D6.7 – Monitored data at the demonstration networks

Renewable and Waste Heat Recovery for Competitive District Heating and Cooling Networks

REWARDHeat

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Lead beneficiary: CARTIF

Ismael Lozano Gabarre, CARTIF

Francesco Turrin, EURAC

Amine Jarraya, EURAC

Anton Soppelsa, EURAC

Amir Jodeiri, EURAC

Christian KEIM, EDF,

Karine PARPILLON, DALKIA

Clement FLINOIS, EDF

Come BISSUEL, EDF

Maxime Dufour, Artelys

Manfred Le Callonnec, Artelys

Nicolas Lair, Artelys

Daniel Stenberg, E.ON Sweden

Konrad Sikora, SEC

Dirk Pietruschka, ENISYST

Mathias Obermüller, ENISYST

Marcus Brennenstuhl, ENISYST

Roberto Fedrizzi, EURAC

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1 Introduction

The REWARDHeat project aims to enhance urban district heating and cooling networks by integrating renewable energy sources and waste heat recovery technologies. This effort focuses on developing competitive, low-temperature DHC networks across various European cities, transforming how these networks manage energy to meet both environmental and operational objectives. The project involves construction, retrofitting, and testing of advanced heating and cooling solutions across multiple demonstration sites, each presenting unique applications and innovations.

This document summarizes the outcomes achieved across these sites, showcasing objectives, construction activities, and technical approaches adopted in cities including Albertslund (Denmark), Gardanne (France), Helsingborg (Sweden), Milan (Italy), Mölndal (Sweden), Szczecin (Poland), and Topusko (Croatia). More detailed information on the activities implemented along the project elaboration are reported in deliverables D6.5 focusing on the construction activities at the demonstration sites and D5.9 on controls development and deployment.

This report evaluates the system's performance based on monitoring data collected during the final phase of the project, spanning autumn 2023 to the end of summer 2024. It outlines both the challenges faced and the achievements made, emphasizing the potential of the implemented solutions while identifying areas for improvement.

The findings aim to inspire further innovation and enhancements in future infrastructure development beyond the current state of the art.

2 Albertslund, Denmark

2.1 Description of the demonstration site

The case study of Albertslund is located about fifteen kilometres west of central Copenhagen. Currently, the existing DHN supplies heat to a major portion of the municipality. The DHN was initially built in 1964 and covers around 90% of the municipality's thermal demand.

This network is connected to the Greater Copenhagen DH transmission network, which integrates heat produced by waste incineration, CHP plants and peak-load boilers, and provides most of the heat uses throughout the year, i.e., 100 MW of heat capacity from the transmission company *VEKS,* supplied at 100-110ºC.

Additionally, to withdrawing energy from the backbone, natural gas and oil boilers are also set up as local reserve sources, accounting for 145 MW of capacity installed, while waste heat from a data centre (0.35 MW approximately, recovered at ~20°C) is also supplied nearly constantly to the DHN by means of a heat pump.

Around 270 GWh are distributed along the DHN and 220 GWh are finally supplied to end users yearly.

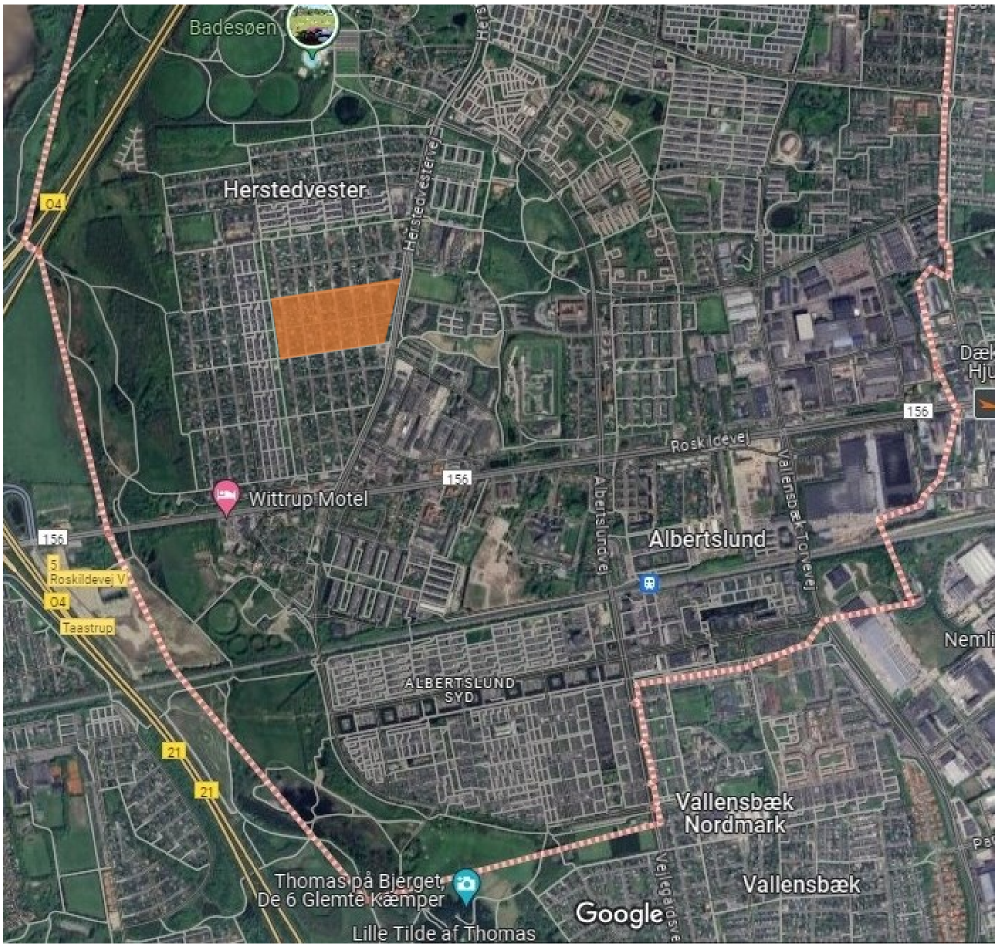


Figure 2.1 – Albertslund municipality; Porsager district in orange

2.1.1 Objectives and main results of the demonstration activity

In the framework of the REWARDHeat project, effort has been placed on lowering the supply temperature to a subnetwork, consisting of around 110 residential houses in Porsager, an area in the South-East of Albertslund. This has been pursued by:

- Installing a shunt valve to lower the district heating supply temperature from 85°C to 60°C across the entire area.
- Developing a datamining software to gather and structure monitoring data from two separated SCADA solutions in place and enable implementing performance optimization.
- Exploration of a data-based approach to minimize DHN operation costs. In particular, it aims at adapting the operation of the shunt in order to control the return temperature

Grundfos was selected as the supplier of shunt valves and associated control systems. The shunt was installed in late 2020, and while the temperature reduction caused minor initial problems for a few consumers in the area, the shunt operated with a higher supply temperature initially, allowing for a comparison of grid loss before and after the temperature adjustment. The reduction to 60°C presented minimal issues; technical interventions and substation adjustments were required for only four homes, with one substation needing a complete replacement.

The shunt is controlled through an online platform, which requires SCADA system communication with a hosted platform. Communication occurs via GSM, which presents some limitations in connection stability. However, the shunt can operate independently, so daily operations are unaffected.

2.2 DH Network conceptual design and management

The connection between the high-temperature district heating system and the Porsager Grid area is shown in Figure 2.2. The shunt functions to lower the temperature of water coming from the high-temperature district heating network before distribution to the local area. This is done by mixing high-temperature water from the DN 300 line with cooler return water from the DN 100 line in a controlled manner. The resulting lower-temperature water is then distributed to the Porsager Grid area via a DN 100 pipeline.

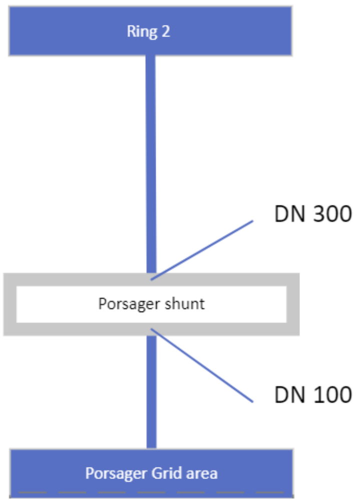


Figure 2.2 - Connection between HTDH and Porsager area in Albertslund demo case

A more detailed view of the distribution network is showed in Figure 2.3. The diagram illustrates a section of the high-temperature district heating system that supplies water to the Porsager Shunt. The water flows through the shunt pump, which facilitates mixing and reduces the temperature before the water enters the local distribution network. A booster pump then ensures that the reduced-temperature water is delivered to the local grid area at the necessary pressure and flow rate for the residential area.

Several measurement points are shown in the diagram, essential for monitoring the system's performance. An energy meter on the primary line before the shunt records the forward flow and both forward and return temperatures. After the shunt, additional sensors monitor differential and absolute pressure, as well as temperature, to verify that the temperature reduction process is operating correctly.

Each household in the local grid area has its own energy meter, which measures the return flow along with supply and return temperatures, enabling precise tracking of energy consumption and system efficiency at the household level.

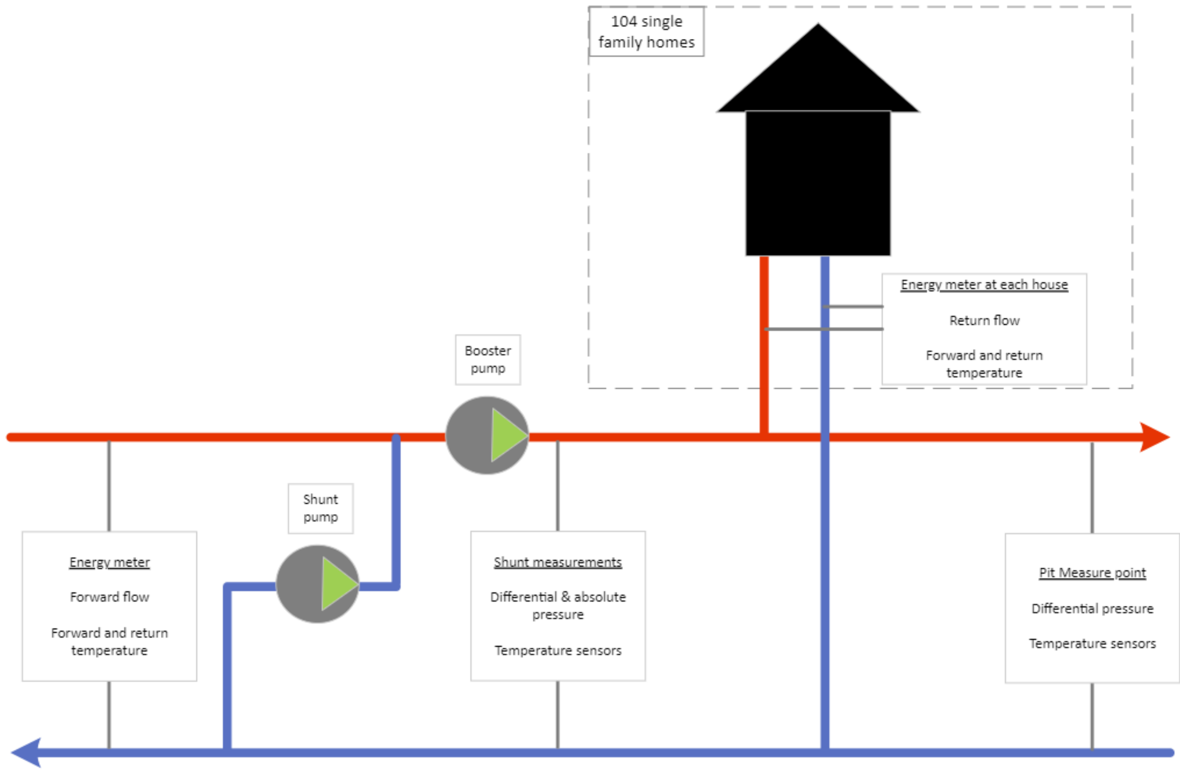


Figure 2.3 - Local distribution network in Albertslund demo case

2.3 Assessment of the network performance

2.3.1 Energy uses insisting on the network

Figure 2.4 shows the building's monthly thermal energy consumption. The heating consumption represents the energy that reaches the buildings.

The building's annual heating consumption totals around 1763 MWh. Most heating consumption occurs obviously in the colder months with a peak load of around 300 MWh in January, while in summer (May to September) the heating consumption is more constant and around 40 MWh/month. This is mainly due to the cold climate, where extended periods of low temperatures lead to significant energy demands. In these conditions, heating needs are likely to be the primary factor in energy consumption profiles, especially in buildings intended for year-round use.

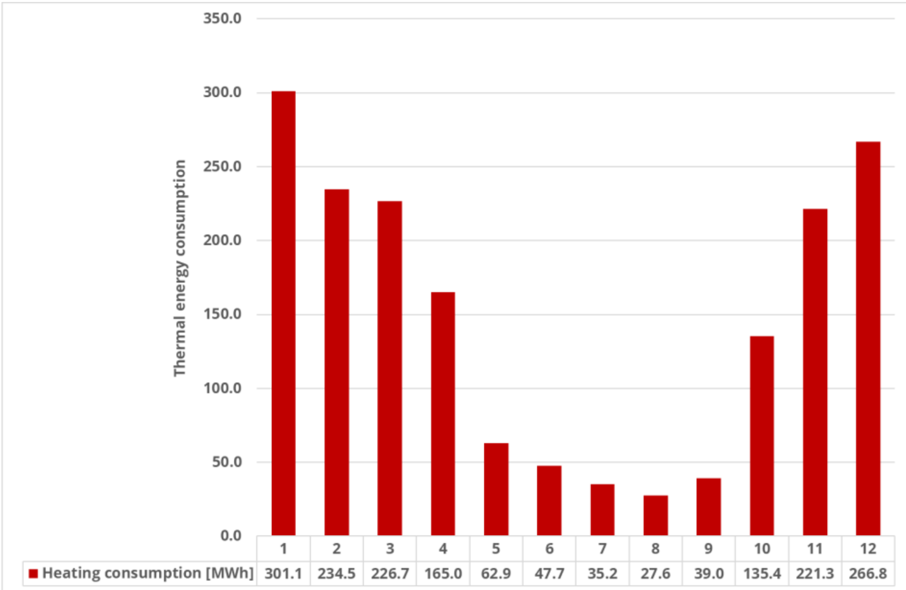


Figure 2.4 - Monthly thermal energy consumption of the buildings

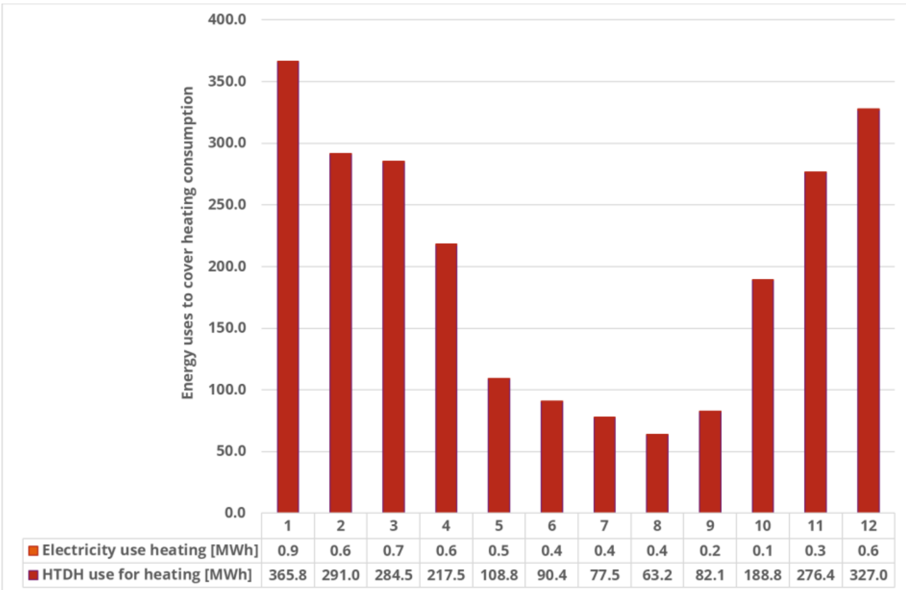


Figure 2.5 - Energies use for heating

Figure 2.5 illustrates the energy vectors used to meet the building's heating demand. Heating is primarily supplied from the DH, while the electricity consumed in the circulation pumps is very low compared to it.

The overall DH energy use amounts to 2,386 MWh, while only 310 MWh of electricity are consumed; the difference between the energy consumed by buildings and the total energy used in the DH is due to heat losses that occur along the distribution network.

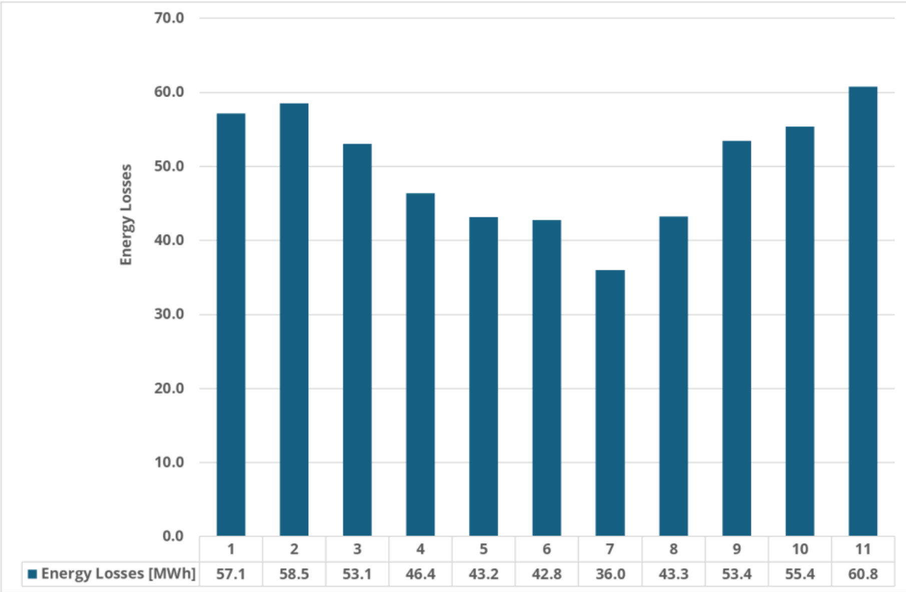


Figure 2.6 - Energy losses along distribution pipelines

2.3.2 Performance indicators assessment

Figure 2.7 illustrates the buildings monthly total primary energy use for heating, alongside the renewable portion of that energy. The primary energy calculation accounts for contributions from electricity and district heating. For each energy vector, specific primary energy factors have been calculated using the energy mix supplying the DH for 2020 and the factors for each fuel [1]:

- DH total primary energy factor → 1.17 (of which 0.83 is considered renewable)
- Electricity total primary energy factor → 2.50 (of which 0.2 is considered renewable)

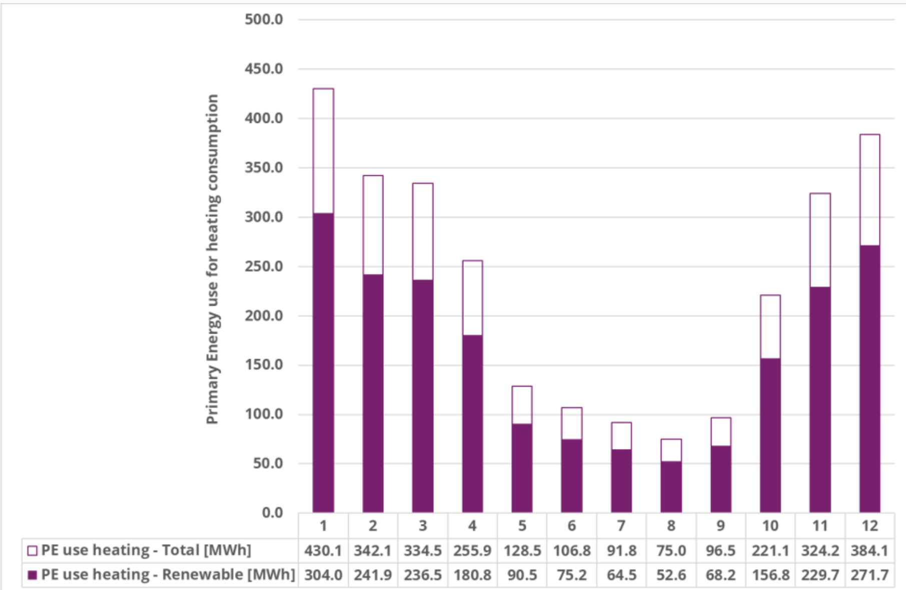


Figure 2.7 - Monthly renewable and total primary energy uses for heating consumption of the buildings

Over the course of the year, the building's total primary energy consumption reaches 2790 MWh. Of this total, 1972 MWh is derived from renewable sources. Primary energy use is markedly linked to the use of the DH since it is the only energy source with the electricity affecting very few in the total amount of primary energy.

The Renewable Energy Ratio (RER), shown in Figure 2.8, quantifies the renewable share by calculating the ratio of renewable primary energy to total primary energy used for heating. The value of the RER is constant during the year in a value around 71%, since it is affected by the renewable composition of the DH.

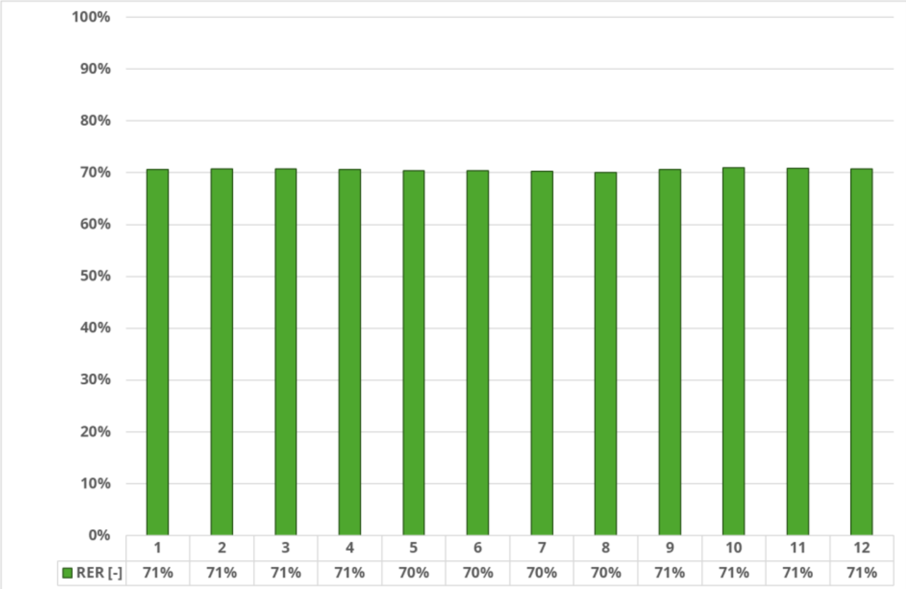


Figure 2.8 - Monthly renewable energy ratio

Figure 2.10 presents the monthly greenhouse gas emissions associated with the energy system. The CO_2 emissions calculations encompass district heating and electricity used by the circulation pumps. The CO_2 emissions are further broken down into specific emissions values, which are calculated using the same methodology used for the primary energy factors. The analysis applies distinct CO_2 emission factors to district heating and electricity vectors [1]:

- District heating CO_2 emission factor → 56.8 g/kWh
- Electrical energy CO2 emission factor → 420 g/kWh

The annual CO_2 emissions from its heating system totals 137,197 kg. A significant portion occurs during the winter months, coinciding with increased heating demand. During these colder months, specific CO_2 emissions range between 70 kg/MWh and 80 kg/MWh.

Although CO_2 emissions during summer decrease drastically, specific CO_2 emissions doubles during that period. This fact is the result of two effects: first the low heating demand during summer and, second, the presence of thermal losses in the distribution network (Figure 2.6) that increases the use of the high temperature DH in relative terms.

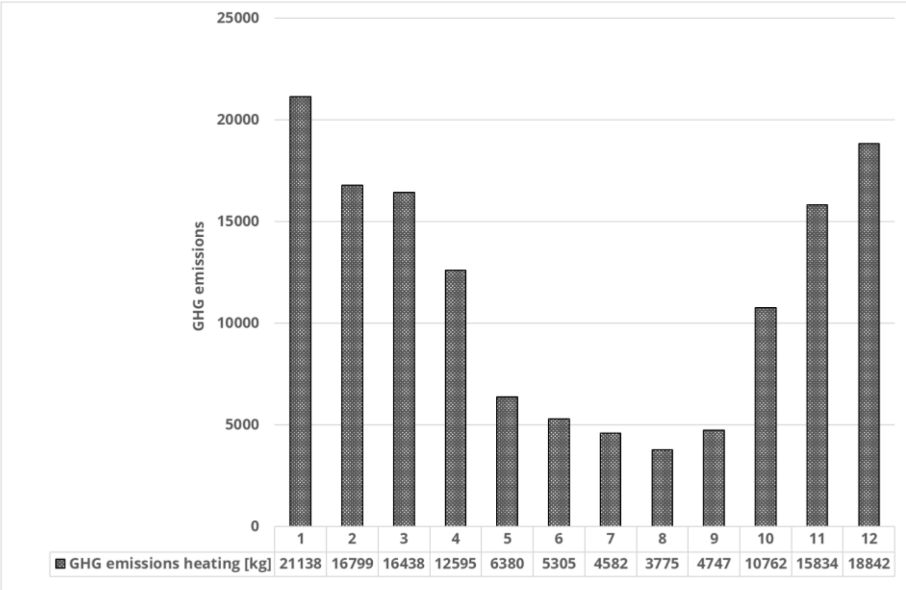


Figure 2.9 Monthly CO2 emissions related to the DH energy uses

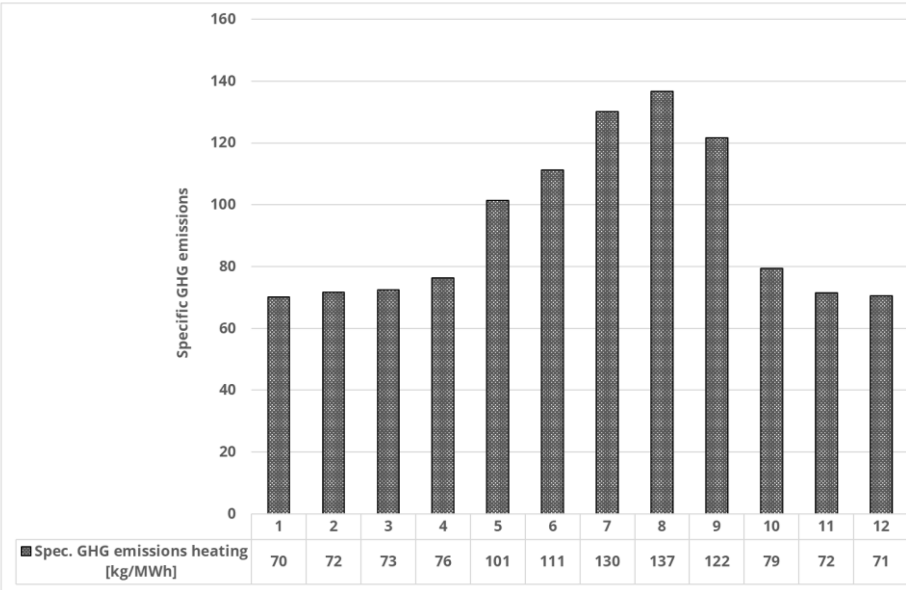


Figure 2.10 - Monthly specific CO2 emissions related to the DH energy uses

In summary, the system environmental performance profile is characterized by higher emissions in winter and quite lower in summer, linked to the heating demand profile and the use of the DH. This effect highlights the need of the decarbonization of high temperature district heating systems through the use of different approaches such as lowering their temperature or the introduction of alternative sources or technologies such as central or distributed heat pumps.

2.4 Remarks

Table 2.1 summarizes the system annual energy needs and environmental performance calculations reported above.

Table 2.1 – Overall system annual energy uses, and performance calculated

Notation	Annual values	Unit of meas.
Heating consumption	1763	MWh/y
Electricity use for heating	5.7	MWh/y
HTDH use for heating	2373	MWh/y
Ren. PE for heating	1973	MWh/y
Total PE for heating	2791	MWh/y
Renewable Energy Ratio	71	%
GHG emissions for heating	137	ton/y

Additionally, we present some key insights gained from the data analysis:

- Energy use concentration in winter: Most heating energy is consumed during colder months, peaking at 300 MWh in January, while summer usage is significantly lower (~40 MWh/month), reflecting the climate's direct impact on demand profiles.
- Lowered DH network supply temperature does not affect the consumers: the installation of a shunt valve successfully reduced the supply temperature from around 75°C on the high-temperature side (of the overall network) to 61-67°C on the low-temperature side; this resulted in minimal consumer impact, requiring technical interventions in only four households.
- Due to ongoing commissioning, communication issues occasionally between the shunt valve and the SCADA system occurred. Moreover, datamining software (see Deliverable 5.9) development activities during the monitoring phase, induced dynamically variable temperature in the network, which caused fluctuations in supply and return temperatures, making it challenging to accurately quantify the reduction in heat losses compared to the baseline.
- Renewable energy integration consistently high: The RER remains steady at around 71% throughout the year, as we did not have access to time varying PE factors of the Copenhagen DH network.
- GHG emissions tied to seasonal demand: CO_2 emissions peak during winter months due to increased energy demand, highlighting the strong seasonal dependence on high-temperature DH system. Summer months see lower absolute emissions but increased specific CO_2 emissions due to network thermal losses.
- Summer thermal losses, coupled with lower heating demand, underscore the importance of exploring further strategies like higher temperature reduction, alternative low-carbon sources, or distributed heat pumps to improve system efficiency and reduce emissions.

3 Gardanne, France

3.1 Description of the demonstration site

Located in the town of Gardanne, the site is an historic coal-mine, operated between 1989 and 2003 and is the largest mining well in Europe, with 1100 m depth, 10 m diameter, currently filled with water as the rest of the mining complex ensuring the geological stability of the terrain. Through the launched district sized real-estate development project, the site aims at becoming the economic hub of the territory with very stringent energy, environmental and social requirements offering 80000 m^2 of offices, companies, or hotel, aiming thus at becoming the driver for employment and social integration in Gardanne. Additionally, it aims at hosting cultural activities with a sciences museum for improving education, science and innovation. The complex is fed by a thermal and electric smart grid, cooling and heating the «Yvon Morandat Well» district.

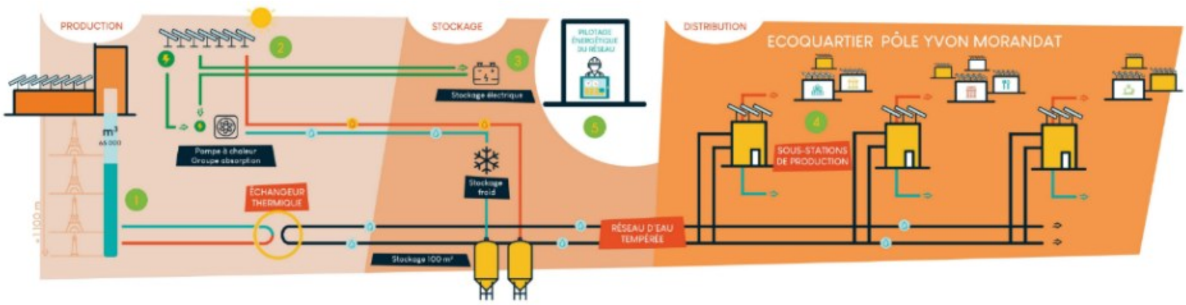


Figure 3.1 : Schematisation of the site's working principle, integrating the thermal and electric smart grids. Source: DALKIA.

The network is partially delivered: the network already connects 3 tertiary and commercial customers and 3 more are under construction, with a foreseen total heating demand of about 2,198 MWh/year and a cooling demand of about 1,425 MWh/year.

The main neutral-temperature network is used for both DH/DC and operates at a temperature between 7-29°C. The extraction depth is at -950 m and injection happens at -264 m, whilst the whole shaft is equipped with a 1 km long optic fibre for temperature data acquisition. Moreover, the system was initially equipped with a 230 kWp PV plant, which produced energy is self-consumed by the network, thanks to a cascade of installed storage means (2x 50m^3 water tanks, a 200 kW Li-Ion BESS and 40 kW second-life BESS as well as an ice-storage).

Once completed, the DHCN should account for a 1,3 km long neutral-temperature network and produce 2.1 GWh/y of heating energy and 1.4 GWh/y of cooling energy.

3.1.1 Objectives and main results of the demonstration activity

The demonstrator leans on the currently developed neutral-temperature DHC network. The project partners involved are ENERGIE SOLIDAIRE, DALKIA and EDF that collaborate to achieve the following goals:

- Set up of PV fields combined with different storage solutions (thermal, electric) to reduce electricity consumption from the grid

- Optimization of RES utilization and energy balancing across the DHC network, to foster "energy solidarity", by integrating production/load forecasts and new optimized operation modes in the automation system
- Utilization of the water well as a seasonal storage aimed to balance injection/extraction of energy in the mineshaft
- Design and set up of a permanent exposition on DHC ,i.e., the "House of Energy", with dedicated guided tours to explain through visual media, renewable based DHC networks.

The work focused on integrating assets effectively, with particular attention to hydraulic systems and control.

Set up of PV fields and electricity sharing: Substation 1 has been upgraded to integrate with Substation 4 for shared PV energy delivery. Copper wiring has been laid to allow PV energy generated at Substation 4 to be conveyed directly to Substation 1's switchboard, helping increase the renewable energy ratio within the network. A total of 90 kWp is planned for Substation 4.

The overall network's control system has been thoroughly revised to include smart integration of solar energy metering (one pyranometer), PV curtailment monitoring, PV forecasting via SolarGIS (providing hourly forecast, 24 hours ahead that accounts for shadowing from surrounding buildings and system efficiency), and improved management of the storage and generation cascade. This data is essential for evaluating curtailed energy, as the PV system is designed without grid injection, leading to curtailment of any excess energy. The objective function of this initiative is to reduce PV curtailment, redirecting energy to storage assets to improve the network's overall carbon footprint and increase the substation's performance.

Thermal energy sharing among substations: A similar approach has been implemented for what concerns thermal energy sharing. Efforts have centred on enabling Substation 1 to manage the neutral-temperature DHCN temperature and, if necessary, serve as a backup source for the mineshaft. Hydraulic connections and control systems have been integrated between Substations 1 and 2, achieving secure energy sharing. This enhancement has provided resilience against mineshaft outages, and all related controls are now integrated into the site's smart control system.

3.2 DHC Network conceptual design and management

The district heating and cooling system at Gardanne is utilizes the flooded mine shaft as the primary energy source. This geothermal energy is drawn from the mine and distributed to multiple substations throughout the network, as showed in Figure 3.2.

A pumping station connected to the mine shaft acts as the central point, extracting geothermal energy and routing it through the user substations. Here reversible heat pumps are set up, with various capacities tailored to the demands encountered.

The system configuration is designed to be adaptable, allowing for the expansion of additional substations in the future, improving network efficiency and extending energy service to more buildings.

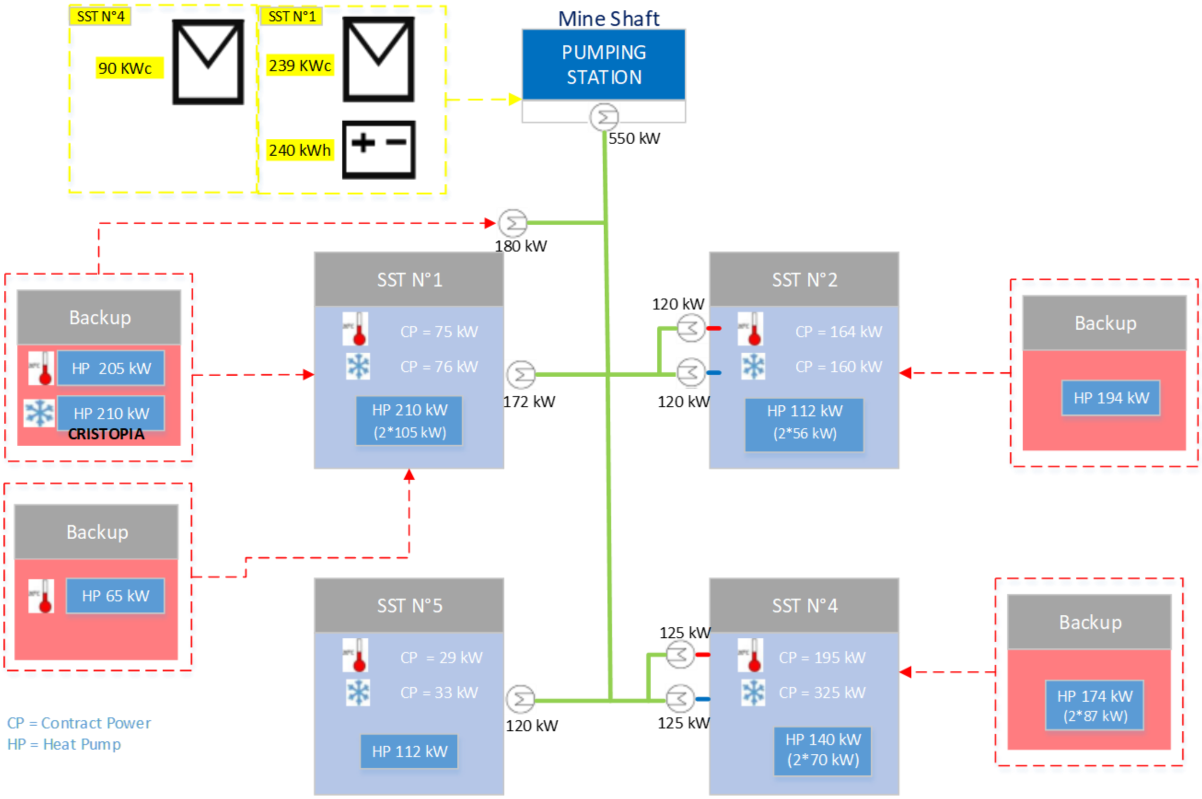


Figure 3.2 - Network conceptual schematic of Gardanne demo site

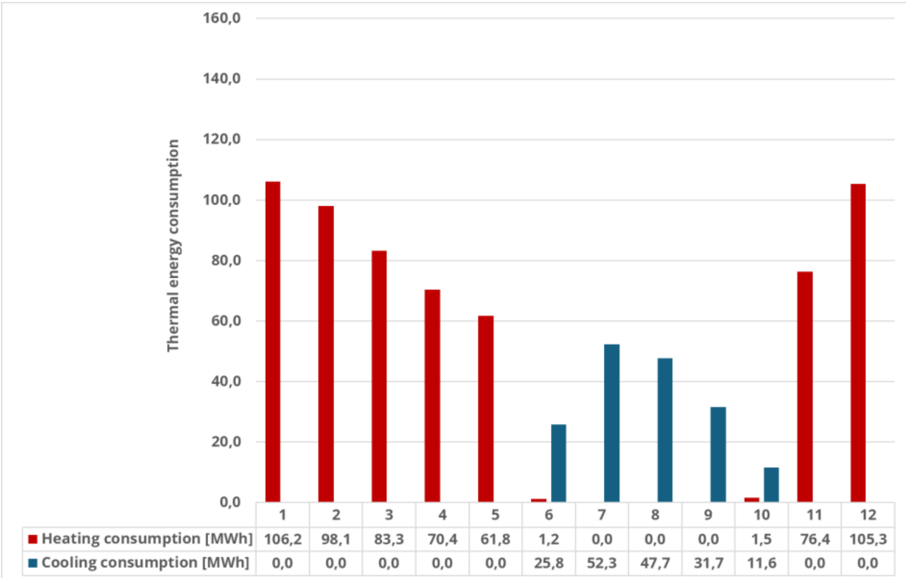
Figure 3.3: View on the main substation as operated today

3.3 Assessment of the network performance

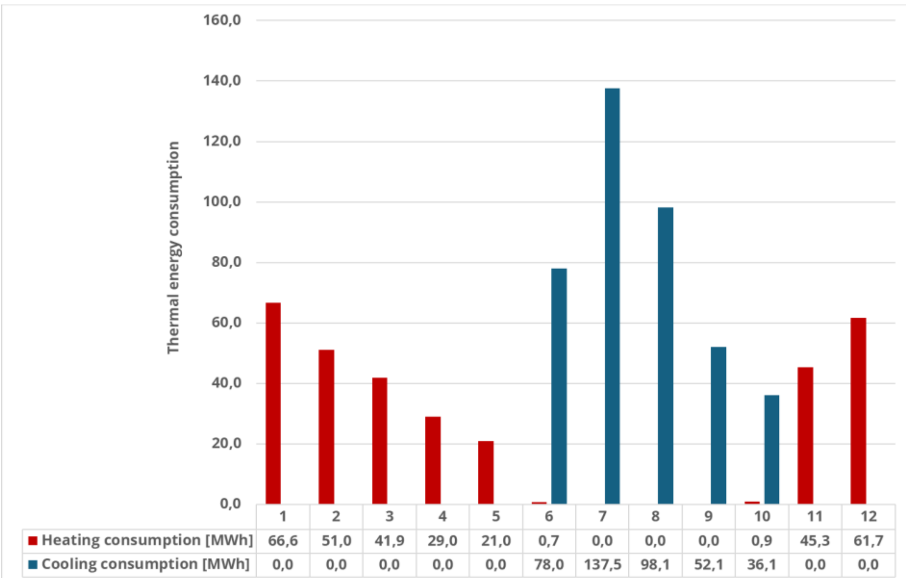
3.3.1 Energy uses insisting on the network

The analysis conducted for this demonstration site has been divided into two main sections: one focusing on the performance of all the substations, and the other addressing the management of the network and the pumping station, which exchanges energy with the mine well.

Figure 3.4a illustrates the aggregated monthly thermal energy consumption of the substations. This includes energy use supplied to the buildings to cover domestic hot water, space heating and space cooling loads. Figure 3.4b represents the thermal energy exchanged at the overall network level, detailing the energy delivered to the substations during heating operations or rejected by the substations during cooling operations.



Analysis for the substations



Analysis for the network and central station

Figure 3.4 - Monthly thermal energy consumption

The annual heating consumption at the substations is approximately 604 MWh, concentrated in the colder months, with peaks reaching around 100 MWh in January and December. Conversely, the annual cooling consumption is around 169 MWh, with a peak of approximately 52 MWh in July.

This pattern is influenced by a combination of climatic conditions, characterized by hot summers and mild winters, with ambient temperatures ranging from 10°C in February to approximately 25°C in July, as well as the diverse buildings energy use profiles, including residential, educational, and tertiary sectors.

The annual heating use insisting on the network totals around 318 MWh occurring similarly during winter season, with peaks of 65 MWh from December to February. The annual cooling consumption amounts to 401 MWh, with a peak of around 140 MWh in July. For both heating and cooling, the differences are due to the electricity use of the HP systems (HP plus distribution system) located at each building concerned.

In this network, the energy rejected by substations primarily used for cooling could be used as waste heat (WH) by other substations with heating needs. This synergy could significantly reduce reliance on other energy sources. However, since the heating and cooling demand is remarkably seasonal, there are few periods when both heating and cooling demands coincide, and the amount of WH reused is minimal.

Figure 3.5 illustrates the distribution of energy sources utilized to meet the heating and cooling demands. For the substations (Figure a)), heating is provided through a combination of district heating (318 MWh) and electricity used by the heat pump compressors and circulation pumps (286 MWh), out of which 42 MWh are provided by PV panels. This has been possible thanks to the share of PV electricity implemented during the project, since not all buildings are set up with PV panels. The average system COP during winter is about 2.5.

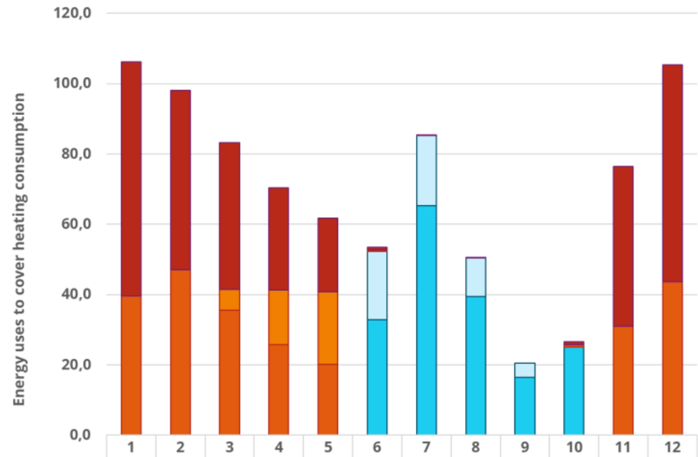
The cooling demand at the substations is fully met through electricity consumption for operating the heat pump systems (233 MWh), which reject heat into the network. Also in this case, about 54 MWh are provided by PV panels. As it can be noticed, the electricity use for cooling purposes is particularly high, resulting in an average system EER around 1, highlighting the necessity for control optimization at the substation level.

From the network perspective, heating supplied to the substations is a combination of energy extracted from the mine well (215 MWh), electricity consumed from the grid (41 MWh) and electricity generated by the PV installation (62 MWh). Notably, during March to October, the heating demand is entirely met by renewable energy.

In summer, the network relies mostly on self-consumed electricity from PV at the pumping station (33 MWh), as the rejected heat is directly dissipated into the mine. This results in exceptionally low energy consumption relative to the cooling demand addressed, highlighting the system's high efficiency in managing cooling requirements.

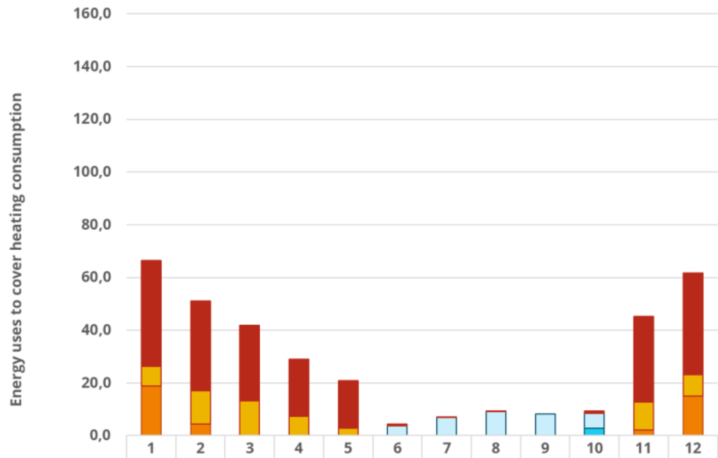
Thanks to PV electricity sharing among substations, out of the total amount of PV energy produced during the period (192 MWh), 95 MWh were self-consumed, and the rest are exported to the grid.

The combination of heat pumps, district heating, mine well renewable energy, and PV production allows the system to maintain a flexible and sustainable energy strategy year-round. By utilizing renewable resources and efficient technologies, it successfully addresses seasonal energy needs, while minimizing reliance on non-renewable sources, especially during the peak loads in winter months. Renewable energy sourced from the mine and gathered from PV on site covers about 67% of the buildings heating consumption and 42% of the space heating uses.



	1	2	3	4	5	6	7	8	9	10	11	12
DH use for heating [MWh]	66,6	51,0	41,9	29,0	21,0	0,7	0,0	0,0	0,0	0,9	45,3	61,7
PV electricity for heating [MWh]	0,0	0,0	5,9	15,6	20,6	0,2	0,0	0,0	0,0	0,0	0,0	0,0
Electricity from grid heating [MWh]	39,6	47,1	35,5	25,8	20,2	0,3	0,0	0,0	0,0	0,6	31,0	43,6
PV electricty for cooling [MWh]	0,0	0,0	0,0	0,0	0,0	19,3	20,0	11,0	4,0	0,0	0,0	0,0
Electricity from grid cooling [MWh]	0,0	0,0	0,0	0,0	0,0	32,9	65,3	39,5	16,5	25,0	0,0	0,0

a) Analysis for the substations



	1	2	3	4	5	6	7	8	9	10	11	12
Mine energy use for heating [MWh]	40,2	34,1	28,8	21,7	18,2	0,7	0,0	0,0	0,0	0,7	32,7	38,5
PV use for heating [MWh]	7,4	12,5	13,1	7,3	2,7	0,0	0,0	0,0	0,0	0,1	10,5	8,1
Grid electricity use heating [MWh]	18,9	4,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	2,1	15,0
PV use for cooling [MWh]	0,0	0,0	0,0	0,0	0,0	3,6	6,9	9,1	8,2	5,6	0,0	0,0
Grid electricity use cooling [MWh]	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	2,9	0,0	0,0

b) Analysis for the network and central station

Figure 3.5 – Monthly utilization of energy resources to cover thermal uses

3.3.2 Performance indicators assessment

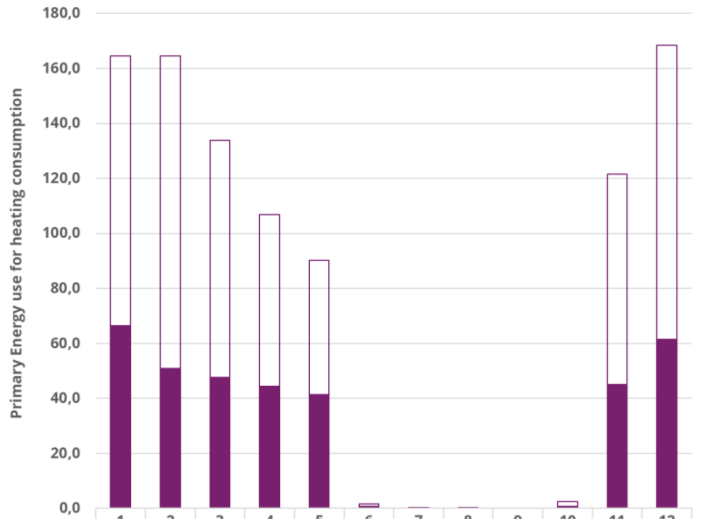
The primary energy calculation accounts for contributions from electricity, local renewable sources, as well as mine well used as an energy source. The energy extracted from the mine as well the one gathered from PV panels is classified as renewable and assigned a total primary energy factor of 1.0. For other energy sources, specific primary energy factors have been applied [2]:

- Electricity total primary energy factor → 2.3 (of which none is considered renewable according to the French electricity mix)

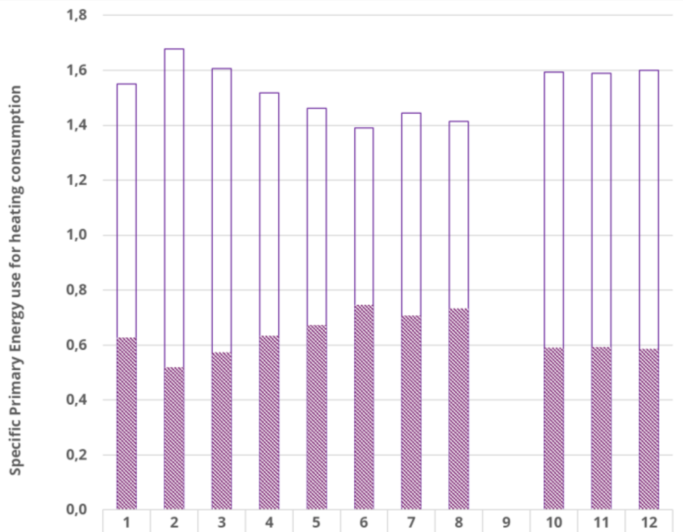
- Thermal energy distributed to the substations through the network total primary energy factor → 1.1 grid electricity contributes for 8% on average (of which 1.0 is considered renewable primary energy)

Over the course of the year, the buildings total primary energy consumption reaches 1,460 MWh, 954 MWh (Figure 3.6) being attributed to heating needs and 506 MWh to space cooling (Figure 3.9).

Although the primary energy use is markedly higher during the winter months the share or renewable primary energy reaches about 38%, thanks to the high renewable energy distributed through the DH (about 92% renewable). Figure 3.7 focuses on the primary energy distributed through the network during the heating season towards the building substations, contributing with about 371 MWh (278 MWh renewable) to the overall primary energy uses for heating purposes.

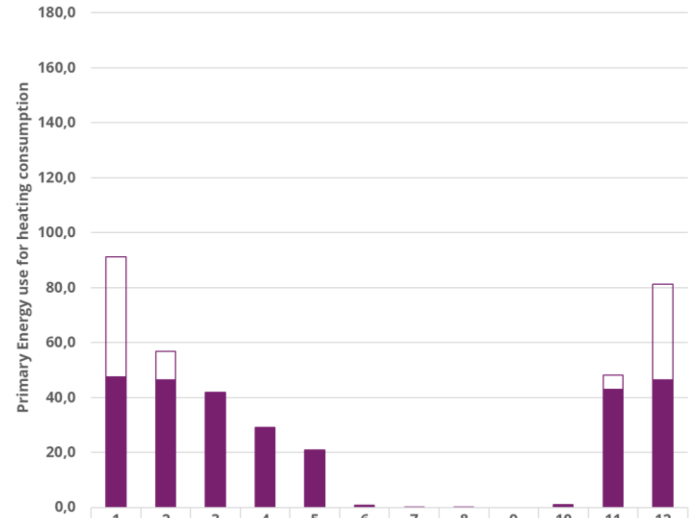


	1	2	3	4	5	6	7	8	9	10	11	12
PE use heating - Total [MWh]	164,6	164,6	133,8	106,9	90,3	1,7	0,0	0,0	0,0	2,5	121,4	168,4
PE use heating - Renewable [MWh]	66,6	51,0	47,8	44,6	41,5	0,9	0,0	0,0	0,0	0,9	45,3	61,7



	1	2	3	4	5	6	7	8	9	10	11	12
Specific PE use heating - Total [-]	1,6	1,7	1,6	1,5	1,5	1,4	1,4	1,4	0,0	1,6	1,6	1,6
Specific PE use heating - Renewable [-]	0,6	0,5	0,6	0,6	0,7	0,7	0,7	0,7	0,0	0,6	0,6	0,6

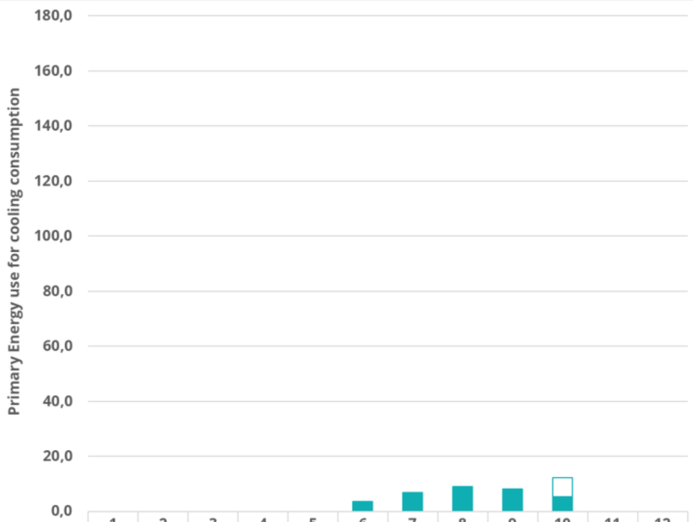
Figure 3.6 - Monthly renewable and total primary energy uses for heating consumption of the buildings. Total (on top) and Specific (per unit floor area on the bottom)



	1	2	3	4	5	6	7	8	9	10	11	12
PE use heating - Total [MWh]	91,1	56,8	41,9	29,0	21,0	0,7	0,0	0,0	0,0	1,0	48,1	81,2
PE use heating - Renewable [MWh]	47,7	46,6	41,9	29,0	21,0	0,7	0,0	0,0	0,0	0,8	43,2	46,6

Figure 3.7 – Primary energy related to the heat distributed through the network during heating season

Similarly, the primary energy required to deliver space cooling to the building substations is almost entirely renewable, as illustrated in Figure 3.8. In contrast, the majority of primary energy use for space cooling occurs at the building level (Figure 3.9), where the share of renewables is low—around 12%. This is due to the limited efficiency of the systems currently in use and the fact that the installed PV capacity has not yet reached the nominal, planned levels (see D6.5).



	1	2	3	4	5	6	7	8	9	10	11	12
PE use cooling - Total [MWh]	0,0	0,0	0,0	0,0	0,0	3,6	6,9	9,1	8,2	12,2	0,0	0,0
PE use cooling - Renewable [MWh]	0,0	0,0	0,0	0,0	0,0	3,6	6,9	9,1	8,2	5,6	0,0	0,0

Figure 3.8 – Primary energy related to the cold distributed through the network during summer season

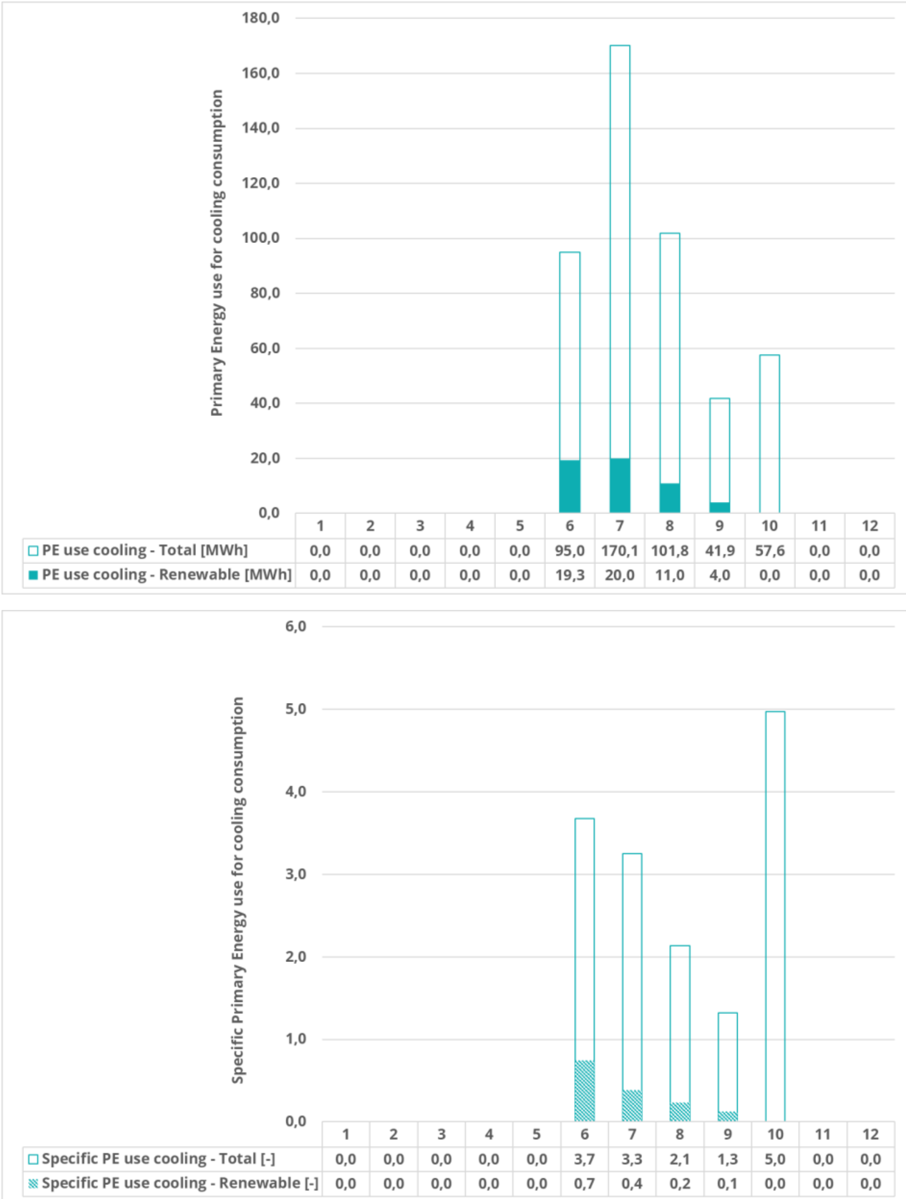
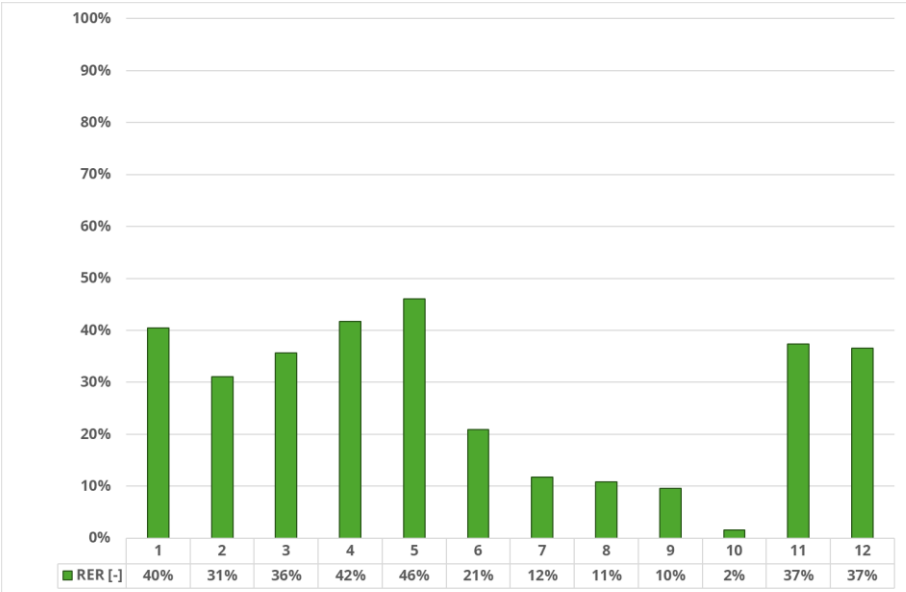


Figure 3.9 - Monthly renewable and total primary energy uses for space cooling consumption of the buildings. Total (on top) and Specific (per unit floor area on the bottom)

The RER shown in Figure 3.10 quantifies the renewable share as the ratio between renewable and total primary energy used for both heating and cooling.

During the winter months, the substations reach approximately a RER of 30-40%, primarily due to the renewable energy supplied by the network. As the support of the network decreases and cooling demand rises in summer covered the RER decreases.

A different trend is observed for the network, with a notably higher RER, driven by the extensive use of mine well water and PV electricity. In winter, as the PV productions decreases, the RER also decreases, reflecting the seasonal shifts in energy sourcing.



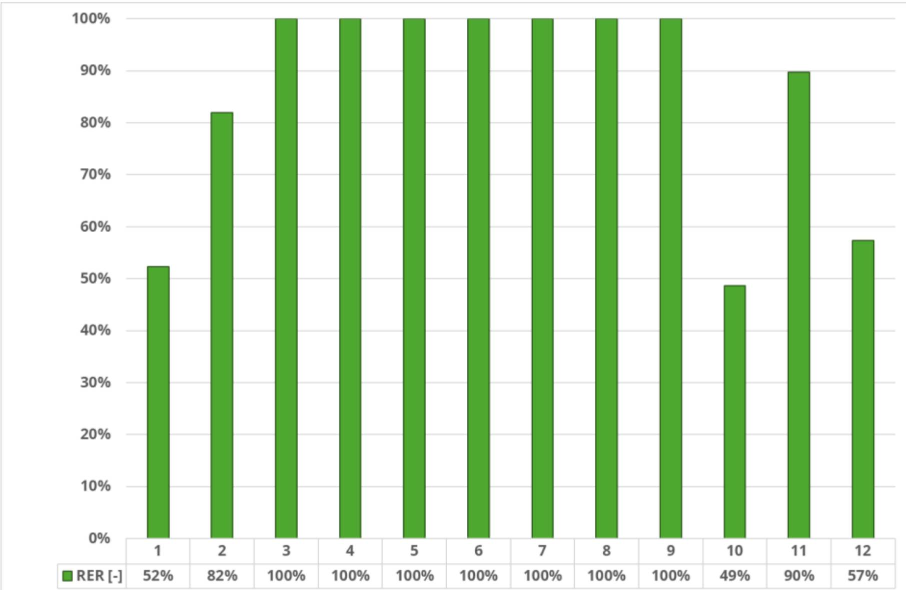
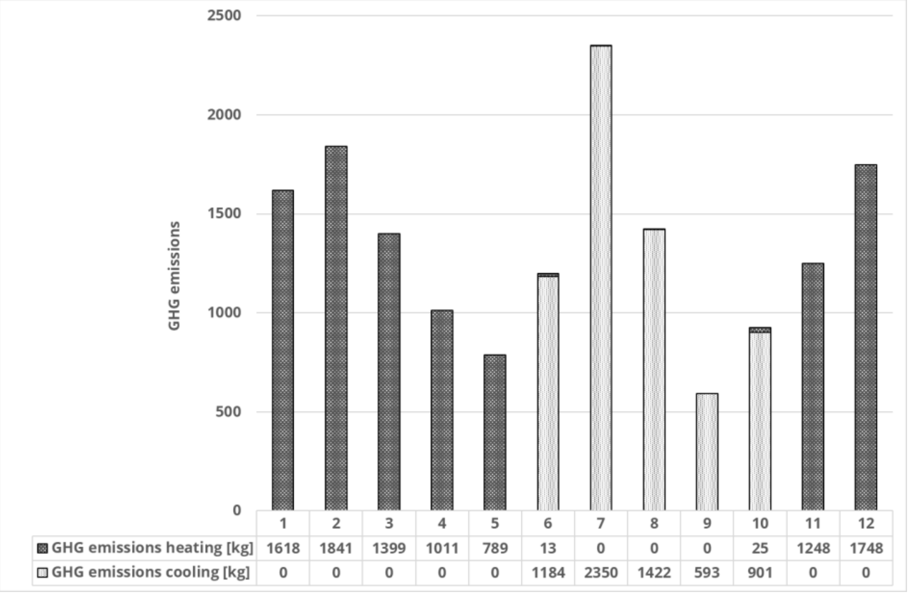


Figure 3.10 - Monthly renewable energy ratio. Analysis for the building substations (top figure) and for the pumping station and network (bottom figure).

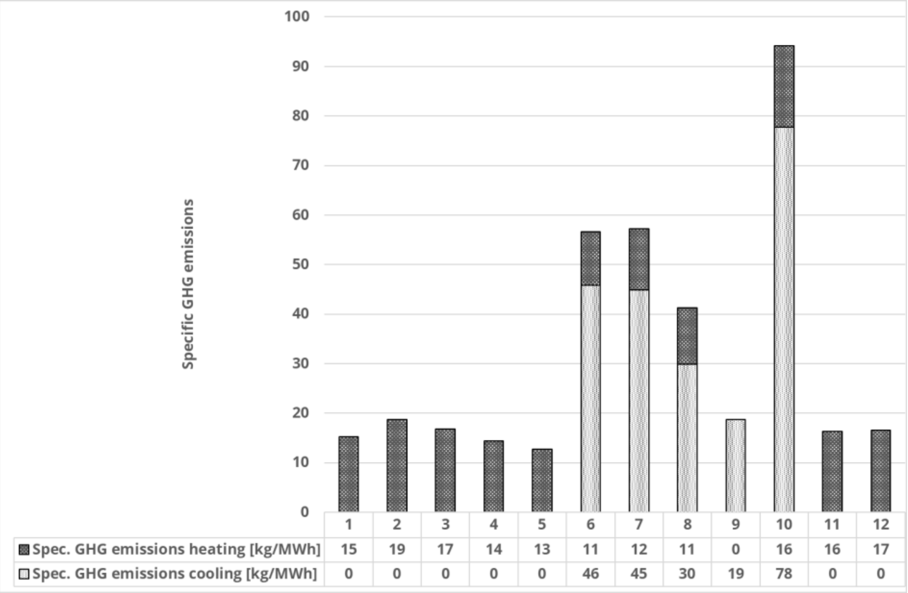
Figure 3.11 and Figure 3.12 presents the monthly greenhouse gas emissions associated with the energy system. The CO_2 emissions calculations derive from the electricity drawn from the grid, accounting for an emission factor extremely low of 36 kg/MWh [3].

The substation's annual CO_2 emissions totals 16,140 kg, with a similar amount produced during the winter months and in summer. On the other hand, the operation of the network shows much lower total CO_2 emissions of 4,994 kg. In the latter case, the emissions present a higher value for heating (73%) than for cooling months.

The average specific CO_2 emissions during the operation of the substations are 16 and 38 kg/MWh for heating and cooling respectively, ranging around 10-20 kg/MWh in winter and 20-75 kg/MWh in summer. The network specific CO_2 emissions range around 5-15 kg/MWh in winter and 3-8 kg/MWh in summer.

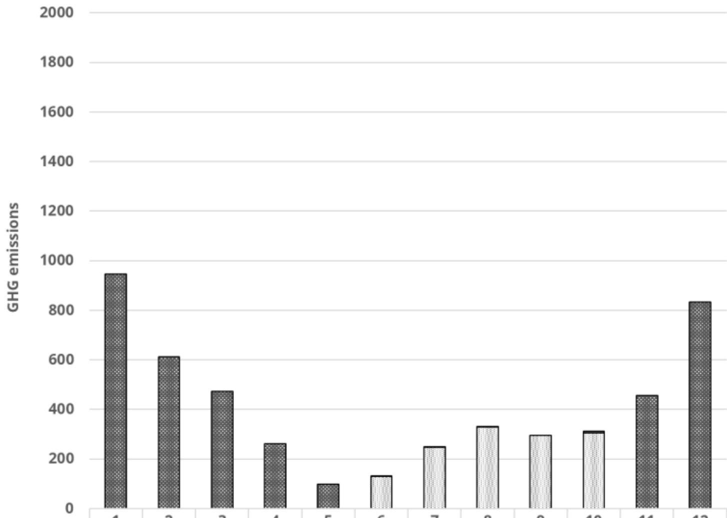


	1	2	3	4	5	6	7	8	9	10	11	12
GHG emissions heating [kg]	1618	1841	1399	1011	789	13	0	0	0	25	1248	1748
GHG emissions cooling [kg]	0	0	0	0	0	1184	2350	1422	593	901	0	0

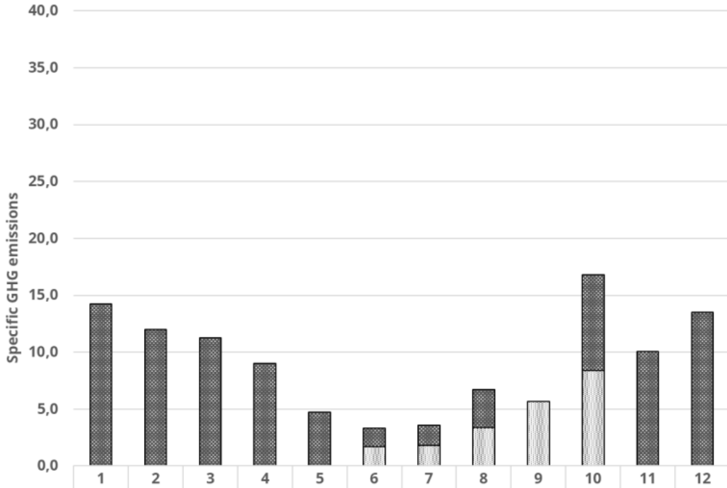


	1	2	3	4	5	6	7	8	9	10	11	12
Spec. GHG emissions heating [kg/MWh]	15	19	17	14	13	11	12	11	0	16	16	17
Spec. GHG emissions cooling [kg/MWh]	0	0	0	0	0	46	45	30	19	78	0	0

Figure 3.11 - Monthly CO2 emissions for heating and cooling at the substations level. Overall emissions on top and specific emissions per unit floor area at the bottom.



	1	2	3	4	5	6	7	8	9	10	11	12
GHG emissions heating [kg]	947	611	472	262	99	1	0	0	0	8	455	834
GHG emissions cooling [kg]	0	0	0	0	0	130	248	328	295	304	0	0



	1	2	3	4	5	6	7	8	9	10	11	12
Spec. GHG emissions heating [kg/MWh]	14,2	12,0	11,3	9,0	4,7	1,7	1,8	3,3	0,0	8,4	10,0	13,5
Spec. GHG emissions cooling [kg/MWh]	0,0	0,0	0,0	0,0	0,0	1,7	1,8	3,3	5,7	8,4	0,0	0,0

Figure 3.12 - Monthly CO2 emissions for heating and cooling purposes relate to pumping from the well and distribution through the network. Overall emissions on top and specific emissions per unit floor area at the bottom.

3.4 Remarks

Table 3.1 summarizes the system annual energy needs and environmental performance calculations reported above.

Table 3.1 – Overall system annual energy uses, and performance calculated

Notation	Annual values SSTs	Annual values Network	Unit of meas.
Heating consumption	604	318	MWh/y
Cooling consumption	169	401	MWh/y
Electricity use for heating	286 (42 from PV)	102 (62 from PV)	MWh/y
Electricity use for cooling	233 (54 from PV)	36 (33 from PV)	MWh/y
Mine use for heating	-	215	MWh/y
Mine use for cooling	-	438	MWh/y
PV Generation	-	192	MWh/y
Local RES use	320	277	MWh/y
Ren. PE for heating	360	278	MWh/y
Total PE for heating	954	371	MWh/y
Ren. PE for cooling	54	33	MWh/y
Total PE for cooling	466	40	MWh/y
Renewable Energy Ratio	0.29	0.76	-
GHG emissions for heating	9.7	3.7	ton/y
GHG emissions for cooling	6.5	1.3	ton/y

Here we highlight a range of key takeaways from the data analysis:

- The integration of a neutral-temperature district heating and cooling network operating between 7-29°C, allows for efficient energy distribution, leveraging renewable energy sources such as mine well water and PV electricity.
- The Renewable Energy Ratio reaches 100% during summer months, driven by the utilization of mine well water and PV energy. However, the RER decreases during winter due to increased reliance on grid electricity for heat pump operations.
- The reliance on renewable energy sources, including geothermal energy from the mine well and PV production, underscores the potential of innovative DHC networks in minimizing non-renewable energy use and associated CO_2 emissions.
- The utilization of renewable energy at substations level is much lower, the RER ranging from about 10% to 45%. The overall renewable energy content in the DHC network mix varies between 67% in winter and 42% in summer, highlighting margins for improvements.
- This is indeed consequence of the higher electricity utilization to run the HPs. In summer specifically, there are margins to significantly improve the efficiency of the substations' operation. Moreover, the amount of PV fields on building roofs is to be increased (as already foreseen), as there are significant margins for utilization on site, without reducing the self-consumption share.

- Thermal energy sharing between substations enhances system resilience and reduces external energy reliance. The same applies to using rejected heat from cooling operations for heating needs. At this site, we observed limited overlaps between heating and cooling loads. To improve this in the future, a greater coexistence of these loads should be pursued by selecting a more suitable mix of building uses and optimizing building loads throughout the seasons.

4 Helsingborg, Sweden

4.1 Description of the demonstration site

This demonstration site is located in the district of Drottninghög in Helsingborg (Sweden), and consists of a newly built, small-size, heating and cooling network supplying energy to four new apartment blocks (5 to 7 floors and 110 apartments, with a total living area of 7,795 m^2, see Figure 4.1. The construction has been implemented by Tornet, who are specialized in construction and management of affordable rental properties, with a commitment to energy efficiency, responsible material utilisation, and sustainable product choices.

Figure 4.1: The four multifamily homes and the energy centre building

The REWARDHeat demo site in Helsingborg stands out due to the close collaboration in its design between the DH operator and the local energy system owner, a partnership that significantly streamlined the construction process.

The Energy Centre at the core of the small network consists of a thermal substation and a 6-pipe distribution network designed to cover the demands for DHW, space heating (SH), and space cooling (SC).

4.1.1 Objectives and main results of the demonstration activity

The project involves three partners: INDEPRO, tasked with strategic planning, ARVALLA, overseeing construction management, and EURAC who developed an optimized RBC for the management of the boreholes field. The project aims to achieve the following objectives:

- Installation of a standardized substation, streamlining construction processes through the deployment of standardized design.
- Integration of a geothermal HP in the substation aimed to minimize the import of energy from the district heating network.

- Integration of PVT panels, reducing electricity consumption from the grid and charging the boreholes field in summer.
- Integration of a state-of-the-art smart monitoring and control hardware and software.
- Assess management strategies aimed to select the most effective way of sourcing heat for the buildings, between the DHN and the borehole field.

The implemented system in Helsingborg is highly flexible, allowing real-time selection of the most optimal energy vector—either DH or electricity for heat pump HP operation—based on economic and environmental performance indicators. In winter, the system primarily relies on the HP for space heating and DHW preparation, with DH covering only peak demands. Conversely, during summer, DH becomes the preferred energy source due to favourable pricing, while HPs are turned off. Waste heat from building cooling is then redirected to recharge the boreholes.

Free cooling alone does not suffice to offset winter heat extraction from the boreholes. To address this, the system employs a recharging strategy, capturing solar thermal energy with PVT panels and recovering waste heat from the AIR Handling Units' (AHU) exhaust duct, providing a steady thermal power of 15kW. This recovered heat is used primarily at the HP evaporator for DHW and space heating delivery, keeping the HP frequently active to capture most of the building's recovered heat. Excess heat that the HP cannot utilize is directed to the boreholes, balancing some of the extracted energy.

Despite these strategies, borehole energy input still does not fully balance extraction. Boreholes can serve as viable thermal storage under certain conditions, but effective control requires collaboration with DH and electric grid authorities. An initial breakeven analysis, using informed assumptions on DH pricing and primary energy factors, indicates modest system benefits.

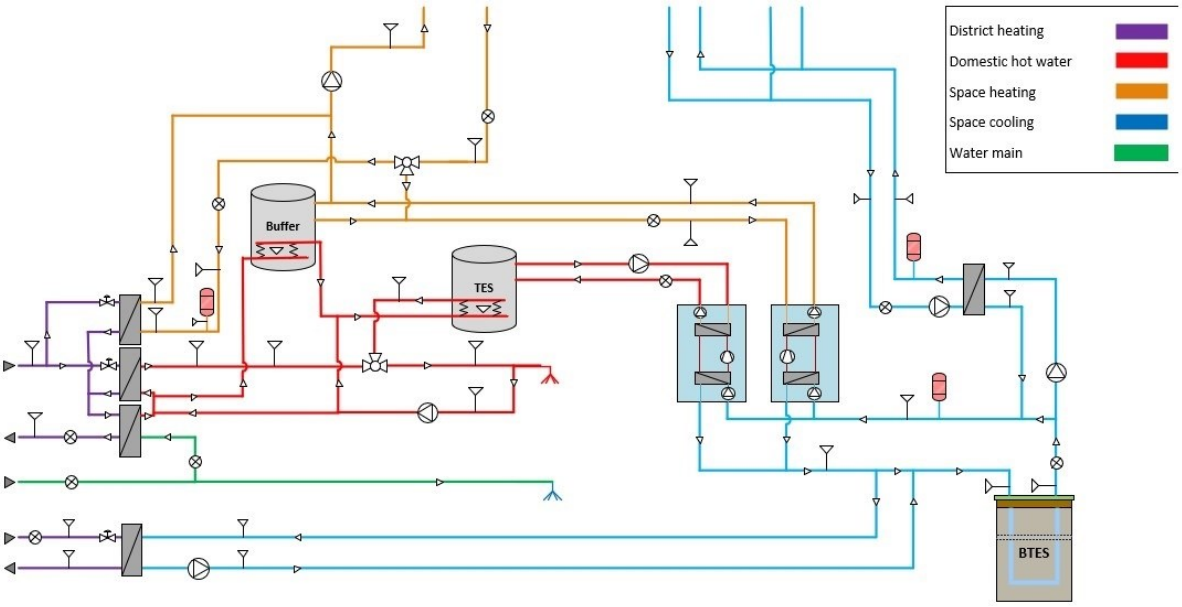


Figure 4.2. Layout of the Tornet Energy Centre in Helsingborg

4.2 DHC Network conceptual design and management

Figure 4.2 shows a simplified P&Id of the system: the energy system interfaces with the Helsingborg DHN network (purple lines) via two counterflow HXs—one dual-stage HX to meet DHW demand (red lines) and one for SH demand (orange lines). The system uses two identical hot water tanks, each with a capacity of 750 litres: a high-temperature TES dedicated to meeting DHW peak loads and a low-temperature buffer that interfaces with the SH system and preheats DHW.

The Energy Centre also integrates a 4-pipe geothermal HP, equipped with a variable-speed compressor and a de-superheater that recovers heat from DHW preparation for space heating purposes. For sake of simplifying the system description, the latter is represented as two separate HPs. The HP is used solely for heating, while SC is achieved through free cooling (blue lines): heat is extracted from the building via the AHU and directed to the boreholes.

A rule-based control is implemented on top of the energy system to manage the operation of the different generation, distribution, and emission units. This can be ideally described as a set of operating schemes:

- Schemes S1 and S2 use either DH or HP energy stored to cover DHW and recirculation loads (Figure 4.3). S1 is mainly used during summer when district heating cost is low. S2 is preferred in winter, when it acts as a primary source for DHW preparation, while DH is used as a backup source.

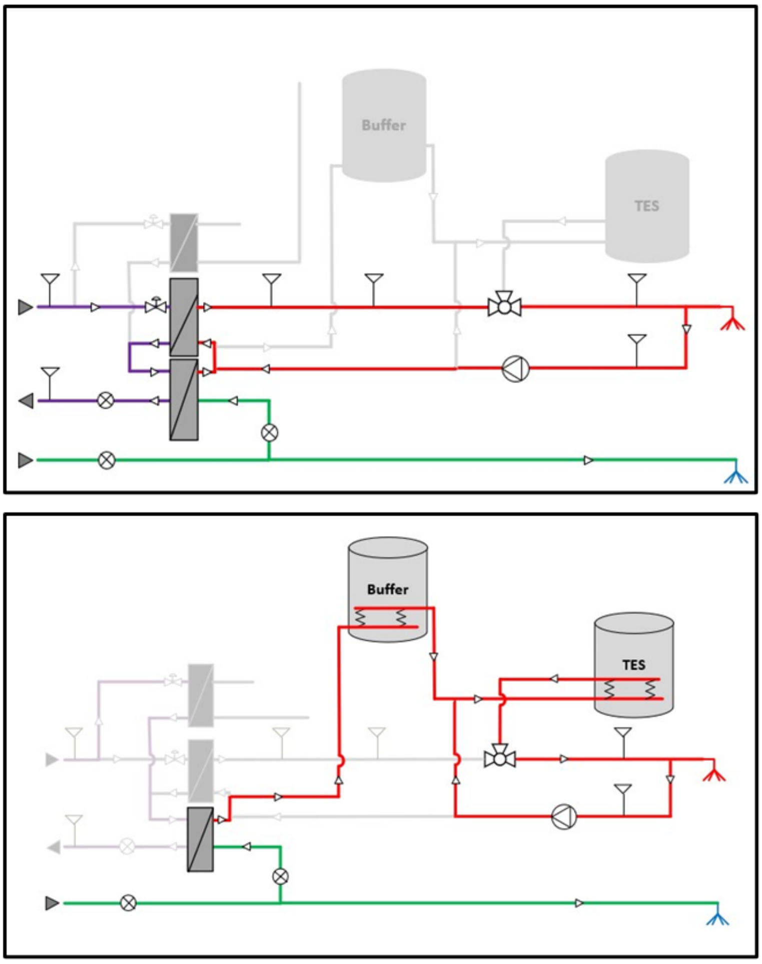


Figure 4.3 – Domestic hot water preparation schemes

- Schemes S3a and S3b (Figure 4.4) are used to store energy in the DHW thermal energy storage through the HP. In the first case, the local renewable energy source is a combination of ground heat, PVT energy and waste heat from AHUs. In the second case, rarely occurring, local RE is only sourced from the ground.

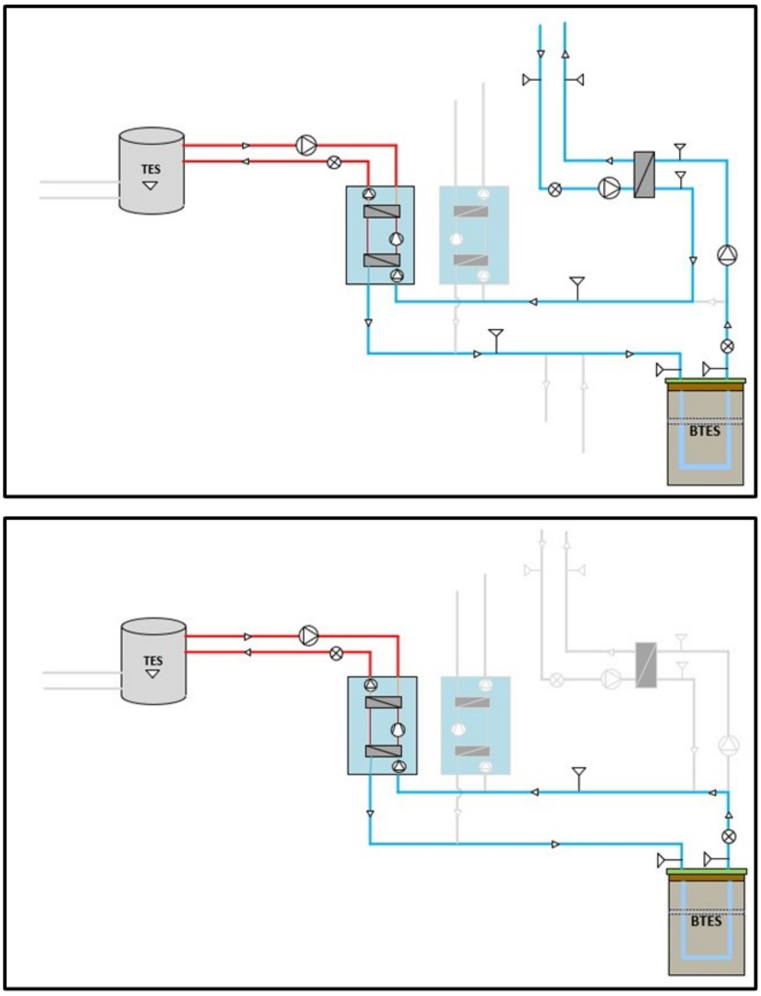


Figure 4.4 – Charge of the TES though the heat pump using combined heat form BTES and AHU+PVT circuit

- In case the HP is off, heat from the AHU+PVT circuit is used to charge the boreholes field (Figure 4.5). This operating scheme is most prominent in summer, when both space cooling and heat from PVT panels are available, with DHW production managed by district heating.
- In winter, however, the heat pump is always in operation to cover shape heating and is capable of handling the rejected heat effectively. Schemes S4a and 4b (Figure 4.6) operate in the same manner as S3a and S3b, delivering heat to the space heating buffer.
- Scheme S6 and S7 (Figure 4.7) Figure 4.6show how space heating is delivered to the buildings both through direct DH energy exploitation and through buffeted energy from the HP.

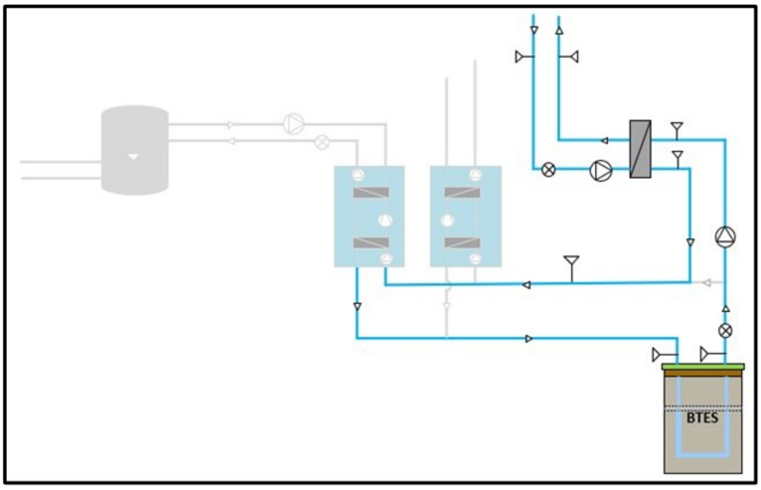


Figure 4.5 – Scheme S3c, charge of BTES and free cooling

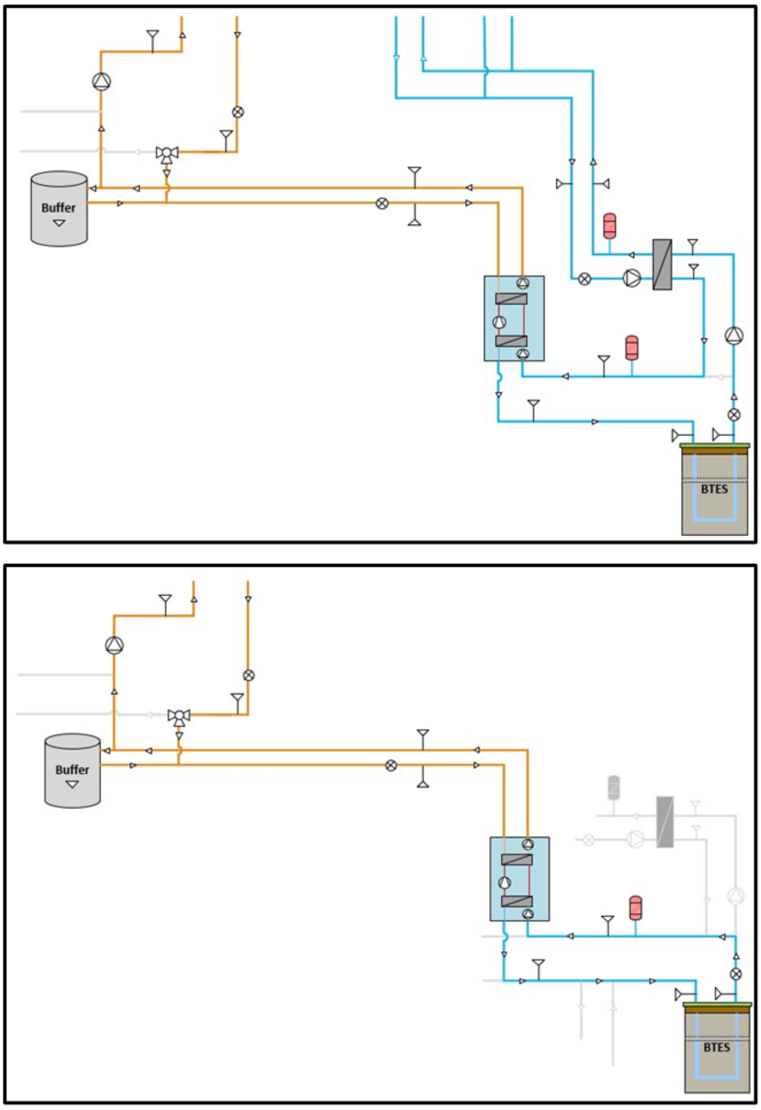
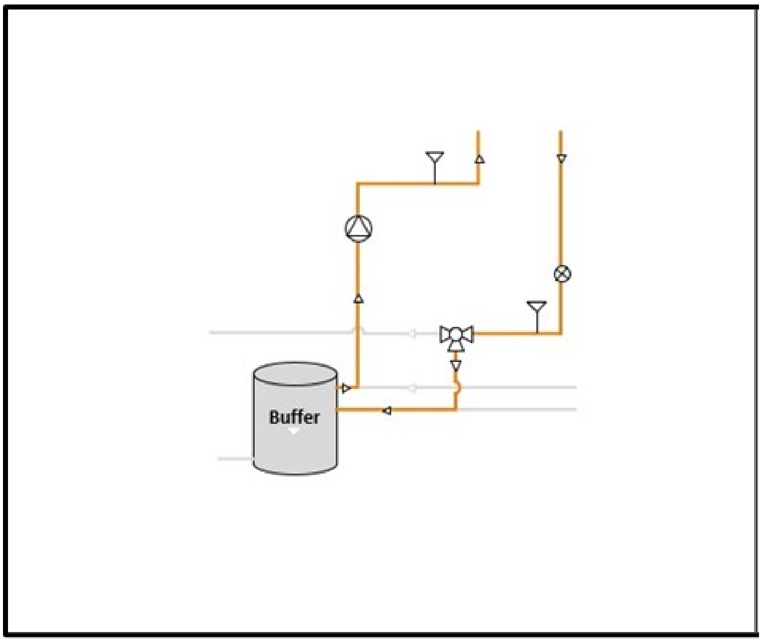


Figure 4.6 – Charge of the space heating buffer though the heat pump using combined heat form BTES and HR/SC+PVT circuit



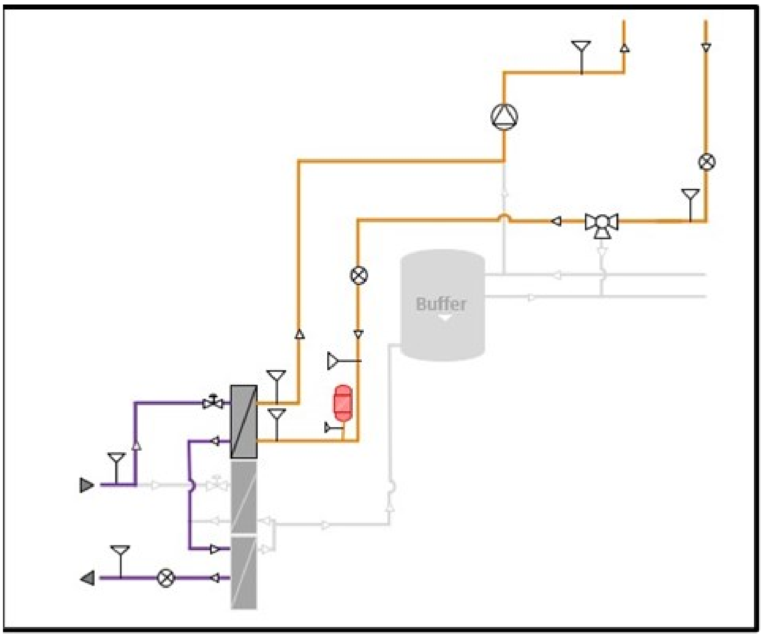


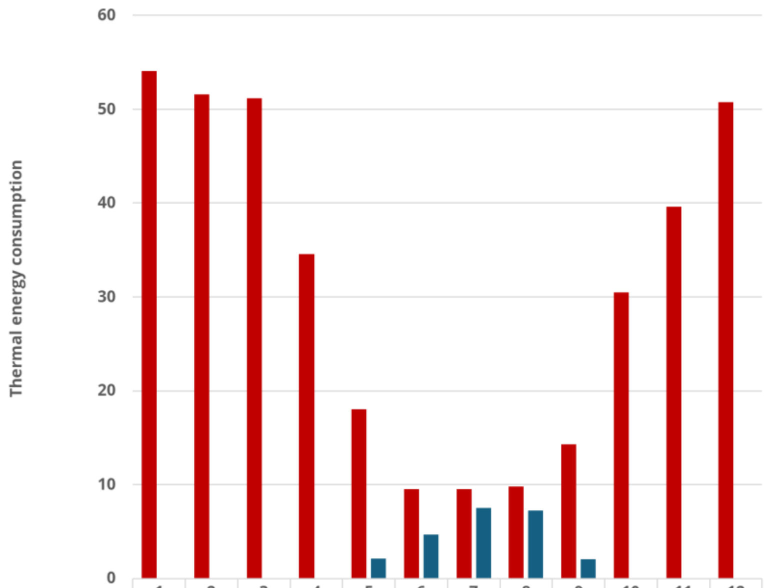
Figure 4.7 – Scheme S5, space heating using the energy stored in the buffer

4.3 Assessment of the network performance

4.3.1 Energy uses insisting on the network

Figure 4.8 shows the building's monthly thermal energy consumption. The heating consumption includes both domestic DHW and space heating demand.

The building's annual heating consumption totals around 373 MWh (48 kWh/m²), with 245 MWh (31 kWh/m²) covering SH demand and the remaining 129 MWh (17 kWh/m²) covering DHW demand. Most heating consumption occurs obviously in the colder months, while DHW demand remains relatively stable at approximately 10 MWh per month. The annual cooling consumption amounts to 24 MWh (3 kWh/m²).



	1	2	3	4	5	6	7	8	9	10	11	12
Heating consumption [MWh]	54.0	51.6	51.2	34.6	18.0	9.5	9.5	9.8	14.3	30.5	39.6	50.8
Cooling consumption [MWh]	0.0	0.0	0.0	0.0	2.1	4.7	7.5	7.2	2.0	0.0	0.0	0.0

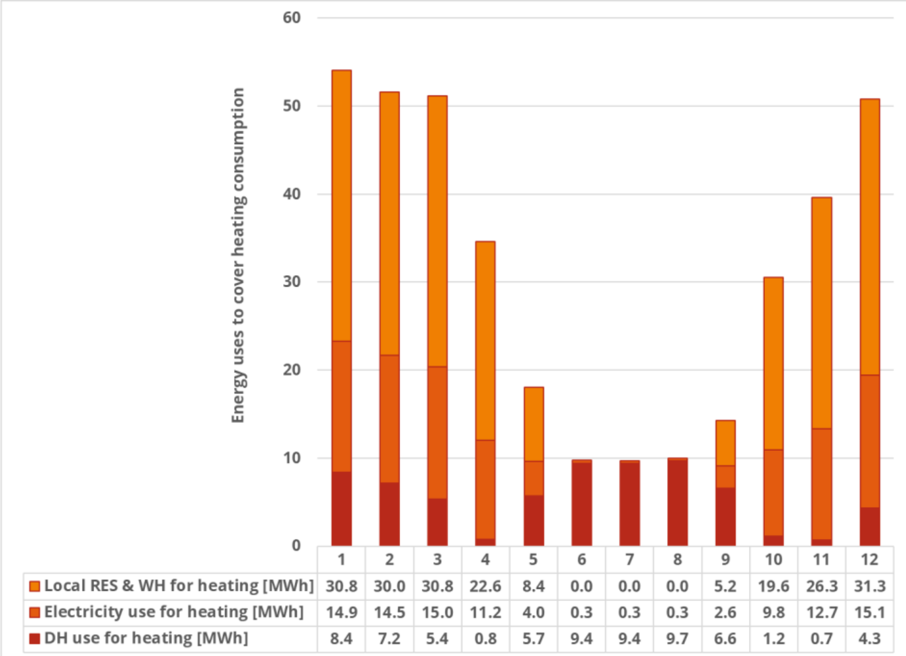
Figure 4.8 - Monthly thermal energy consumption of the buildings

Figure 4.9 and Figure 4.10 illustrate the energy sources used to meet the building's heating and cooling demand. Heating is primarily supplied through a combination of DH energy, electricity, and local RE (i.e., ground and solar heat), supplemented by WH recovery.

In this specific system, AHUs equipped with heat recovery functionality recovers heat from the building's exhaust air both during summer and winter. In the latter case Rather than using this recovered heat to warm fresh intake air directly, it is routed to preheat the fluid entering the heat pump's evaporator. By raising the evaporator's inlet temperature, this strategy boosts the HP's COP. This strategy is alternative to a passive heat recovery from waste air using a dedicated heat exchanger in the AHU. As this configuration leads to a higher-than-expected space heating demand compared to waste heat being recovered in the AHUs directly, it proves more effective only when the heat pump operates at lower COP levels, where the reduction in electricity use from an improved COP becomes substantial, and when the heat pump runs continuously for most of the day.

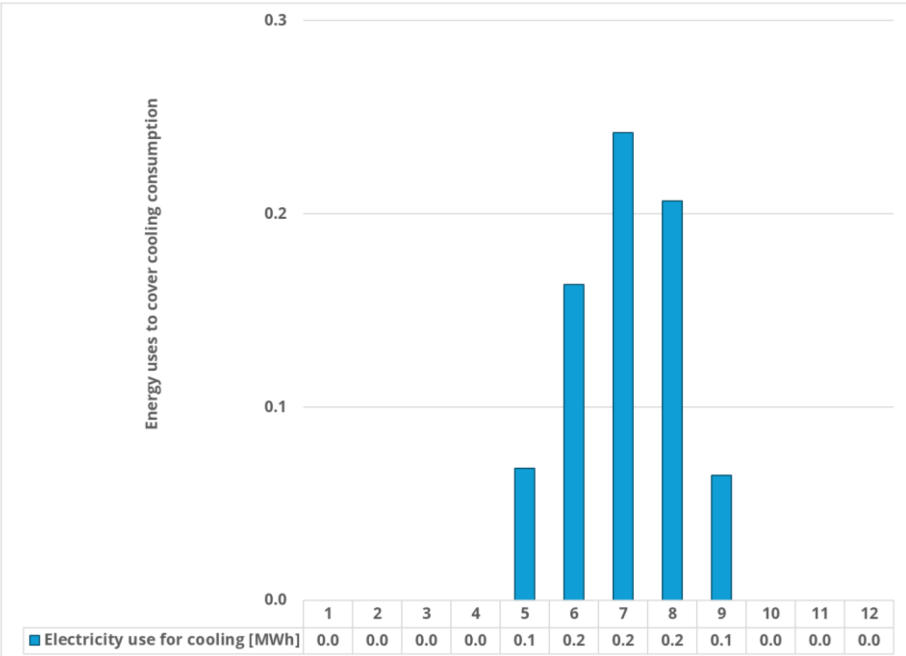
Balancing the allocation of recovered heat between the heat pump and direct building heating presents a challenge in optimizing both energy efficiency and comfort levels in cold climates. In future designs, careful consideration of these trade-offs could help optimize energy use and provide insights into the best strategies for balancing heat recovery, heat pump efficiency, and building heating demand.

Thanks to the above strategy, the heat pump system operates with a COP of approximately 3.1, including electricity consumed by both the heat pump compressor and the circulation pumps. However, during particularly cold hours, the HP's thermal capacity is not always sufficient to meet the full heating demand, requiring district heating as a supplemental source to cover the shortfall. In the warmer months, the heating demand is limited to DHW, and the heat pump is not in operation as DH energy is cheaper and the boreholes field must be recharged (see deliverable 4.5). A minimal amount of electricity is still used for circulating pumps.



	1	2	3	4	5	6	7	8	9	10	11	12
Local RES & WH for heating [MWh]	30.8	30.0	30.8	22.6	8.4	0.0	0.0	0.0	5.2	19.6	26.3	31.3
Electricity use for heating [MWh]	14.9	14.5	15.0	11.2	4.0	0.3	0.3	0.3	2.6	9.8	12.7	15.1
DH use for heating [MWh]	8.4	7.2	5.4	0.8	5.7	9.4	9.4	9.7	6.6	1.2	0.7	4.3

Figure 4.9 - Energies use for heating



	1	2	3	4	5	6	7	8	9	10	11	12
Electricity use for cooling [MWh]	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.1	0.0	0.0	0.0

Figure 4.10 - Energies use for cooling

In summer, the system employs a free cooling approach, which minimizes energy consumption. Space cooling is achieved by circulating cold fluid from the BTES directly through the building, hence, the only energy consumption for cooling is the electricity needed to run the circulation pumps.

Overall, this combination of district heating, heat pumps, renewable energy from BTES, and waste heat recovery allows the building to achieve a balanced and adaptive energy strategy across seasons. The system leverages renewable sources and energy-efficient technologies to meet demand in a way that minimizes reliance on import of energy from outside the property's borders, especially during high-demand winter months. The use of district heating for DHW in summer further illustrates the system's adaptability, as it allows for a simple and cost-effective solution for low season heating requirements.

The overall DH energy use amounts to 63 MWh a year (8 kWh/m²). The building's total annual electrical consumption amounts to 101 MWh (13 kWh/m²). Of this, only 0.7 MWh (0.1 kWh/m²) is required for cooling.

Overall, the monthly electrical consumption trends demonstrate a seasonal energy profile, with high demand during winter, when less PV is available and minimal use during summer when more PV is available. Therefore, considering only the electrical consumption of the energy system, the PV self-sufficiency and self-consumption are quite low. This should be better considered in the future, when new systems will be planned and deployed.

4.3.2 Performance indicators assessment

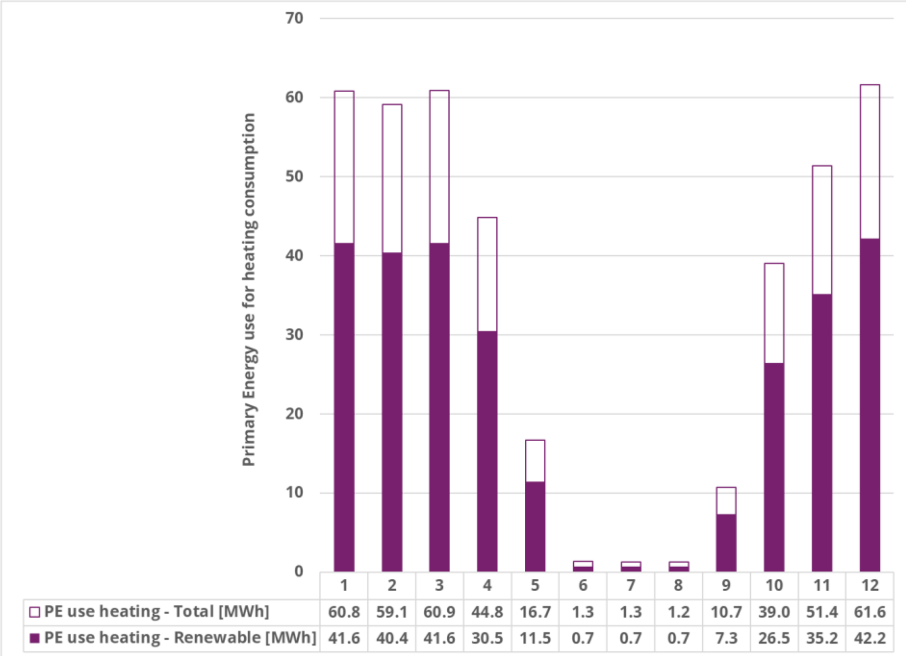
Figure 4.11 illustrates the buildings monthly total primary energy use for heating and cooling, alongside the renewable portion of that energy. The primary energy calculation accounts for contributions from electricity, district heating, and local renewable sources, as well as waste heat recovery. The energy extracted from boreholes, as well as WH from AHUs is assigned a total primary energy factor of 1. For other energy sources, specific primary energy factors have been applied:

- DH total primary energy factor → 0.07 [4] (of which 0.05 is considered renewable)
- Electricity total primary energy factor → 1.98 [5] (of which 0.7 is considered renewable)

Over the course of the year, the building's total primary energy consumption reaches 410 MWh, which translates to 53 kWh/m². Of this total, 280 MWh (36 kWh/m²) is derived from renewable sources. Nearly all of this primary energy use consumption is attributed to heating needs, reflecting the share of energy demands in the building.

Primary energy use is markedly higher during the winter months when the heat pump is in operation. This increase is partly due to the total primary energy factor for electricity being approximately 30 times higher than that of DH. As a result, the use of electricity during winter for heating substantially raises the primary energy requirement, even though the building's heating system incorporates significant RE contributions.

The RER shown in Figure 4.12, quantifies the renewable share by calculating the ratio of renewable primary energy to total primary energy used for both heating and cooling. During the months when the heat pump operates, the RER approaches 70%, largely due to the renewable energy supplied by the boreholes and the recovered waste heat.



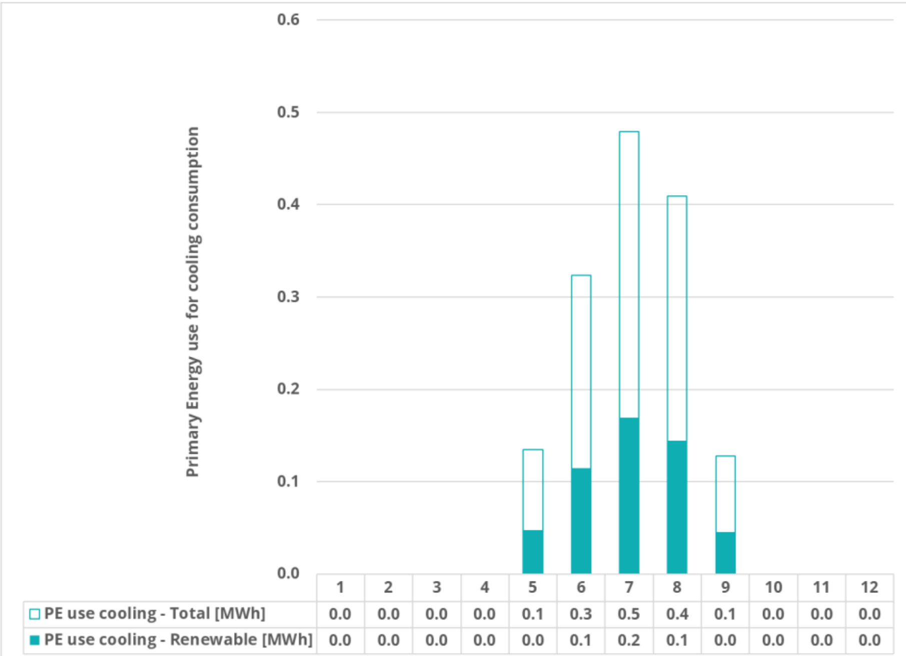


Figure 4.11 - Monthly renewable and total primary energy uses for heating (top) and cooling (bottom) consumption of the buildings

However, in the summer months, when heating needs are minimal and the heat pump is largely inactive, the RER decreases to around 50%. In this period, renewable primary energy depends solely on the electricity and district heating energy mixes, both of which include renewable components.

Nonetheless, it is important to note that even during this period, some renewable processes continue indirectly supporting the building's winter energy performance. Specifically, the heat recovered from the AHUs and PVT panels is directed into the borehole field, reflects on the system performance of the next winter season: by recharging the borehole field in summer, the system maximizes renewable energy input when demand is low, setting up a stronger renewable profile and higher operational efficiency for the winter heating period.

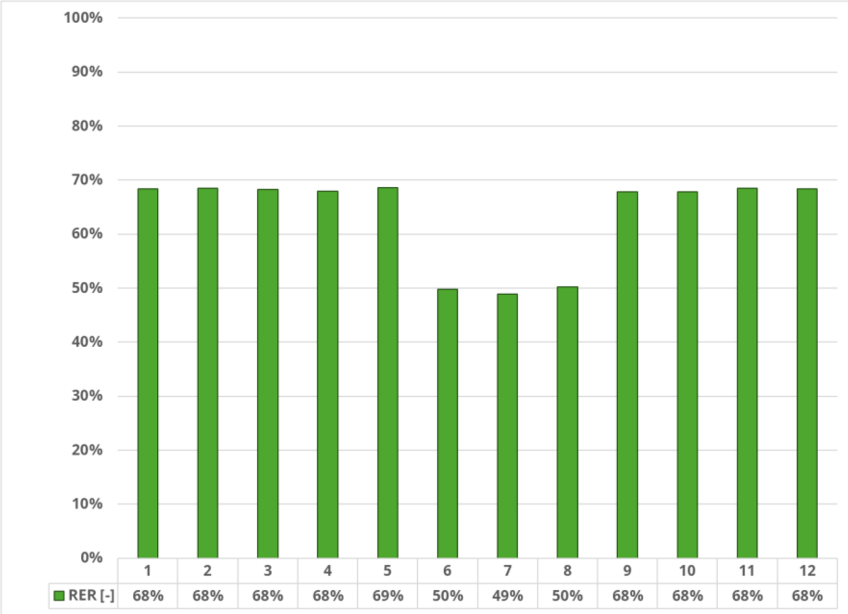


Figure 4.12 - Monthly renewable energy ratio

Figure 4.13 presents the monthly greenhouse gas emissions associated with the building's energy system. The CO_2 emissions calculations encompass district heating, electricity used by the heat pump, and the circulation pumps. It's important noticing that emissions from other energy uses, such as lighting, appliances, and ventilation, are excluded from this calculation to maintain a clear focus on the thermal needs of the buildings.

The CO_2 emissions are broken down into specific emissions values, which are calculated by dividing the total CO_2 emissions by the energy consumption values provided in Figure 4.8. The analysis applies distinct CO_2 emission factors to district heating and electricity sources:

- District heating CO_2 emission factor → 4.8 g/kWh [4]
- Electric energy CO2 emission factor → 28 g/kWh [6]

The building's annual CO_2 emissions from its heating and cooling systems total 3,167 kg. A significant portion of the CO_2 emissions occurs during the winter months, coinciding with increased heating demand. During these colder months, specific CO_2 emissions range between 8 kg/MWh and 9 kg/MWh. This is largely due to the system's dependence on electricity, which has a relatively high CO_2 emission factor. Still specific values in winter are comparable to summer ones (around 6 kg/MWh), demonstrating the effectiveness of the management strategy implemented.

Interestingly, specific CO_2 emissions for cooling become notable during the summer months, despite the overall low total values. Since cooling energy demand is minimal and covered exclusively by circulation pumps, the specific emissions per unit of cooling energy increase. This trend reflects the calculation method, where specific emissions are measured against the low summer cooling load, leading to higher values per-unit.

In summary, the buildings environmental performance profile is characterized by higher emissions in winter due to electricity, with district heating's lower emissions factor helping to curb emissions in summer. This seasonal shift underscores the significant role of the energy mix in influencing the building's carbon footprint and highlights the efficiency of utilizing district heating during periods of low heating demand, and the margins for further refining the system overall control strategy to reduce the energy uses at energy system level, beyond the minimization of the energy import to the property.

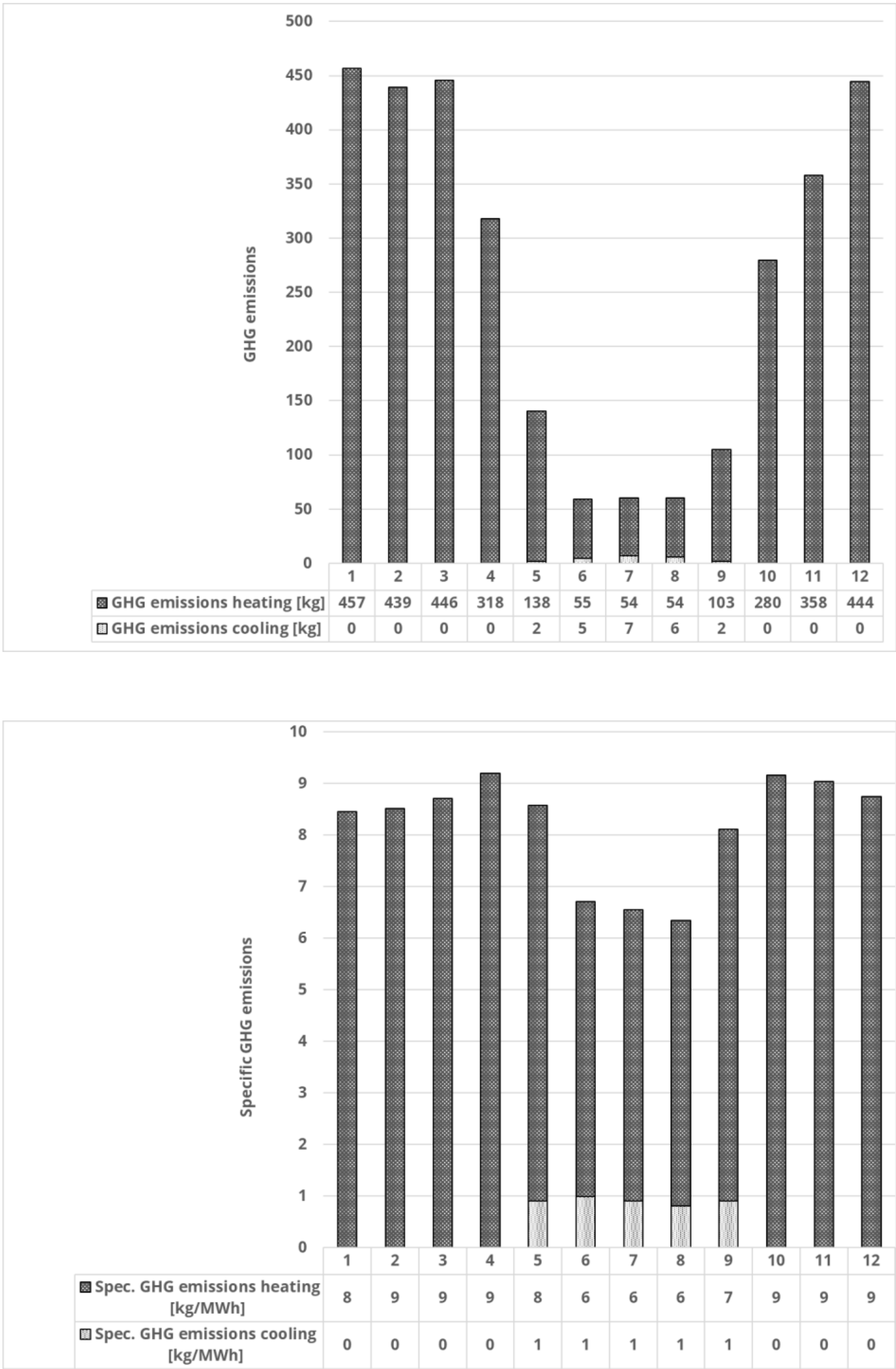


Figure 4.13 - Monthly CO_2 emissions (top) and specific CO_2 emissions (bottom) for heating and cooling

4.4 Remarks

Table 4.1 summarizes the system annual energy needs and environmental performance calculations reported above.

Table 4.1 – Overall system annual energy uses, and performance calculated

Notation	Annual values	Unit of meas.
Heating consumption	373 (48)	MWh/y (kWh/m²y)
Cooling consumption	24 (3)	MWh/y (kWh/m²y)
Electricity use for heating	101 (13)	MWh/y (kWh/m²y)
Electricity use for cooling	0.7 (0.1)	MWh/y (kWh/m²y)
DH use for heating	69 (9)	MWh/y (kWh/m²y)
Local RES use	205 (26)	MWh/y (kWh/m²y)
Ren. PE for heating	279 (36)	MWh/y (kWh/m²y)
Total PE for heating	409 (52)	MWh/y (kWh/m²y)
Ren. PE for cooling	0.5 (0.07)	MWh/y (kWh/m²y)
Total PE for cooling	1.5 (0.19)	MWh/y (kWh/m²y)
Renewable Energy Ratio	0.64	-
GHG emissions for heating	3146 (404)	kg/y (g/m²y)
GHG emissions for cooling	21 (3)	kg/y (g/m²y)

- The heat pump achieves a high COP of around 3.1 during colder months, thanks to using recovered heat from the building connected to the correct sizing of the unit; on the other hand, this requires supplemental district heating when demand peaks.
- Leveraging RE and WH improves efficiency, reducing the buildings dependency on non-renewable sources.
- Free Cooling reduces cooling-related consumptions. By using free cooling for space cooling, the building minimizes electricity use for cooling, relying solely on electricity consumption of circulation pumps. This demonstrates the potential of passive and free cooling techniques to reduce both energy consumption and emissions during warmer months.
- Renewable energy plays a greater role in colder months due to borehole storage and waste heat recovery, with the RER nearing 70%. In summer, when renewable resources are limited to district heating and electricity, the RER falls to around 50%, highlighting the need for seasonal storage and/or supplementary RES integrated in the overall energy system.
- Primary Energy demand tends to increase with electricity dependence, at least until the electric grid is substantially decarbonized. This calls for balancing electrical systems with alternative heating sources.
- Specific CO_2 emissions drop in summer due to the lower CO_2 emission factor of district heating compared to electricity, emphasizing the importance of energy source choice. Using DH to charge the BTES could be a valuable strategy to reduce winter electricity use. However, it requires in-depth analysis, considering hourly primary energy factors and BTES heat losses (see deliverable 5.9).

5 La Seyne-sur-Mer, France

5.1 Description of the demonstration site

The demonstration site located in La Seyne-sur-Mer is a DHC network operated at different temperature levels to accommodate different needs encountered along the expansion. The DHC network is operational since 2008, while DALKIA took over ownership and management starting 2019. The network was extended along the project elaboration, as shown in the map of Figure 5.1, and the number of customers raised from 4 to 14 in 2024.

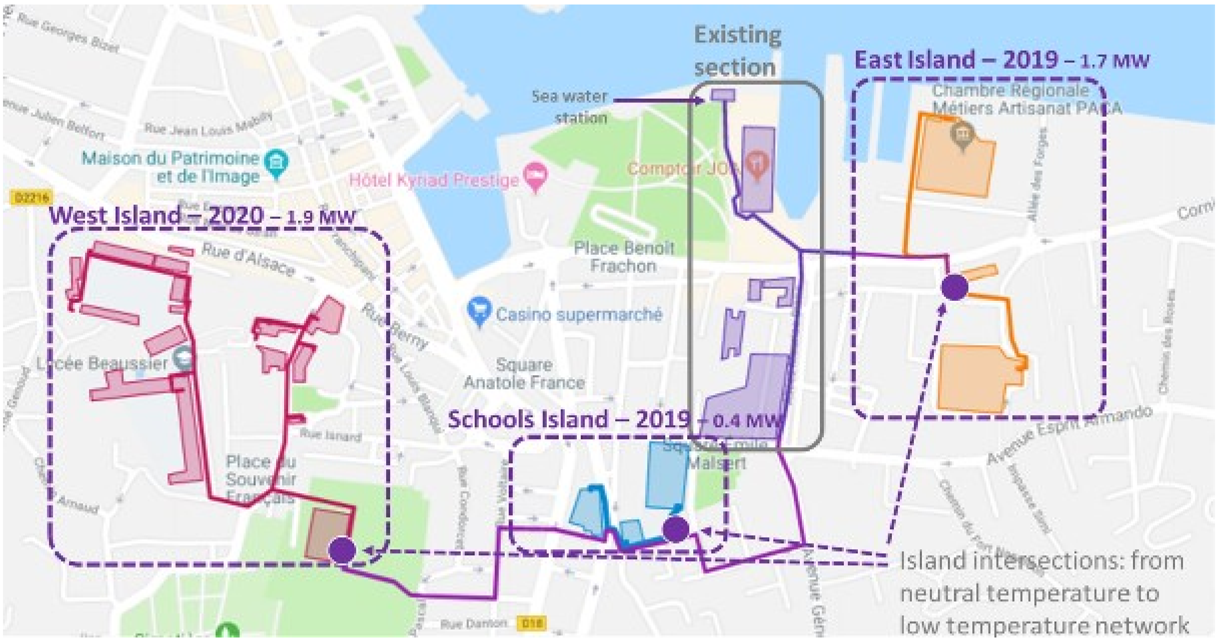


Figure 5.1: Expansion at the demonstration site in La Seyne-sur-Mer.

The neutral-temperature DHCN initially set up uses seawater as energy source and sink, and allows to cover both heating and cooling needs, as it is operated between 13-24°C, the temperature varying over the year according to the seawater temperature and the extent of heating and cooling, partially loads balancing out over the network.

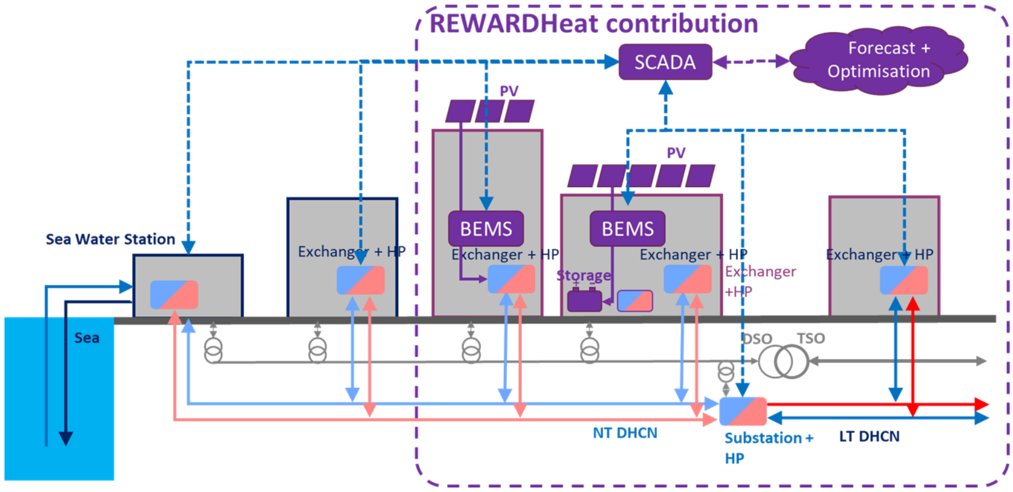


Figure 5.2: Overview of the technologies that will be implemented at the demo case of LSSM.

5.1.1 Objectives and main results of the demonstration activity

The project involves two partners: DALKIA, who owns and manages the DHCN, and EDF who developed the advanced control tools and implemented them in DALKIA's platforms. Overall, the project aimed to improve the energy efficiency of the DHCN through new equipment installation and advanced control strategies integration. Particularly, the following objectives have been pursued:

- Replacement of the seawater filters and installation of variable speed pumps at the central pumping station in order to reduce flow, raise the temperature difference between supply and return temperature, hence lower electricity consumptions overall
- Upgrade of the PLCs and the functional analysis implemented at the central pumping station and all customer substations. These have been improved continuously along the project elaboration, thanks to the feedback received while modelling or simulating the network substations for forecast, optimisation or simulation purposes
- Establishment of a reliable 4G communication link between substations and the SCADA system, along with an upgrade of the entire DALKIA's ICT infrastructure to enhance the reliability and stability of data flows
- Development and deployment of a centralised, advanced supervision and control system based on model predictive based optimisation techniques.

Over the project duration, the DHCN has reached its full capacity, and the renovation of the sea-water central pumping station, together with the SCADA system upgrade have been accomplished. In 2023, the network produced 2.3 GWh of heating and 1.5 GWh of cooling respectively.

As already outlined in Deliverable 6.5, the DHC network underwent a significant upgrade to both the seawater pumping station and the overall monitoring and control systems, with measures touching improvements to SCADA and communication reliability.

The overhaul of data systems has already improved reliability, enabling DALKIA to monitor and control the network remotely, with the main EMS and substation automation integrated directly into the SCADA system.

Overall, the project demonstrated how adaptable forecasting, advanced modelling, and flexible optimisation can greatly enhance decentralised DHCN efficiency, while future efforts will focus on refining these solutions to support broader application within next-generation energy networks.

5.2 DHC Network conceptual design and management

Figure 5.3 shows the scheme of the DHCNs with technical information of each substation.

The buildings connected directly onto the core network are set up with substations exploiting water-to-water heat pumps to draw or reject thermal energy from/into the network.

The networks stemming from the core one are conceived as semi-decentralized ones, as substations integrating large HPs connect the extensions, as represented in Figure 5.2. Depending on the energy uses of the buildings integrated in the subnetworks, those can be operated in heating mode only or provide both heating and cooling.

While SH and, eventually, SC loads are consistently covered by the DHCN, DHW preparation is addressed occasionally. In most cases, the secondary network operator ensures the DHW preparation via existing or refurbished means. In 3 substations, gas boilers are still present and falling under the public delegation of service contract of DALKIA and are used basically as back-up: in HLM PRESENTATION (residential building) gas in used as back-up or when the gas is cheaper than electricity, taking COP of the systems into consideration; in School Malsert gas is only used as back-up; in School Jaurès gas is used for heating and DHW as HPs are sub-dimensioned and do not reach the needed set temperature, and are thus used for preheating the return flow of the boiler.

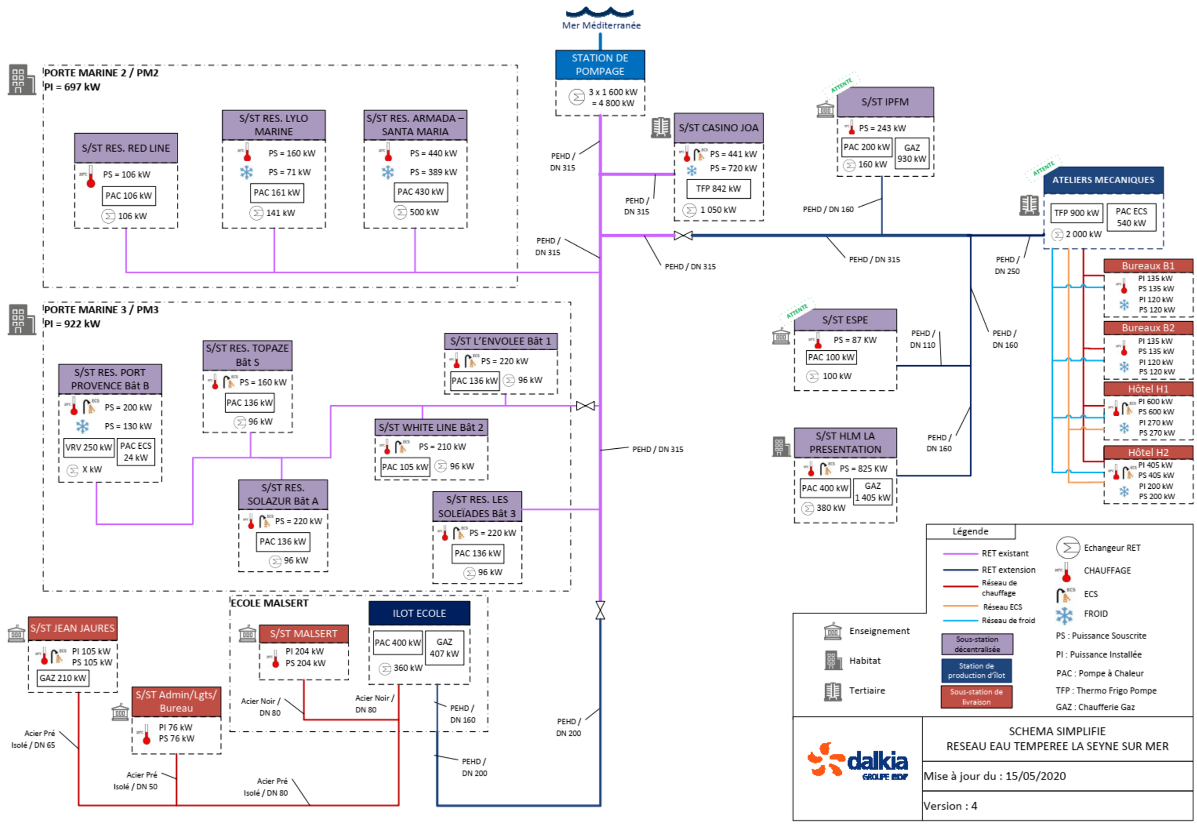


Figure 5.3: Scheme of the La Seyne-Sur-Mer DHCNs. Source: DALKIA

5.3 Assessment of the network performance

5.3.1 Energy uses insisting on the network

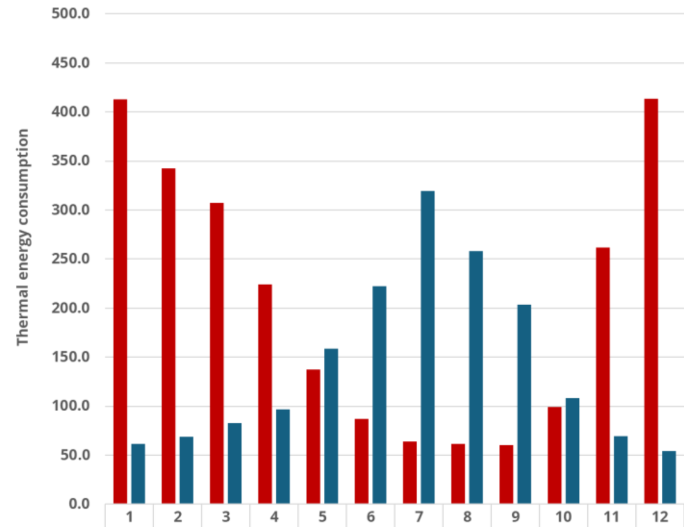
The analysis conducted for this demo site has been divided into two main sections: one focusing on the performance of the distributed substations and the other addressing the management of the network and the pumping station, which exchanges energy with the sea.

Figure 5.4a illustrates the monthly thermal energy consumption of the substations. This includes energy usage for DHW and the demand for SH grouped together and space cooling, which is ultimately supplied to the buildings. Figure 5.4b represents the energy delivered to the substations during heating operations or rejected into the DHC network by the substations during cooling operations.

The annual heating consumption of the substations is approximately 2,472 MWh, concentrated in the colder months, with peaks reaching 400 MWh in January and December. Conversely, the annual cooling consumption is around 1,704 MWh, with a peak of approximately 325 MWh in July. While the buildings heating consumption exceeds its cooling demand, both remain within a similar range.

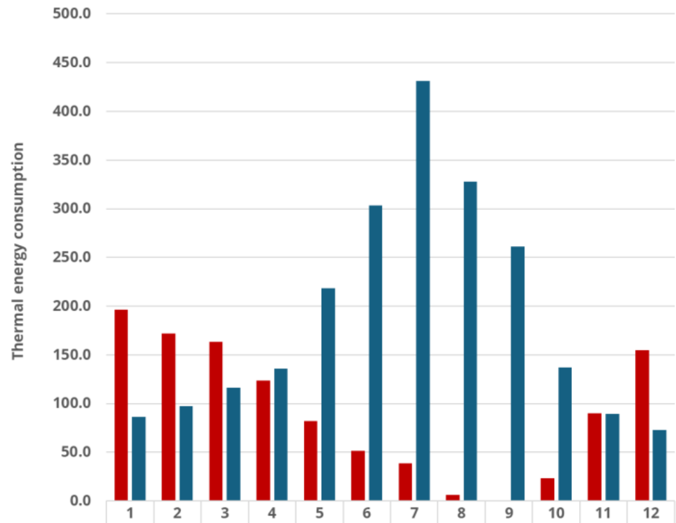
This pattern is influenced by the same conditions as described in the case of Gardanne demo site, which are the climatic conditions, characterized by hot summers and mild winters and the diverse usage profiles of the buildings, including residential, educational, and tertiary sectors.

The annual heating consumption insisting on the DHC network totals around 1,102 MWh occurring similarly during winter season, with peaks of 150-200 MWh from December to March. The annual cooling consumption amounts to 2,273 MWh, with a peak of around 425 MWh in July. The higher cooling demand is the result of the energy rejection from the substations since they are equipped with HPs, grouping the cooling demand from the buildings and the electricity consumed in the HPs.



	1	2	3	4	5	6	7	8	9	10	11	12
Heating consumption Buildings [MWh]	413.0	342.6	307.4	224.4	137.3	86.8	64.0	61.6	60.6	99.3	261.9	413.3
Cooling consumption Buildings [MWh]	61.6	68.7	82.8	96.8	158.4	222.1	319.7	258.4	203.5	108.1	69.4	54.4

a) Analysis for the substations



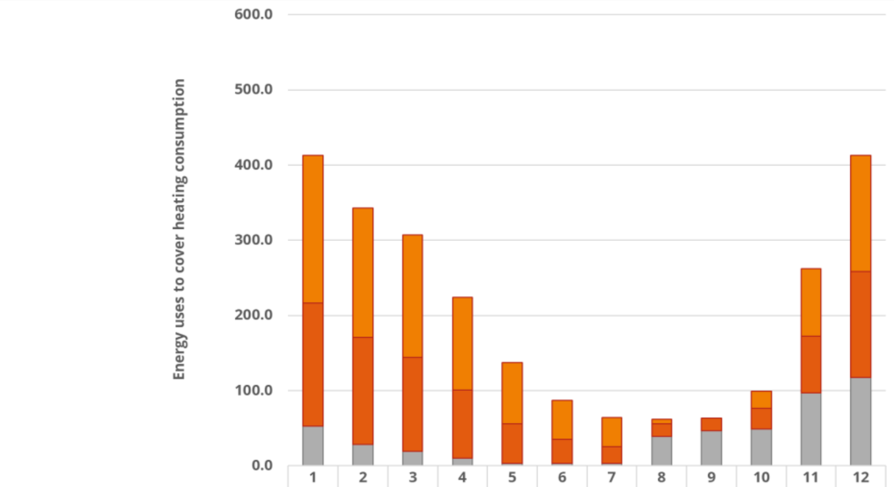
	1	2	3	4	5	6	7	8	9	10	11	12
Heating consumption to SSTs [MWh]	196.4	171.8	163.4	123.9	81.9	51.8	38.7	6.0	0.0	23.3	89.9	154.7
Cooling consumption from SSTs [MWh]	86.1	97.3	116.4	135.7	218.2	303.2	431.5	327.6	261.5	137.3	89.2	72.9

b) Analysis for the network and central station

Figure 5.4 - Monthly thermal energy consumption

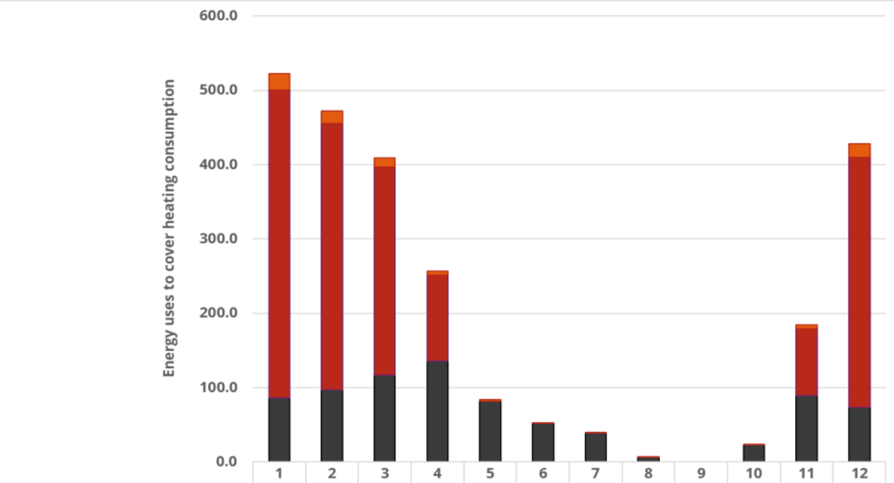
In this system, the energy rejected by the substations used to deliver space cooling is utilized as WH by other substations with heating needs, facilitated through the network acting as a short-term thermal storage. This synergy significantly reduces reliance on external energy sources. The effect is particularly notable during spring and autumn when heating and cooling demands are more balanced.

Figure 5.5 and Figure 5.6 illustrate the energy sources utilized to meet the heating and cooling demands. From the substations perspective, heating is primarily provided through a combination of RES and WH from district heating (i.e., sea water 1,102 MWh), electricity used by the heat pump compressors and circulation pumps (904 MWh), and natural gas boilers (469 MWh). The substations operate with a COP ranging from 2.0 to 2.7 to meet the heating demand. However, during particularly cold months, the capacity of the heat pumps may not be sufficient in some buildings to fully cover the demand, necessitating the use of natural gas boilers. These boilers are being progressively replaced by increasing heat pumps capacity, which is expected to result in a reduction of gas consumption.



	1	2	3	4	5	6	7	8	9	10	11	12
Local RES & WH for heating [MWh]	196.4	171.8	163.4	123.9	81.9	51.8	38.7	6.0	0.0	23.3	89.9	154.7
Electricity use heating [MWh]	164.0	142.6	125.0	90.3	51.9	31.7	22.4	16.5	17.3	26.8	74.8	140.9
Gas use for heating [MWh]	52.6	28.2	19.0	10.2	3.5	3.3	2.9	39.0	46.3	49.2	97.2	117.7

a) Analysis for the substations



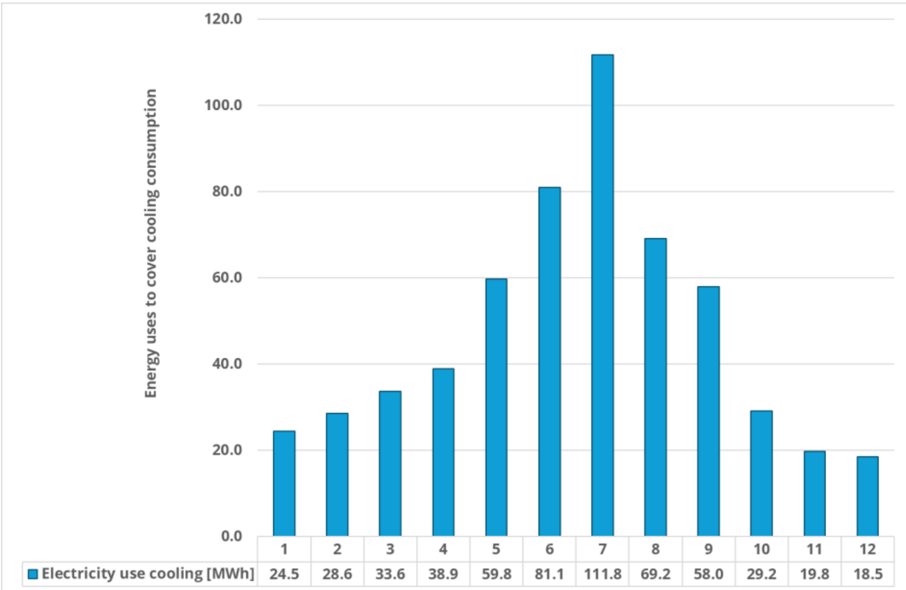
	1	2	3	4	5	6	7	8	9	10	11	12
Electricity use heating [MWh]	21.8	16.9	12.8	5.6	1.7	0.9	1.1	0.2	0.0	0.8	5.4	18.3
Sea use for heating [MWh]	414.4	358.3	280.2	115.7	0.0	0.0	0.0	0.0	0.0	0.0	89.8	337.1
Waste Heat [MWh]	86.1	97.3	116.4	135.7	81.9	51.8	38.7	6.0	0.0	23.3	89.2	72.9

b) Analysis for the network and central station

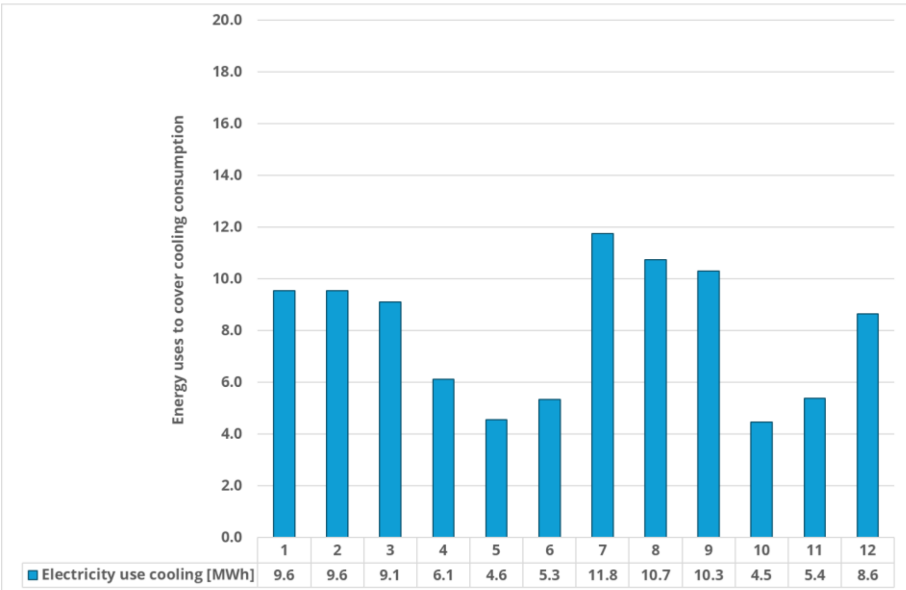
Figure 5.5 - Energies use for heating

The cooling demand in the substations is fully met through electricity consumption for operating the heat pumps (573 MWh), which reject heat to the network. In this case, the system achieves an EER between 2.5 and 3.5.

From the network perspective, heating is primarily supplied through a combination of WH generated by energy rejection from the substations (800 MWh), energy extracted from the sea (1,596 MWh), and a small amount of electricity consumed by the pumping station (86 MWh). Notably, during the summer periods, the heating demand is entirely met by waste heat, whereas in the winter months, the majority of the required energy is extracted from the sea via the pumping station.



a) Analysis for the substations



b) Analysis for the network and central station

Figure 5.6 - Energies use for cooling

To meet the cooling demand, the network relies solely on electricity consumption at the pumping station (96 MWh), as the rejected heat is directly dissipated into the sea. This results in exceptionally low energy consumption relative to the cooling demand addressed, highlighting the system's high efficiency in managing cooling requirements.

Overall, the integration of heat pumps with district heating, renewable energy sourced from the sea, and waste heat recovery enables the system to implement a balanced and adaptive energy strategy throughout the year. By leveraging renewable energy sources and energy-efficient technologies, the system effectively meets seasonal demand, while significantly reducing dependence on non-renewable energy sources, particularly during the high-demand winter months.

5.3.2 Performance indicators assessment

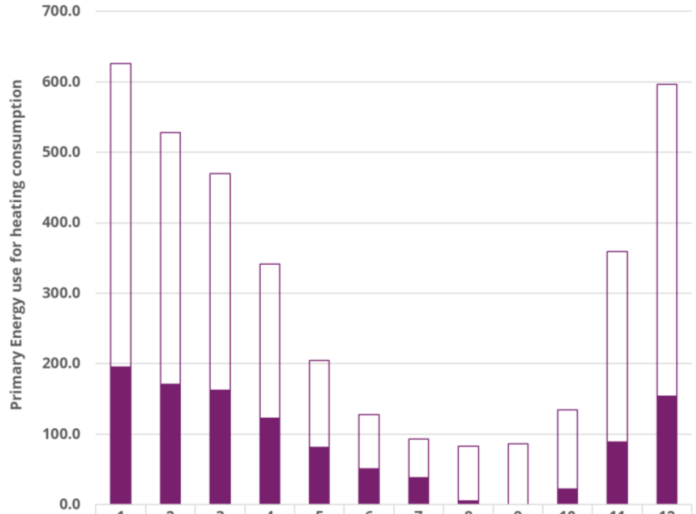
Figure 5.7 and Figure 5.8 illustrate the monthly total primary energy use for heating and cooling, alongside the renewable portion of that energy. The primary energy calculation accounts for contributions from electricity, local renewable sources, natural gas, as well as waste heat recovery. For other energy sources, specific primary energy factors have been applied [2]:

- Natural gas total primary energy factor → 1.0 (of which 0.0 is considered renewable)
- Electricity total primary energy factor → 2.3 (of which 0.0 is considered renewable)

Over the course of the year, the substations total primary energy consumption reaches 4,968 MWh. Of this total, 1,102 MWh is derived from renewable sources. Most of this primary energy use is attributed to heating needs (3,650 MWh).

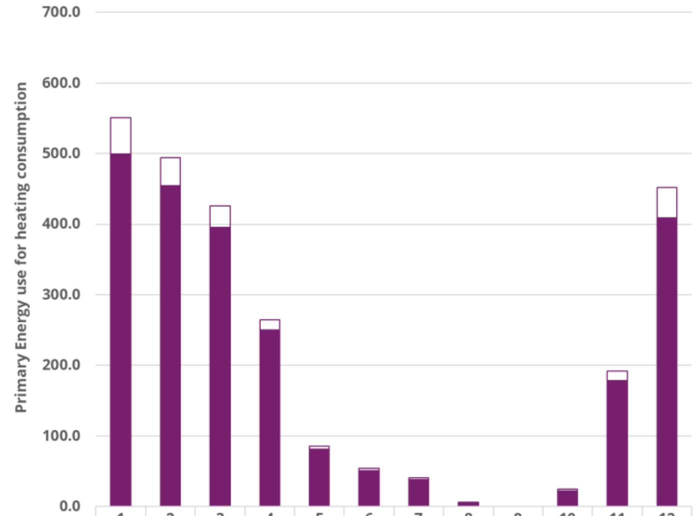
Primary energy consumption is significantly higher during the winter months due to the intensive operation of the heat pumps and the partial exploitation of gas boilers: the reliance on electricity for heating during winter substantially elevates the primary energy requirement, despite the substation's heating system integrates a considerable share of renewable energy contributions.

The analysis done for the network accounts for 2,811 MWh of total primary energy and 2,395 MWh from renewable sources. The trend observed in the substation analysis is even more pronounced here, with 92% of the total primary energy consumed to cover heating demand. This is primarily due to the minimal electricity consumption required for cooling, as the system efficiently dissipates heat directly to the sea.



	1	2	3	4	5	6	7	8	9	10	11	12
PE use heating - Total [MWh]	626.1	528.0	469.9	341.7	204.7	128.0	93.1	83.0	86.0	134.2	359.0	596.4
PE use heating - Renewable [MWh]	196.4	171.8	163.4	123.9	81.9	51.8	38.7	6.0	0.0	23.3	89.9	154.7

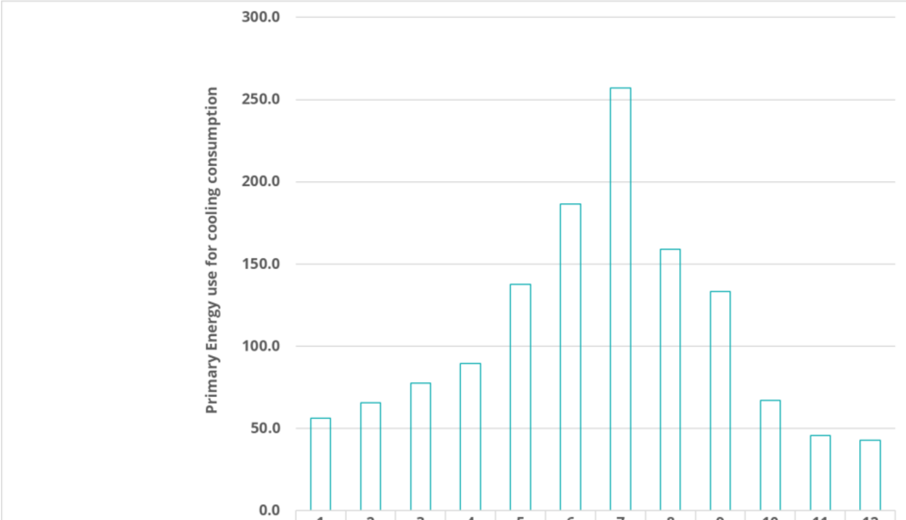
Analysis for the substations



	1	2	3	4	5	6	7	8	9	10	11	12
PE use heating - Total [MWh]	550.7	494.4	426.0	264.3	85.8	53.9	41.1	6.5	0.0	25.0	191.5	452.2
PE use heating - Renewable [MWh]	500.5	455.6	396.6	251.5	81.9	51.8	38.7	6.0	0.0	23.3	179.0	410.0

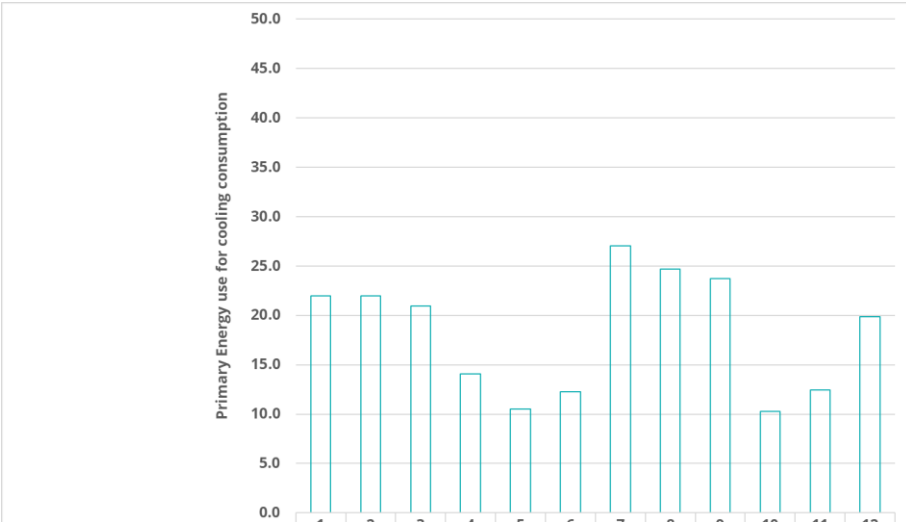
Analysis for the network and central station

Figure 5.7 - Monthly renewable and total primary energy uses for heating consumption of the buildings



	1	2	3	4	5	6	7	8	9	10	11	12
PE use cooling - Total [MWh]	56.3	65.7	77.4	89.6	137.6	186.5	257.2	159.2	133.4	67.2	45.6	42.6
PE use cooling - Renewable [MWh]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Analysis for the substations

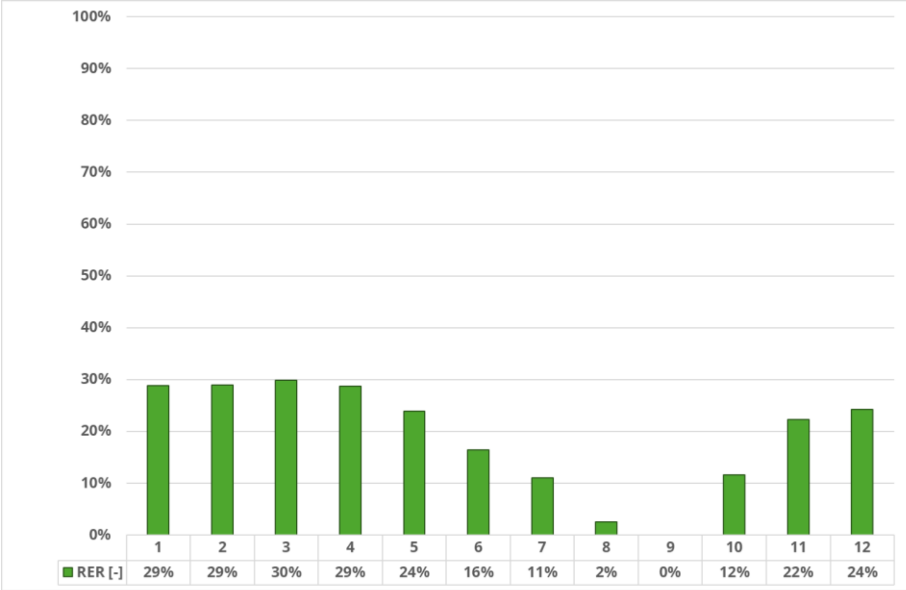


	1	2	3	4	5	6	7	8	9	10	11	12
PE use cooling - Total [MWh]	22.0	22.0	20.9	14.1	10.5	12.3	27.1	24.7	23.7	10.3	12.4	19.9
PE use cooling - Renewable [MWh]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

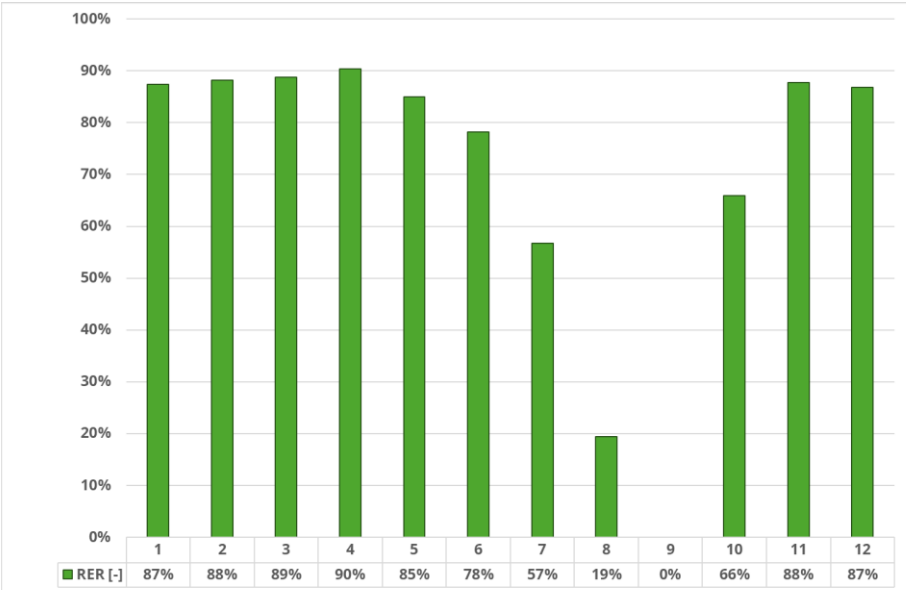
Analysis for the network and central station

Figure 5.8 - Monthly renewable and total primary energy uses for cooling consumption of the buildings

The RER shown in Figure 5.9, quantifies the renewable share by calculating the ratio of renewable primary energy to total primary energy used for both heating and cooling.



Analysis for the substations



Analysis for the network and central station

Figure 5.9 - Monthly renewable energy ratio

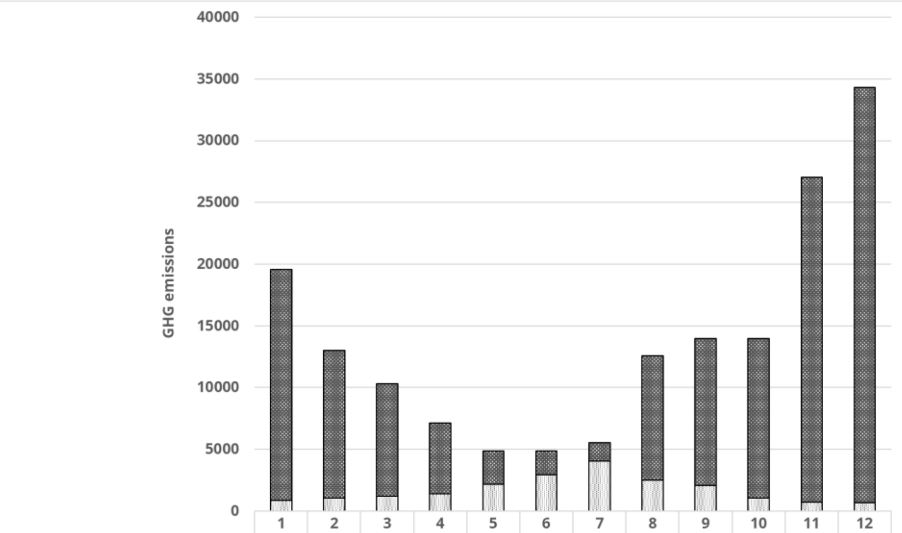
For the substations, during the winter months, the RER reaches approximately 20-30%, primarily due to the use of renewable energy supplied by the network and waste heat recovery. However, this value remains relatively low because of the significant contribution from electricity and natural gas. In the summer months, as network usage decreases and cooling demand rises, mostly covered by non-renewable sources, the RER decreases progressively.

For the network, a similar trend is observed, but with a notably higher RER during the winter months, approaching 90%, driven by the extensive use of sea water as the primary energy source.

In summer, as the utilization of sea water decreases and the cooling demand relies more on electricity, the RER also rises, reflecting the seasonal shifts in energy sourcing also in this case.

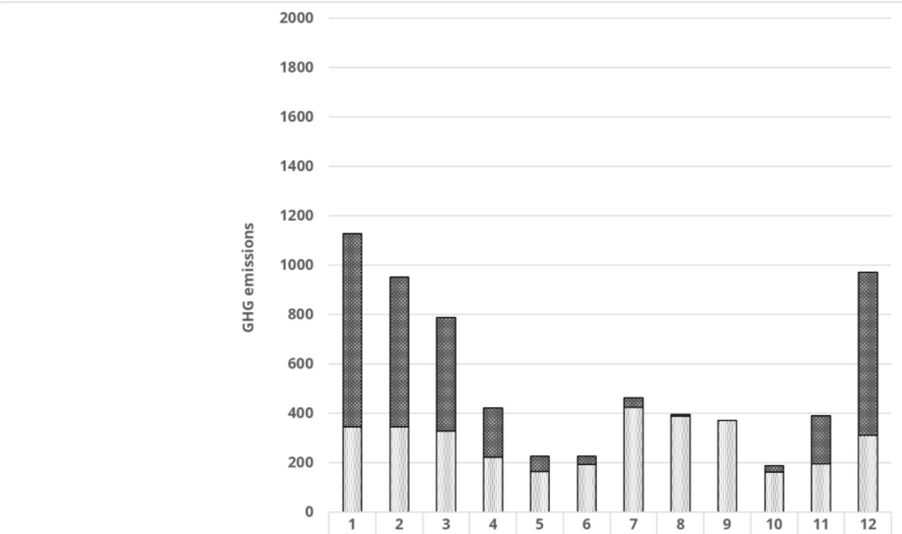
Figure 5.10 and Figure 5.11 presents the monthly greenhouse gas emissions associated with the energy system. The CO_2 emissions calculations encompass electricity, local renewable sources, natural gas, as well as waste heat recovery. The analysis applies distinct CO_2 emission factors to natural gas and electricity sources:

- Natural gas CO2 emission factor [7] → 243 g/kWh
- Electrical energy CO_2 emission factor [3] → 36 g/kWh



	1	2	3	4	5	6	7	8	9	10	11	12
GHG emissions heating [kg]	18678	11993	9124	5720	2725	1950	1512	10078	11876	12921	26318	33665
GHG emissions cooling [kg]	881	1029	1211	1402	2154	2919	4025	2491	2088	1051	713	667

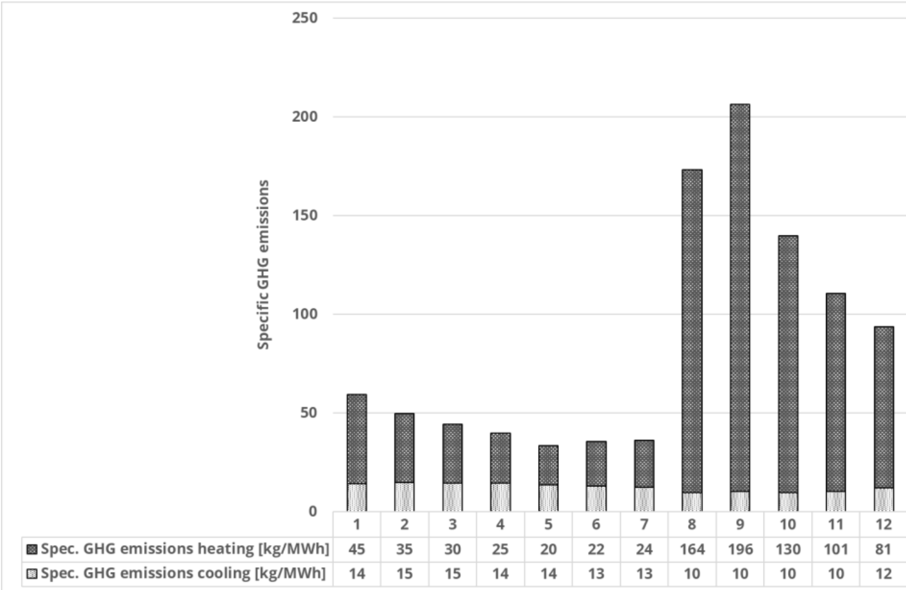
Analysis for the substations



	1	2	3	4	5	6	7	8	9	10	11	12
GHG emissions heating [kg]	785	608	460	201	62	33	38	7	0	27	196	660
GHG emissions cooling [kg]	344	344	328	220	164	192	423	387	371	161	194	311

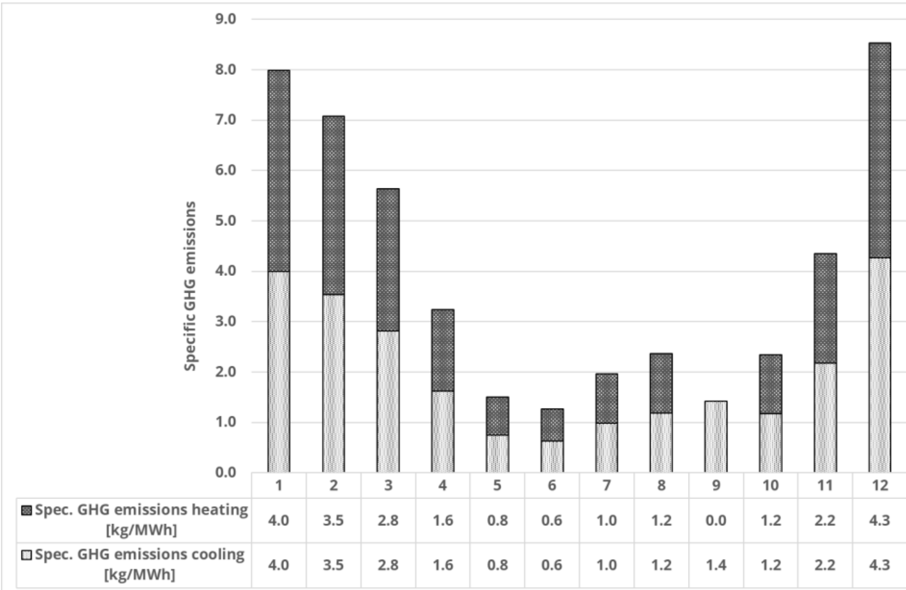
Analysis for the network and central station

Figure 5.10 - Monthly CO2 emissions for heating and cooling



	1	2	3	4	5	6	7	8	9	10	11	12
Spec. GHG emissions heating [kg/MWh]	45	35	30	25	20	22	24	164	196	130	101	81
Spec. GHG emissions cooling [kg/MWh]	14	15	15	14	14	13	13	10	10	10	10	12

Analysis for the substations



	1	2	3	4	5	6	7	8	9	10	11	12
Spec. GHG emissions heating [kg/MWh]	4.0	3.5	2.8	1.6	0.8	0.6	1.0	1.2	0.0	1.2	2.2	4.3
Spec. GHG emissions cooling [kg/MWh]	4.0	3.5	2.8	1.6	0.8	0.6	1.0	1.2	1.4	1.2	2.2	4.3

Analysis for the network and central station

Figure 5.11 - Monthly specific CO2 emissions for heating and cooling

The substation's annual CO_2 emissions from its heating and cooling systems totals 167,191 kg. Most of the CO_2 emissions occurs during the winter months, coinciding with increased heating demand. On the other hand, the operation of the network shows much lower total CO_2 emissions of 6,517 kg due to the use of low carbon electricity. In this case, the emissions present a similar value for heating and cooling months.

The average specific CO_2 emissions during the operation of the substations are 59 and 12 kg/MWh for heating and cooling respectively. Although both values are lower compared to other systems, that for cooling operation draws attention due to the effective use of the HPs.

Similarly, for the operation of the network, the specific CO_2 emissions are 1.9 and 2.0 kg/MWh for heating and cooling respectively.

5.4 Remarks

Table 5.1 summarizes the system annual energy needs and environmental performance calculations reported above.

Table 5.1 – Overall system annual energy uses, and performance calculated

Notation	Annual values SSTs	Annual values Network	Unit of meas.
Heating consumption	2742	1102	MWh/y
Cooling consumption	1704	2277	MWh/y
Electricity use for heating	904	85.5	MWh/y
Electricity use for cooling	573	95.6	MWh/y
Gas use for heating	469	-	MWh/y
Sea use for heating	-	1596	MWh/y
Sea use for cooling	-	909	MWh/y
Local RES & WH use	1102	2395	MWh/y
Ren. PE for heating	1102	2395	MWh/y
Total PE for heating	3650	2591	MWh/y
Ren. PE for cooling	-	-	MWh/y
Total PE for cooling	1318	220	MWh/y
Renewable Energy Ratio	0.22	0.85	-
GHG emissions for heating	146.5	3.1	ton/y
GHG emissions for cooling	20.6	3.4	ton/y

- La Seyne-sur-Mer DHCN operates between 13-24°C, effectively leveraging seawater as a renewable energy source for heating and cooling needs, significantly reducing dependence on non-renewable energy sources. Moreover, the system utilizes WH from cooling operations to meet heating needs during spring and autumn when heating and cooling demands balance, minimizing reliance on external energy sources.
- While natural gas is still used in some substations as a backup or for DHW preparation, the ongoing replacement of gas boilers with heat pumps is enhancing renewable energy integration and system efficiency.
- The substations show a balanced performance with significant renewable energy contributions, but their RER is limited by the reliance on electricity and natural gas. However, progressive replacement of natural gas boilers with heat pumps is expected to improve both efficiency and renewable energy integration in the future. The network, on the other hand, showcases a superior RER, especially during winter months, with up to 90% of energy demand met through renewable sources.
- It should be noted that the contribution of the installed PV fields was not considered in this analysis. This is due to two main reasons: firstly, the installation of new PV panels did not reach the scale initially anticipated at the project's outset; secondly, it was not possible to monitor their production in conjunction with electricity usage.

- Although the primary energy use is relatively high, the network exhibits remarkably low specific CO_2 emissions (1.9-2.0 kg/MWh for heating and cooling), highlighting efficient use of seawater and decarbonized electricity. Substations' specific CO_2 emissions are higher (59 kg/MWh for heating), underscoring the impact of natural gas reliance.

Overall, the system exemplifies a modern approach to sustainable energy management by optimizing resource utilization and minimizing emissions. The results underline the importance of renewable energy integration and energy-efficient design in reducing the environmental impact of heating and cooling systems, offering a scalable and replicable model for future energy systems.

6 Milan, Italy

6.1 Description of the demonstration site

The demonstration site in Milan is a newly built neutral-temperature DHCN, set up by the utility company A2A. This innovative system, located near the Parco della Resistenza in the southern part of the city, uses groundwater as an energy source. Groundwater is pumped from aquifer monitoring wells beneath the park and distributed to the three buildings involved in the project. Using heat pumps, the energy from the water is harnessed to heat indoor spaces in winter and produce domestic hot water, while in summer it can be used for cooling. This system reduces electricity usage and takes advantage of waste heat produced by the buildings themselves.

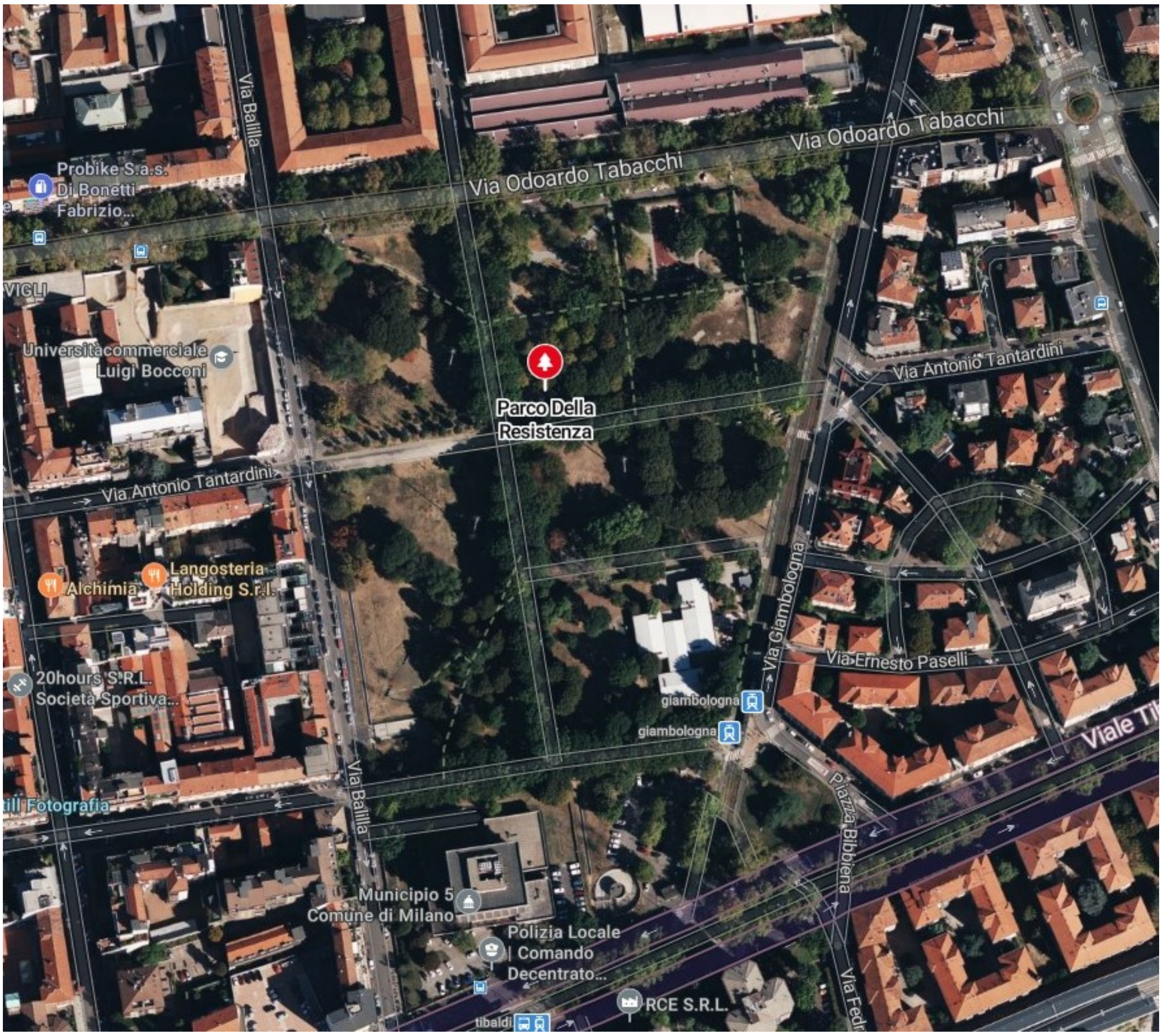


Figure 6.1: Aerial view of the area concerned with the demonstration site

Heat from the water wells is distributed at around constant 15°C along the year. A kindergarten (via Giambologna), a municipal centre (via Tibaldi) and a multifamily home (via Balilla) are the first users of the DHC network. While the first two only require space heating and DHW being covered, the municipal centre also requires space cooling in summer.

At the project's start, the buildings used gas boilers for heating: the kindergarten with a 90 kW boiler, the municipal centre with a 1,000 kW boiler and a reversible heat pump for heating and cooling, and the residential building with an 80 kW oil boiler. While the newly installed substations now supply the majority of heating and cooling needs, the gas boilers at the kindergarten and municipal centre remain as backups for peak loads and any substation malfunctions. The oil boiler at the residential building, however, has been removed.

6.1.1 Objectives and main results of the demonstration activity

In the framework of the REWARDHeat project, the following objectives have been pursued:

- Design and set up of the groundwater intakes and installation of the new neutral-temperature DHC network
- Installation of heat pump integrated substations at each of the three buildings
- Implementation of monitoring and control hardware and software
- Investigation on contractual models adapted to the local context.

During the project elaboration, A2A finalised the design and implementation of the neutral temperature DHC network. Water at approximately 15°C is distributed through the network to the three buildings, where heat pumps raise the temperature to the required level for the heating systems or dissipate waste heat from air conditioning in summer.

An interception pit collects water from the primary groundwater channel, supplying it to the DHCN. The main distribution substation has been installed in the technical room of the kindergarten, alongside the heat pump-integrated substation dedicated to that building. Additional dedicated heat pump-integrated substations have been installed at the municipal building and a multifamily residence.

The activities at the Milan demo site have successfully demonstrated the feasibility of using groundwater—abundantly available in many European cities—as a source for building heating and cooling through heat pumps. Establishing a neutral temperature DHC network minimises heat losses during distribution from source to buildings, which is particularly beneficial during part-load operation. This solution has enabled the three buildings to largely phase out fossil fuels, resulting in a substantial reduction in greenhouse gas emissions associated with their heating and cooling systems.

6.2 DHC Network conceptual design and management

The neutral-temperature DHC network operates according to the following five functional blocks as exemplified in Figure 6.2:

Interception pits: The technical solution involved constructing a small interception pit to house a buffer tank and two submersible circulation pumps, which handle distribution to the main heat exchanger of the DHC network and discharge water back into the receiving body.

Network energy distribution station: a main distribution station is installed in the technical room of the kindergarten, designed to transfer heat from the water well and distribute energy to users. Distribution pumps regulate the supply temperature to an optimal set point, while a 3m^3 buffer tank decouples the primary distribution flow from the secondary, enabling effective load balancing. This setup helps match warm and cold thermal loads across the network, accommodating any temporal load mismatches.

Kindergarten substation: The substation is designed to meet the school's heating needs via the heat pump (110 kW heating capacity). The heat pump controls the two circuit pumps based on the control signal received by the overall BMS. A temperature sensor located downstream of the heat pump's output adjusts the pump's activation and modulation to maintain the set temperature.

The new unit provides most of the energy, while the gas boiler backups when supply temperature cannot reach the set 70°C agreed by contract.

Municipal Centre substation: This system is designed to provide thermal energy to the civic centre through two new heat pumps: one reversible unit (450 kW heating capacity) for both heating and cooling, and a second (300 kW heating capacity) in cascade for raising the supply temperature for end-users.

The heat pumps serve two circuits—high and low temperature—with priority given to the low-temperature circuit. The non-reversible high-temperature heat pump operates depending on available power on the evaporator side.

Multifamily home substation: The operating logic of the residential substation is designed to meet the space heating uses of the condominium, as DHW is produced in the single apartments. The heat pump (92 kW heating capacity) is backed up by means of two 45 kW backup electric boilers.

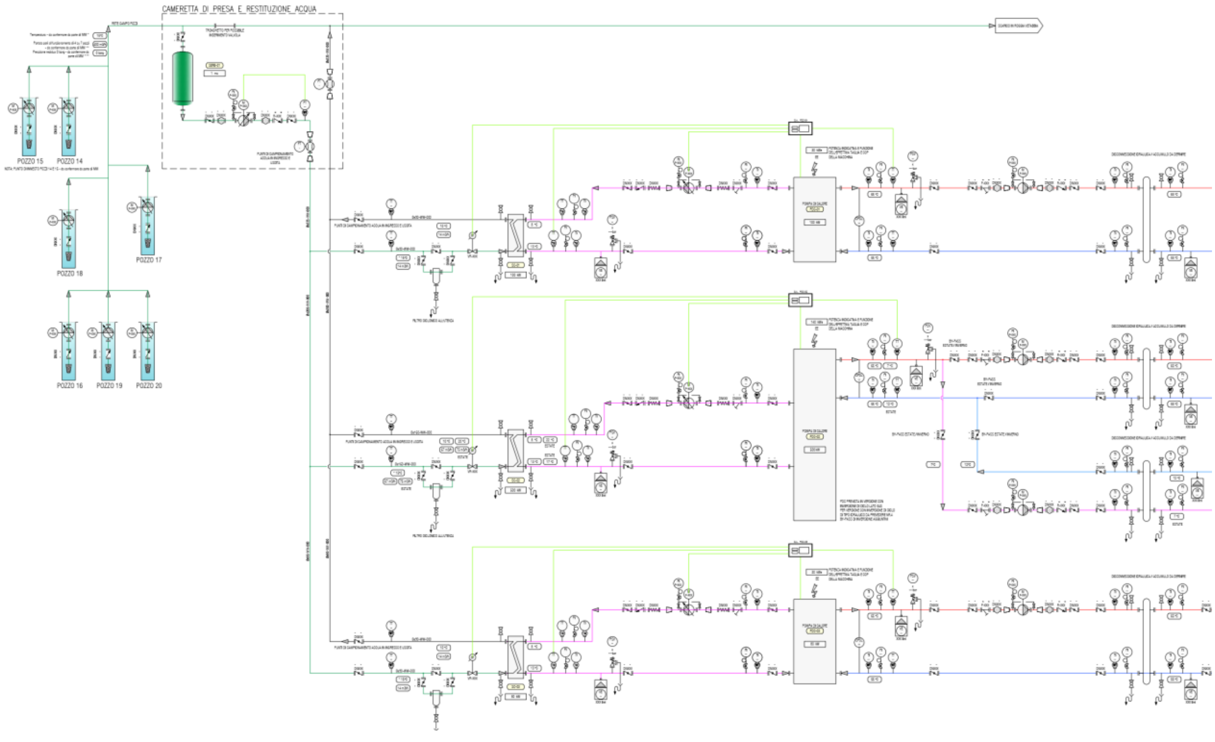


Figure 6.2: Overall system principle diagram

6.3 Assessment of the network performance

6.3.1 Energy uses insisting on the network

Figure 6.3 shows the monthly thermal energy consumption for the multifamily houses building concerned at this demonstration site. The annual space heating uses amount to 63 MWh, delivered partly by means of geothermal energy (43 MWh) and partly through electricity used to run the building's heat pump and water distribution system (see Figure 6.4).

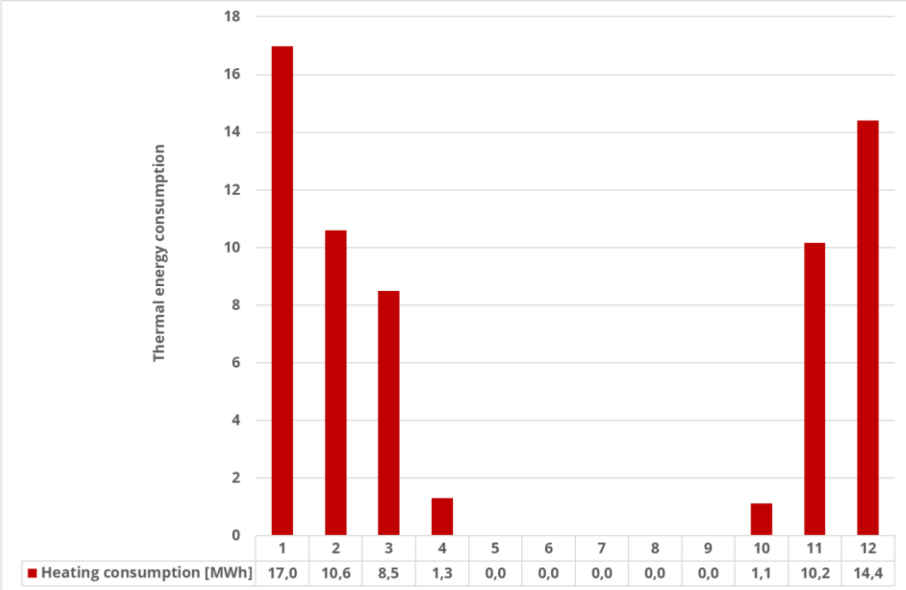


Figure 6.3 – Thermal loads related to the multifamily home

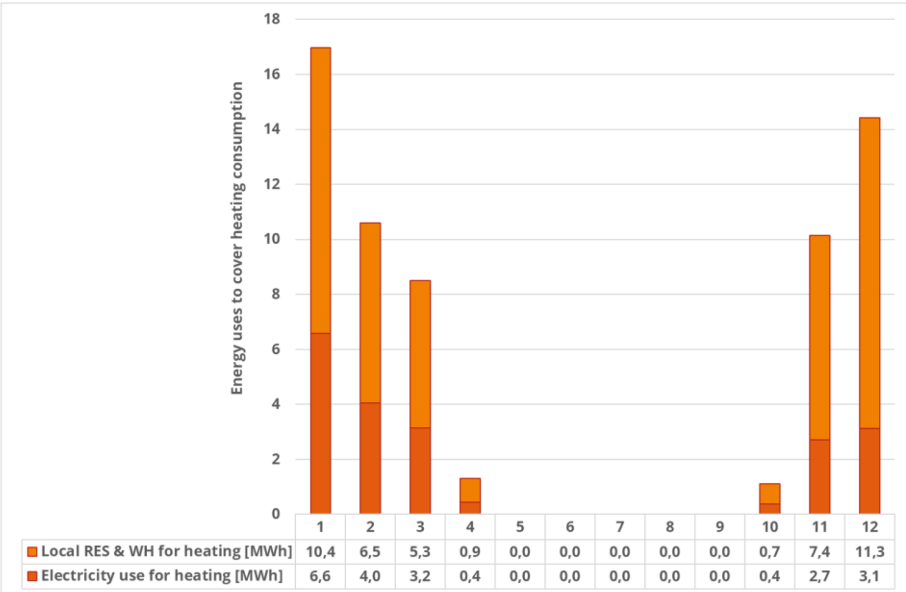


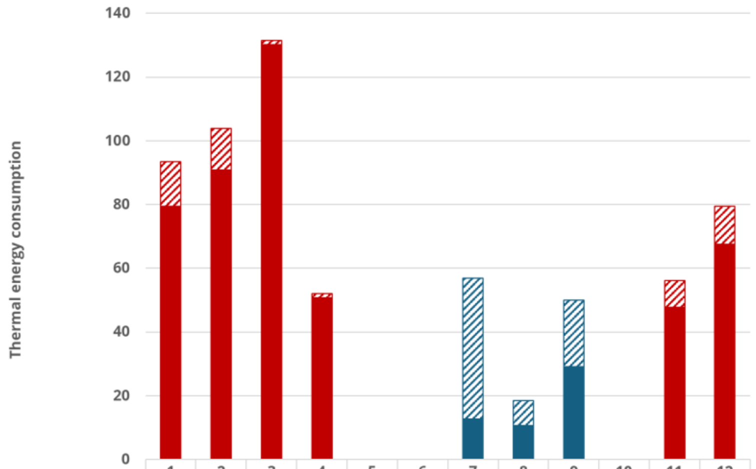
Figure 6.4 – Energy vectors used at the multifamily home

Energy use at the municipal building is indeed more significant (Figure 6.5). Heating consumption amounts to about 517 MWh, while space cooling needs total 126 MWh year-round. It is important to note that the system was commissioned in December 2023. The data from January to September are based on monitored data acquired during 2024, while the values for October to December are extrapolated from the previous data, considering the climate severity of the same months in 2023.

In this figure, the thermal loads covered by the REWARDHeat system installed are reported as plain bars (i.e., 466 MWh and 53 MWh respectively for what concerns heating and space cooling uses respectively), while the contributions of the gas boiler and air-water chiller pre-existing systems are represented with the dashed bars.

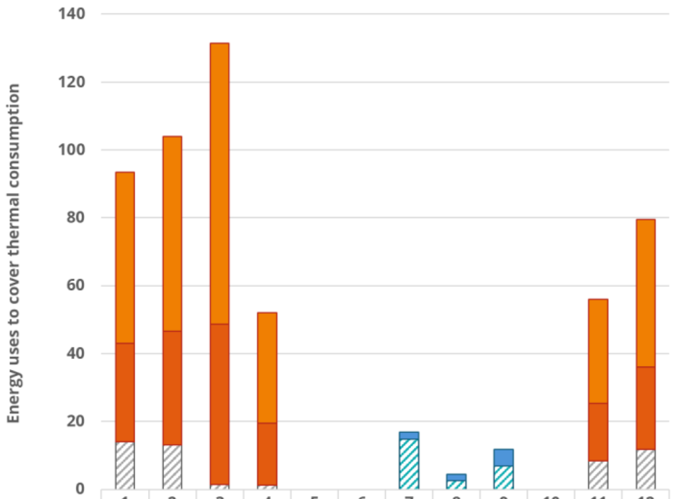
Figure 6.6 illustrates the energy sources used to meet the thermal energy consumption of the buildings. Natural gas accounts for 51 MWh of heating demand (approximately 10% of the total), while the remainder is supplied by geothermal energy (296 MWh) and electricity for heat pumps and the water distribution system (169 MWh).

During the summer, the electricity required to operate the backup chillers constitutes the majority of cooling energy consumption, amounting to 24 MWh out of the 33 MWh total. This highlights opportunities for system management improvements in the next warm season.



	1	2	3	4	5	6	7	8	9	10	11	12
Heating cons. incl. backup [MWh]	93,5	104,0	131,5	52,0	0,0	0,0	0,0	0,0	0,0	0,0	56,1	79,5
Heating cons. [MWh]	79,5	90,9	130,1	50,8	0,0	0,0	0,0	0,0	0,0	0,0	47,7	67,6
Cooling cons. Incl. backup [MWh]	0,0	0,0	0,0	0,0	0,0	0,0	57,0	18,5	50,0	0,0	0,0	0,0
Cooling cons. [MWh]	0,0	0,0	0,0	0,0	0,0	0,0	12,8	10,6	29,1	0,0	0,0	0,0

Figure 6.5 – Thermal loads related to the municipal centre



	1	2	3	4	5	6	7	8	9	10	11	12
Local RES & WH for heating [MWh]	50,4	57,5	82,9	32,6	0,0	0,0	0,0	0,0	0,0	0,0	30,7	43,4
Electricity use for heating [MWh]	29,1	33,4	47,2	18,2	0,0	0,0	0,0	0,0	0,0	0,0	17,0	24,1
Natural Gas use for heating [MWh]	14,0	13,1	1,4	1,3	0,0	0,0	0,0	0,0	0,0	0,0	8,4	11,9
Electricity use for cooling [MWh]	0,0	0,0	0,0	0,0	0,0	0,0	2,1	1,8	4,9	0,0	0,0	0,0
Eletricity for backup cooling [MWh]	0,0	0,0	0,0	0,0	0,0	0,0	14,7	2,6	7,0	0,0	0,0	0,0

Figure 6.6 – Energy vectors used at the municipal building

Finally, Figure 6.7 shows the heating consumption assessed at the kindergarten totals 113 MWh over the monitoring period, with a peak of approximately 33 MWh in January. The REWARDHeat system at this site requires improvement, as a significant portion of the heating demand—over 50%—is still met using natural gas. Enhancing communication and cooperation between the pre-existing BMS and the newly installed controller is essential to optimize system performance and reduce reliance on non-renewable energy sources.

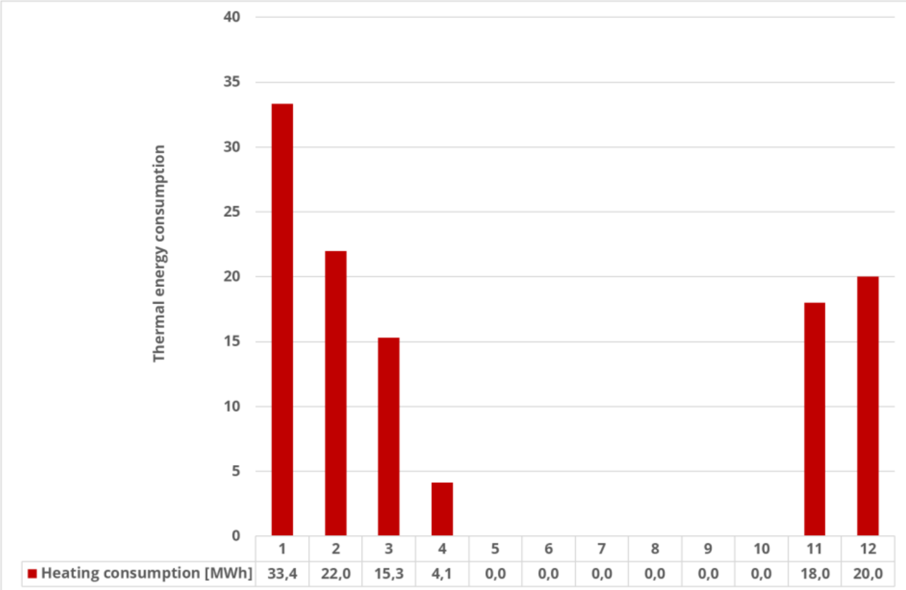


Figure 6.7 – Thermal loads related to the kindergarten

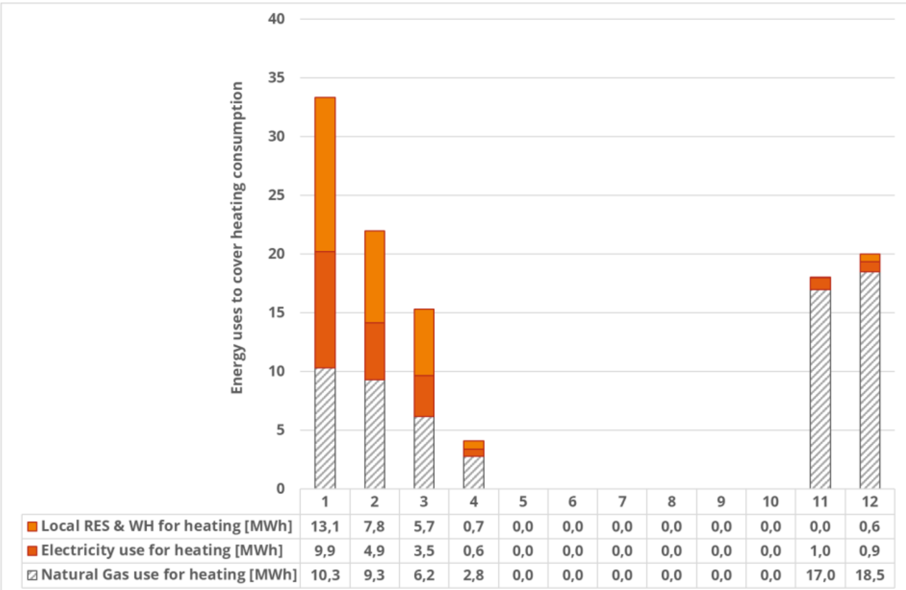


Figure 6.8 – Energy vectors used at the kindergarten

The electricity used to distribute water in the system is not measured separately, but it can be estimated in around 5% of the geothermal energy made available at the buildings inlet, thereof amounting to about 20 MWh over the year (about 10% of the overall electricity uses), for the entire network.

The coexistence of heating and cooling loads is minimal, as space cooling is implemented in only one building and occurs during months when other buildings have no heating demands (e.g., the kindergarten is closed, and DHW is produced decentrally in the multifamily building). As the network expands, achieving a better balance between heating and cooling loads should be prioritized by connecting buildings with complementary energy profiles.

6.3.2 Performance indicators assessment

The primary energies calculation accounts for contributions from electricity, natural gas and local renewable sources. The energy extracted from boreholes, as well as WH from the municipal centre space cooling is assigned a total primary energy factor of 1. For other energy sources, specific primary energy factors have been applied [8]:

- Natural gas primary energy factor → 1,05 (of which none is considered renewable)
- Electricity total primary energy factor → 2,42 (of which 0.47 is considered renewable)

It is important to note that the above values reflect the energy mix as of 2015. While the primary energy factor for natural gas remains largely unchanged, the electricity mix has significantly decarbonized over the past decade. Therefore, the value used here should be regarded as a conservative estimate.

The CO_2 emissions calculated based on the specific emissions factors of the energy vectors reported in Figure 6.4, Figure 6.6 and Figure 6.8 [9]:

- Natural gas CO_2 emission factor → 202 g/kWh
- Electric energy CO2 emission factor → 285 g/kWh

Multifamily home

The primary energy consumption at the multifamily building reflects closely the energy uses reported in Figure 6.4. Over the course of the year, the building's total primary energy consumption reaches 92 MWh (about 1,5 MWh/MWh of heating consumed); of this, 52 MWh (around 0,8 MWh/MWh of heating use) are derived from renewable sources.

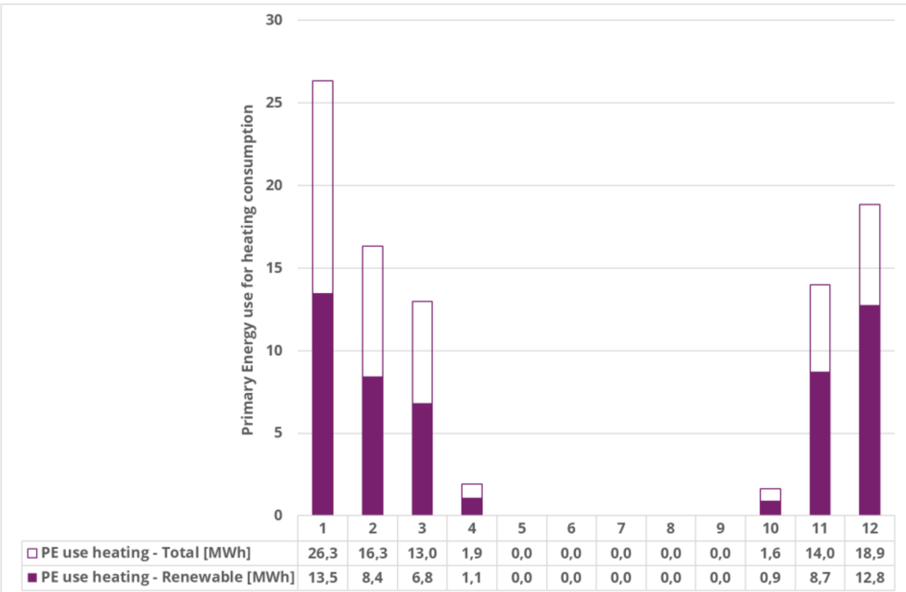


Figure 6.9 – Primary energy uses related to the multifamily building

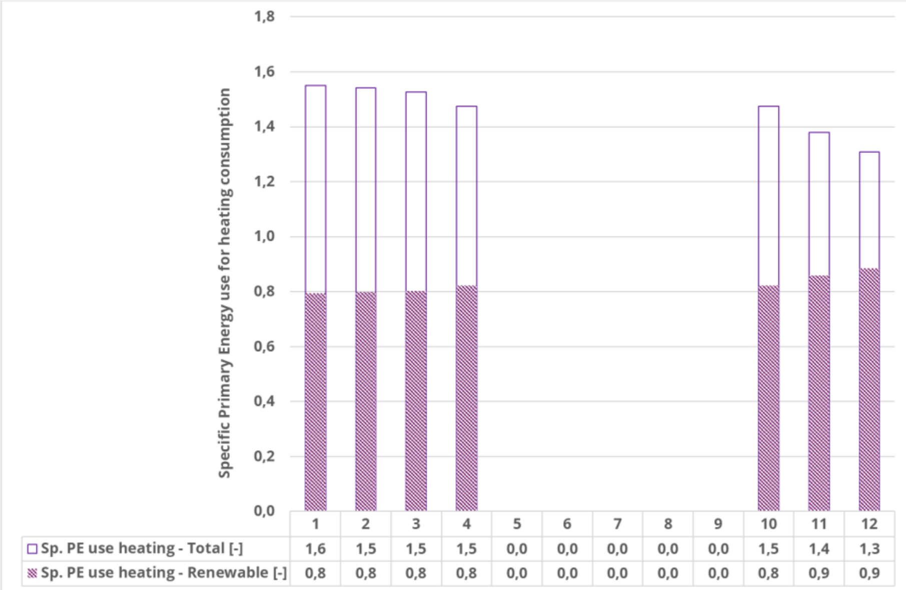


Figure 6.10 – Specific primary energy uses related to the multifamily building

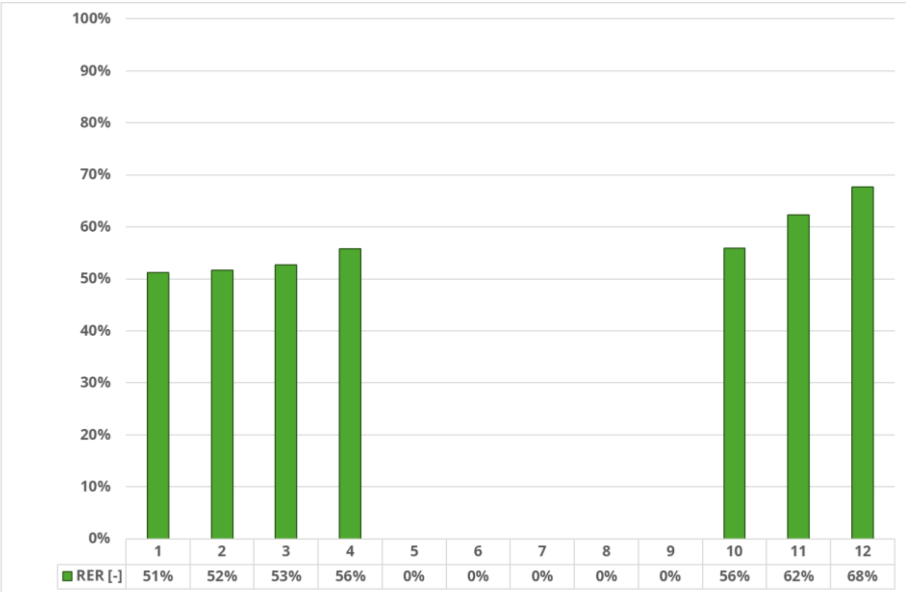


Figure 6.11 – RER calculated for the multifamily building

The RER shown in Figure 6.11 ranges between 50% and 70%, largely due to the renewable energy supplied by the wells water.

The building's annual CO_2 emissions from its heating and cooling systems total 5,821 kg. A significant portion of the CO_2 emissions occurs during the winter months, coinciding with increased heating demand. During these colder months, specific CO_2 emissions range around 110 kg/MWh. This is largely due to the system's dependence on electricity, which has a high CO_2 emission factor.

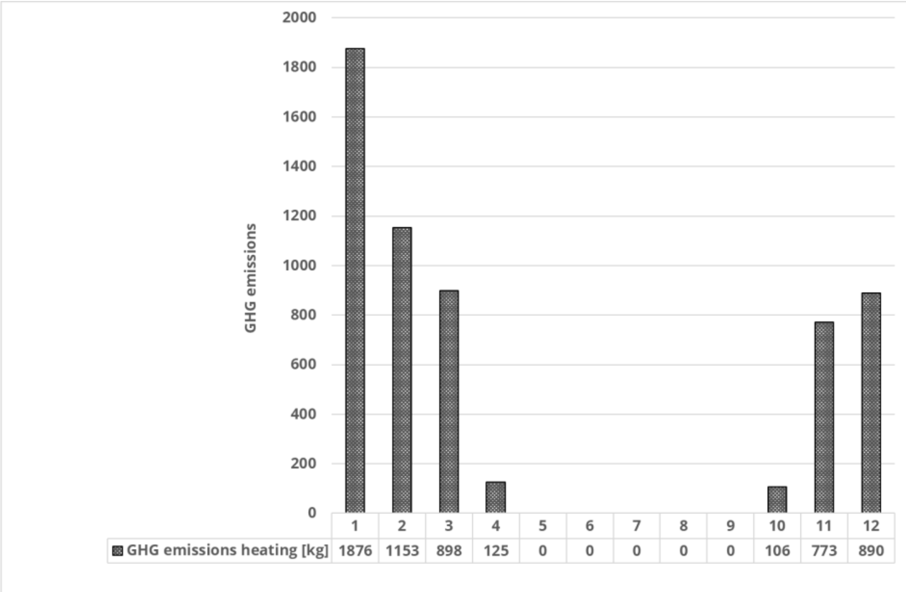


Figure 6.12 – Overall CO_2 emissions related to the multifamily building

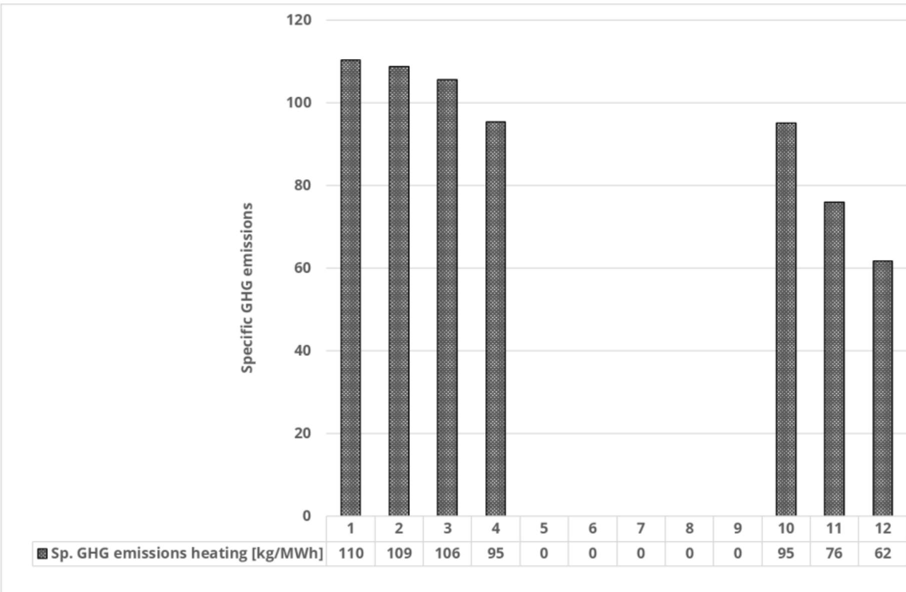
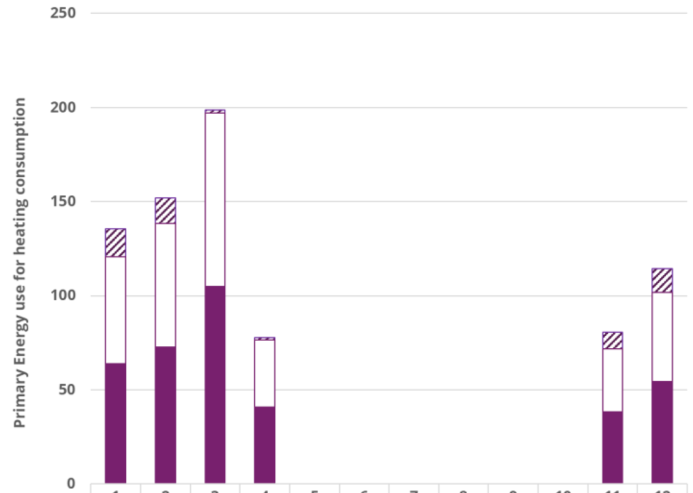


Figure 6.13 - Specific CO_2 emissions related to the multifamily building

Municipal centre

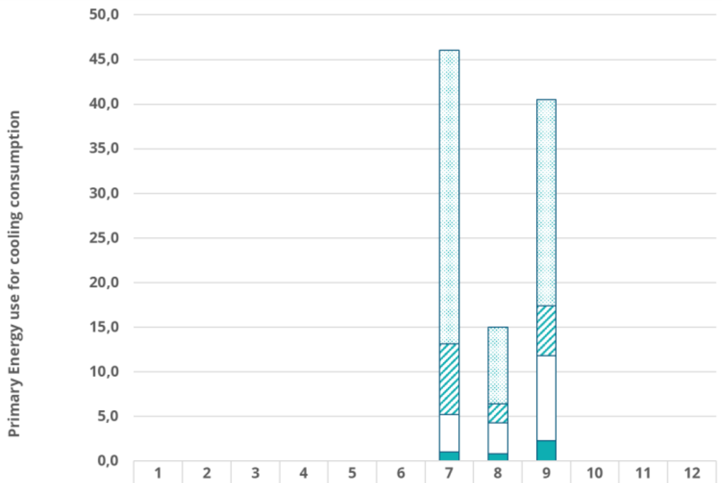
Similar to the multifamily home, the primary energy consumption of the municipal building closely aligns with the energy uses outlined in Figure 6.6. Over the year, the REWARDHeat system primary energy consumption for heating purposes amounts to 707 MWh, of which 307 MWh come from renewable sources. The backup gas boilers add 52 MWh to the total primary energy employed.

When cooling is considered, the REWARDHeat system primary energy consumption amounts to 21 MWh, 4 MWh deriving from renewable sources. As already mentioned, the backup chillers had a relevant contribution during the monitoring period, adding 59 MWh to the total primary energy employed to the total (16 MWh renewable).



	1	2	3	4	5	6	7	8	9	10	11	12
PE use heat. incl. backup [MWh]	135,4	152,1	198,7	77,9	0,0	0,0	0,0	0,0	0,0	0,0	80,7	114,3
PE use heating - Total [MWh]	120,8	138,3	197,2	76,5	0,0	0,0	0,0	0,0	0,0	0,0	71,9	101,8
PE use heating - Renewable [MWh]	64,1	73,2	105,1	41,1	0,0	0,0	0,0	0,0	0,0	0,0	38,7	54,8

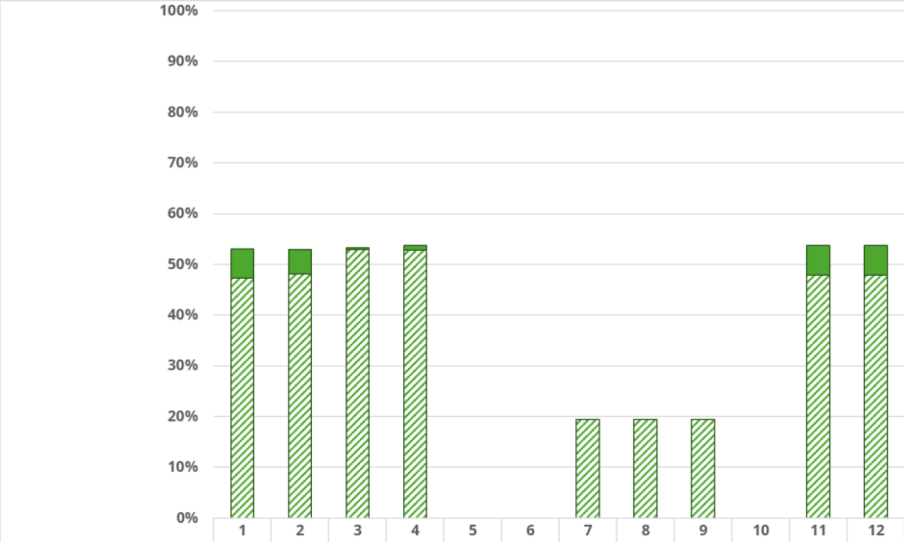
Figure 6.14 - Primary energy uses related to the municipal building heating



	1	2	3	4	5	6	7	8	9	10	11	12
PE cool. - Total incl. backup [MWh]	0,0	0,0	0,0	0,0	0,0	0,0	46,0	15,0	40,5	0,0	0,0	0,0
PE cool. - Renew. incl. backup [MWh]	0,0	0,0	0,0	0,0	0,0	0,0	13,1	6,4	17,4	0,0	0,0	0,0
PE cooling - Total [MWh]	0,0	0,0	0,0	0,0	0,0	0,0	5,2	4,3	11,8	0,0	0,0	0,0
PE cooling - Renewable [MWh]	0,0	0,0	0,0	0,0	0,0	0,0	1,0	0,8	2,3	0,0	0,0	0,0

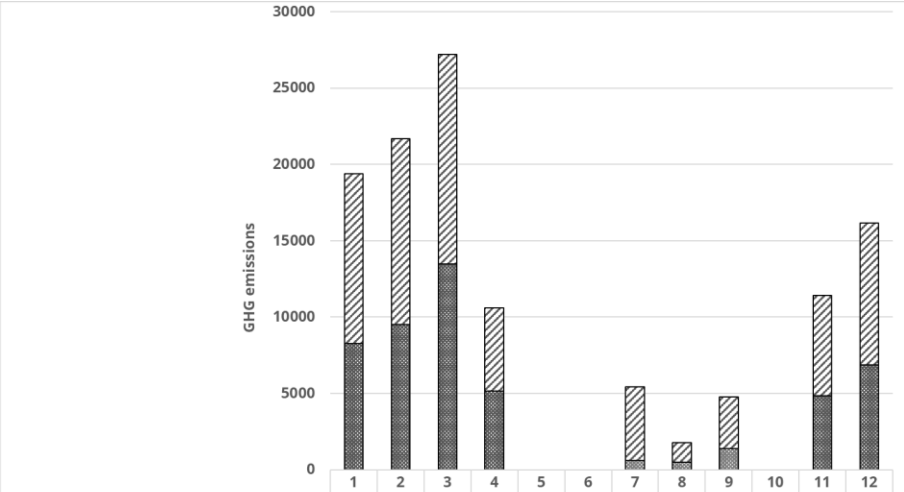
Figure 6.15 - Primary energy uses related to the municipal building cooling

As shown in Figure 6.16, The RER of the REWARDHeat system averages around 50%, primarily due to the renewable energy supplied by well water. However, the backup fossil-fuelled heaters slightly reduce the overall RER. During the summer, system performance decreases to approximately 20%, as the contributions from the REWARDHeat system and backup chillers become roughly equal, with electricity being the sole contributing energy source.



	1	2	3	4	5	6	7	8	9	10	11	12
RER [-]	53%	53%	53%	54%	0%	0%	19%	19%	19%	0%	54%	54%
RER including backup [-]	47%	48%	53%	53%	0%	0%	19%	19%	19%	0%	48%	48%

Figure 6.16 – RER related to the municipal building energy uses



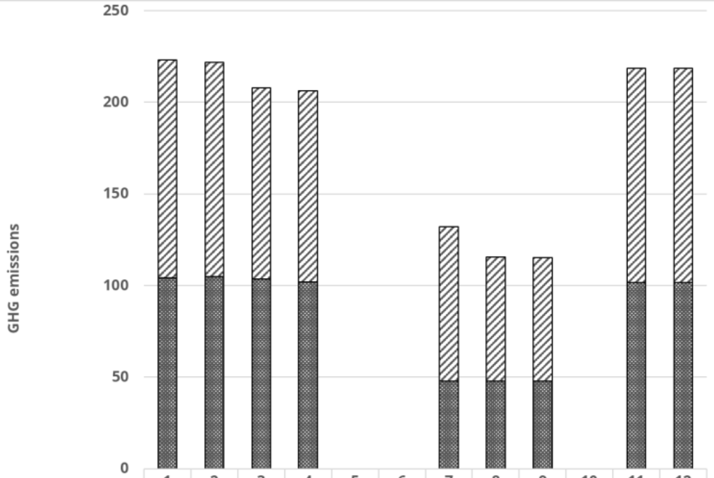
	1	2	3	4	5	6	7	8	9	10	11	12
GHG emis. heating backup [kg]	11105	12168	13742	5430	0	0	0	0	0	0	6550	9279
GHG emis. cooling backup [kg]	0	0	0	0	0	0	4810	1256	3378	0	0	0
GHG emis. heating REWARDHeat [kg]	8282	9518	13464	5177	0	0	0	0	0	0	4855	6878
GHG emis. cooling REWARDHeat [kg]	0	0	0	0	0	0	611	508	1391	0	0	0

Figure 6.17 - Overall CO_2 emissions related to the municipal building

The building's heating and cooling systems produce annual CO_2 emissions of 67,717 kg, including the contributions of the backup solutions; the REWARHEAT contributes through 50,683 kg to the total.

A substantial portion of these emissions occurs during the winter months, coinciding with increased heating demand. Notably, the overall and specific CO_2 emissions are similar for both the REWARDHeat system and the backup heaters, despite the latter contributing only 10% to the building's heating demand. This underscores the significant potential of the innovative REWARDHeat system in reducing GHG emissions.

During this period, specific CO_2 emissions average approximately 200 kg/MWh, primarily due to the reliance on natural gas, which has a high CO_2 emission factor. In contrast, emissions decrease in the summer, reflecting lower loads and the high efficiency of the implemented systems.



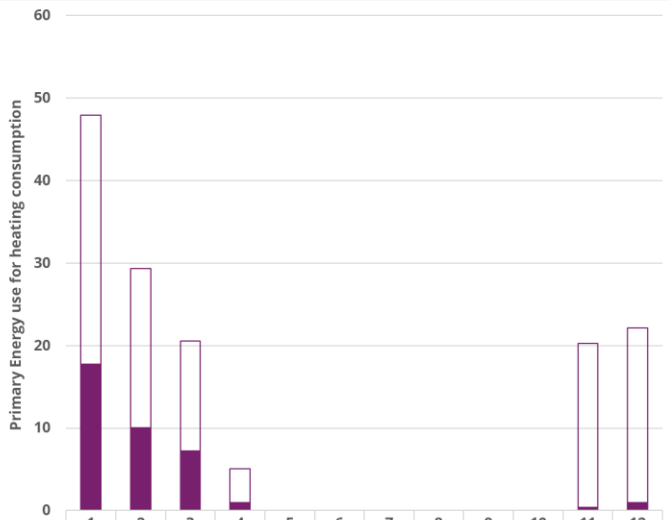
	1	2	3	4	5	6	7	8	9	10	11	12
Sp. GHG emissions heating [kg/MWh]	119	117	104	104	0	0	0	0	0	0	117	117
Sp. GHG emissions cooling [kg/MWh]	0	0	0	0	0	0	84	68	68	0	0	0
Sp. GHG emissions heating [kg/MWh]	104	105	103	102	0	0	0	0	0	0	102	102
Sp. GHG emissions cooling [kg/MWh]	0	0	0	0	0	0	48	48	48	0	0	0

Figure 6.18 - Specific CO_2 emissions related to the municipal building

Kindergarten

The kindergarten consumed a total of 145 MWh of primary energy during the monitoring period, averaging approximately 1.5 MWh per MWh of heating consumed. However, only 38 MWh came from renewable energy sources, reflecting a significant dependency on natural gas.

This reflects significantly on the RER moving from 40% to about 10% (see Figure 6.19). The building's heating systems generate annual CO_2 emissions of 18,831 kg.



	1	2	3	4	5	6	7	8	9	10	11	12
PE use heating - Total [MWh]	47,9	29,4	20,6	5,1	0,0	0,0	0,0	0,0	0,0	0,0	20,2	22,2
PE use heating - Renewable [MWh]	17,8	10,1	7,3	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	1,1

Figure 6.19 - Primary energy uses related to the kindergarten heating

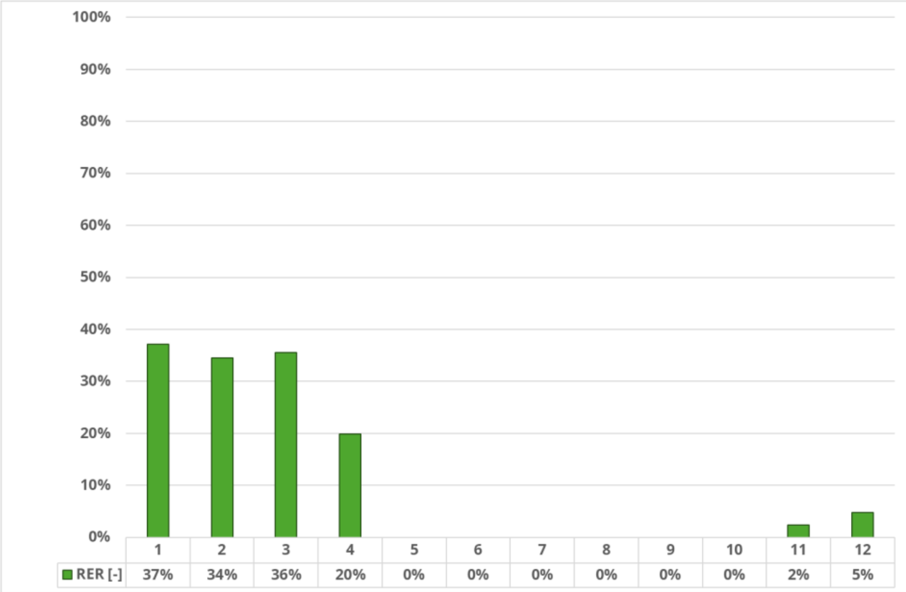


Figure 6.20 – RER related to the municipal building energy uses

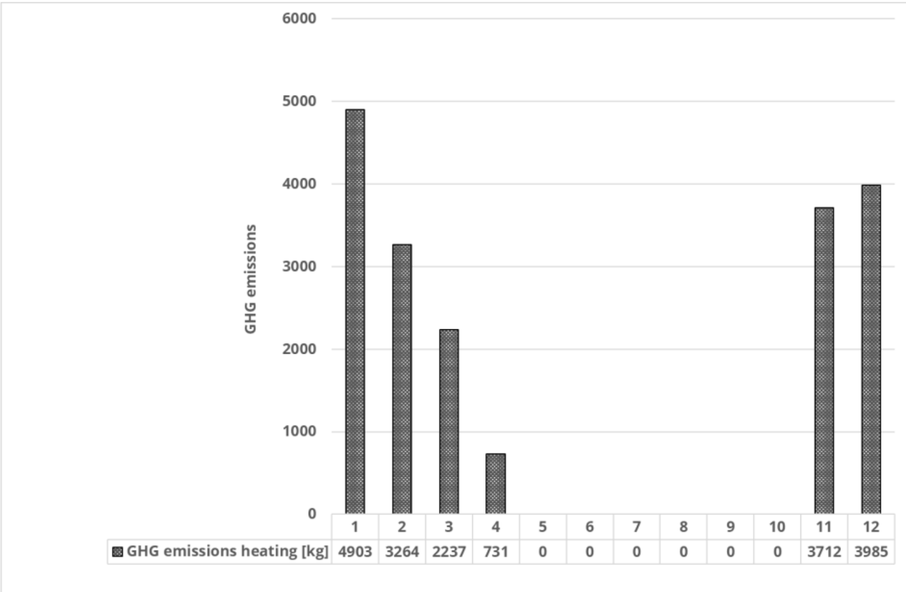


Figure 6.21 - Overall CO_2 emissions related to the kindergarten

6.4 Remarks

Table 6.1 summarizes the system annual energy needs and environmental performance calculations reported above.

The REWARDHeat system demonstrates notable performance across its network, with some areas showing strong reliance on renewable energy sources, while others reveal opportunities for optimization.

- The electricity used for water distribution in the system is estimated at 20 MWh annually, representing approximately 5% of the geothermal energy supplied and 10% of the network's total electricity consumption.

- Heating and cooling loads barely overlap, as space cooling is limited to one building and occurs during periods when other buildings do not require heating. To improve system efficiency, future network expansion should focus on connecting buildings with complementary energy demand profiles to balance heating and cooling loads.
- The renewable energy ratio varies largely along the seasons and with respect to the buildings considered. Work on improving control is needed to improve use of the REWARDHeat systems and their effectiveness.

Table 6.1 – Overall system annual energy uses, and performance calculated

Notation	Multifamily home	Municipal building	Kindergarten	Unit of meas.
Heating consumption	63	517	113	MWh/y
Cooling consumption	-	126	-	MWh/y
Electricity use for heating	20	169	21	MWh/y
Electricity use for cooling	-	33		MWh/y
Natural gas use for heating	-	51	64	MWh/y
Local RES use	43	296	28	MWh/y
Ren. PE for heating	52	307	38	MWh/y
Total PE for heating	92	759	145	MWh/y
Ren. PE for cooling	-	20	-	MWh/y
Total PE for cooling	-	80	-	MWh/y
Renewable Energy Ratio	50%-70%	20%-50%	10%-40%	%
GHG emissions for heating	5,821	58,273	18,831	kg/y
GHG emissions for cooling	-	9,444	-	kg/y

7 Mölndal, Sweden

7.1 Description of the demonstration site

The demonstration site in Mölndal features a newly constructed, small-scale, low-temperature district DHC network, developed as the extension of a neighbouring existing high-temperature DHN. This original network supplies heating to old tertiary and residential buildings and is connected to the Gothenburg DH backbone. Due to the characteristics of these buildings, the supply temperature is high, at around 80°C, with a limited temperature drop.

To optimize the return temperature to the backbone, the newly built low-temperature section, which serves both newly built tertiary and residential buildings, has been connected to the return line of the existing network via a heating central constructed underground. As such, this new network operates at temperatures below 60°C, which effectively lowers the return temperature to the backbone to below 50°C.

Figure 7.1 shows the area concerned with the REWARDHeat project in the red contour, right to the south of the existing city quarter. Six new multifamily homes, together with one hotel have been connected to the new network: the residential buildings only receive heating, while the hotel also receives cooling.

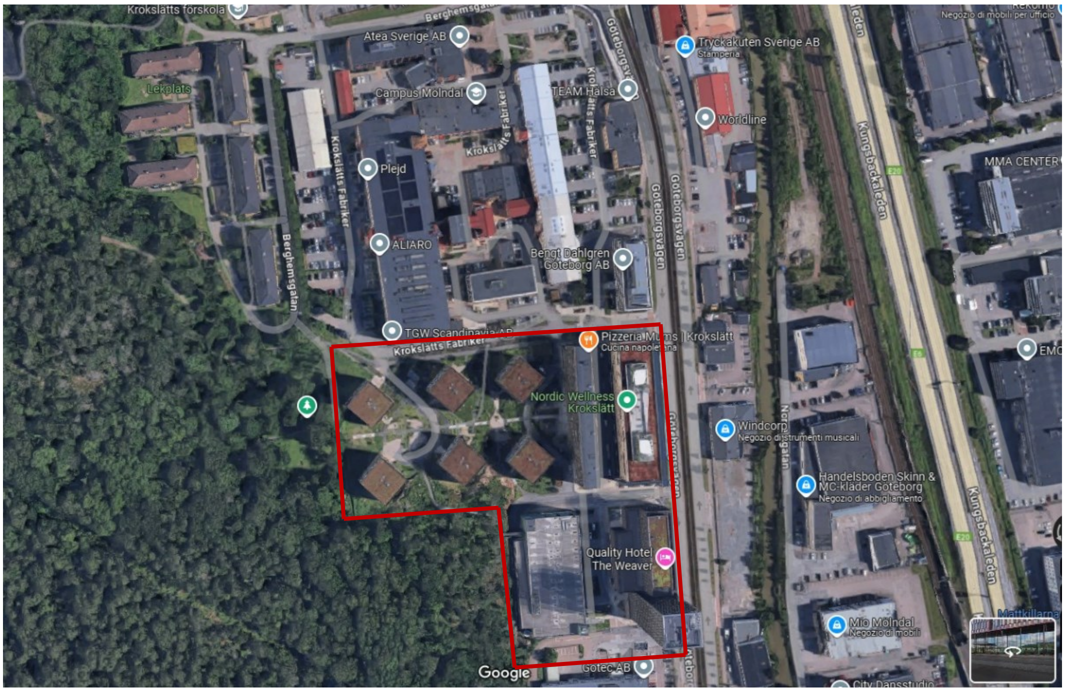


Figure 7.1: Newly built city quarter concerned in the REWARDHeat project

7.1.1 Objectives and main results of the demonstration activity

The main beneficiaries of the project include INDEPRO, responsible for feasibility studies, and ARVALLA, which managed procurement and installation activities. Beyond the primary project partners, other key stakeholders are Husvärden (the property owner) and Mölndal Energy DH along with Krokslätt Energi AB, which serve as the backbone network owner and energy distribution manager respectively.

Efforts to enhance heating and cooling efficiency for the buildings have focused on the following actions:

- Establishing a central energy system with boreholes and a geothermal heat pump.
- Connecting the newly constructed energy central to the existing district heating network.
- Equipping each building with substations that include booster heat pumps for optimal energy delivery.

During the REWARDHeat project, a new heating central was established, along with the installation of a geothermal field and associated heat pumps, as well as substations for multifamily homes and a hotel. The secondary loop from the heating central operates below 50°C, sometimes reaching as low as 30°C, depending on weather conditions.

The new heating central is also equipped with geothermal heat pumps that generate heating during periods of low electricity costs, while also enabling space cooling distribution to the tertiary buildings, thus boosting both utility and energy efficiency, by allowing to select the most environmentally friendly and affordable energy vector on an hourly basis. While space heating and cooling are generated centrally, since the network's distributed temperature is insufficient for DHW preparation, booster heat pumps are installed in each building to meet DHW requirements.

7.2 DHC Network conceptual design and management

The newly built heating central features three geothermal heat pumps (each with a thermal capacity of 630 kW). Thermal energy made available is distributed to buildings after being buffered in a series of five large TES tanks, enabling flexible heat pump utilisation, and eventually mixed with return water from the pre-existing network.

Free-cooled or chilled water (using a water-to-water chiller) is distributed directly to the hotel and other tertiary buildings and returns at a higher temperature to recharge the boreholes.

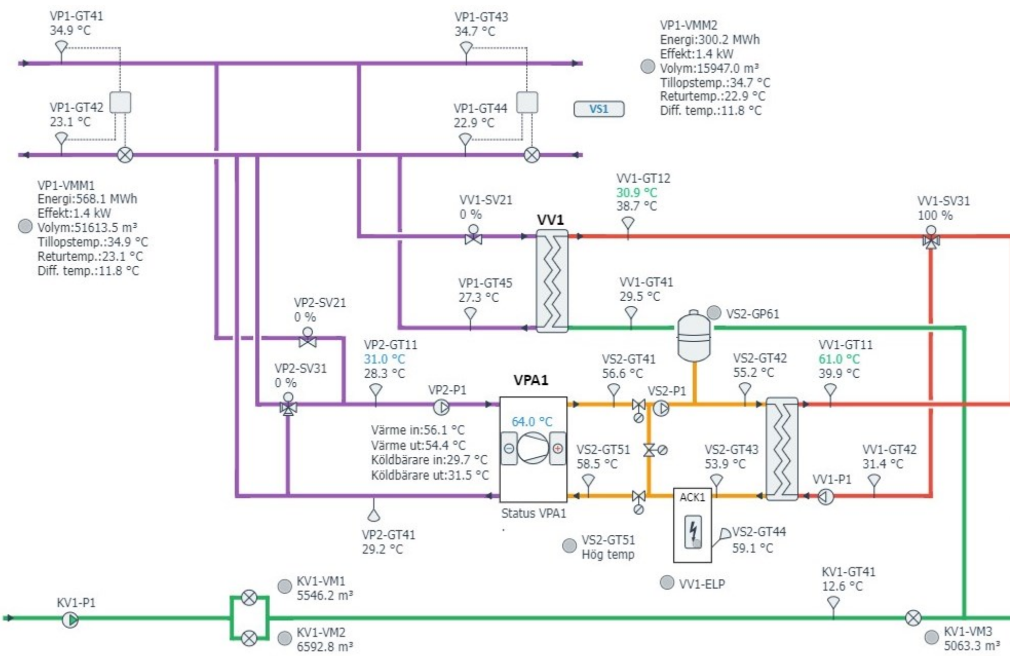


Figure 7.2: Multifamily Homes Substations principle Scheme and Typical Operation Parameters

The system incorporates a smart management strategy that dynamically selects between DH and heat pump heating based on forecasted system COP, as well as hourly electricity and DH energy prices provided in day-ahead communications.

As already highlighted, space heating and cooling is made available centrally and distributed. On the contrary, DHW needs local heat pumps in a booster configuration (see Figure 7.2 for residential buildings system) to meet user temperatures.

7.3 Assessment of the network performance

7.3.1 Energy uses insisting on the network

Figure 7.3 shows the monthly thermal energy consumption for six multi-family houses (MFH), with total DH use separated into DHW and SH components.

The annual heating uses amount to 390 MWh allocated to DHW and 320 MWh dedicated to SH. This corresponds to the local DH network delivering 624 MWh, while electricity contributes with an extra 86 MWh through HPs and distribution system operation. As expected, SH demand is highest in the colder months, peaking at 81 MWh in January, and drops to exactly zero during the summer months of May through September, when all district heating is allocated solely to DHW. In contrast, DHW demand remains steady year-round, averaging around 33 MWh per month.

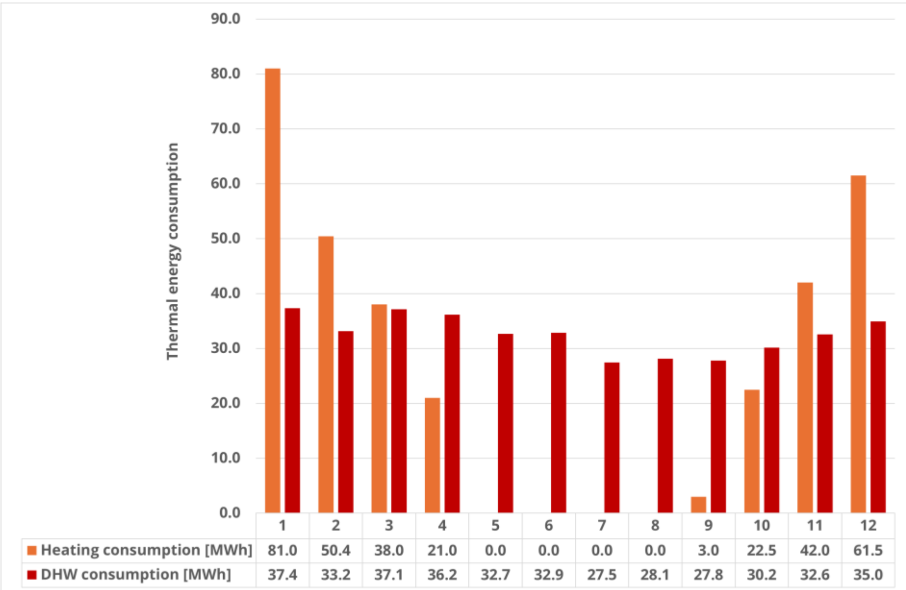
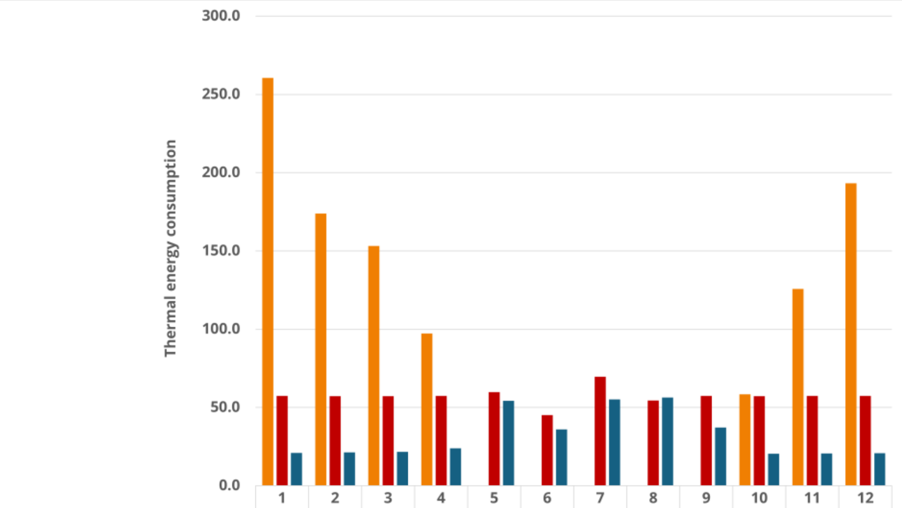


Figure 7.3 Monthly thermal energy consumption of the 6 MFHs

Figure 7.4 shows "The Weaver" hotel's monthly thermal energy consumption, broken down into SH and DHW, along with space cooling energy needs.

The annual district heating consumption totals approximately 1748 MWh, with 1062 MWh allocated to SH and 688 MWh DHW preparation. Cooling consumption adds another 389 MWh annually. The SH demand peaks to 261 MWh in January and tapers off entirely from May through September. DHW demand averages 57 MWh per month, with a slight increase in the summer months, peaking at 70 MWh in July, possibly reflecting higher water usage due to customers summer activities. Unlike the residential buildings, the hotel also has a significant cooling demand, peaking at 56 MWh in August and maintaining lower levels in winter.

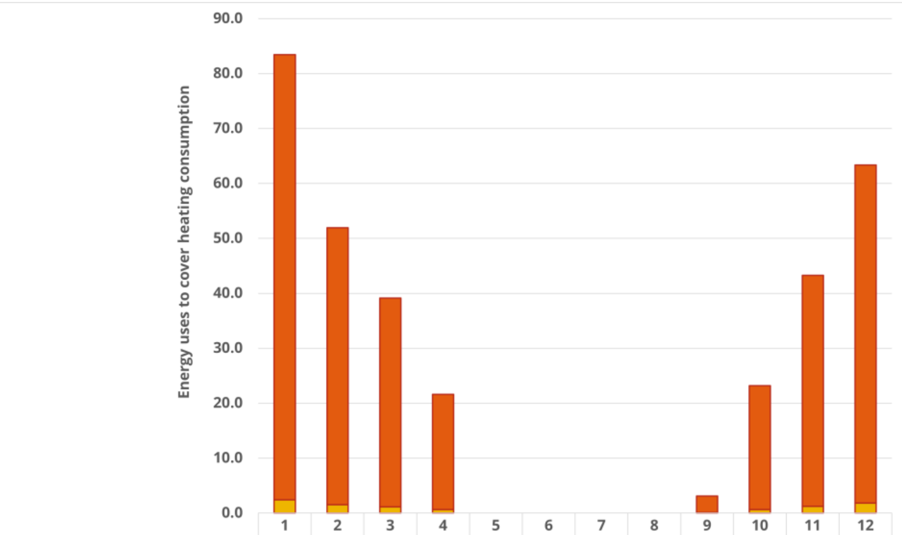


	1	2	3	4	5	6	7	8	9	10	11	12
Heating Consumption [MWh]	260.6	173.9	153.1	97.3	0.0	0.0	0.0	0.0	0.0	58.4	125.8	193.2
DHW Consumption [MWh]	57.4	57.3	57.2	57.3	59.8	45.1	69.7	54.5	57.4	57.3	57.4	57.3
Cooling Consumption [MWh]	21.0	21.4	21.7	23.8	54.2	36.0	55.2	56.4	37.1	20.5	20.6	20.8

Figure 7.4 Monthly thermal energy consumption of the Hotel (The Weaver)

Figure 7.5 and Figure 7.6 analyse the monthly utilization of the different energy vectors for the multi-family homes. The local district heating is the dominant source. Electricity use for space heating is minimal in comparison, around 1-2 MWh in January, primarily supporting circulation pumps and other minor components necessary for heat distribution.

Figure 7.6 illustrates the energy consumption dedicated to meeting DHW requirements, which remain consistent year-round. Local DH demand stays between 21 and 30 MWh monthly, while electricity use remains steady at approximately 7 MWh each month.



	1	2	3	4	5	6	7	8	9	10	11	12
DH use for heating [MWh]	81.0	50.4	38.0	21.0	0.0	0.0	0.0	0.0	3.0	22.5	42.0	61.5
Electricity use heating [MWh]	2.4	1.5	1.1	0.6	0.0	0.0	0.0	0.0	0.1	0.7	1.3	1.8

Figure 7.5 Energies use for Space Heating for MFH

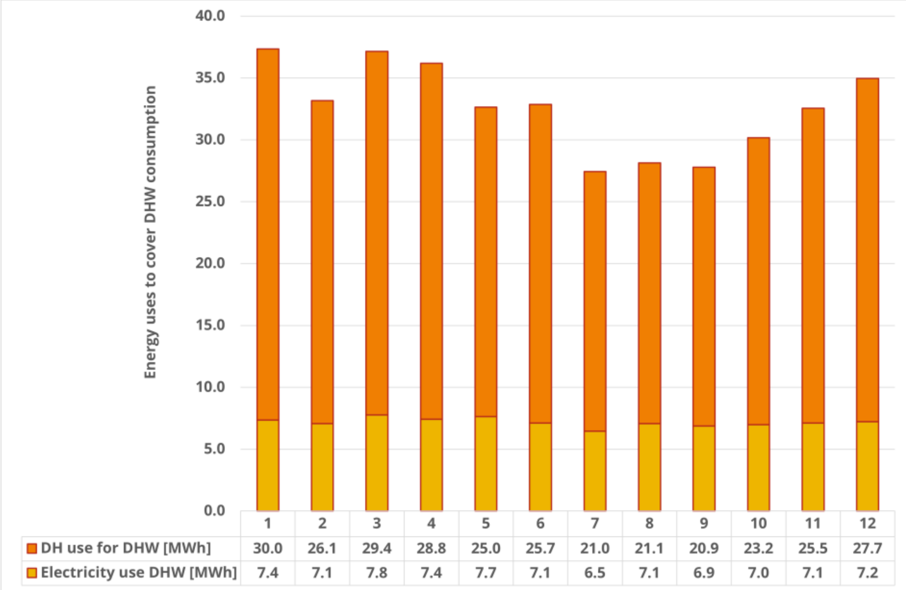


Figure 7.6 Energies use for DHW for MFH

Figure 7.7 and Figure 7.8 show the hotel's energy vectors uses. The reliance on DH allows the hotel to maintain a steady and efficient heating solution that aligns with seasonal variations in demand, particularly leveraging DH during winter when heating needs are highest. The minimal use of electricity for space heating, primarily for circulation and auxiliary functions, further emphasizes the efficiency of this setup, as DH meets the bulk of demand, reducing the need for supplemental energy.

In summer, the hotel's energy strategy adjusts seamlessly to meet a baseline demand for DHW. The DH usage for DHW remains stable across the year but increases slightly in summer, peaking at 49 MWh in July. This spike likely reflects higher occupancy rates and greater hot water demand during peak tourist season, which the system accommodates effectively. Electricity use for DHW also follows this pattern, reaching its peak in July at 21 MWh, which aligns with the highest DH demand for DHW, indicating a well-coordinated system that adapts to increased needs.

This strategic use of local DH energy, with a minor yet stable role for electricity, ensures that the hotel can meet fluctuating demands without relying heavily on non-renewable sources.

Similarly, in Figure 7.9 for the energy strategy for cooling consumption where the hotel utilizes district cooling (DC), mainly using geothermal free-cooling as the primary source to meet its needs. District cooling consumption rises significantly from May to August, with a maximum of 53 MWh in August. Electricity usage for cooling remains relatively low but shows a corresponding increase, peaking at 3.4 MWh in July and August.

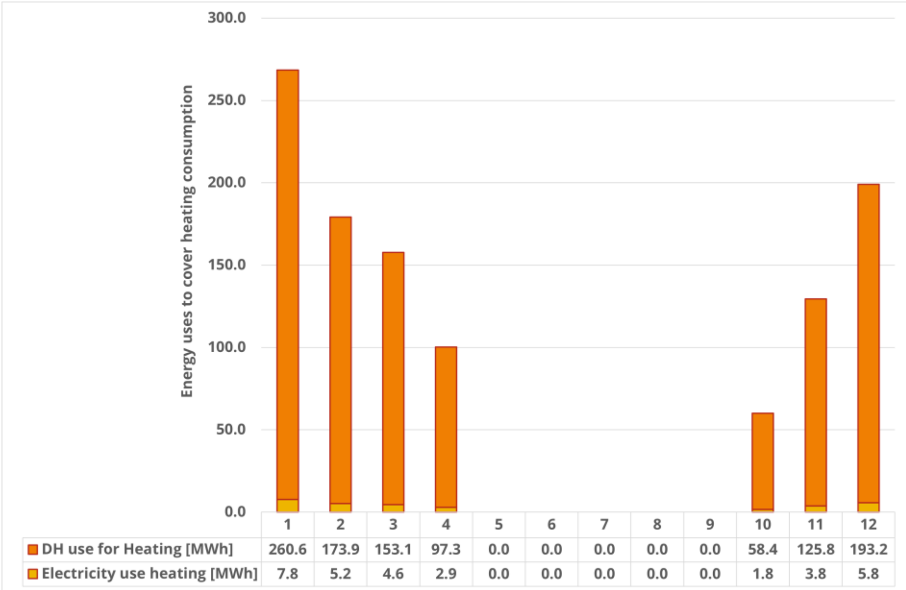


Figure 7.7 Energies use for Heating for Hotel

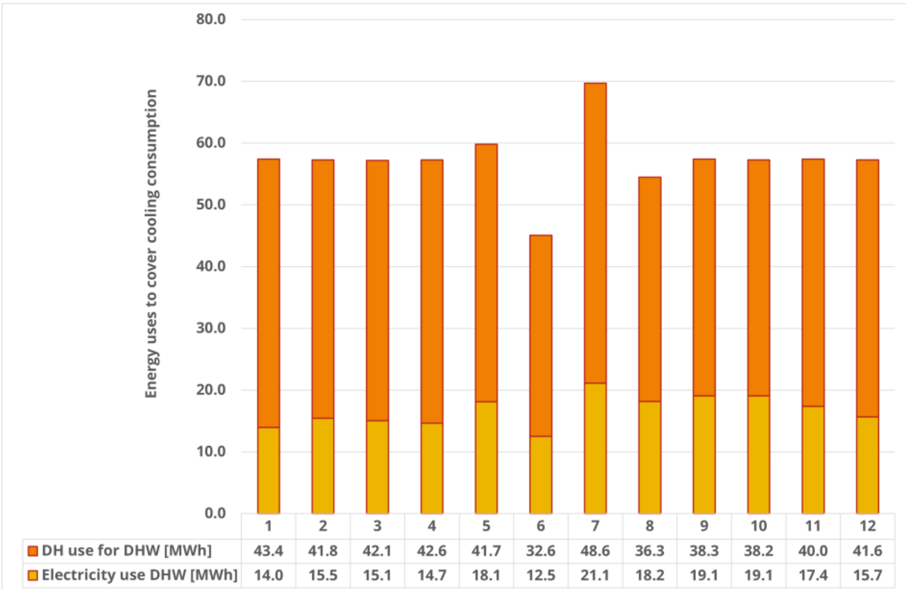
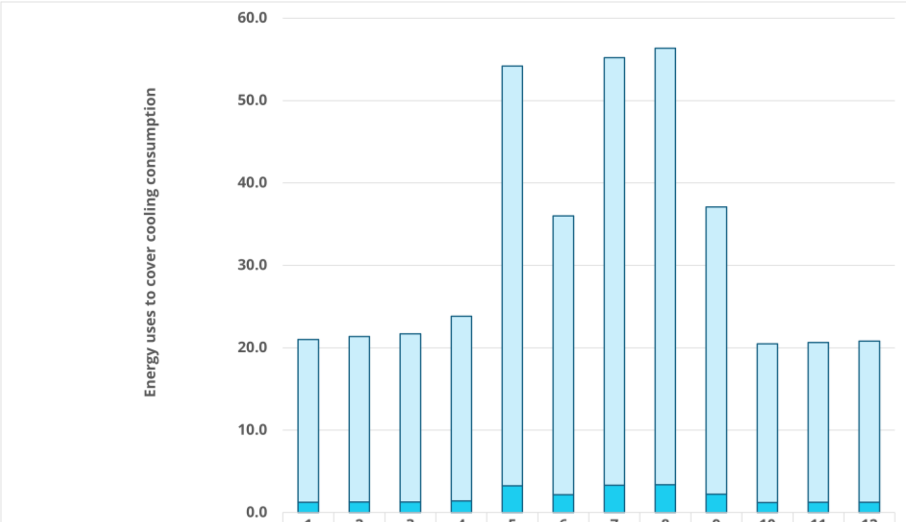


Figure 7.8 Energies use for DHW for Hotel



	1	2	3	4	5	6	7	8	9	10	11	12
District cooling [MWh]	19.7	20.1	20.4	22.4	50.9	33.8	51.9	53.0	34.9	19.2	19.4	19.6
Electricity use for cooling [MWh]	1.3	1.3	1.3	1.4	3.3	2.2	3.3	3.4	2.2	1.2	1.2	1.2

Figure 7.9 Energies use for cooling for hotel

7.3.2 Performance indicators assessment

Primary energy consumption includes DH and electricity, each with specific primary energy factors:

- Local DH total primary energy factor → 0.69 (of which 0.25 is renewable)
- Electricity total primary energy factor → 1.98 (of which 0.7 is considered renewable)

It is to be noted that the primary energy factors for the local DH system were calculated as a weighted average of the energy vectors' factors used in the energy central (see deliverable 6.5). The energy mix comprises approximately 18% DH energy from the city backbone, 34% electricity powering central heat pumps and the distribution system, and 48% geothermal energy[1]. For this calculation, the same factors as those used for Helsingborg's DH network were applied, as actual values were unavailable, and the two systems are quite similar in terms of energy mixes.

Figure 7.10 illustrates the monthly total primary energy use for space heating and domestic hot water in the multi-family houses, with each segment showing its renewable portion.

Space heating primary energy use peaks in January at 61 MWh, and gradually decreasing as outdoor temperatures rise, reaching minimal levels in summer. Renewable contributions to space heating mirror the total demand pattern, providing approximately 22 MWh of renewable energy in January and diminishing during warmer months, the RER being almost constant around 36%.

In contrast, DHW energy consumption remains relatively stable across the year, with primary energy use ranging from 27 MWh in July to 36 MWh in March. Renewable energy input for DHW follows this uniform trend, contributing between 10 MWh and 13 MWh monthly throughout the year, and resulting in a RER of about 33%.

[1] For this calculation, the same factors as those used for Helsingborg's DH network were applied, as actual values were unavailable, and the two systems are quite similar in terms of energy mixes.

These uniform ratios indicate that seasonal variations in renewable energy contributions were not accounted for. Additionally, they reflect the share of electricity—assigned a high non-renewable primary energy factor—used for domestic hot water (DHW) preparation at both the central and building levels.

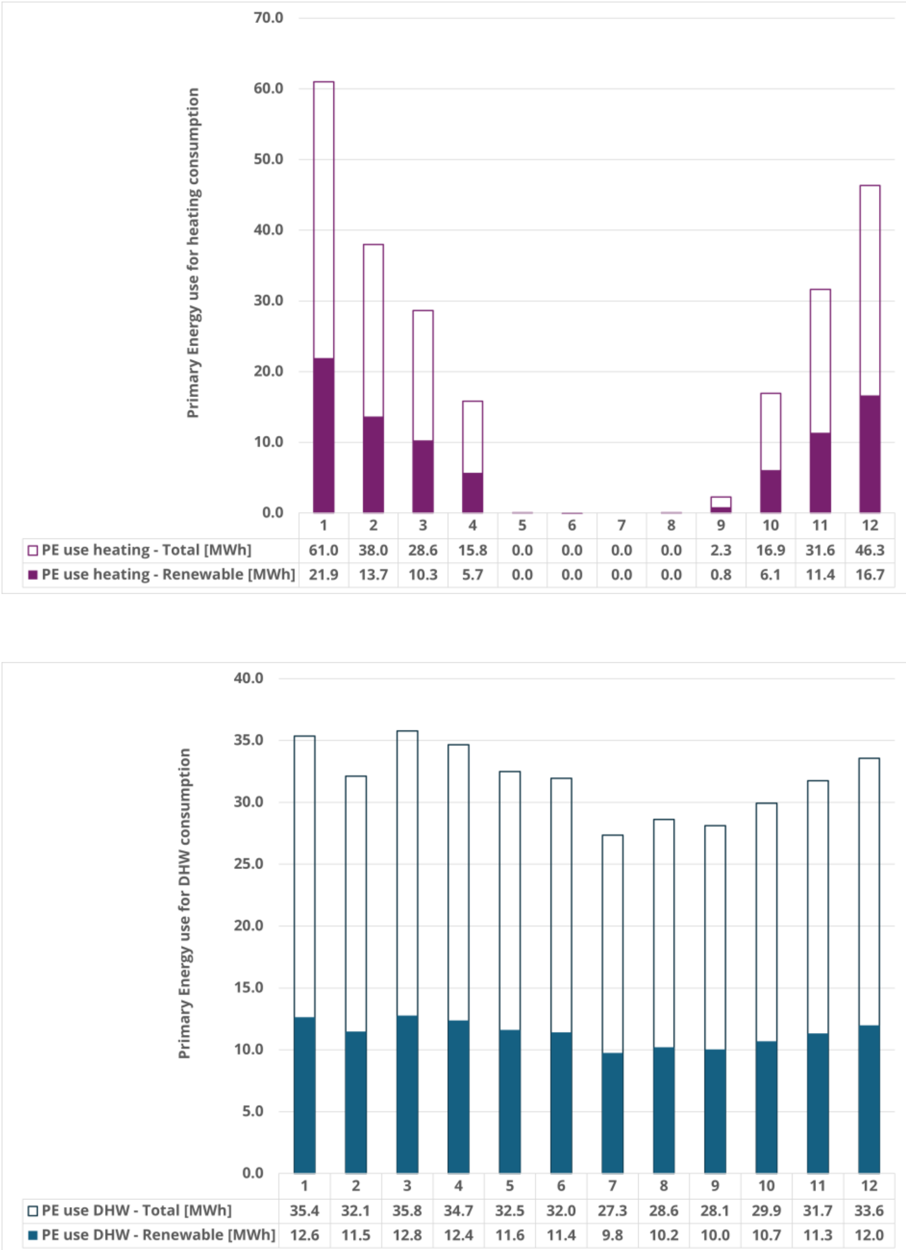
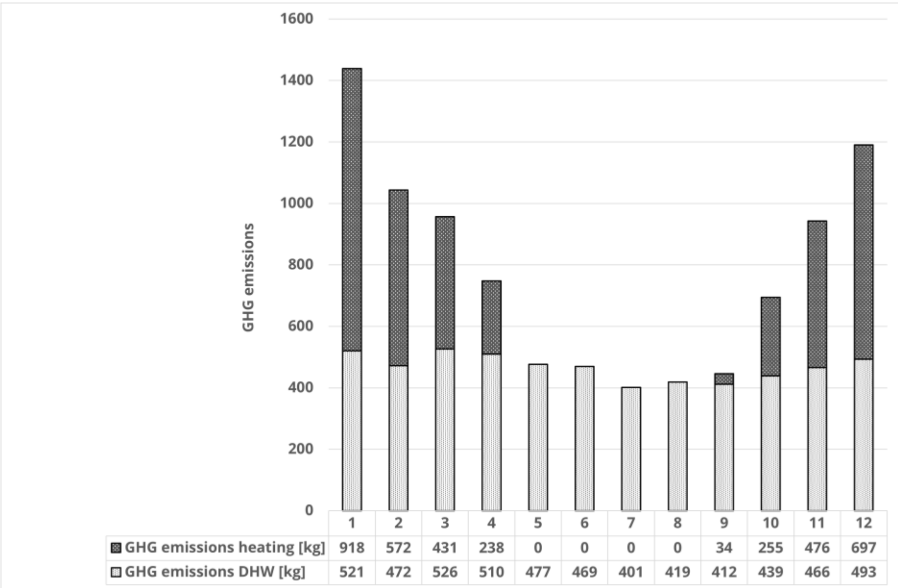


Figure 7.10 Monthly renewable and total primary energy uses for heating (top) and DHW (bottom) consumption of the MFH

The RER does not directly represent the actual amount of RES used to meet the thermal loads of buildings. For a clearer understanding, an assessment of GHG emissions provides a more accurate perspective. Figure 7.11 displays the monthly GHG emissions attributed to the building's energy system. These calculations cover the local district heating energy use as well as the electricity used[2]. Specific GHG emissions are calculated by dividing the total GHG emissions by the energy consumption shown in Figure 7.3. The following GHG emission factors are applied:

- District heating GHG emission factor: 10 g/kWh
- Electricity GHG emission factor: 28 g/kWh



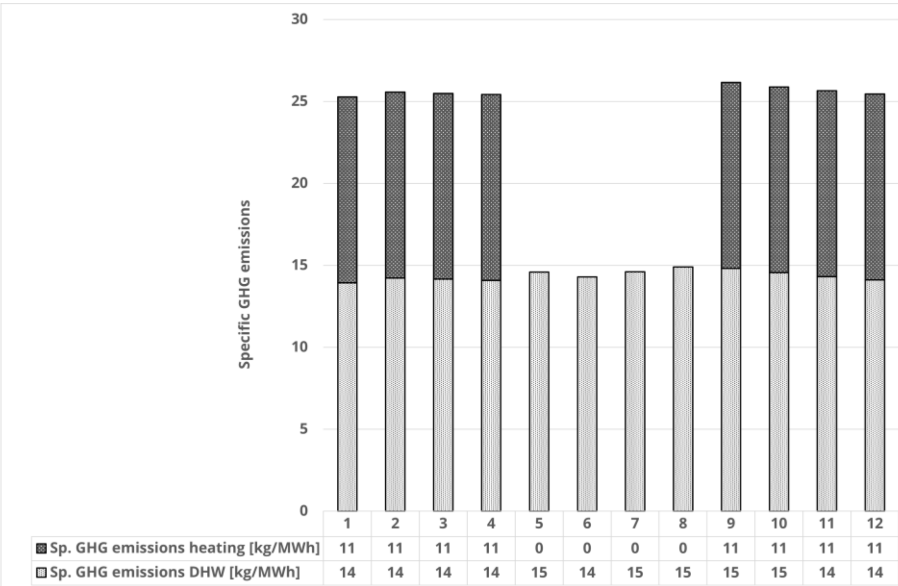
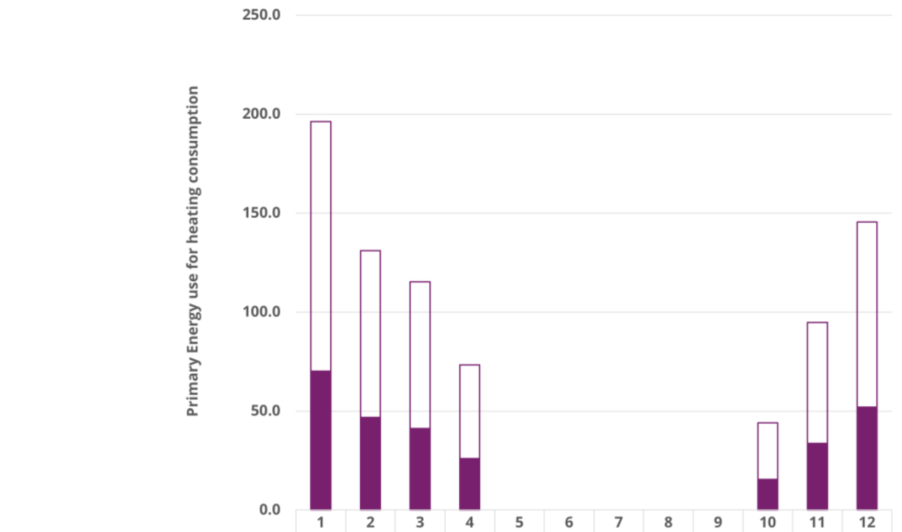


Figure 7.11 Monthly CO2 emissions (top) and specific CO2 emissions (bottom) for heating and DHW for MFH

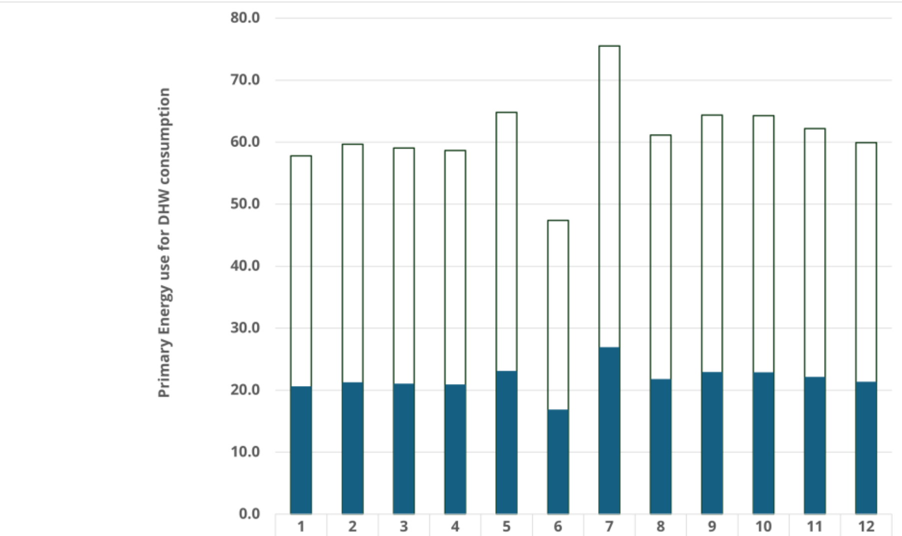
[2] Emissions related to other energy uses, such as lighting, appliances, and ventilation, are not included to ensure that the analysis remains focused on thermal energy requirements.

The above values are particularly low compared to other sites, reflecting the high share of RES, averaging 85% for DH and about 70% for what concerns the electricity mix.

Over the course of the year, the building's total GHG emissions for heating and DHW amount to approximately 9,227 kg. During colder periods, specific GHG emissions for space heating vary between 11 and 15 kg/MWh, while DHW emissions remain relatively steady throughout the year, around 14 to 15 kg/MWh. For the hotel structure, Figure 7.12 and Figure 7.13 displays space heating demand peaks in January at 196 MWh, with renewable energy contributing 71 MWh, and drops to minimal levels during summer. DHW use remains consistent year-round, ranging from 47 MWh in June to 76 MWh in July, with renewable contributions between 17 and 27 MWh. Cooling energy use peaks in summer at 7 MWh, with renewable inputs ranging from 0.9 to 2 MWh.



	1	2	3	4	5	6	7	8	9	10	11	12
PE use heating - Total [MWh]	196.3	131.0	115.3	73.3	0.0	0.0	0.0	0.0	0.0	44.0	94.8	145.6
PE use heating - Renewable [MWh]	70.6	47.1	41.5	26.4	0.0	0.0	0.0	0.0	0.0	15.8	34.1	52.4



	1	2	3	4	5	6	7	8	9	10	11	12
PE use DHW - Total [MWh]	57.8	59.6	59.1	58.6	64.8	47.4	75.5	61.1	64.4	64.3	62.2	59.9
PE use DHW - Renewable [MWh]	20.6	21.3	21.1	20.9	23.1	16.9	26.9	21.8	22.9	22.9	22.2	21.4

Figure 7.12 Monthly renewable and total primary energy uses for space heating (top) and DHW (bottom) of the hotel

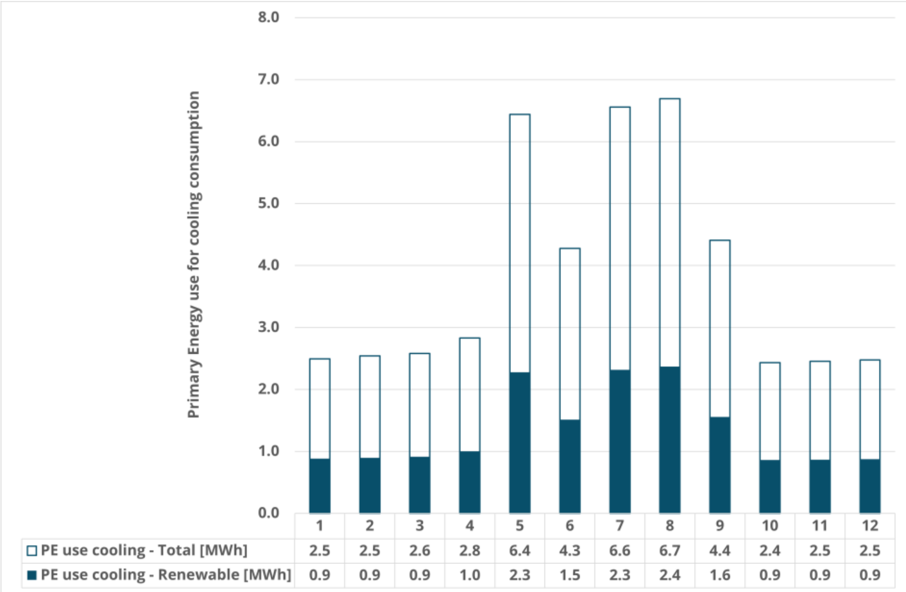
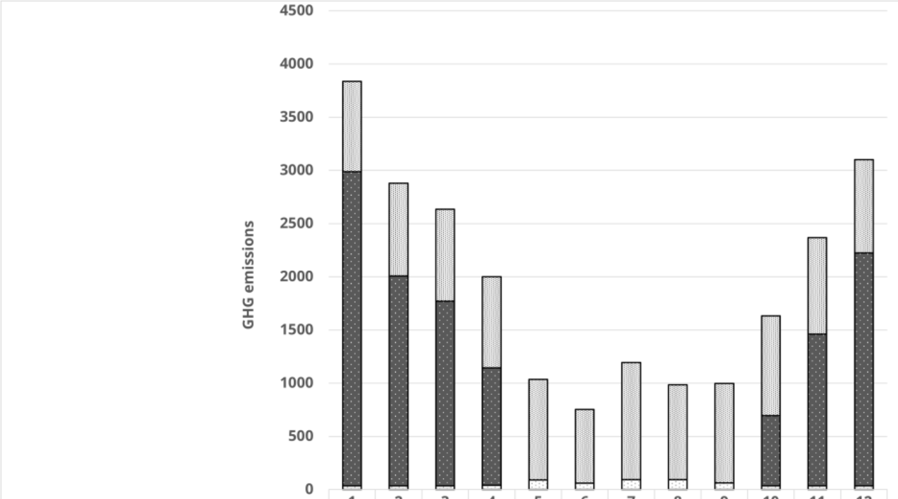


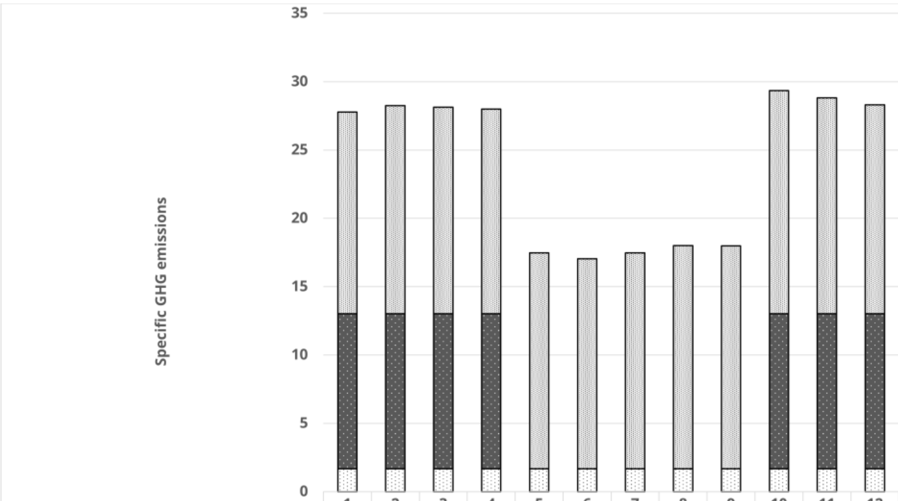
Figure 7.13 Monthly renewable and total primary energy use for space cooling (bottom) of the hotel

Once more the RER is stable at around 36% throughout the year.

Figure 7.14 presents the monthly greenhouse gas (GHG) emissions associated with the hotel's energy system. The total annual GHG emissions for reach approximately 23,420 kg. Emissions are highest in winter, with specific GHG emissions for space heating reaching up to 11 kg/MWh, while DHW emissions remain steady at around 15 kg/MWh. Cooling-related emissions, peaking in summer months, have a specific GHG value of around 2 kg/MWh, contributing a smaller share to the overall emissions profile.



	1	2	3	4	5	6	7	8	9	10	11	12
GHG emissions DHW [kg]	847	872	864	858	945	692	1101	890	937	935	907	876
GHG emissions heating [kg]	2954	1972	1736	1103	0	0	0	0	0	662	1426	2190
GHG emissions cooling [kg]	35	36	36	40	91	60	93	95	62	34	35	35



	1	2	3	4	5	6	7	8	9	10	11	12
Sp. GHG emissions DHW [kg/MWh]	15	15	15	15	16	15	16	16	16	16	16	15
Sp. GHG emissions heating [kg/MWh]	11	11	11	11	0	0	0	0	0	11	11	11
Sp. GHG emissions cooling [kg/MWh]	2	2	2	2	2	2	2	2	2	2	2	2

Figure 7.14 Monthly CO2 emissions (top) and specific CO2 emissions (bottom) for space heating, DHW and cooling

7.4 Remarks

Table 7.1 summarizes multi-family houses' and hotel's annual energy needs and environmental performance calculations reported above.

Table 7.1 – Overall annual energy uses, and performance calculated for the multifamily homes and the hotel

Notation	Multifamily homes	Hotel	Unit of meas.
Heating consumption	319	1060	MWh/y
Cooling consumption		389	MWh/y
DHW consumption	391	688	MWh/y
Electricity use for heating	10	32	MWh/y
Electricity use for cooling		23	MWh/y
Electricity use for DHW	86	201	MWh/y
Local DH use for heating	319	1060	MWh/y
Local DH use for DHW	304	487	MWh/y
Ren. PE for heating	87	287	MWh/y
Total PE for heating	239	795	MWh/y
Ren. PE for cooling		16	MWh/y
Total PE for cooling		46	MWh/y
Ren. PE for DHW	137	262	MWh/y
Total PE for DHW	381	733	MWh/y
Renewable Energy Ratio	36	36	%-
GHG emissions for heating	4	12	ton/y
GHG emissions for cooling		0.7	ton/y
GHG emissions for DHW	6	11	ton/y

By efficiently managing local DH for both winter heating and year-round DHW, the buildings concerned benefit from a cost-effective, locally supported energy supply.

- The buildings' booster heat pumps achieve a high annual COP for DHW, averaging 3.5 at multifamily homes and 4.5. This technology is supplemented by local DH, which provides a significant portion of the annual DHW and space heating needs.
- The local DH supplies heat at low temperature to the newly built constructions, mainly driven by geothermal energy -i.e., 52%. This indeed requires heat central heat pumps, operating with an average COP of 2.5, and introducing 34% of grid electricity in the local DH mix. The rest of the energy delivered to the buildings is provided by the Gothenburg DH backbone.
- Although both energy mixes (i.e., Swedish electricity and Gothenburg DH) are highly decarbonized, importing energy from outside the property, specifically electricity featuring a high total primary energy factor, results in modes RERs around 1/3. Integrating higher energy shares of local RES for example through PV or PVT fields installed like in the demonstration case in Helsingborg would easily increase such percentage.

- Free Cooling reduces cooling-related consumptions. By using free cooling for space cooling, the building minimizes electricity use for cooling, relying solely on electricity consumption of circulation pumps.
- The demonstration site is equipped with numerous sensors, which posed challenges in synchronizing data due to differing signal frequencies—some data is recorded every 10 minutes, others every 20 minutes. This inconsistency caused issues in harmonizing the datasets. To address this, the data frequency was standardized to a 30-minute interval, effectively bridging gaps in the data and ensuring more reliable analysis.

8 Szczecin, Poland

8.1 Description of the demonstration site

Szczecin's demonstration site is located on the Łasztownia river island, and constitutes the first case of low temperature, hybrid DHC network in Poland.

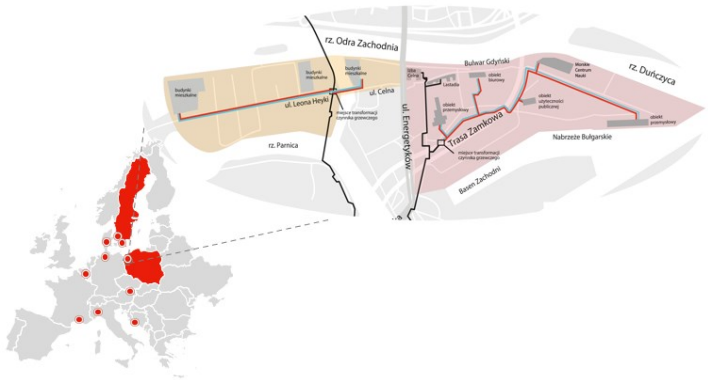


Figure 8.1: Łasztownia Island. On the Right, red highlighted, the area interested by the REWARDHeat Project

The newly developed network follows the E.ON ectogrid™ concept. Typical operating temperatures range from 30-50 °C at the supply pipe in summer and winter, respectively, and 25-35 °C at the return. A Heat Balancing Station (HBS) connects the new network to the existing high-temperature DH system and adiabatic coolers, enabling the distribution of both heating and cooling to users. Currently, the HBS supplies the Maritime Science Centre (MSC). The system is designed to accommodate future expansions, supporting 3450 kW for heating and 2250 kW for cooling, as the DHC network approaches its nominal capacity.

Figure 8.2 provides an overview of the general system layout on Łasztownia. On the left, it illustrates the installation at the HBS, including a water tank used for storing excess heat. On the right, the MSC is depicted, with a green line indicating the ownership boundary.

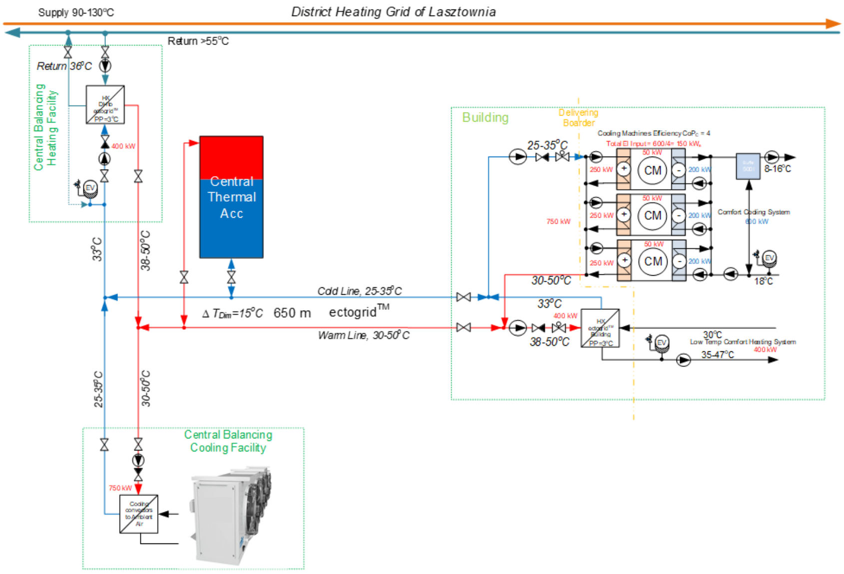


Figure 8.2: Scheme of the low temperature DHC network on Łasztownia Island in Szczecin

8.1.1 Objectives and main results of the demonstration activity

The scope of the demonstration activity is to supply heating and cooling to the MSC. Specifically, the objectives pursued during the project are:

- Development and set up of the initial low temperature DHC network backbone
- Construction of the HBS and set up of the first customer substation
- Implementation of the HBS management system, aimed to optimize mass flow and temperature in the network based on demand side loads assessment
- Assessment and improvement of the solutions implemented and development of recommendations for replication
- Analysis of the available waste heat on the island from identified potential sources: a chocolate factory and a food cold storage facility.

Along with the REWARDHeat project, SEC achieved to set up the new DHC network as described above.

The HBS has been set up to maintain optimal temperatures in the warm and cold pipes through the ectocloud™ system. This system controls the average temperature of the thermal buffer tank to ensure consistent heating or cooling within the specified temperature range. By managing storage temperatures, the system maximises efficiency for both heating and cooling and minimises reliance on the conventional DH backbone during colder months.

Automation programming is implemented to support smooth HBS operation, with the ectocloud™ system enabling dynamic, intelligent control. The automation system adapts to real-time demands, optimising the heating and cooling processes within the required temperature range for energy-efficient management.

The MSC's space heating and DHW loads are covered with direct heating in winter. Polyvalent, 4-pipes, water-water chillers cover DHW and space cooling needs in mid- and summer seasons and reject waste heat into the network. The chillers draw water from the network's return pipe, ensuring the condenser operates within its permitted temperature ranges throughout the year.

Figure 8.3 presents a P&I diagram illustrating the interface between the DHC network and the MSC. Here, the local control system addresses the building's heating and cooling needs while regulating energy returned to the network at the appropriate temperature. This enables internal heat recovery by the building's chillers, maintaining optimal temperatures for energy balancing and waste heat recovery, which is expected to play an increasingly important role in the future.

To achieve this, the substation delivers hot water for heating through the hot pipe (shown in red) and supports chillers through the cold pipe (shown in blue). While the building typically requires either heating or cooling, this setup allows the system to provide both simultaneously if needed. The hot pipe can supply high temperatures, and the cold pipe ensures temperatures compatible with chiller operations.

All assets on the secondary side at the MSC are supervised by a local BMS and managed by the building energy manager. Both, HBS and MSC transfer data in two directions to and from the DHC network SCADA system.

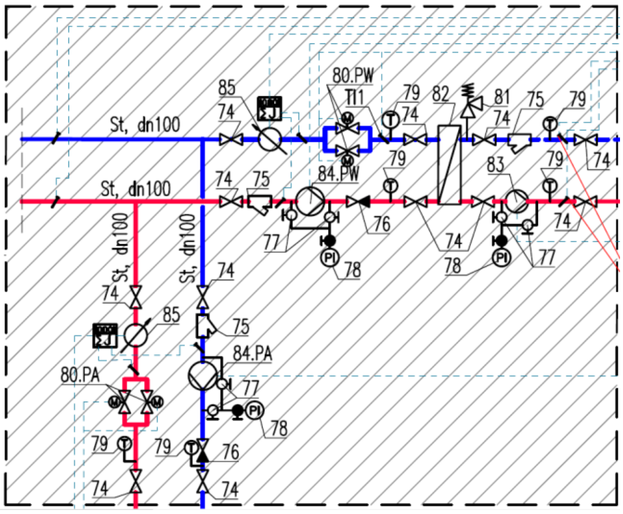


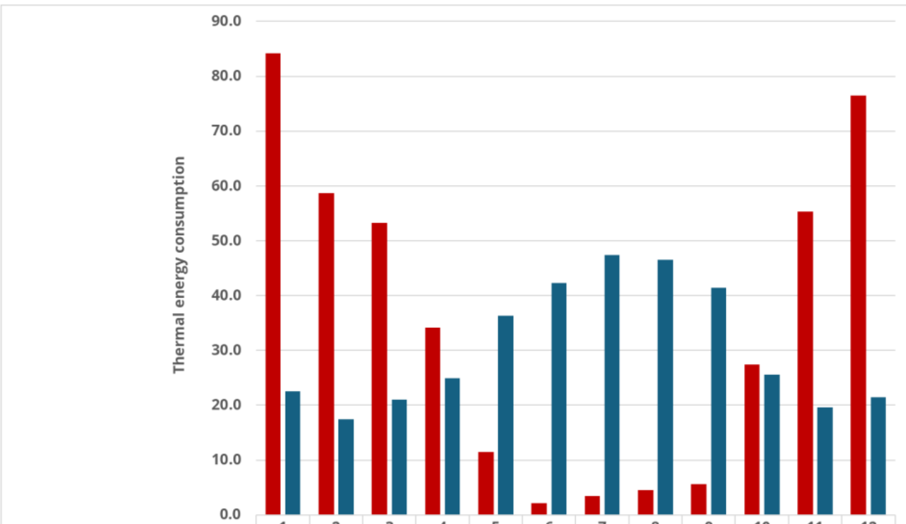
Figure 8.3: P&I diagram detail of the of substation in MSC

8.2 Assessment of the network performance

8.2.1 Energy uses insisting on the network

Figure 8.4 shows the building's monthly space heating and cooling demand. As mentioned earlier, the utility managing the network is responsible for the infrastructure up to the building's edge. Therefore, in this case, the heating consumption is the energy that flows from the DH to the primary side of the MSC's HX, while the cooling consumption is the energy rejected by the chillers to the DH, overall representing the connection to the Maritime Science Centre, as shown in Figure 8.3.

The building's annual heating consumption totals around 416 MWh. Most energy consumption occurs in the colder months, with peaks of around 80 MWh in January and December. The annual cooling consumption amounts to 367 MWh.



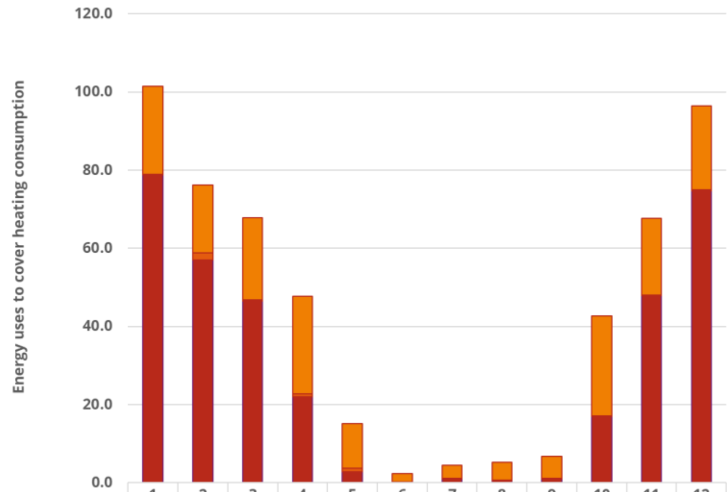
	1	2	3	4	5	6	7	8	9	10	11	12
Heating consumption [MWh]	84.2	58.6	53.3	34.1	11.5	2.1	3.4	4.5	5.7	27.4	55.3	76.5
Cooling consumption [MWh]	22.5	17.4	21.0	25.0	36.4	42.3	47.4	46.6	41.4	25.5	19.6	21.5

Figure 8.4 - Monthly thermal energy consumption of the buildings

The building's heating and cooling demand annual values are in the same range. This is primarily due to the typical behaviour of a tertiary building that shows cooling demands even during winter periods. Regarding the heating profile, it presents a higher dependency to the ambient temperature, with high values during winter season and very low during summer.

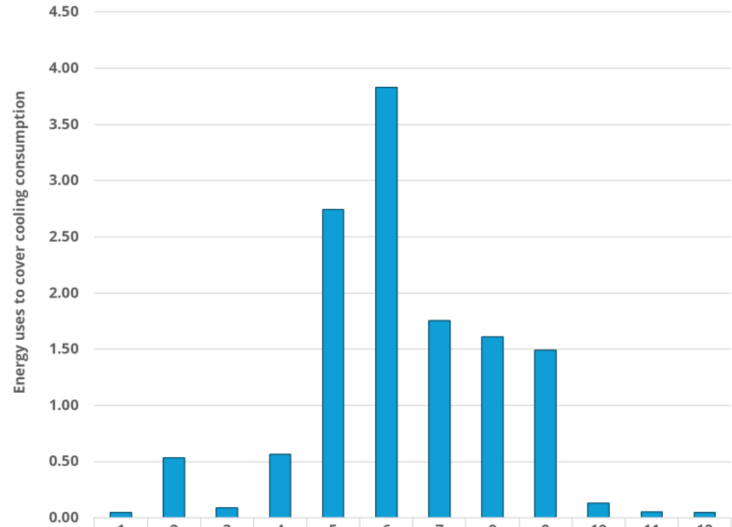
Figure 8.5 and Figure 8.6 illustrate the energy sources used to meet the building's heating and cooling demand. Heating is primarily supplied by the city DH (350 MWh), complemented with electricity used in the central station (18 MWh), and local waste heat rejected the chillers (180 MWh, around 1/3 of the heating uses).

The cooling demand in the substations is fully met through electricity consumption for operating the circulation pumps and cooling towers (13 MWh), which reject heat to the ambient. This results in exceptionally low energy consumption relative to the cooling demand addressed, highlighting the system's high efficiency in managing cooling requirements.



	1	2	3	4	5	6	7	8	9	10	11	12
Local RES & WH for heating [MWh]	22.5	17.4	21.0	25.0	11.5	2.1	3.4	4.5	5.7	25.5	19.6	21.5
Electricity use heating [MWh]	0.18	1.80	0.23	0.77	0.86	0.19	0.13	0.16	0.20	0.14	0.15	0.17
DH use for heating [MWh]	78.7	57.0	46.5	22.0	2.8	0.0	0.9	0.5	1.0	17.0	47.9	74.7

Figure 8.5 - Energies use for heating



	1	2	3	4	5	6	7	8	9	10	11	12
Electricity use cooling [MWh]	0.05	0.54	0.09	0.56	2.74	3.83	1.76	1.61	1.49	0.13	0.05	0.05

Figure 8.6 - Energies use for cooling

Although the MSC managers do not provide data on electricity use at the building level, the electricity consumption required to operate chillers during the summer and to supplement DHW preparation when the district heating and cooling (DHC) supply temperature is too low can be estimated based on DH water and user temperatures.

During the coldest winter months, water enters the heat exchanger at approximately 50°C. However, from March to November, the supply temperature decreases from 45°C to around 33°C. To heat water on the secondary side to the 50°C set point, chillers operate with an average COP of about 10. Simultaneously, the same units deliver space cooling with an average COP of 5.5. As a result, customers experience exceptionally low electricity consumption.

8.2.2 Performance indicators assessment

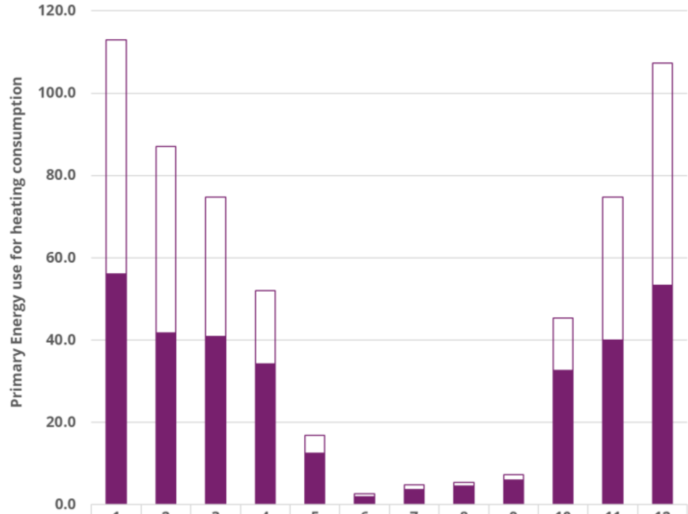
Figure 8.7 illustrates the monthly total primary energy use for heating and cooling, alongside the renewable portion of that energy. The primary energy calculation accounts for contributions from electricity, local renewable sources, as well as the city DH used as an energy source. An equivalent primary energy factor has been calculated for the latter, using the mix of energy used and its individual primary energy factors [9]:

- Electricity total primary energy factor → 2.5 (of which none is considered renewable)
- High Temperature District Heating → 1.14 (of which 0.43 is considered renewable)

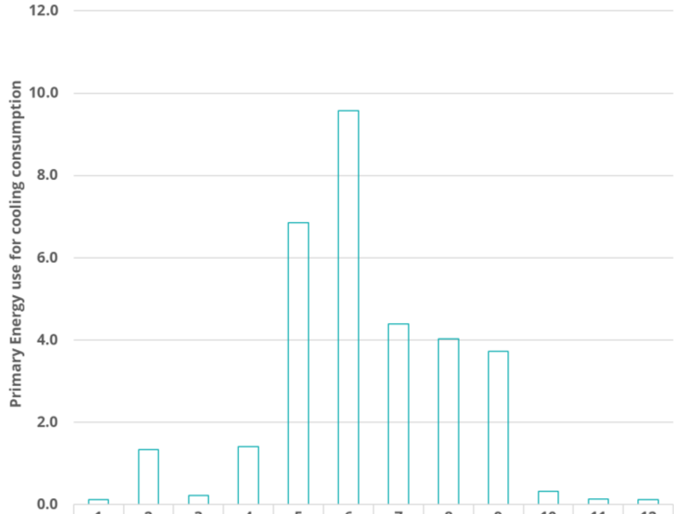
Over the course of the year, the total primary energy consumption reaches 623 MWh. Of this total, 329 MWh is derived from renewable sources. Most of this primary energy use consumption is attributed to heating needs (591 MWh).

Primary energy consumption is significantly higher during the winter months due to the intensive use of the high temperature DH; the reliance on this source for heating during winter substantially elevates the primary energy requirement, despite the substation's heating system integrates an important share of renewable energy contributions. During summer, all the primary energy consumed is considered non-renewable covered by electricity.

The RER shown in Figure 8.8 varies around 50%, primarily due to the use of the energy rejected by the chillers and the partial mix of renewables in the energy coming from the high temperature DH. The RER shows an increment during spring and autumn, when the share of WH used increases. As network usage decreases and cooling demand rises, mostly covered by non-renewable sources, the RER decreases.



	1	2	3	4	5	6	7	8	9	10	11	12
PE use heating - Total [MWh]	113.0	87.1	74.8	52.1	16.9	2.6	4.8	5.5	7.2	45.3	74.7	107.3
PE use heating - Renewable [MWh]	56.2	41.9	41.0	34.4	12.7	2.1	3.8	4.7	6.1	32.8	40.1	53.5



	1	2	3	4	5	6	7	8	9	10	11	12
PE use cooling - Total [MWh]	0.1	1.3	0.2	1.4	6.9	9.6	4.4	4.0	3.7	0.3	0.1	0.1
PE use cooling - Renewable [MWh]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 8.7 - Monthly renewable and total primary energy uses for heating (top) and cooling (bottom) consumption of the buildings

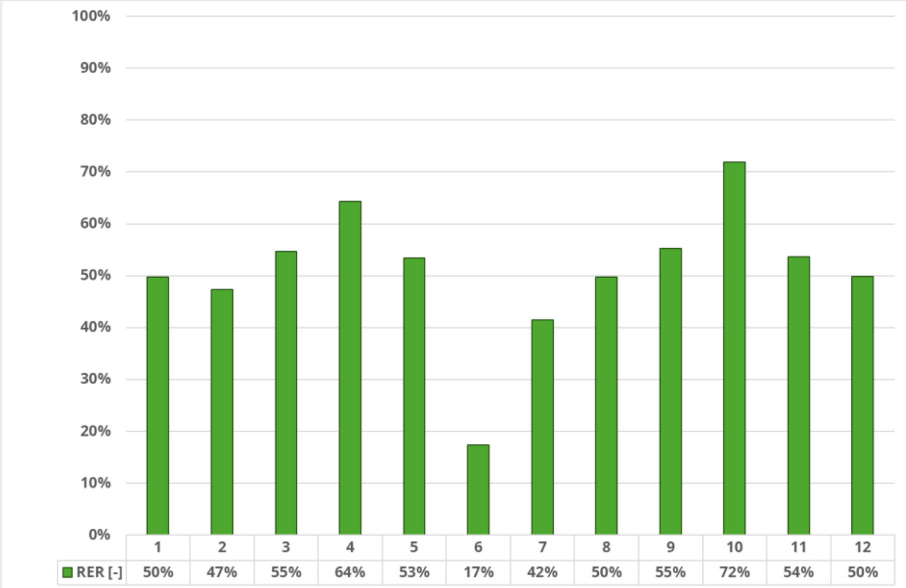


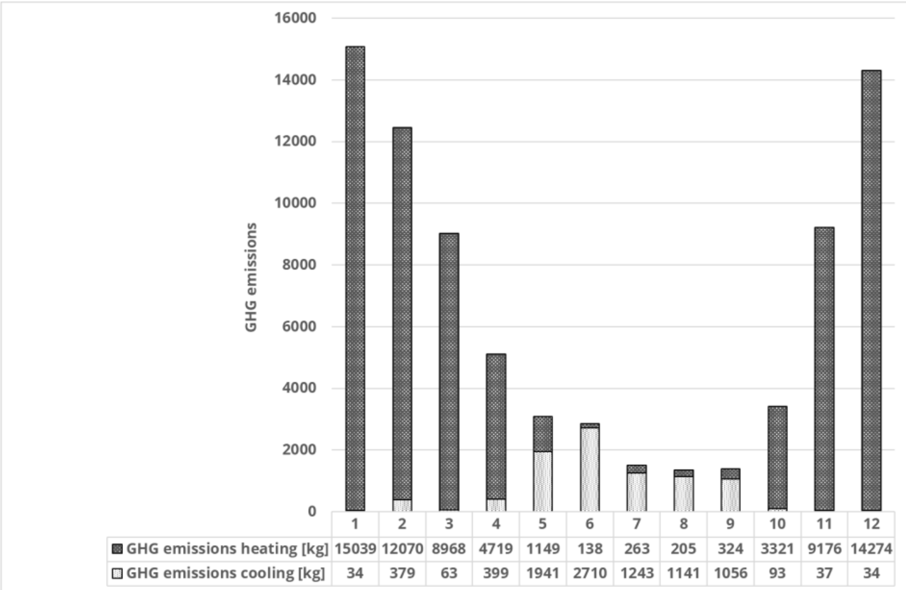
Figure 8.8 - Monthly renewable energy ratio

Figure 8.9 presents the monthly CO_2 emissions and the specific values. The analysis applies distinct CO_2 emission factors to HTDH and electricity source [9]:

- High temperature DH CO_2 emission factor → 189 g/kWh
- Electrical energy CO2 emission factor → 708 g/kWh

The network annual CO_2 emissions total 78,776 kg. Most of them occur during the winter months, coinciding with increased heating demand and used of the backbone DH. Although the extremely high factor associated to the electrical vector, the CO_2 emissions in summer are limited.

The average specific CO_2 emissions are 167 and 25 kg/MWh for heating and cooling respectively. This efficiency underscores the system's strong reliance on renewable energy sources and its minimal environmental impact.



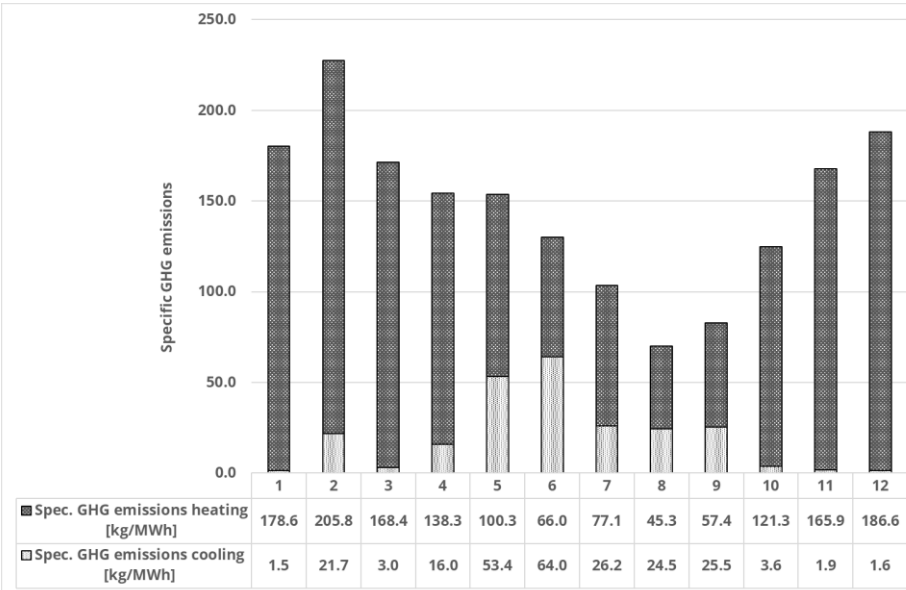


Figure 8.9 - Monthly CO2 emissions (top) and specific CO2 emissions (bottom) for heating and cooling

8.3 Remarks

The system showcases a contemporary approach to sustainable energy management by maximizing resource efficiency, minimizing energy losses, and utilizing waste heat to meet heating demands. The findings emphasize the significant role of waste heat integration and energy-efficient design in lowering the environmental impact of heating and cooling systems, offering a scalable and adaptable framework for future energy solutions.

Table 8.1 summarizes the system annual energy needs and environmental performance calculations reported above.

Table 8.1 – Overall system annual energy uses, and performance calculated

	Notation	Annual values	Unit of meas.
	Heating consumption	416	MWh/y
	Cooling consumption	367	MWh/y
	Electricity use for heating	5	MWh/y
	Electricity use for cooling	13	MWh/y
	HTDH use for heating	350	MWh/y
	Local WH use	180	MWh/y
	Ren. PE for heating	330	MWh/y
	Total PE for heating	591	MWh/y
	Ren. PE for cooling	0	MWh/y
	Total PE for cooling	32	MWh/y
	Renewable Energy Ratio	53	%
	GHG emissions for heating	70	ton/y
	GHG emissions for cooling	9	ton/y

- The demonstration site is Poland's first low-temperature hybrid DHC network, utilizing the E.ON ectogrid™ concept to supply heating and cooling within a temperature range of 25-50°C, enabling energy-efficient operations.
- Renewable contributions to heating are derived from waste heat and the partially renewable energy mix of the high-temperature DH source. However, summer cooling relies on non-renewable electricity, indicating room for further improvement.
- Waste heat from chillers plays a significant role in meeting heating demand, contributing to an annual RER of about 50%. During spring and autumn, increased waste heat use elevates the RER further.
- Annual CO_2 emissions total 78,776 kg, with heating accounting for higher emissions due to reliance on the high-temperature DH system. The system achieves strong environmental performance with specific emissions of 167 kg/MWh for heating.
- Cooling demand is effectively met with minimal energy consumption, using circulation pumps and cooling towers, resulting in specific CO_2 emissions of just 25 kg/MWh for cooling.

9 Topusko, Croatia

9.1 Description of the demonstration site

The area of Topusko is rich in thermal springs. The concessionaire for the extraction of geothermal hot water is Health Spa Topusko and Top-Terme LCC, who manage a large healthcare structure including hotels, mud baths and swimming pools.

Heating and DHW preparation for all buildings and facilities takes place inside the central thermal station (CTS, Figure 9.1): geothermal water is collected from the TEB-4 well @ 62°C and used to condition technical water to the different temperature levels needed; technical water is then distributed from here to the uses.

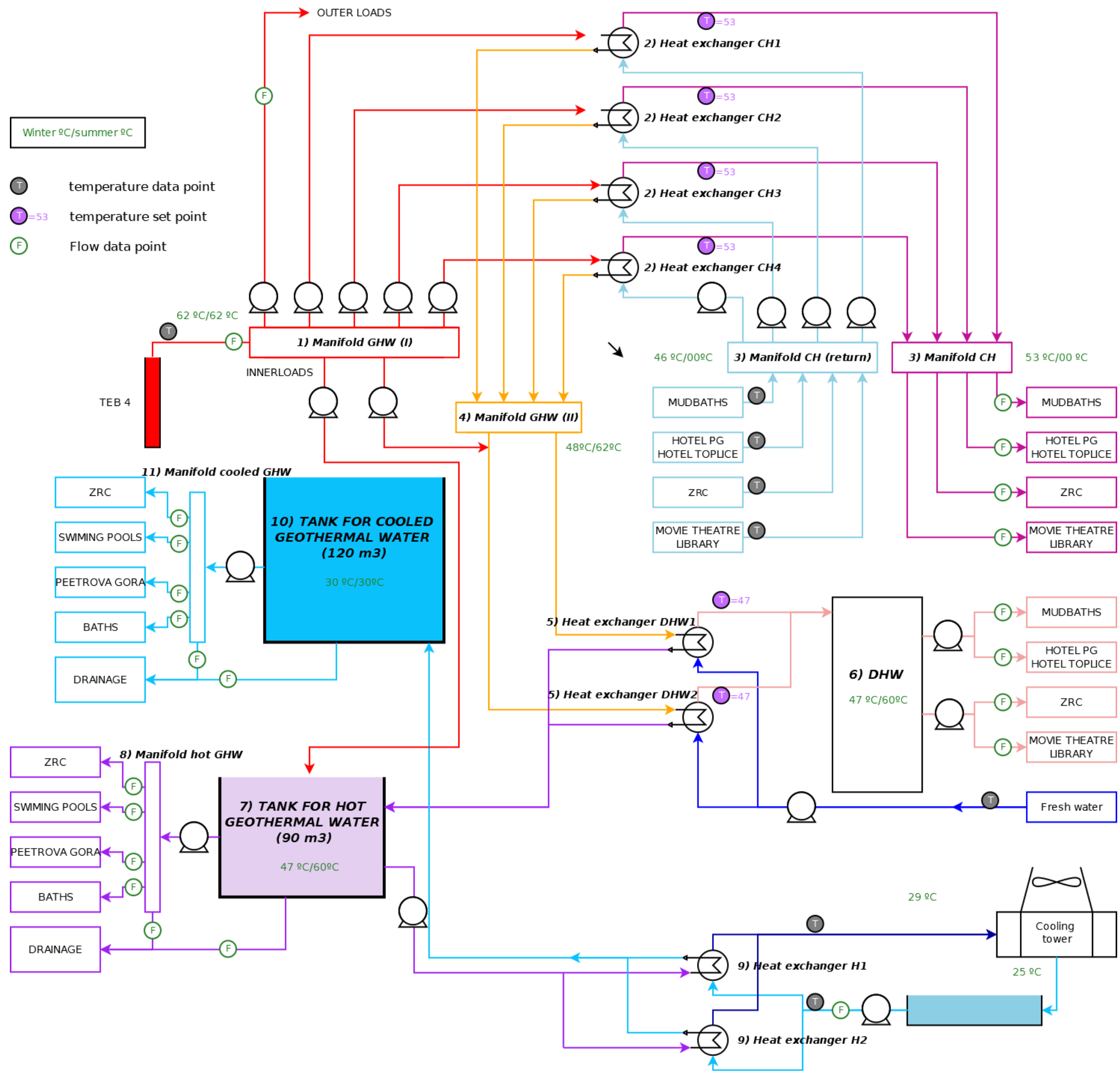


Figure 9.1: Scheme of energy facilities in Topusko.

Four heat exchangers, 712 kW_{th} capacity each, generate heating for all buildings @ 50°C. From here, geothermal water is cascaded to the heat exchangers devoted to the preparation of DHW stored @47 °C in one 10m^3 TES, and further distributed to the water storages for balneology and swimming pools. Two concrete tanks store water at high temperature (90 m^3 @ 47°C) and low temperature (120 m^3 @ 30°C). In the latter case, water is preliminary cooled by means of a wet cooling tower. Water from the two TES is distributed to baths or swimming pools where it is mixed to obtain the needed temperature level.

In addition to distributing geothermal and technical water throughout the healthcare facility, high electricity consumption is also required to operate the wet cooling tower. This demand is particularly pronounced during the summer when there is no need for space heating, hence higher temperature water is available after DHW preparation.

9.1.1 Objectives and main results of the demonstration activity

Within REWARDHeat a complete refurbishment of the CTS and of the structure's DH network has been performed, aimed to significantly increase the overall system energy efficiency. The following measures have been implemented:

- All pipelines from TEB-4 to CTS and from CTS to all uses have been replaced with insulated ones
- CTS pipes have been substituted, constant speed pumps and wet cooling tower's fans have been replaced with inverter-controlled, variable-speed ones, and manual valves have been replaced with remotely controlled ones. This allowed to implement an active control of both mass flows and temperature set points at the CTS.

Specifically. the main supply pipeline from TEB-4 to the CTS was renewed. Significant changes within the CTS include reconstructing the main inlet divider for geothermal water from TEB-4. New geothermal pipelines in the CTS are made of AISI 316L stainless steel to increase durability; new frequency-regulated circulation pump and automatic valve flow regulators were installed on the new pipeline to regulate the flow based on outlet and external air temperatures.

Dividers for chilled and hot geothermal water were reconstructed; flow meters were installed on main output pipelines to internal consumers. DHW systems were implemented, featuring DHW tanks with internal spiral heaters at various heating substations. Additionally, five 3 m^3 DHW tanks were installed across locations. For DHW preparation, new exchangers were installed in the CTS to use geothermal energy from two sources: either directly from the main inlet divider or from the war concrete tank.

Alongside system upgrades, the outdated control cabinet was replaced with new cabinets that house instrumentation and the central control unit. This central control unit monitors and regulates the entire system, collecting data and adjusting outputs to maximise efficiency. It reduces the need for manual intervention, enhances efficiency, and enables real-time detection of failures and leaks. Developed using ENISYST solutions under the REWARDHeat project, the control system significantly improves monitoring and metering accuracy, offering enhanced insights into consumption and system performance (see Deliverable 5.9 for further details).

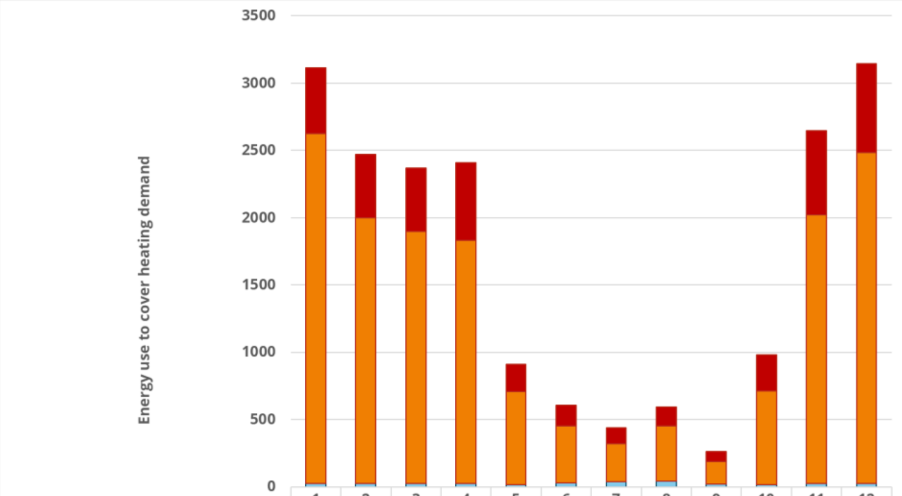
Although building substations could not be substituted nor can be controlled actively as they are owned by the building owners, heat meters have been installed also and connected to the CTS automation system.

9.2 Assessment of the network performance

9.2.1 Energy uses insisting on the network

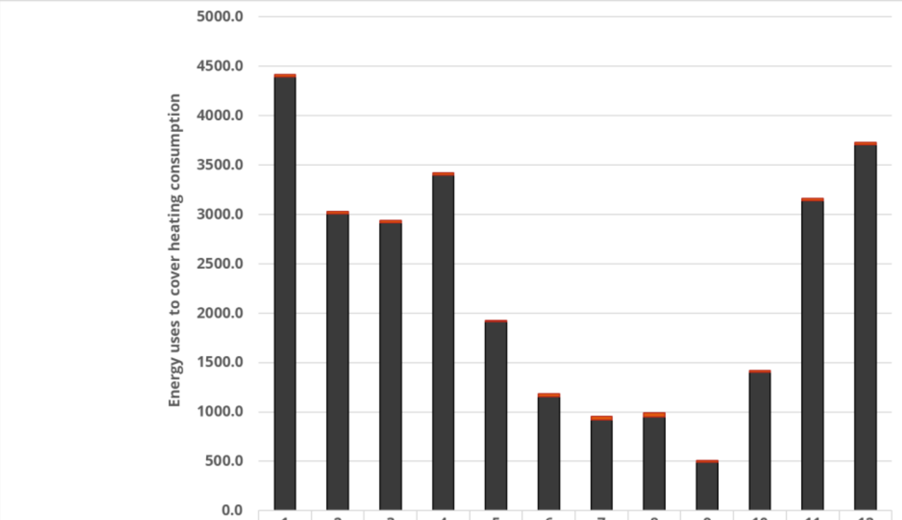
Figure 9.2 shows the building's monthly thermal energy consumption: the heating consumption represents the energy that reaches the different buildings connected to the DH and totals around 15,385 MWh/year, with a peak load of around 2,500 MWh in January and December, while in summer (May to September) the heating consumption is lower and less than 500 MWh/month.

Additionally, swimming pools and outer consumers require around 4561 MWh of geothermal heat for their operation.



	1	2	3	4	5	6	7	8	9	10	11	12
Pools & outer consumers [MWh]	488	471	473	578	203	155	116	139	78	268	623	659
Buildings heating demand [MWh]	2599	1975	1874	1807	695	421	283	411	168	697	1997	2460
Electricity use [MWh]	27	25	24	23	14	31	39	43	18	16	26	25

Figure 9.2 - Monthly thermal energy consumption of the buildings, pools and outer consumers



	1	2	3	4	5	6	7	8	9	10	11	12
Electricity use heating [MWh]	26.6	24.6	23.7	22.6	13.6	30.7	39.5	43.3	18.4	15.7	26.2	25.3
Energy from TEB [MWh]	4393.6	3006.1	2914.2	3398.4	1914.5	1156.5	917.4	949.4	491.4	1403.8	3136.6	3704.3

Figure 9.3 - Energies use for heating

Figure 9.3 illustrates the energy vectors used to meet the heating demand. Heating is primarily supplied from the thermal energy borehole (TEB), while the electricity consumed in the circulation pumps is extremely low compared to the overall figures. The overall TEB energy use amounts to 27,373 MWh, while only 310 MWh of electricity are consumed. Although the optimization work performed with respect to the water distribution from the TEB to the users, the energy losses still about to 25% of the energy extracted and peak to about 50% in summer, highlighting margins for further improvement.

9.2.2 Performance indicators assessment

Figure 9.4 illustrates the buildings monthly primary energy use for heating. For each energy vector, specific primary energy factors have been applied according to the regulation of the country [10]:

- TEB total primary energy factor → 1.0 (of which 1.0 is considered renewable)
- Electricity total primary energy factor → 2.20 (of which 0.62 is considered renewable)

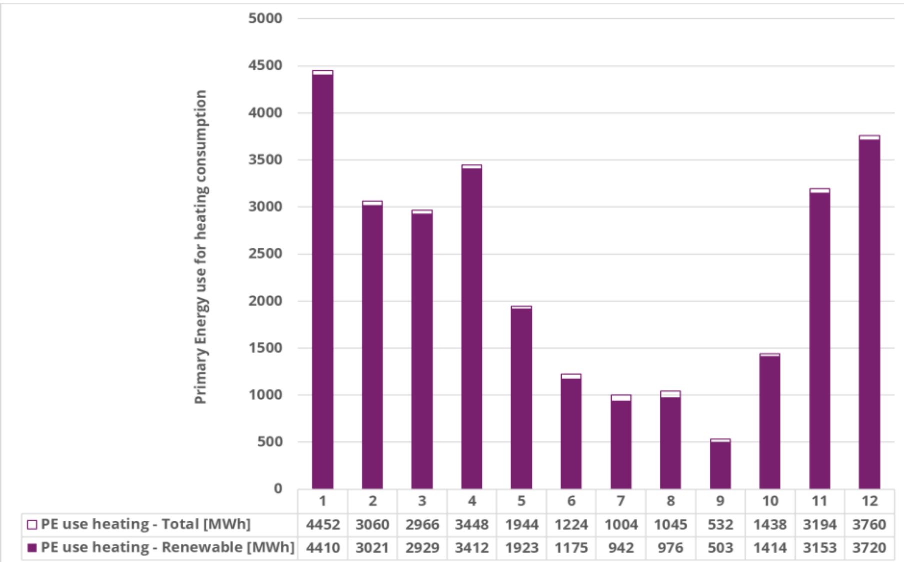


Figure 9.4 - Monthly renewable and total primary energy uses for heating consumption of the buildings

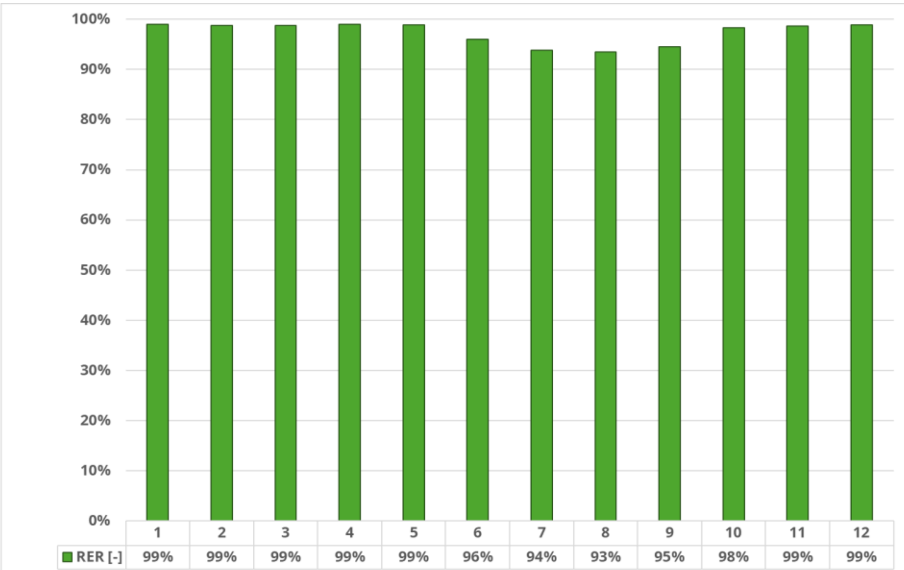
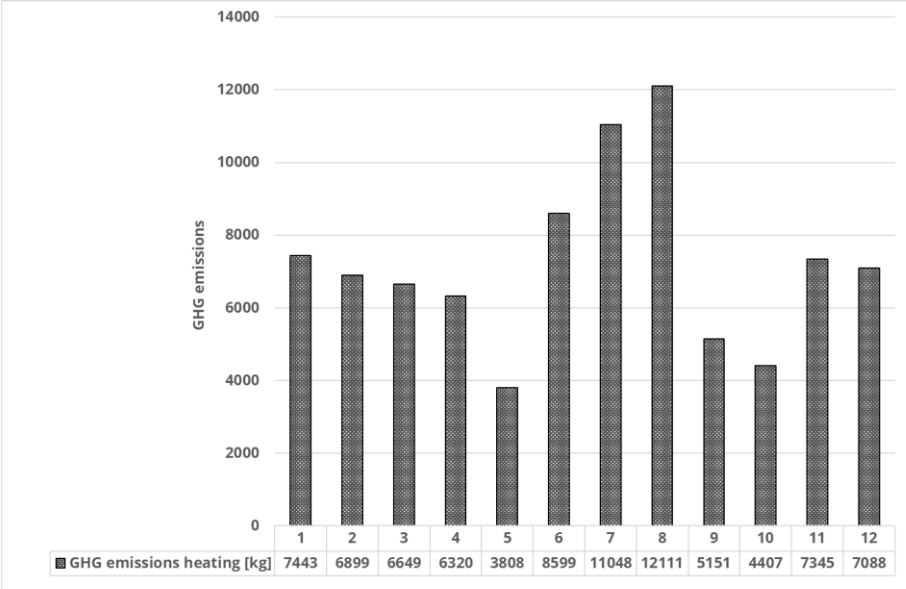


Figure 9.5 - Monthly renewable energy ratio

Over the course of the year, the building's total primary energy consumption reaches 28,069 MWh. Of this total, 27,577 MWh is derived from renewable sources. Primary energy use is markedly linked to the use of the TEB since it is the only energy source with the electricity affecting very few in the total amount of primary energy.

The RER shown in Figure 9.5 varies in the range between 95% and 99% along the year, following the variation of electricity uses.



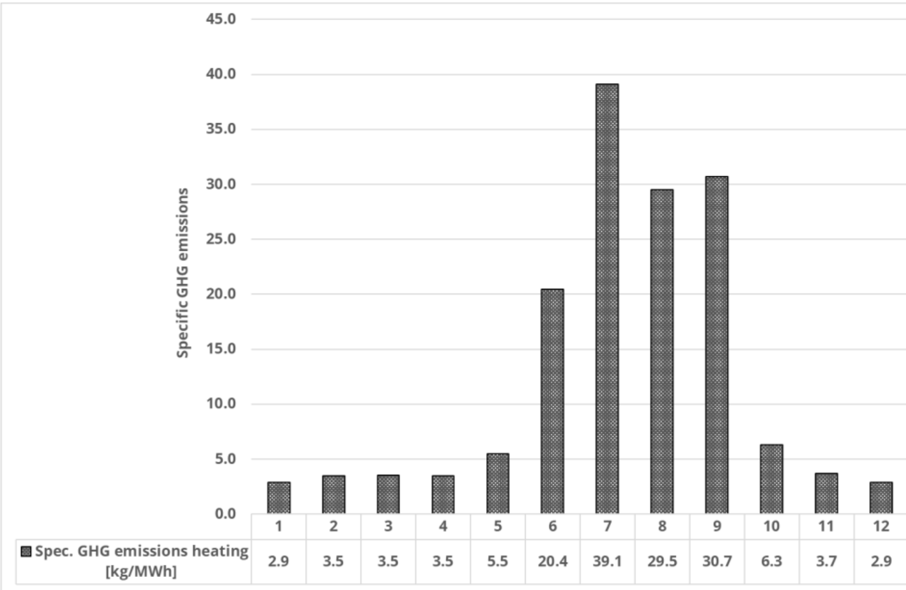


Figure 9.6 - Monthly CO2 emissions (top) and specific CO2 emissions (bottom) for heating

Figure 9.6 represents the monthly greenhouse gas emissions associated with the energy system. The CO_2 emissions assessment accounts for an electricity CO_2 emission factor of 280 g/kWh [11].

The annual CO_2 emissions from its heating system totals 72,845 kg linked to the electricity used in the circulation pumps. A significant portion of the CO_2 emissions occurs during the winter months, coinciding with increased heating demand. During these colder months, specific CO_2 emissions range between 3 and 6 kg/MWh. The rest occurs during summer (June to August) due to the use of additional electricity used in the cooling towers. Similarly, the specific CO_2 during summer shows higher values than during winter ranging between 20 and 40 kg/MWh due to the use of more electricity but presenting lower heating demands. However, the yearly averaged specific CO_2 emission factor of the DH shows a very low value around 5.5 kg/MWh.

9.3 Remarks

Table 9.1 summarizes the system annual energy needs and environmental performance calculations reported above.

Table 9.1 – Overall system annual energy uses, and performance calculated

	Notation	Annual values	Unit of meas.
	Heating consumption	19636	MWh/y
	Electricity use for heating	310	MWh/y
	Local RES use - Geothermal	27063	MWh/y
	Ren. PE for heating	27537	MWh/y
	Total PE for heating	27735	MWh/y
	Renewable Energy Ratio	0.98	-
	GHG emissions for heating	73	ton/y

The system's environmental performance shows higher emissions during summer and lower emissions in winter, driven by seasonal heating demands and electricity usage patterns. Despite these variations, the system's low absolute emissions and specific CO_2 emission factor, combined with its exceptionally high RER, demonstrate a renewable district heating model that sustainably utilizes geothermal resources.

- Upgrades to the central thermal station (CTS) and DH network have significantly enhanced energy efficiency and operational flexibility. The newly implemented ENISYST control system facilitates real-time monitoring and efficient flow management, reducing manual interventions and optimizing system performance.
- The integration of geothermal energy with advanced control technologies and an efficient system design provides a replicable blueprint for sustainable district heating systems, particularly in regions with abundant geothermal resources.
- Despite relying on pumps and cooling towers, electricity consumption is minimal relative to the geothermal energy used, further minimizing the environmental impact. In summer, excess geothermal energy is managed via cooling towers to meet pool temperature requirements. This operation slightly increases specific CO_2 emissions (20-40 kg/MWh) due to higher electricity usage during this period.

10 Conclusions

In this section, we present the cumulative yearly results for the eight demonstration sites assessed (see tables attached at the end of the section), aiming to summarize the achievable objectives of the REWARDHeat technologies. These objectives include renewable energy utilization, primary energy savings, and CO_2 emissions reductions, compared to a reference system meeting equivalent heating and cooling demands using individual gas boilers and chillers in single buildings.

Unlike in the previous chapters, the renewable energy content in this analysis also accounts for energy imported from electricity grid and district heating city backbones, in addition to locally harvested renewable energy, contributing further to lowering the non-renewable primary energy content and CO_2 emissions compared to the reference system concerned.

- The overall renewable energy content across the demonstration cases varies significantly, ranging from approximately 50% to nearly 100%. Sites achieving the highest renewable energy share are those where renewable heat is either locally harvested or transported via a city's backbone network with a high renewable energy content. Conversely, sites relying heavily on electricity for heating and cooling production through reversible heat pumps show lower renewable energy shares. This is due to several factors: (i) the imported electricity from the grid still contains a relatively low share of renewable energy, ranging from nearly zero in France to about 40% in Italy; (ii) some demonstration sites, such as Gardanne and La Seyne-sur-Mer, are still in the process of installing PV plants intended to supply local renewable electricity; and (iii) these systems are designed to address both heating and cooling demands. Particularly in the case of cooling, regardless of how high the system's seasonal Energy Efficiency Ratio is, achieving 100% renewable energy coverage is inherently impossible.
- In terms of non-renewable primary energy use, significant reductions are observed compared to the reference systems, ranging from 55% to nearly 70%. However, networks that depend on heat pumps tend to exhibit lower reductions, with the cases in Gardanne and La Seyne-sur-Mer even showing an increase. This is attributed to substantial distribution losses that necessitate high electricity consumption for pumping, underscoring the critical importance of optimizing the distribution circuit, even for neutral-temperature DHC networks.
- CO_2 emissions demonstrate an impressive reduction across the board, ranging from 60% to 98%. This dynamic is particularly evident in the French demonstration networks, which benefit significantly from the country's reliance on nuclear power for electricity generation. While this observation is not intended as an endorsement of increased nuclear energy production for heating and cooling purposes, it highlights the inherent flexibility of these systems to adapt to future improvements in both local energy generation and the broader energy system. Only the Italian network reports more modest reductions, due to one of the connected buildings still relying significantly on fossil gas, highlighting the need for further improving the building control strategy.
- These findings emphasize the critical need to increase the share of renewable energy, ideally through local harvesting or by importing energy from "renewable" grids. While DHC networks that rely on heat pumps are already demonstrating significant reductions in CO_2 emissions, their potential can be further maximized by utilizing electricity sourced through Power Purchase Agreements, as these agreements ensure the renewable origin of the energy. Moreover, as electricity grids continue to integrate higher proportions of decarbonized energy sources, the overall environmental performance of these networks will improve even further.

		Albertslund (DK)			Gardanne (FR)			Helsingborg (SE)			La Seyne-sur-Mer (FR)		
		Renewable energy [MWh]	Non Renewable energy [MWh]	Total energy [MWh]	Renewable energy [MWh]	Non Renewable energy [MWh]	Total energy [MWh]	Renewable energy [MWh]	Non Renewable energy [MWh]	Total energy [MWh]	Renewable energy [MWh]	Non Renewable energy [MWh]	Total energy [MWh]
Heating	Electricity	4,8	0,9	5,7	77,0	207,2	284,2	70,3	30,4	100,7	245,0	659,2	904,2
	DH	2253,9	118,6	2372,5	0,0	0,0	0,0	68,6	0,1	68,7	1101,8	0,0	1101,8
	Gas	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	469,1	469,1
	Local RES&WH	0,0	0,0	0,0	319,6	0,0	319,6	205,0	0,0	205,0	0,0	0,0	0,0
	Total	2258,6	119,6	2378,2	396,6	207,2	603,8	343,9	30,5	374,4	1346,8	1128,3	2475,1
Cooling	Electricity	0,0	0,0	0,0	49,3	132,8	182,1	0,6	0,2	0,8	155,3	417,7	573,0
	DH	0,0	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0	0,0	0,0
	Gas	0,0	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0	0,0	0,0
	Local RES&WH	0,0	0,0	0,0	87,7	0,0	87,7	22,7	0,0	22,7	1130,9	0,0	1130,9
	Total	0,0	0,0	0,0	137,0	132,8	269,8	23,3	0,2	23,5	1286,2	417,7	1703,9
Total	Electricity	4,8	0,9	5,7	126,4	339,9	466,3	70,8	30,7	101,5	400,3	1076,9	1477,2
	DH	2253,9	118,6	2372,5	0,0	0,0	0,0	68,6	0,1	68,7	1101,8	0,0	1101,8
	Gas	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	469,1	469,1
	Local RES&WH	0,0	0,0	0,0	407,3	0,0	407,3	227,7	0,0	227,7	1130,9	0,0	1130,9
	Total	2258,6	119,6	2378,2	533,7	339,9	873,6	367,2	30,7	397,9	2633,0	1546,0	4179,0
% Renewable energy	Heating	95,0%			65,7%			91,9%			54,4%		
	Cooling				50,8%			99,0%			75,5%		
	Total	95,0%			61,1%			92,3%			63,0%		
CO2	[kg]	137197			21145			3167			173600		
CO2 with gas	[kg]	371817			149206			78935			690844		
CO2 difference	[-]	-63%			-86%			-96%			-75%		
PE non ren	[MWh]	818			1106			131			4282		
PE non ren with gas	[MWh]	1851			748			397			4022		
PE difference	[-]	-56%			48%			-67%			6%		

		Milan (IT)			Mölndal (SE)			Szczecin (PL)			Topusko (HR)		
		Renewable energy [MWh]	Non Renewable energy [MWh]	Total energy [MWh]	Renewable energy [MWh]	Non Renewable energy [MWh]	Total energy [MWh]	Renewable energy [MWh]	Non Renewable energy [MWh]	Total energy [MWh]	Renewable energy [MWh]	Non Renewable energy [MWh]	Total energy [MWh]
Heating	Electricity	91,9	118,3	210,2	314,4	136,0	450,4	1,3	3,6	5,0	210,9	99,3	310,2
	DH	0,0	0,0	0,0	2062,4	108,5	2170,9	86,9	262,1	349,0	0,0	0,0	0,0
	Gas	0,0	114,2	114,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Local RES&WH	367,9	0,0	367,9	0,0	0,0	0,0	179,7	0,0	179,7	19638,0	0,0	19638,0
	Total	459,8	232,5	692,3	2376,7	244,6	2621,3	267,9	265,7	533,7	19848,9	99,3	19948,2
Cooling	Electricity	14,5	18,6	33,1	16,3	7,0	23,3	3,3	9,0	12,4	0,0	0,0	0,0
	DH	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Gas	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Local RES&WH	0,0	0,0	0,0	365,3	0,0	365,3	0,0	0,0	0,0	0,0	0,0	0,0
	Total	14,5	18,6	33,1	381,6	7,0	388,6	3,3	9,0	12,4	0,0	0,0	0,0
Total	Electricity	106,3	137,0	243,3	330,6	143,1	473,7	4,7	12,7	17,4	210,9	99,3	310,2
	DH	0,0	0,0	0,0	2062,4	108,5	2170,9	86,9	262,1	349,0	0,0	0,0	0,0
	Gas	0,0	114,2	114,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Local RES&WH	367,9	0,0	367,9	365,3	0,0	365,3	179,7	0,0	179,7	19638,0	0,0	19638,0
	Total	474,2	251,2	725,4	2758,3	251,6	3009,9	271,3	274,8	546,1	19848,9	99,3	19948,2
% Renewable energy	Heating	66,4%			90,7%			50,2%			99,5%		
	Cooling	43,7%			98,2%			27,0%					
	Total	65,4%			91,6%			49,7%			99,5%		
CO2	[kg]	92369			33700			79000			73000		
CO2 with gas	[kg]	154350			522749			191669			4771548		
CO2 difference	[-]	-40%			-94%			-59%			-98%		
PE non ren	[MWh]	659			1405			293			198		
PE non ren with gas	[MWh]	796			2674			705			20618		
PE difference	[-]	-17%			-47%			-58%			-99%		

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