Str. Oneștilor nr. 11, Oradea, Romania

PRELIMINARY STUDY CONCERNING THE USE OF HEAT PUMPS FOR HEATING AND D.H.W. PREPARATION

2023

Table of content

General considerations

The study was realized for …, located in …, as beneficiary, and refers to an alternative heating and D.H.W. system, based on high temperature heat pumps.

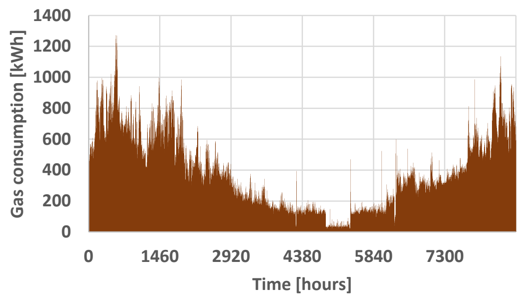
The study was realized because the beneficiary intends to reduce (and if possible, to eliminate) the gas consumption for heating.

The location of the beneficiary is presented in the figure below.

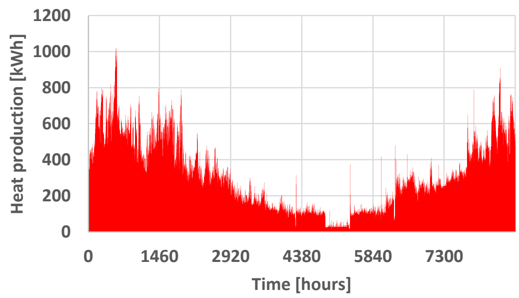
The location of the beneficiary. Google Maps

The purpose of the study was to investigate the behavior of an alternative heating system based on high temperature heat pumps with CO_2 (R744) as refrigerant. These heat pumps can provide thermal agent at temperatures up to 90 °C, being compatible with any industrial heating and D.H.W. preparation system.

The actual hourly gas consumption, and the actual heat consumption of the beneficiary, are presented in the figure below.



The actual hourly gas consumption



The actual hourly heat consumption

The heat consumption was estimated considering an average efficiency of the boilers of 80 %.

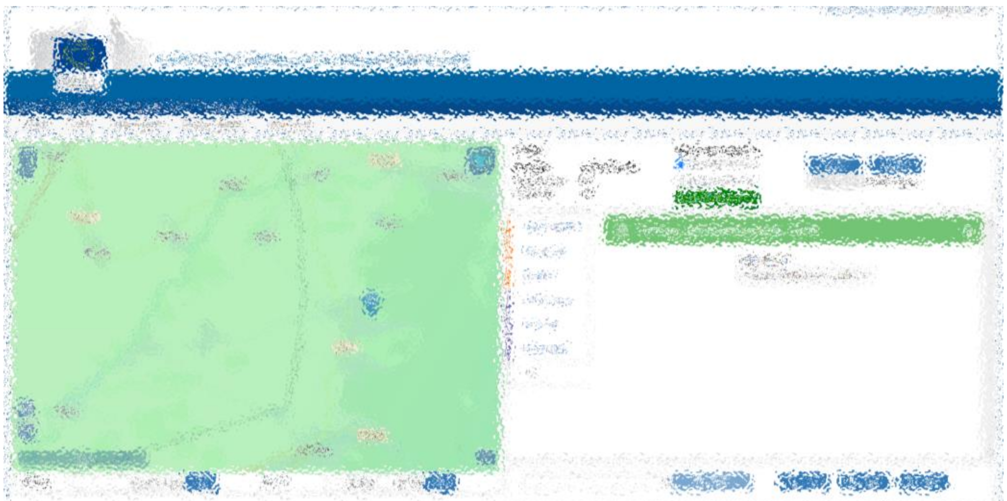
It can be observed that the maximum heat demand is about 1000 kW (1 MW), and that there is a period in the end of July – beginning of August in which the heat consumption is reduced (probably because of the holiday period) comparing to the rest of the summer and of the year.

Climatic conditions

The geographical coordinates of the beneficiary location are: … North and … East.

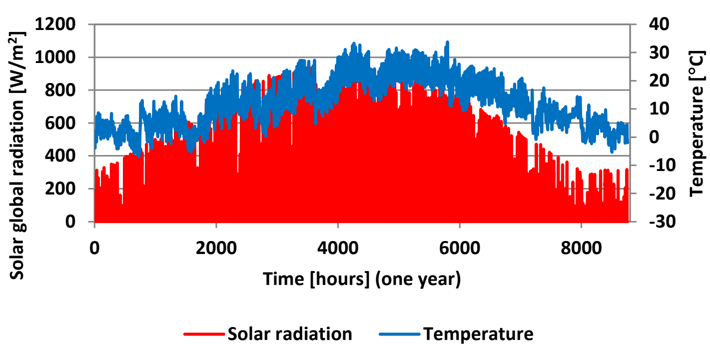
The climatic parameters influencing the thermal behavior of the system and of the heat pumps are the solar radiation and the ambient temperature. The values of the climatic parameters for the considered location were taken from the Typical Meteorological Year (TMY), determined based on measurements realized in the period 2005-2020.

In the figure below is presented the interface for climatic data according to the TMY, available on the web site of the European Union, at the address: https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html



The interface for climatic data according to the TMY
https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html

In the figure below are presented the variation curves of the ambient temperature and of the solar radiation for the considered location.

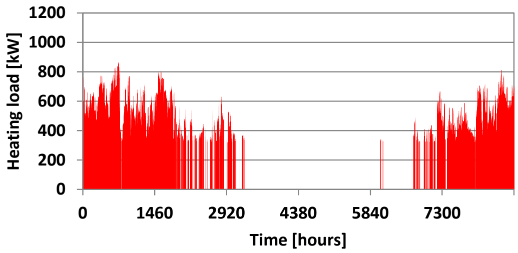


The variation curves of the ambient temperature and of the solar radiation

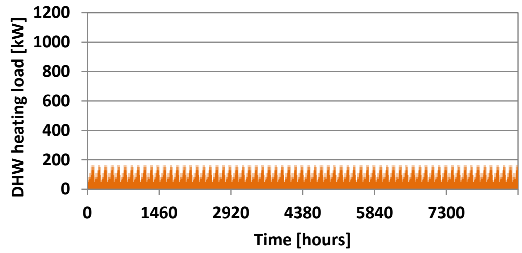
Calculated heat demand

The heat demand for heating depends on the ambient temperature and it is considered that heating is not required if the ambient temperature is higher than 12 °C, and between the period 1.06 – 31.08.

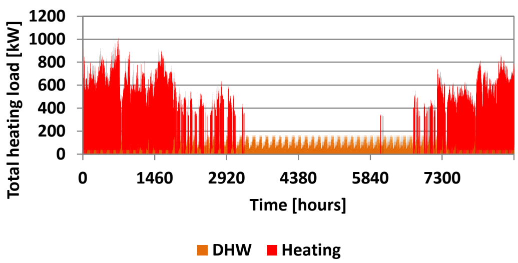
The variation curves of the heating load, the one considered for the D.H.W. and the one for the total heat load are presented below.



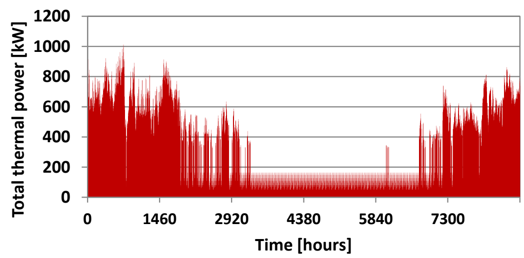
The heating load



The D.H.W. load



The heating load components

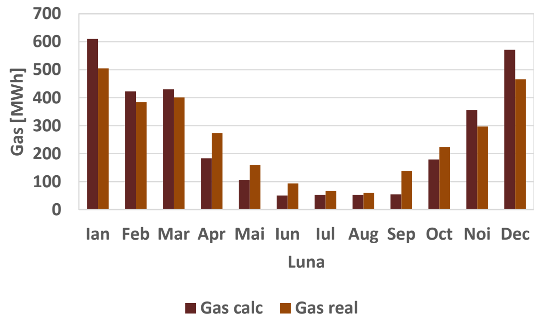


The total heating load

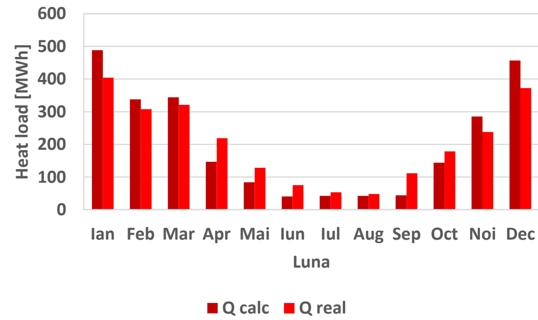
It can be observed that the total heating load is comparable to the actual heating load, having the same maximum of 1 MW and almost similar heating load in the summer. In the calculation of the total heat load, based on the TMY, the holiday period was not considered.

The total heating load must be provided by the alternative system based on heat pumps.

The figures below compare the actual monthly values of the gas consumption and of the actual heat load, with the monthly computed values of the gas consumption (considering the same efficiency of the boilers of 80 %) and of the calculated heat load.



The actual and calculated gas consumption



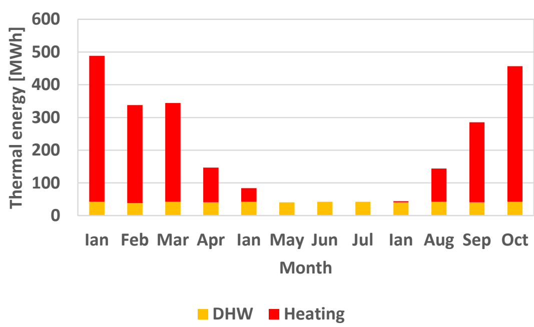
The actual and calculated heating load

It can be observed that small differences appear in almost each month, because of the differences between the real ambient temperature variation and the ambient temperature variation considered in the calculation (based on TMY).

The yearly actual and calculated values of the gas consumption and of the heat load are almost similar:

- Annual gas consumption (real): 3071 MWh
- Annual gas consumption (calculated): 3070 MWh
- Annual heat load (real): 2457 MWh
- Annual heat load (calculated: 2456 MWh

The figure below presents the monthly heat demand components.



Monthly heat demand components

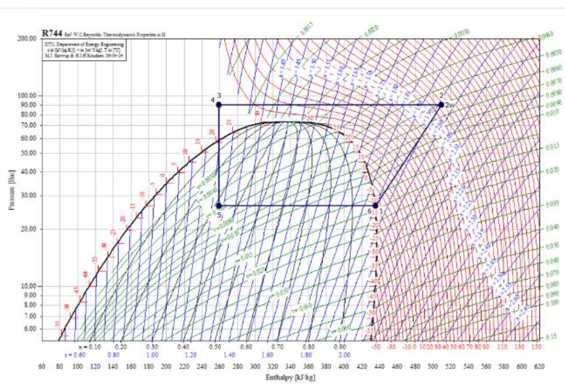
The characteristics of the heat pumps

The parameters of performance of the heat pumps are the produced thermal power (Q [kW]), the consumed electric power (P [kW]) and the report between the two, named coefficient of performance (COP [-]).

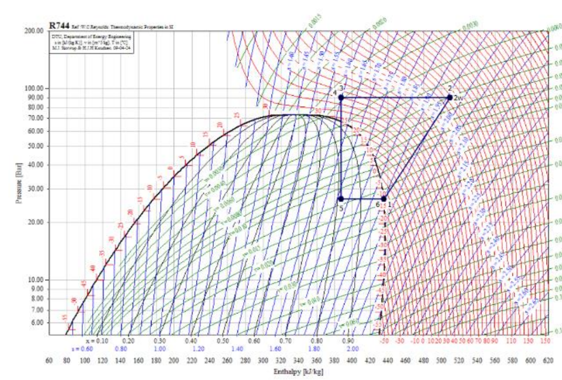
These parameters depend by the working conditions of the heat pumps.

The air to water heat pumps is working with CO_2 (R744) as refrigerant and the working conditions are variable. The parameters of performance are depending by the ambient temperature, by the temperature of the thermal agent and by the return temperature of the heating system.

In the figures below are presented two transcritic working cycles of the heat pumps with CO2, one with the outlet temperature of the gas cooler at 25 °C (the return temperature of 20 °C) and one with the outlet temperature of the gas cooler at 45 °C (the return temperature of 40 °C).



The outlet temperature of the gas cooler 25 °C (the return temperature 20 °C)

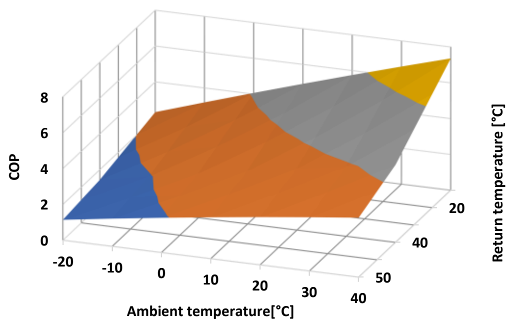


The outlet temperature of the gas cooler 45 °C (the return temperature 40 °C)

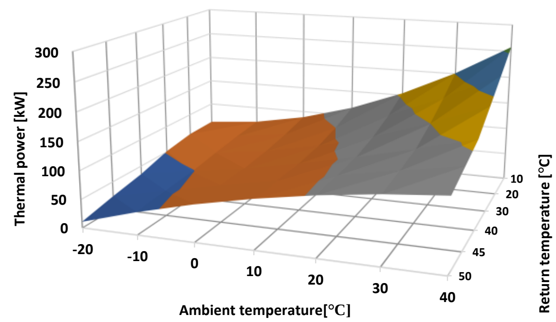
From the comparative analysis of the two cycles, it can be observed that both the produced thermal power and the efficiency are decreasing with the increasing of the return temperature.

In the study it was considered that the flow temperature of the thermal agent is variable with the ambient temperature (higher when the ambient temperature decreases), the return temperature in heating mode is 40 °C and the return temperature in DHW mode is 20 °C. The ambient temperature was considered variable according to the particularities of the considered location.

The figures below present the variations of the COP and of the heating power for the air to water heat pumps with CO_2 with the nominal thermal power of 120 kW.



COP (air – water HP with CO_2 120 kW)



Thermal power (air – water HP with CO_2 120 kW)

In the tables below are presented the values of COP and of the thermal power for the air to water heat pumps with CO_2 and the nominal thermal power of 120 kW.

COP for air to water heat pumps with CO_2 and the nominal thermal power of 120 kW

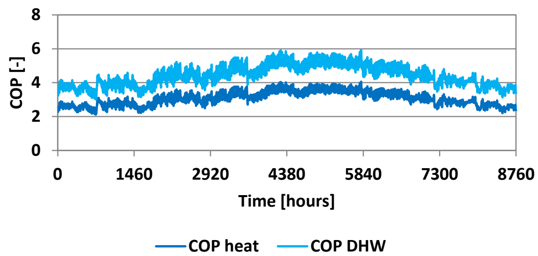
		Return temperature [°C]					
		50	**45**	**40**	**30**	**20**	**10**
Ambient temperature [°C]	**-20**	1.14	1.29	1.43	1.73	2.02	2.31
	-10	1.55	1.76	1.96	2.37	2.78	3.20
	0	1.94	2.21	2.47	3.00	3.53	4.07
	10	2.31	2.64	2.96	3.62	4.27	4.92
	20	2.67	3.05	3.44	4.21	4.98	5.75
	30	3.00	3.45	3.89	4.79	5.68	6.57
	40	3.32	3.83	4.33	5.34	6.35	7.37

Thermal power for air to water heat pumps with CO_2 and the nominal thermal power of 120 kW

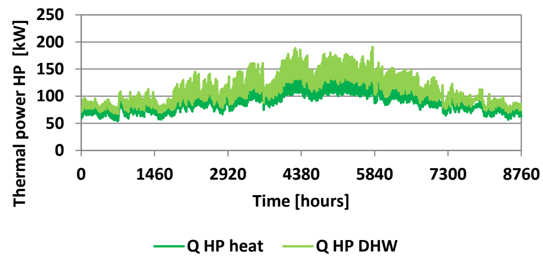
		Return temperature [°C]					
		50	**45**	**40**	**30**	**20**	**10**
Ambient temperature [°C]	**-20**	10.9	23.8	34.9	51.3	60.0	61.1
	-10	39.9	44.7	49.2	57.3	64.2	69.9
	0	64.9	65.1	66.0	70.2	77.6	88.2
	10	86.0	84.9	85.2	89.9	100.3	116.2
	20	103.0	104.2	106.8	116.4	132.1	153.8
	30	116.1	122.9	130.8	149.8	173.2	201.0
	40	125.2	141.1	157.2	190.0	223.5	257.8

For the ambient temperature of -20 °C and the return temperature of 45 °C, and 50 °C, it was calculated the values for COP and for the thermal power, but the operation in these conditions is not possible.

In the figures below are presented the variation of the COP and of thermal power during the year, in the heating mode and in the DHW mode.

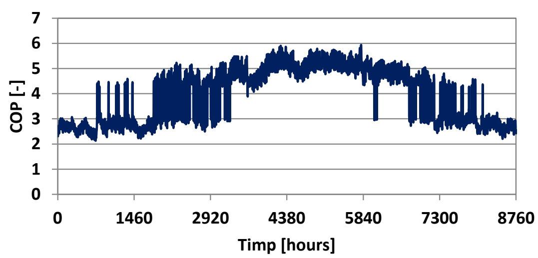


Variation of COP

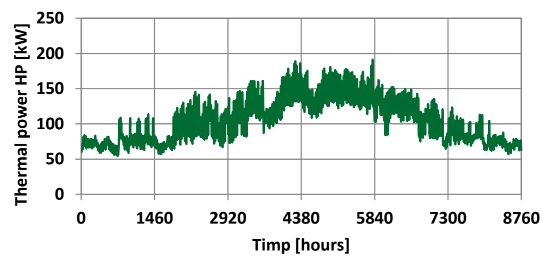


Variation of thermal power

In the figures below are presented the variation of the COP and of thermal power during the year, in the mixt heating and DHW mode.



Variation of COP

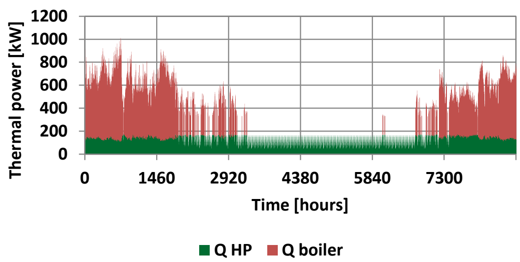


Variation of thermal power

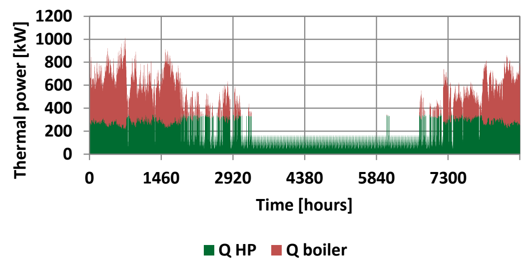
Hourly analysis of the heat pumps behavior

As follows are presented the variation curves (for one year with time step of one hour) of the heating power provided by the heat pumps and by the boilers, to provide the required heating load. The number of heat pumps was considered from 1 to 18 (the number required to eliminate gas consumption).

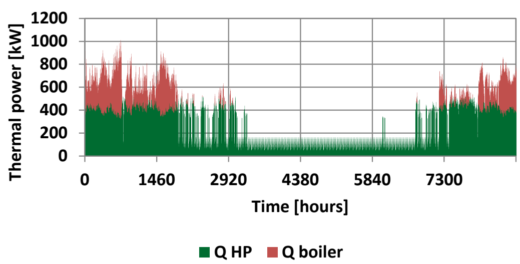
It was considered that if the thermal power produced by the heat pumps is lower than the required heating power, the difference is provided by the boilers.



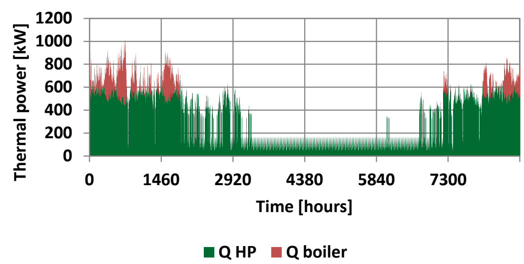
2 heat pumps



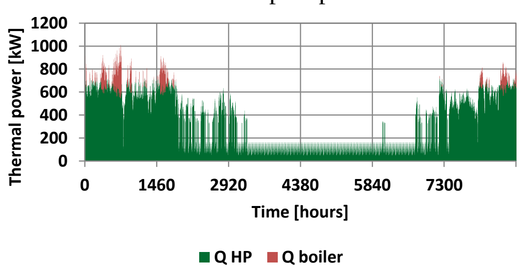
4 heat pumps



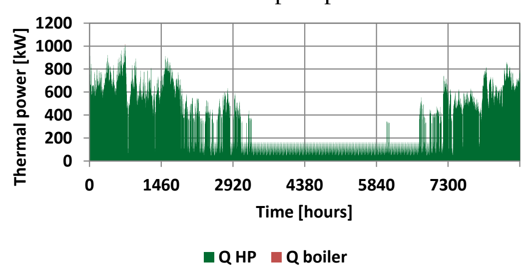
6 heat pumps



8 heat pumps



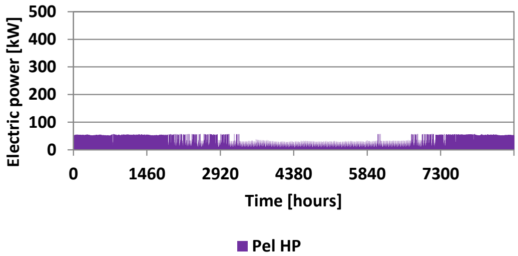
10 heat pumps



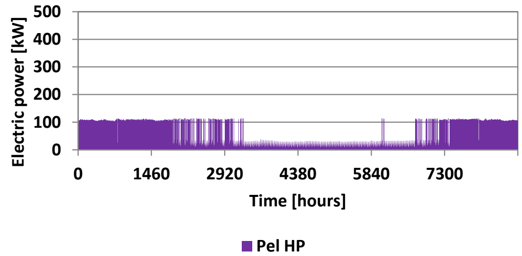
18 heat pumps

As the number of heat pumps increases, the total share of heat provided by the heat pumps increases and the share of heat provided by the boilers decreases.

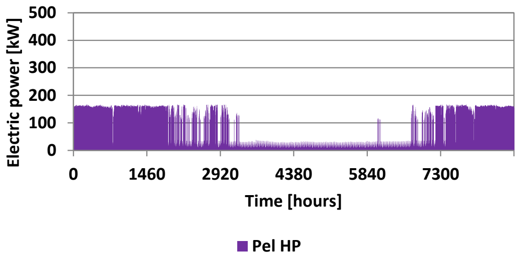
In the figures below is presented the electric power required for the operation of the heat pumps.



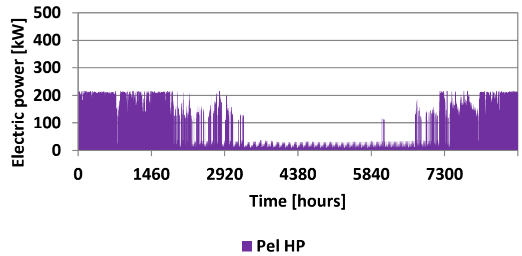
2 heat pumps



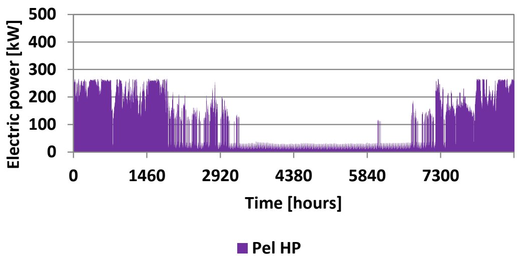
4 heat pumps



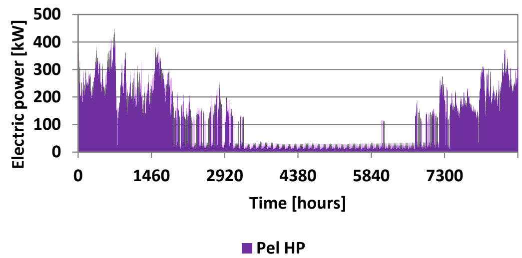
6 heat pumps



8 heat pumps



10 heat pumps

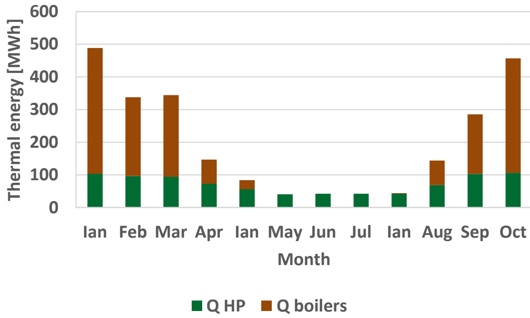


18 heat pumps

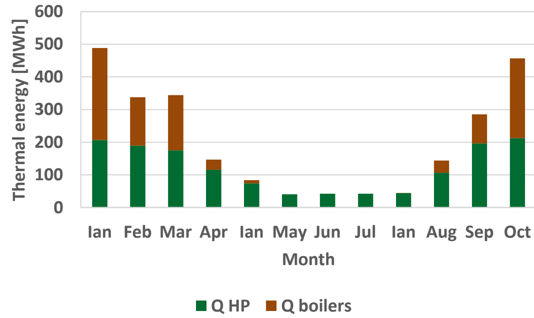
As the number of heat pumps increases, the total required electric power increases.

Monthly analysis of the heat pumps behavior

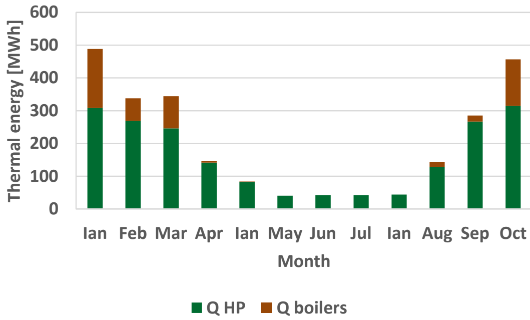
As follows are presented the monthly variation curves of the heat provided by the heat pumps and by the boilers. The number of heat pumps was considered from 1 to the number required to eliminate gas consumption.



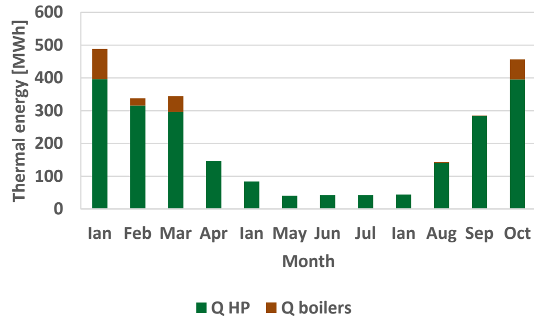
2 heat pumps



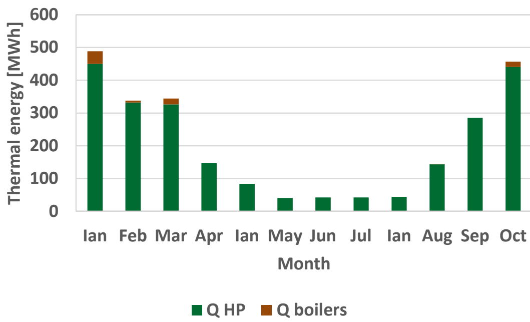
4 heat pumps



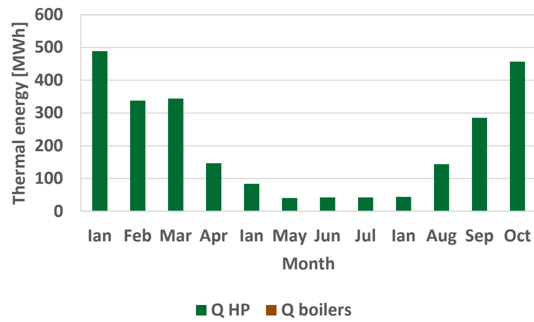
6 heat pumps



8 heat pumps



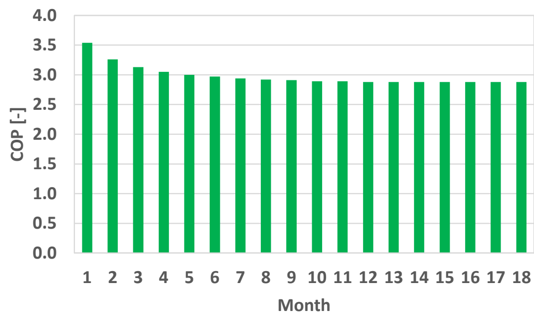
10 heat pumps



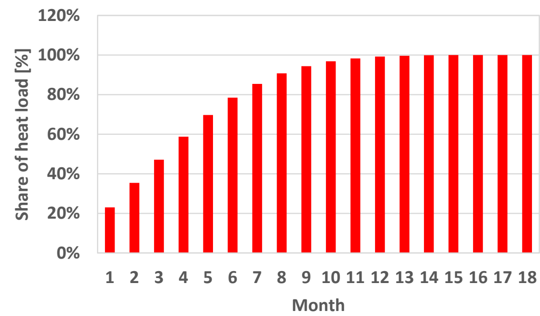
18 heat pumps

As the number of heat pumps increases, the total required electric power increases.

The figures below show the annual COP and the share of the total energy provided by the heat pumps.



COP variation with the no. of HP



Share of the total thermal energy with the no. of HP

It can be observed that as the number of heat pumps increases, the global COP decreases and the share of the thermal energy (heat) provided by the heat pumps increases.

COP decreases with the number of heat pumps because the first heat pumps operate all the year (including in the summer) with high efficiency, but the last heat pumps operate mostly in winter with low efficiency.

The first 4 heat pumps can reduce the global energy consumption (natural gas) by almost 60 %. The first 6 heat pumps can reduce the global energy consumption (natural gas) by almost 80 %. The next 12 heat pumps can reduce the rest of the global energy consumption (natural gas) up to 100 %, but in a less efficient way.

It is difficult to cover the whole thermal power with the heat pumps because the last heat pumps operate mostly in winter with low thermal power, thus each of the last heat pumps provide reduced thermal power.

The number of operating hours for the last heat pumps will be reduced, thus the economic efficiency of the last heat pumps will be reduced.

Hourly analysis of the PV system

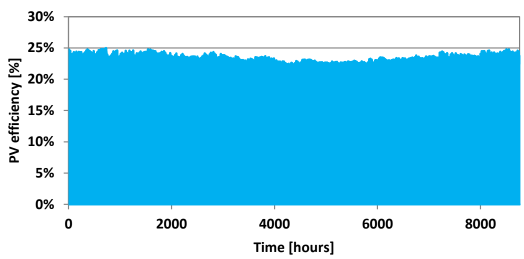
The total surface of the roof is about 20000 m^2, and approximately 15 % is occupied with different equipment, meaning that the available surface of the roof is about 17000 m^2. It was considered that the total surface of the PV panels can be approximately 50 % of the available surface of the roof, meaning about 8500 m^2 (max ≈3900 panels).

It was considered the use of a PV model with high performances:
- Peak power: 480 W
- Reference efficiency: 22.24 %
- Surface of the panel: 2.14 m^2

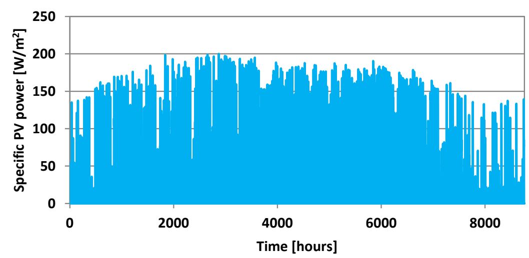
The figures below, presents the variation curves of the following characteristics of the PV system:
- Efficiency
- Specific electric (PV) power (reported to the PV panel surface unit)
- Electric (PV) total power

It was considered that the PV panels are oriented South and tilted with 30 ° from the horizontal.

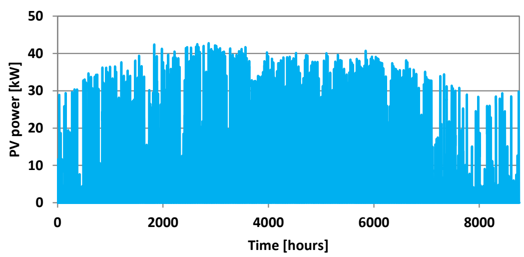
It was considered the configuration of the PV system with 100 PV panels (47.6 kW).



Efficiency of the PV system

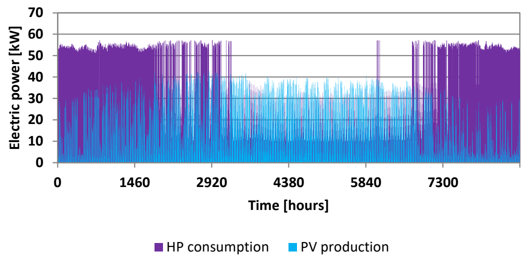


Specific electric power



Total PV power (100 panels)

The figure below presents the electric power consumption of the heat pumps and the electric power production of the PV system (for 2 heat pumps). For a higher number of heat pumps, the power consumption will increase in winter but will remain constant in summer, when the heat consumption is determined only by the DHW preparation load.



The electric power consumption of the heat pumps and the electric power production of the PV system

It can be observed that the PV production is comparable and sometimes higher than the heat pumps consumption in the summer, and lower in the winter.

It was considered the efficiency and PV power variation with the solar radiation and with the ambient temperature.

Annual analysis of the energy production and consumption

The annual values of the different forms of energy considered in the study are presented in the table below as function of the number of heat pumps.

Parameter	u.m.	Value	1 HP	2 HP	3 HP	4 HP	5 HP	6 HP	7 HP	8 HP	9 HP	10 HP	12 HP	14 HP	18 HP
Required heating load	MWh	1959													
Required DHW load	MWh	497													
Required total thermal load	MWh	2456													
Thermal energy boilers	MWh	2456	1889	1587	1299	1011	744	528	358	228	138	78	21	4	0
Share boiler	%	100	76.9	64.6	52.9	41.2	30.3	21.5	14.6	9.3	5.6	3.2	0.8	0.1	0.0
Thermal energy HP	MWh	-	566	869	1157	1445	1712	1928	2098	2227	2318	2378	2435	2452	2456
Share heat pumps	%	-	23.1	35.4	47.1	58.8	69.7	78.5	85.4	90.7	94.4	96.8	99.2	99.9	100
Electric energy HP (no PV)	MWh	-	160	267	370	473	570	649	713	762	798	822	845	853	854
COP HP (no PV)	-	-	3.54	3.26	3.13	3.05	3.00	2.97	2.94	2.92	2.91	2.89	2.88	2.88	2.88
Electric energy HP (with PV)	MWh	-	118	223	327	430	526	606	670	719	755	778	802	809	811
COP HP (with PV)	-	-	4.79	3.89	3.54	3.36	3.25	3.18	3.13	3.10	3.07	3.05	3.04	3.03	3.03
Electric energy of PV	MWh	-	66	66	66	66	66	66	66	66	66	66	66	66	66

When the number of heat pumps increases, the share of the boiler thermal energy production decreases, and the share of the thermal energy production of the heat pumps increases. At the same time, the COP of the heat pumps decreases slightly.

The PV system, if available, can increase the efficiency and the yearly COP of the heat pumps.

The efficiency of the first heat pumps is high and decreases with the number of heat pumps, meaning that the first heat pumps are the most important.

Synthesis:
The heat pumps production and efficiency vary as follows:

- ***2 heat pumps*** *(produces 35.4 % of the thermal energy with COP=3.26 / 3.89 with PV)*
- ***6 heat pumps*** *(produces 78.5 % of the thermal energy with COP=2.97 / 3.18 with PV)*
- ***10 heat pumps*** *(produces 96.8 % of the thermal energy with COP=2.89 / 3.05 with PV)*
- ***14 heat pumps*** *(produces 99.9 % of the thermal energy with COP=2.88 / 3.03 with PV)*
- ***18 heat pumps*** *(produces 100 % of the thermal energy with COP=2.88 / 3.03 with PV)*

Recommendation:
The heat pumps acquisition can be realized (based on the technical analysis) in stages:

- *1-st stage: 6 heat pumps (significant reduction of the gas consumption)*
- *2-nd stage: 14 heat pumps (almost complete reduction of the gas consumption)*
- *3-ed stage: 18 heat pumps (if complete elimination of gas consumption is desired)*

Economic analysis

The table below presents the most relevant economic parameters, considering the natural gas price of 130 Euro/MWh, and the electric energy price of 200 Euro/MWh.

Changes in these two prices will significantly influence the economic analysis.

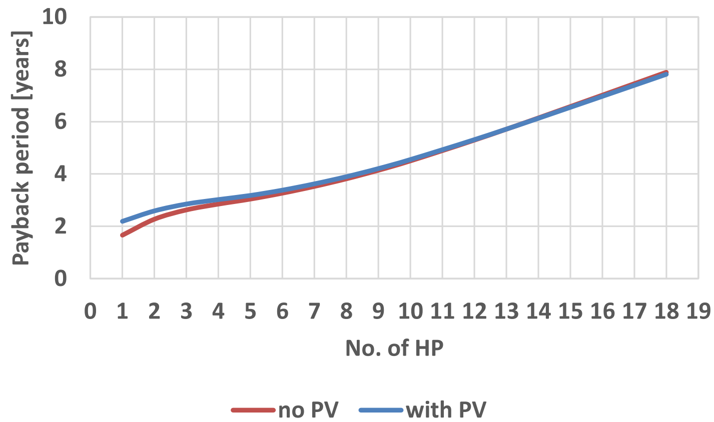
If the CO_2 certificates will be needed to be paid, this will also significantly influence the economic analysis.

The most relevant economic parameters

Parameter	u.m.	Value	1 HP	2 HP	3 HP	4 HP	5 HP	6 HP	7 HP	8 HP	9 HP	10 HP	12 HP	14 HP	18 HP
Required heating load	MWh	1959													
Required DHW load	MWh	497													
Required total thermal load	MWh	2456													
Thermal energy (boilers)	MWh	2456													
Gas consumption (boilers)	MWh	3070													
Gas cost (boilers)	k Euros	399													
Thermal energy HP	MWh	-													
Electric energy HP (no PV)	MWh	-													
Electric energy cost (no PV)	k Euros														
Electric energy HP (with PV)	MWh	-													
Electric energy cost (with PV)	k Euros														
Operation cost (gas + electr.) (no PV)	k Euros														
Operation cost (gas + electr.) (with PV)	k Euros														
Operation economy (no PV)	k Euros														
Operation economy (with PV)	k Euros														
Cost of HP	k Euros														
Cost of PV	k Euros														
Payback period (no PV)	Years														
Payback period (with PV)	Years														

Other costs (design, mounting, automation, puffer, etc.), depending on the chosen number of heat pumps will exist, but were not considered in this analysis.

The figure below presents the variation curves of the payback period as function of the number of heat pumps (with and without PV system).



The variation curves of the payback period as function of the number of heat pumps

Recommendation:

The heat pumps acquisition can be realized (based on the economic analysis) in stages:

- *1-st stage:* *5-7 heat pumps (the lower payback period)*
- *2-nd stage:* *14 heat pumps*
- *3-ed stage:* *18 heat pumps (if complete elimination of gas consumption is desired)*