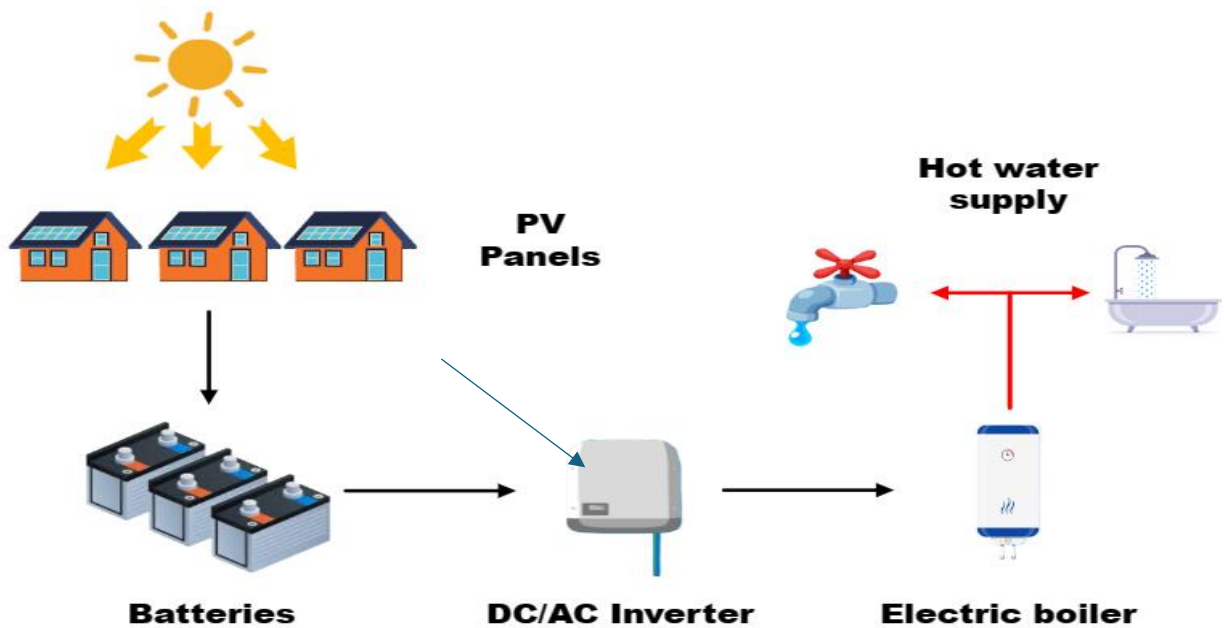


Figure 3: System map of PV and electric boiler

### 2.4.3. PV and heat pump

In the PVHP scenario the system setup is exactly the same as in the PVEB scenario but instead of the electric boiler the electricity is supplied to air-to-water heat pumps with the help of the ambient outside air heats up water for the hot water use. In this scenario an air-to-water heat pump is chosen because it would be easiest to implement as drilling and implementing a ground source heat pump directly in the city is not optimal. The system map can be seen in Figure 4.

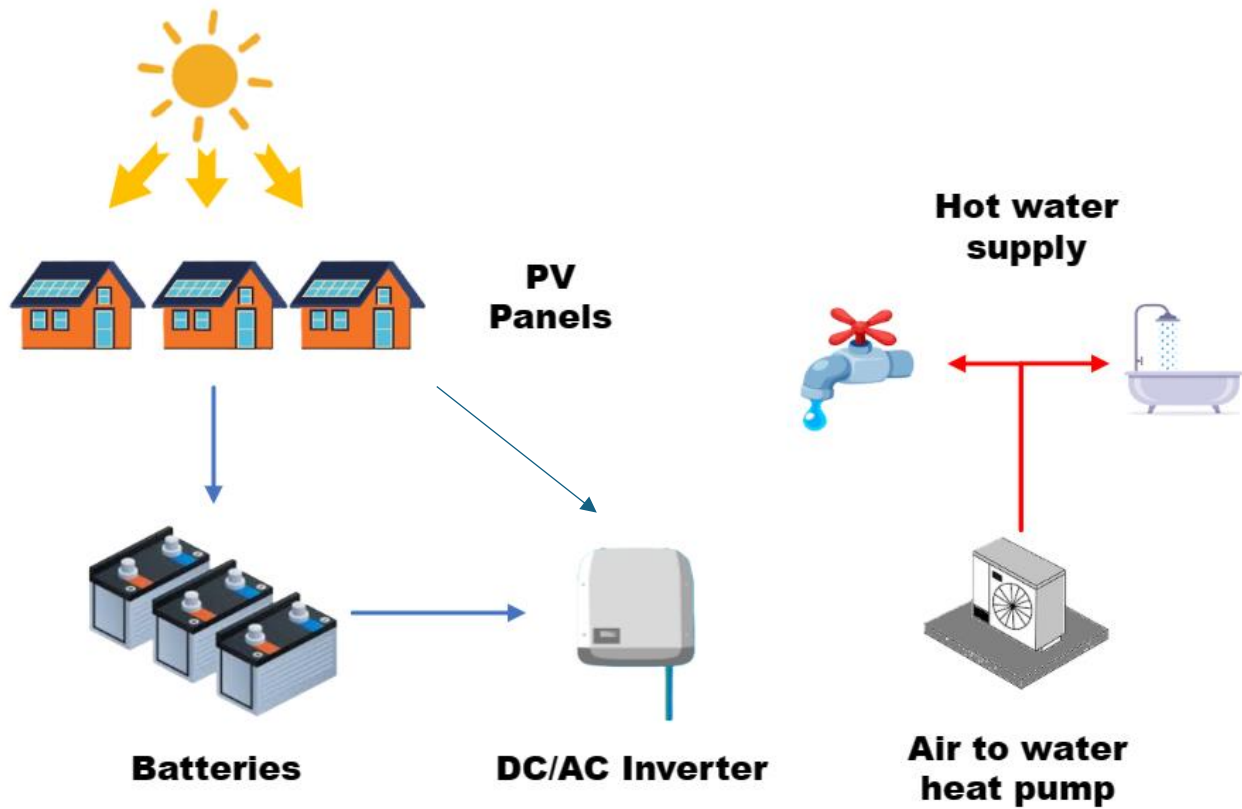


Figure 4: System map of PV and heat pump

#### 2.4.4. Solar thermal collectors

For the STCTES scenario solar thermal collectors are used instead of electric PV panels to collect the energy from the sun. The hot water is therefore directly supplied to the apartments by the solar thermal collectors that directly transfer the solar heat to the water that flows through them. This system is also equipped with a thermal energy storage so the system is able to store the hot water during the day and supply it during the night when no new hot water can be produced. The system map is presented in Figure 5.

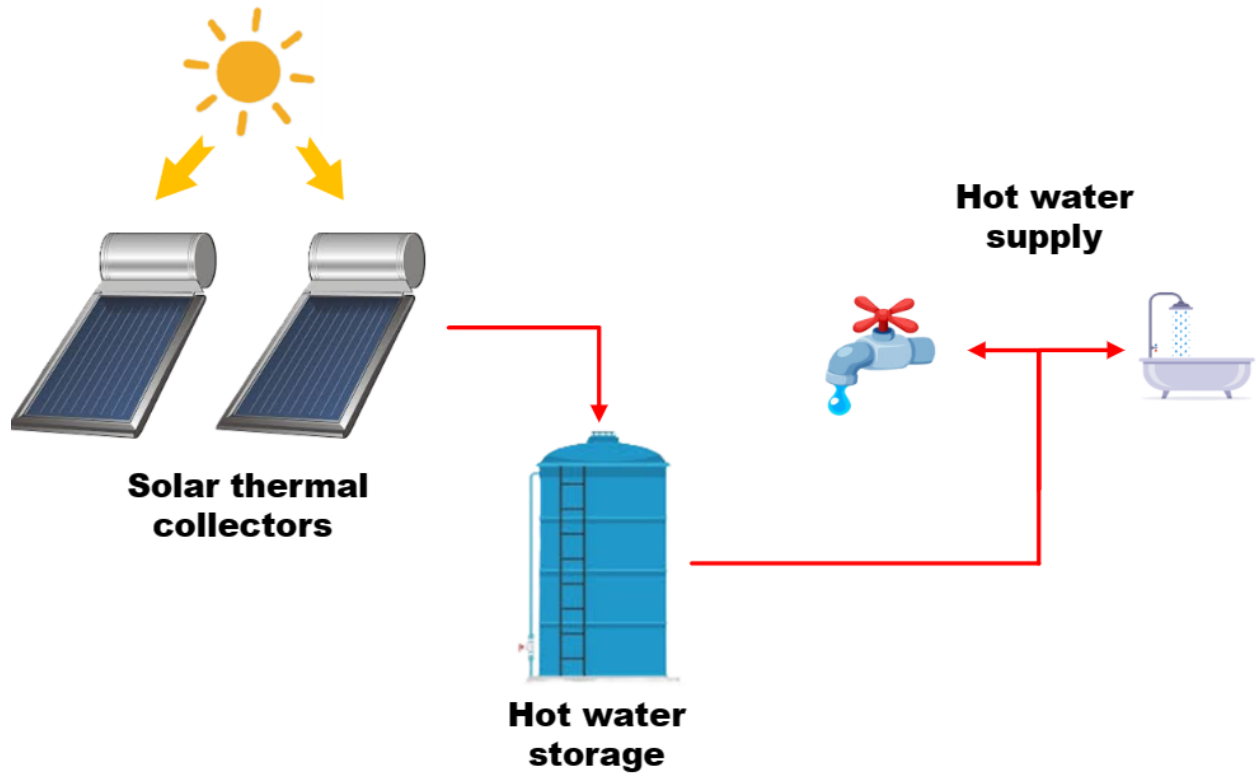
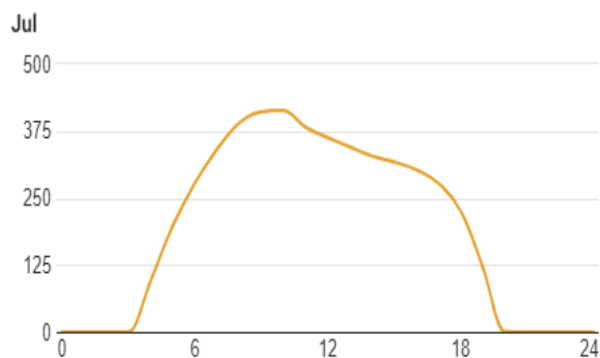
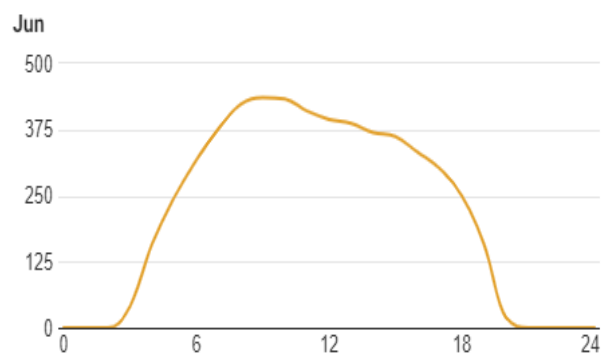
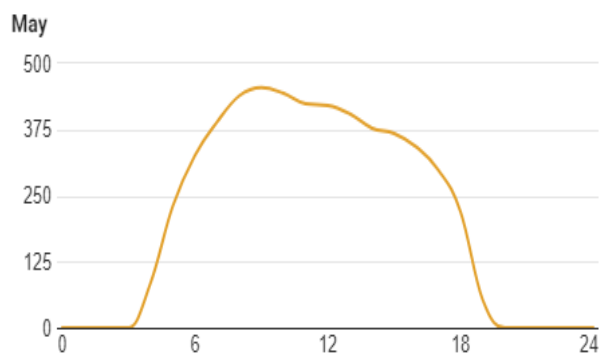


Figure 5: System map of solar thermal collectors and thermal energy storage

### 3.1. Solar irradiation computation

The initial step involved calculating the maximum available solar irradiation. To accomplish this, the average hourly profiles of solar irradiation for all summer months were obtained. September was selected as the case study month, as it exhibits the lowest solar irradiation based on the solar hourly profiles presented in the following figures. Consequently, if demand can be met in September, it can also be met during the other summer months.



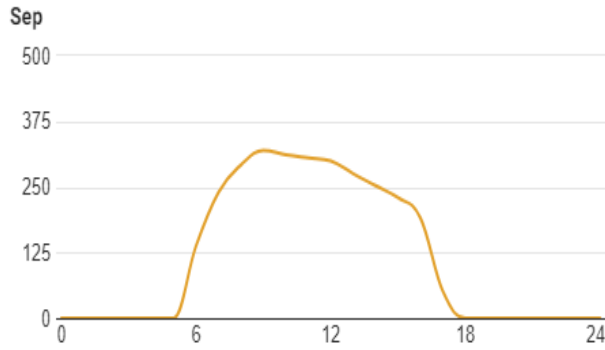


Figure 6: Hourly profile of solar irradiation from May to September

The calculations for the maximum available daily solar irradiation for the month of September are provided in the Appendix.

### 3.2. Demand computation

In this section it is computed the annual monthly and hourly heating demand.

#### 3.2.1. Annual heating demand

Annual heating demand computation is done as shown in Table 1.

Table 1: Computation of annual heating demand

	Value	Source
Total number of apartments	423	[1]
Total number of buildings	33	[1]
Average apartment area (m <sup>2</sup> )	47	[1]
Average energy usage per square meter (MWh / m <sup>2</sup> )	131	[6]

Therefore, the total annual average energy usage =  $131 * 47 * 423 * 10^{-3} = 2604.4$  MWh/ year

#### 3.2.2. Monthly heating demand

To aid the computation, monthly and daily heating demand was necessary. Monthly demand was obtained by scaling up the graphical values obtained from the average monthly district heating demand graph, under the assumption that the daily demand curve from a household will be like

the average daily district heating demand curve [8]. Constant daily demand was assumed for each month. Then it was multiplied by number of hours and total number of days in each month. The sum gave the heating demand per year (MWh/ year). This was compared with the year's demand computed above for the whole buildings in order to find the heating demand for each month. The following graph shows the obtained monthly heating demand for our case.

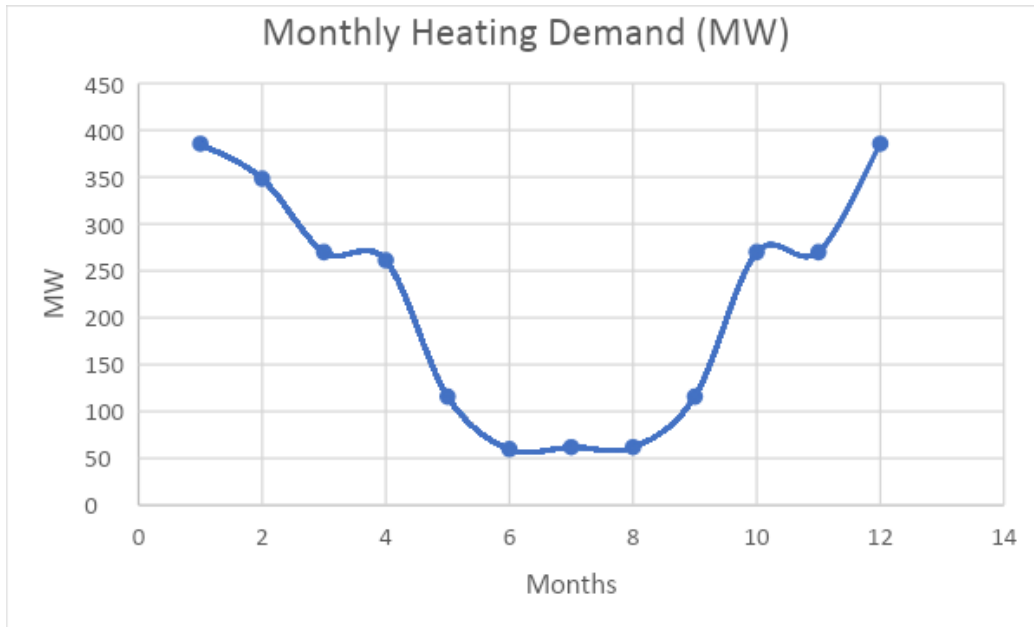


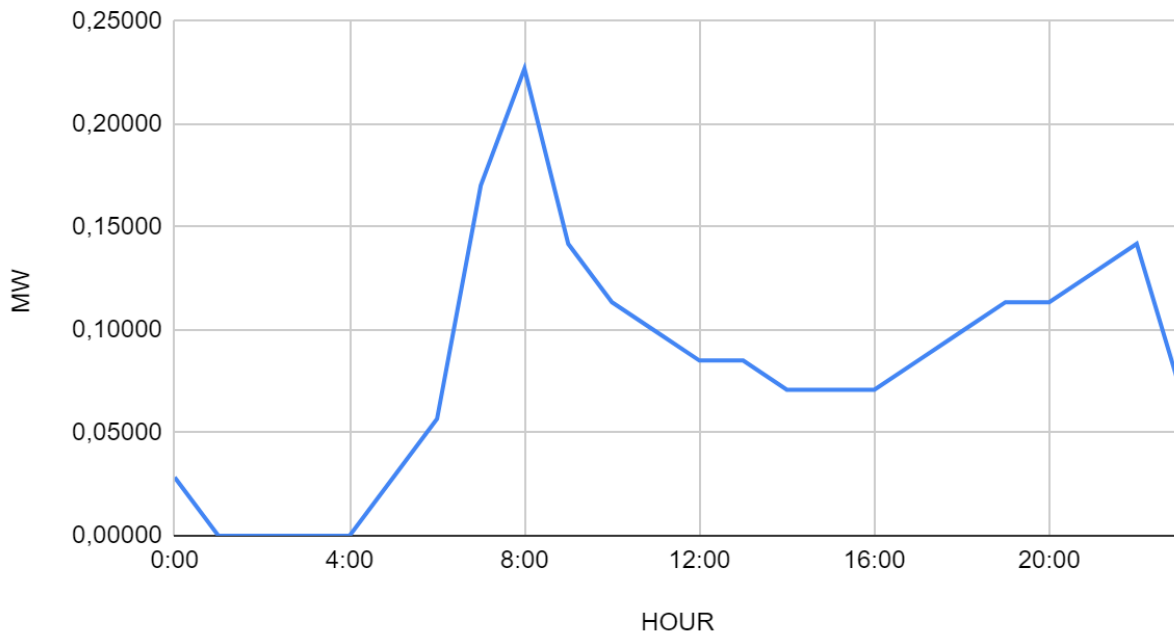
Figure 7: Monthly heating demand

### 3.2.3 Hourly heating demand

As mentioned before, the hot water demand is assumed to be constant throughout all these months and equal to the heating demand during June, July and August (60 MWh) because then it was considered that the total heating was used only for hot water production. This constant demand for each month is divided by the number of days in a month. Thus, the daily heating demand is obtained for a day in the month of September .

Similarly, based on the average hourly demand curve of district hot water consumption for the EU and considering the daily demand assumed above an hourly demand curve was calculated for a day in September. [9]

## Hourly demand



*Figure 8: Hourly heating demand*

The analytical calculations for the monthly and hourly demand are provided in the Appendix.

### 3.3. System configuration

In this section the needed electricity demand and needed required number of system components are calculated for the different scenarios.

#### 3.3.1. District heating system

In district heating system the heating cost has been 3.5 million SEK per year. As before, it is also conducted an interpolation analysis in order to define how much of that cost is from May to September. With the Excell it is calculated that this cost amounts to 52898 USD (556871 SEK).

### 3.3.2. PVs and electric boiler

To model the Solar PV and Electric Boiler system we have taken a day in the month of September. The hourly heating demand and the electricity requirement of boiler are provided in Table 11 in the Appendix.

The electricity would be generated by solar PV from 06:00 to 18:00 hours to cover the entire demand. The battery will only be used in the hours when PV can't meet the demand (i.e. before 10:00 and after 17:00 hours). Hence the minimum battery requirement is equal to the demand during these hours, which is equal to 994.2 kWh/day. Considering the battery efficiency (90%), inverter efficiency (95%) and depth of discharge for the battery (80%) it is calculated the **battery capacity requirement = 1453.5 kWh /day**

The boiler is selected in such a way that the peak demand should be met by the boiler capacity. Therefore, the **boiler capacity = 0.227 MW**.

The costs at different capacities of electric boilers available in market are shown in Table 2.

*Table 2: Costs for different capacities of electric boilers*

<b>Capacity (kW)</b>	<b>Cost (GBP)</b>
115	6076.17
48	2600
14.4	1300
19	1700
12	3000
6	619

Based on the available data a trend line was drawn as shown in Figure 9:

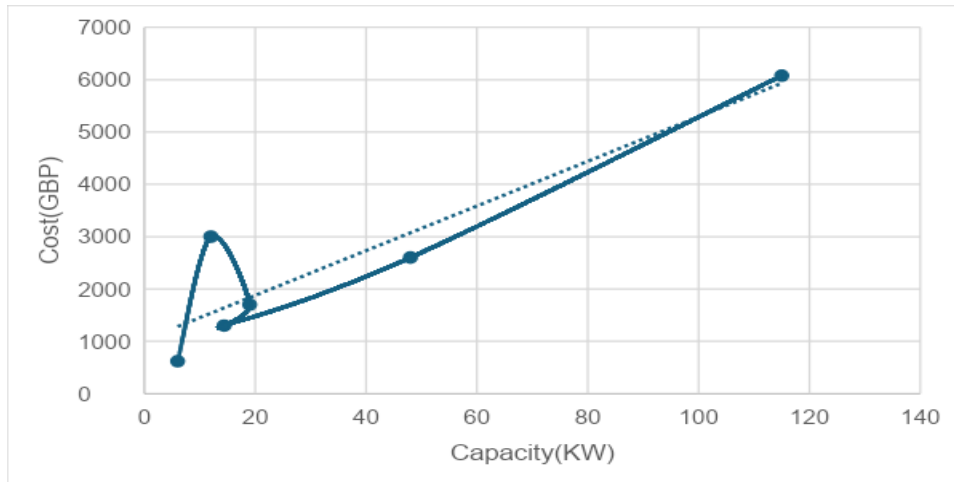


Figure 9: Electric boiler cost trendline

From the equation obtained from the above graph the capital cost of the boiler was calculated to 13779 USD.

### Validation of Solar potential

Surplus electricity produced by PV = 139.6 kWh

Demand during the hours solar light is absent = 994.2 kWh

Since production is LESS than demand, the design is **not feasible** to meet 100% demand. So the remaining 854.6 kWh should be met from district heating. The demand fulfilled will only be 14.04%.

### Area and Number of solar PV required by the Solar PV-Electric boiler system

To cover the demand it is necessary to be covered the whole available rooftop area. It is considered a useable fraction of 60% of the rooftop area to be available for the installation of PV panels. The total area is 3460 m<sup>2</sup>. It is used the PV. SunPower model SPR-MAX7- 445-PT with capacity 0.45kW and area 1.86m<sup>2</sup>.

Number of PVs required = 1116

The capital and operating cost per kW of PV modules, heat pump and energy storage per capacity are shown in Table 3.

Table 3: CAPEX and OPEX of the 2<sup>nd</sup> scenario

	CAPEX (USD/kW)	OPEX (USD/kW/Year)
Solar PV	876	7.7
Boiler	51.6	0.16
Energy storage	518.5	1.57
TOTAL (USD)	1208231	6899

### 3.3.3. PV and heat pump

As before, it was calculated the hourly heating demand and electricity requirement for the heat pump and the results are shown in Table 12 in the Appendix.

In that case, it is observed that the solar irradiation can meet the total demand.

The electricity would be generated by solar PV during the sunlight from 06:00 to 18:00 hours to cover the demand. The battery will only be used in the hours when PV can't meet the demand (i.e. before 06:00 and after 17:00 hours). Hence, the minimum battery requirement is equal to the demand during these hours, which is equal to 249.4 kWh/day. Considering the battery efficiency (90%), inverter efficiency (95%) and depth of discharge for the battery (80%).

**Battery requirement = 364.6 kWh/day**

The heat pump is selected in such a way that the peak demand should be met by the heat pump capacity.

Peak demand = 0.227 MW

COP = 3

Electricity demand = 75.66 kW

**Heat pump requirement = 79.65 kW**

#### Number of Solar PVs and the area required

With 2076m<sup>2</sup> (60% of total area) of roof area we can generate 1145.5kwh/day

So for generating 666.7kWh (demand of electricity for heat pump) we would need 1208.3m<sup>2</sup>.

The PV module used is SunPower model SPR-MAX7- 445-PT with capacity 0.45 kW and area 1.86m<sup>2</sup>.

Number of panels required = 649

The capital and operating cost per kW of PV modules, boiler and energy storage per capacity are shown in Table 4.

Table 4: CAPEX and OPEX of the 3<sup>rd</sup> scenario

	CAPEX (USD/kW)	OPEX (USD/kW/Year)
Solar PV	876	7.7
Heat pump	1415	0.054
Energy storage	518.5	1.57
TOTAL (USD)	448886	2833

### 3.3.4. Solar thermal collectors

#### System Requirements

- Application: Domestic hot water heating (primary). with potential for space heating support.
- Daily Energy Demand: 2000 kWh
- Peak Load: 0.227 MW
- Available Roof Area: 2076 m<sup>2</sup>

#### Collector Selection

- Type: Glazed flat-plate collectors were determined to be the optimal technology due to their temperature range, cost-efficiency, and ease of installation.
- Model: Wagner-Solar Wagner C20 AR-M collectors were selected based on:
  - High efficiency (85.4% optical efficiency, 96% light transmissivity, selective absorber coating)
  - Excellent thermal insulation
  - Proven reliability and market availability
  - Installation flexibility and support

A depiction of the selected solar thermal collector is in Figure 10.

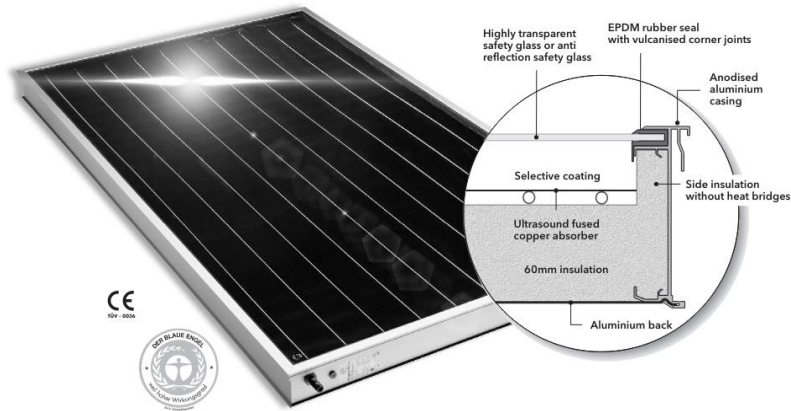


Figure 1 The EURO C20/C22 - powerful, versatile and rapidly installed

Figure 10: Wagner-Solar Wagner C20 AR-M Solar Thermal Collector

### System Design

- Total Collector Area: 206 m<sup>2</sup>
- System Sizing: System Advisor Model (SAM) was used for the initial sizing and technical specifications

### Benefits

- Reduced Energy Costs: Significant savings on household energy bills are expected.
- Environmental Impact: Reduction in greenhouse gas emissions through the displacement of conventional energy sources.
- Sustainability: Solar thermal energy contributes to a sustainable energy mix.

### Technical Specifications

Table 5: Solar thermal collector characteristics

Type of Collector	Heat Transfer Unit	Operating Pressure	Stagnation Temperature	Optical Efficiency	Max Steam Pressure	Collector Size	Area
Glazed Flat-Plate	Water-Glycol	1000	232	85.4%	10 bar	2151 x 1215 x 110 mm	2.61m <sup>2</sup>

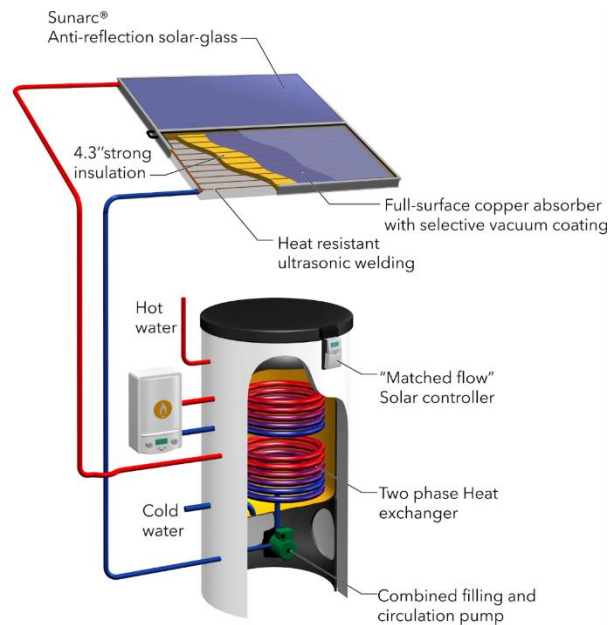


Figure 11: STC design

In that case, it is observed that the solar irradiation can meet the total demand.

The heat would be generated by STC during the sunlight from 06:00 to 18:00 hours to cover the demand. The thermal storage will only be used in the hours when STC can't meet the demand (i.e. before 06:00 and after 18:00 hours). Hence, the minimum TES requirement is equal to the demand during these hours, which is equal to 723.4 kWh/day. Considering the TES efficiency (75%), and depth of discharge for the storage (80%).

**Thermal energy storage = 1205.7 kWh/day**

**Number of Solar Thermal Collectors and the area required**

With 2076m<sup>2</sup> of roof area we can generate 5148.5kWh/day

So, for generating 2000kWh we would need area 806.4m<sup>2</sup>

Consider the solar collector with capacity 1.698 KW and area 2.61 m<sup>2</sup>

Number of collectors required = 309

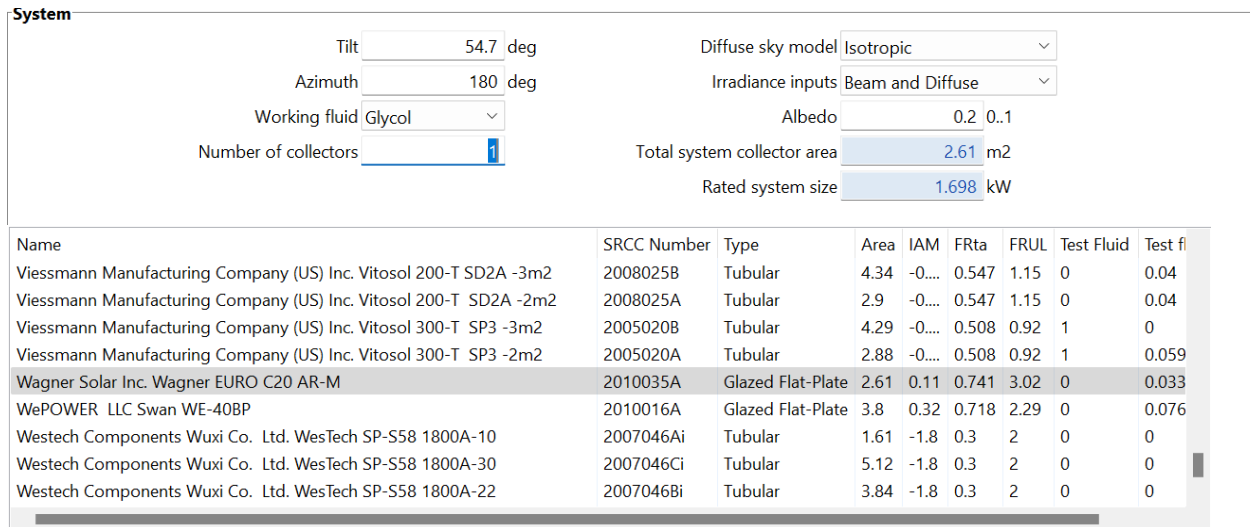


Figure 12: Snapshot from System Advisor Model (SAM)

### Calculation of the volume of the thermal energy storage

The volume of TES for a temperature difference from 25 to 60°C is calculated:

$$\text{Volume} = E_{\text{TES}} / \rho C_p (T_{\text{max}} - T_{\text{min}}) = \mathbf{2.95\text{m}^3}$$

The capital and operating cost per kW of solar thermal collectors and thermal energy storage per capacity are shown in Table 6.

Table 6: CAPEX and OPEX for the 4th scenario

	CAPEX (USD/kW)	OPEX (USD/kW/Year)
STC	470	0.023
TES	8.11	0.621
TOTAL (USD)	256332	776

# 4

## RESULTS & DISCUSSION

### 4.1. Proposed solution

Comparing the four scenarios they have been calculating the following KPIs:

Table 7: KPIs calculation

	District heating	PVs and electric boiler	PVs and heat pump	Solar thermal collectors
Energy Yield (kWh)	2000	139.6	2000	2000
Demand fulfilled (%)	100	14.04	100	100
CAPEX (USD)	-	1208231	448886	256332
OPEX (USD/year)	52898	6899	2833	776
LCoE (USD/MWh)	26.4	604.1	225.9	128.6
PBP (years)	-	27	9	5

It is observed that all the scenarios apart from the PVs and electric boiler scenario can cover the total demand. The scenario with the lowest CAPEX and OPEX is the 4<sup>th</sup> scenario with the solar thermal collectors while the scenario with the lowest LCoE is the district heating scenario. The 4<sup>th</sup> scenario has also the lowest payback period, followed by the 3<sup>rd</sup>, while the payback period of the second scenario is very high. Therefore, the scenario that is selected as the best solution, according to the KPIs is the 4th scenario.

The CAPEX, OPEX, LCoE and PBP compared for all the scenarios are illustrated in Figure 13.

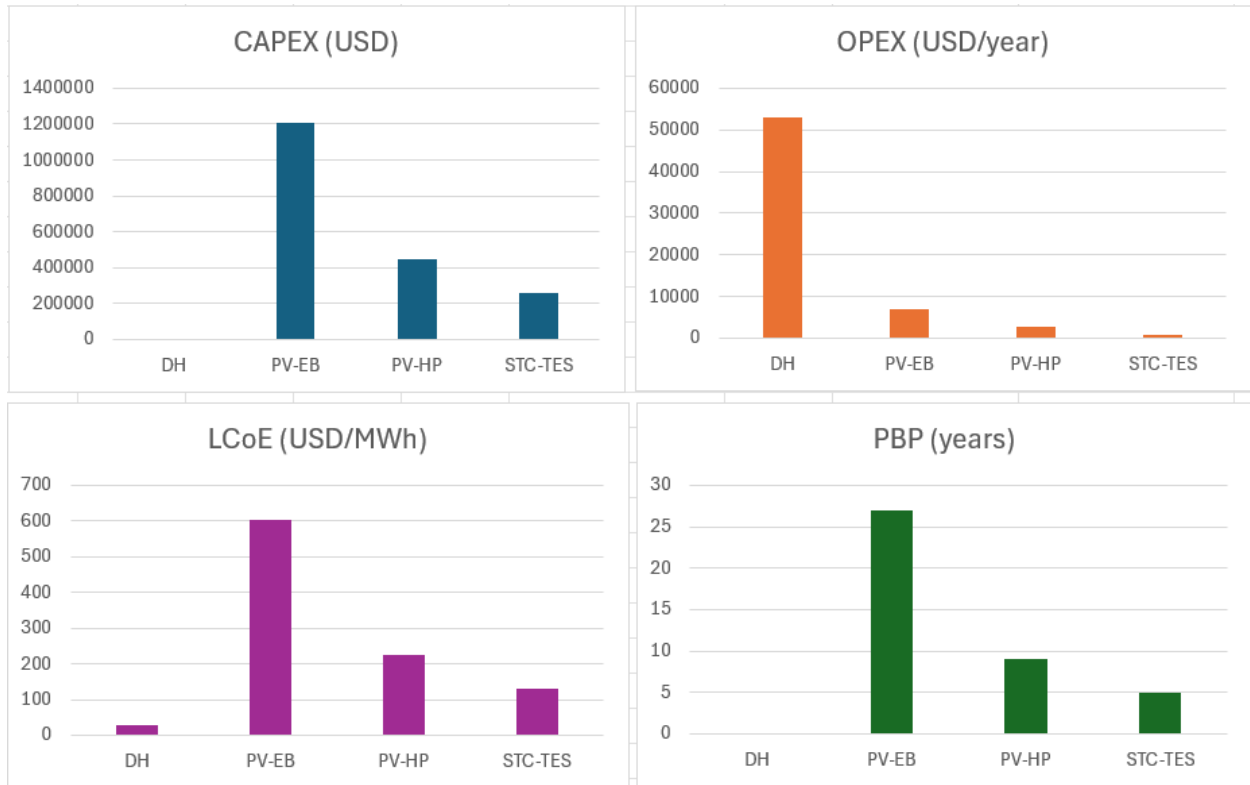


Figure 13: Comparison of CAPEX, OPEX, LCoE and PBP for all the scenarios

## 4.2. Potential winter contribution

In order to calculate the potential winter contribution we consider the best scenario which is the thermal solar collectors and we calculate the heating that they can provide during the year by multiplying the capacity of the panels with the number of the days of each month and the number of the hours of each day that has sunlight.

Potential heating = 188.9 MWh

The total demand for hot water production = 720 MWh

Therefore, the winter contribution = 18.9%

### 4.3. Sensitivity analysis

A sensitivity analysis was conducted in order to determine which of the scenarios is most affected by the KPIs of CAPEX and OPEX.

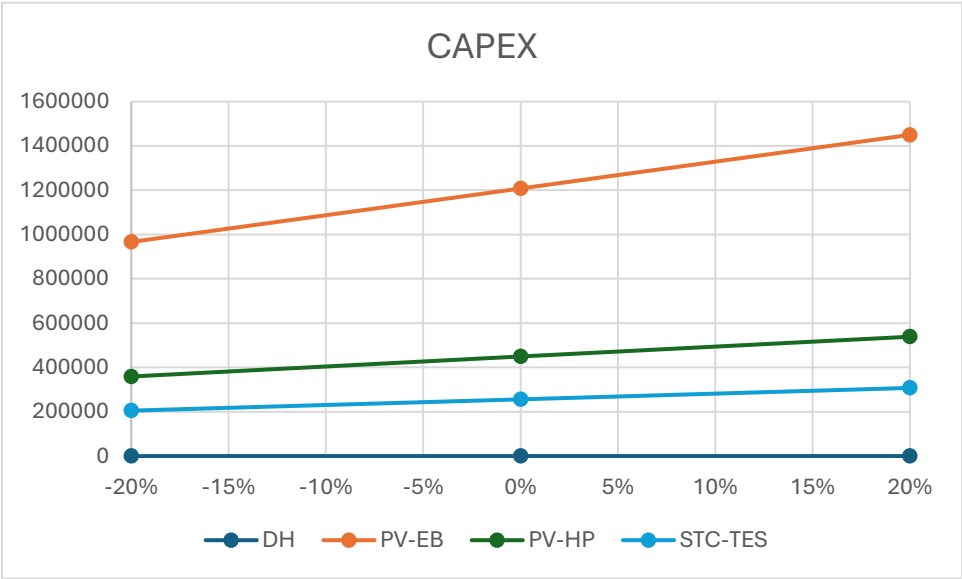


Figure 14: Sensitivity analysis for CAPEX

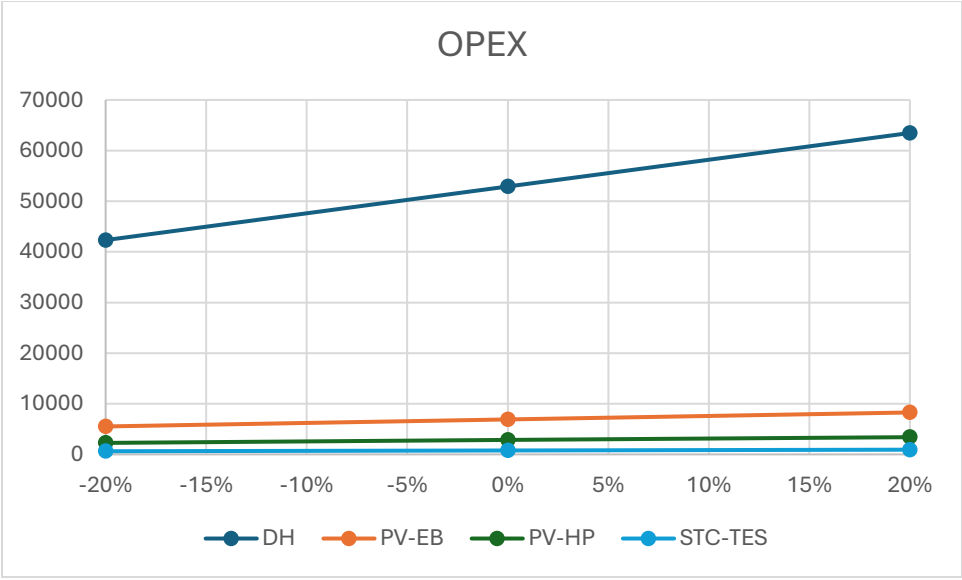


Figure 15: Sensitivity analysis for OPEX

It is observed that the CAPEX mainly affects the PVs and electric boiler scenario while the OPEX affects the District Heating.

#### 4.4. Conclusion

In conclusion it is observed that the best scenario to replace the district heating demand are the solar thermal collectors. Their PBP is only 5 years while they can also contribute to the winter hot water generation by about 20%.

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*LITERATURE*

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- 1 <https://www.allabrf.se/brf-arstaterrassen/summering>
- 2 <https://www.linkedin.com/pulse/swedens-district-heating-system-based-reusing-resources-a3s6f>
- 3 <https://www.stockholmexergi.se/en/district-heating/>
- 4 <https://www.veolia.co.uk/what-is-district-heating>
- 5 <https://docs.energytransitionmodel.com/main/heat-networks/>
- 6 <https://www.renewableenergyworld.com/solar/demystifying-lcoe/>
- 7 <https://www.energimyndigheten.se/statistik/den-officiella-statistiken/statistikprodukter/energistatistik-for-flerbostadshus/>
- 8 <https://www.sciencedirect.com/science/article/pii/S0306261913000391>
- 9 <https://doi.org/10.1016/j.rser.2017.05.229>.

# APPENDIX

Table 8: Computation of solar irradiation

Hour	Solar Irradiation (Wh/m <sup>2</sup> )	Solar Irradiation (kWh)
0:00	0	0
1:00	0	0
2:00	0	0
3:00	0	0
4:00	0	0
5:00	0	0
6:00	137.6	54.3
7:00	239.5	94.5
8:00	291.9	115.1
9:00	319.7	126.1
10:00	311.3	122.8
11:00	305.3	120.4
12:00	299.8	118.3
13:00	275.3	108.6
14:00	252.4	99.6
15:00	229.3	90.4
16:00	190.9	75.3
17:00	51.0	20.1
18:00	0	0
19:00	0	0
20:00	0	0
21:00	0	0
22:00	0	0
23:00	0	0
<b>SUM</b>	2904	1145.5

Table 9: Computation of monthly demand

	Literature monthly demand (MW)	Literature monthly demand (MWh)	Monthly demand (MWh)
JAN	250	186000	385.5
FEB	250	168000	348.2
MAR	175	130200	269.9
APR	175	126000	261.2
MAY	75	55800	115.7
JUN	40	28800	59.7
JUL	40	29760	61.7
AUG	40	29760	61.7
SEP	75	55800	115.7
OCT	175	130200	269.9
NOV	175	130200	269.9
DEC	250	186000	385.5
<b>SUM</b>		1256520	<b>2604.4</b>

Table 10: Computation of hourly demand

Hour	Percentage of hourly demand (%)	Hourly demand (kWh)
0:00	1,42	28,4
1:00	0,00	0,0
2:00	0,00	0,0
3:00	0,00	0,0
4:00	0,00	0,0
5:00	1,42	28,4
6:00	2,84	56,7
7:00	8,51	170,2
8:00	11,35	227,0
9:00	7,09	141,8
10:00	5,67	113,5
11:00	4,96	99,3
12:00	4,26	85,1
13:00	4,26	85,1
14:00	3,55	70,9
15:00	3,55	70,9
16:00	3,55	70,9
17:00	4,26	85,1
18:00	4,96	99,3
19:00	5,67	113,5
20:00	5,67	113,5
21:00	6,38	127,7
22:00	7,09	141,8
23:00	3,55	70,9
<b>SUM</b>	100,00	2000,0

Table 11: Electric boiler demand

Hour	Heating demand (kWh)	Maximum available electricity from solar irradiation (kWh)	Electricity Demand from boiler (kWh)	Demand and Supply Difference for boiler (kWh)
0:00	28.4	0	28.4	-28.4
1:00	0.0	0	0.0	0.0
2:00	0.0	0	0.0	0.0
3:00	0.0	0	0.0	0.0
4:00	0.0	0	0.0	0.0
5:00	28.4	0	28.4	-28.4
6:00	56.7	54.3	56.7	-2.5
7:00	170.2	94.5	170.2	-75.7
8:00	227.0	115.1	227.0	-111.8
9:00	141.8	126.1	141.8	-15.7
10:00	113.5	122.8	113.5	9.3
11:00	99.3	120.4	99.3	21.1
12:00	85.1	118.3	85.1	33.1
13:00	85.1	108.6	85.1	23.5
14:00	70.9	99.6	70.9	28.6
15:00	70.9	90.4	70.9	19.5
16:00	70.9	75.3	70.9	4.4
17:00	85.1	20.1	85.1	-65.0
18:00	99.3	0	99.3	-99.3
19:00	113.5	0	113.5	-113.5
20:00	113.5	0	113.5	-113.5
21:00	127.7	0	127.7	-127.7
22:00	141.8	0	141.8	-141.8
23:00	70.9	0	70.9	-70.9
<b>SUM</b>	<b>2000</b>	<b>1145.5</b>	<b>2000</b>	<b>-854.5</b>

Table 12: Heat pump demand

Hour	Demand (kWh)	Maximum available electricity from solar irradiation (kWh)	Electricity Demand from heat pump (kWh)	Demand and Supply Difference for heat pump (kWh)
0:00	28.4	0	9.5	-9.5
1:00	0.0	0	0.0	0.0
2:00	0.0	0	0.0	0.0
3:00	0.0	0	0.0	0.0
4:00	0.0	0	0.0	0.0
5:00	28.4	0	9.5	-9.5
6:00	56.7	54.3	18.9	35.4
7:00	170.2	94.5	56.7	37.7
8:00	227.0	115.1	75.7	39.5
9:00	141.8	126.1	47.3	78.8
10:00	113.5	122.8	37.8	85.0
11:00	99.3	120.4	33.1	87.3
12:00	85.1	118.3	28.4	89.9
13:00	85.1	108.6	28.4	80.2
14:00	70.9	99.6	23.6	75.9
15:00	70.9	90.4	23.6	66.8
16:00	70.9	75.3	23.6	51.7
17:00	85.1	20.1	28.4	-8.3
18:00	99.3	0	33.1	-33.1
19:00	113.5	0	37.8	-37.8
20:00	113.5	0	37.8	-37.8
21:00	127.7	0	42.6	-42.6
22:00	141.8	0	47.3	-47.3
23:00	70.9	0	23.6	-23.6
<b>SUM</b>	<b>2000</b>	<b>1145.5</b>	<b>666.7</b>	<b>478.8</b>

Table 13: Solar thermal collectors demand

Hour	Demand (kWh)	Maximum available heat from solar thermal collectors (kWh)	Demand and Supply Difference for solar thermal collectors (kWh)
0:00	28.4	0.0	-28.4
1:00	0.0	0.0	0.0
2:00	0.0	0.0	0.0
3:00	0.0	0.0	0.0
4:00	0.0	0.0	0.0
5:00	28.4	0.0	-28.4
6:00	56.7	244.0	187.2
7:00	170.2	424.6	254.4
8:00	227.0	517.5	290.6
9:00	141.8	566.8	425.0
10:00	113.5	551.9	438.4
11:00	99.3	541.3	442.0
12:00	85.1	531.5	446.4
13:00	85.1	488.1	403.0
14:00	70.9	447.5	376.6
15:00	70.9	406.5	335.6
16:00	70.9	338.4	267.5
17:00	85.1	90.4	5.3
18:00	99.3	0.0	-99.3
19:00	113.5	0.0	-113.5
20:00	113.5	0.0	-113.5
21:00	127.7	0.0	-127.7
22:00	141.8	0.0	-141.8
23:00	70.9	0.0	-70.9
<b>SUM</b>	<b>2000</b>	<b>5148.5</b>	<b>3148.5</b>