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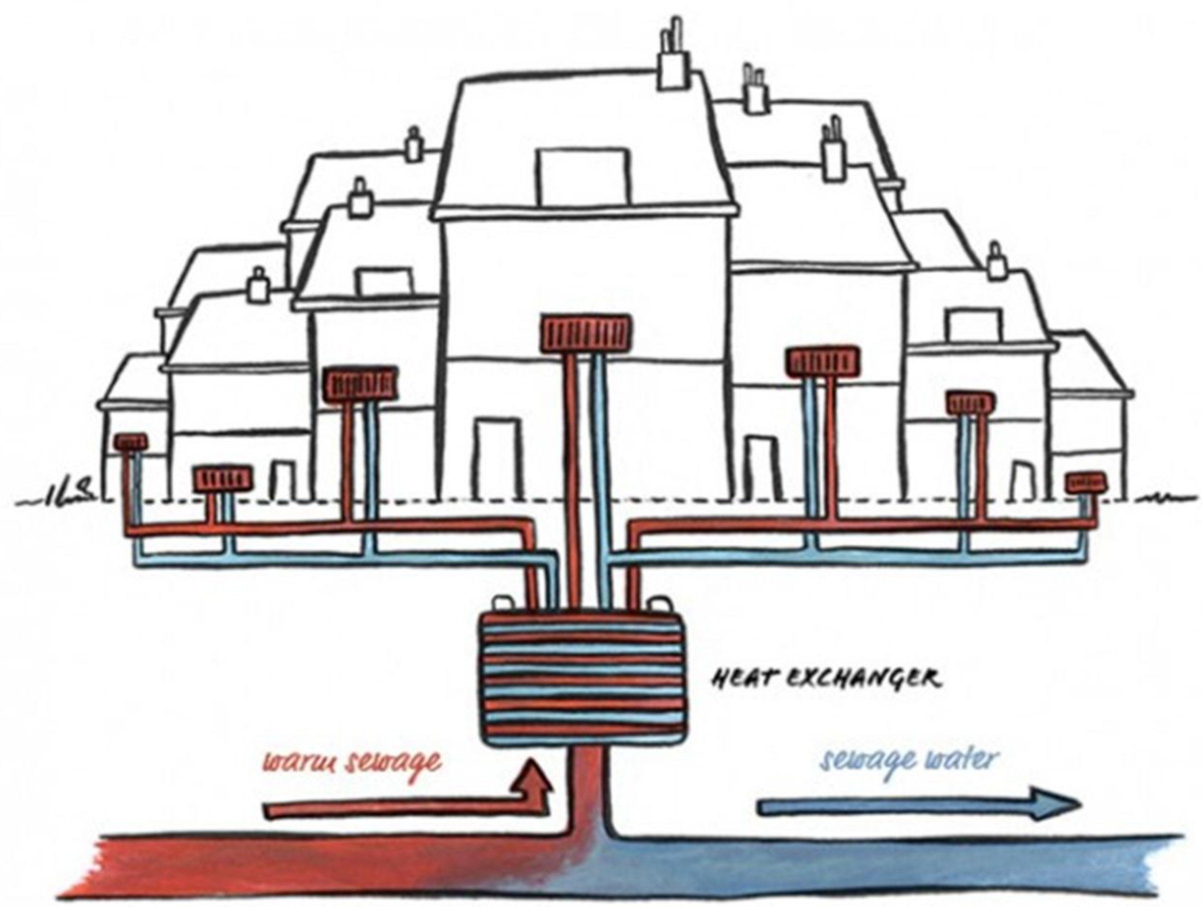
Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

INTERREG IVB

Appendix 6

Heat recovery from the sewer system



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Summary

The demonstration project in Leuven is part of work package 2 of the INNERS project and demonstrates a sewage heat recovery system in a residential context. Sewage heat is used for the heating of 91 apartments in Belgium, using a heat exchanger and a heat pump. The heat exchanger extracts heat from the warm wastewater (17-19°C during winter) and a heat pump delivers the heat at temperatures up to 55°C to a heating circuit. The heat pump has an overall Coefficient of Performance (COP) of 4,5. This means, for every 4,5 kWh added to the heating circuit the heat pump consumes 1 kWh of electricity. According to the UCPTE (Union for the Coordination of Transmission of Electricity in Europe) 1 kWh electricity corresponds with 2,5 kWh of fossil based primary energy (for example gas).

Therefore, the CO_2 emissions of fossil fuel based systems (e.g. gas condensing boiler) are considerably higher than CO_2 emissions of heat recovering systems.

In this demonstration project we aim to maximize the CO_2 reductions and match the available sewage heat with the residential heat demand in a renovated apartment dating from 1980.

The following problems occurred during the start-up and were corrected:

1. The sieve, lying in the sewer pipe, prevents the connection pipe between sewer and sump to block. Bigger pieces flowing through the sewer though can get stuck and can cause a total or partial clogging of the sieve.
2. The collector, located below the sieve, can clog as sand accumulates. The accumulation of sand occurs when the water level in the sump remains high and no water flows from the sewer into the sump.
3. Fouling of the heat exchanger as biofilm grows on the plates.

Measurements of the wastewater temperature during winter (December 2014 – January2015) show a temperature of 17-19°C at dry weather and a temperature of 14-15,5°C during rain at outdoor temperatures going below zero °C.

1 Background

One possibility to reduce the need for fossil energy for households is heat recovery from wastewater running in sewers. At this moment, the method of recovering heat sewers is not common in Belgium. By showing the feasibility and the potential gain of thermal energy from municipal sewers, the use of this technology shall be promoted and adapted.

In this demonstration project, VLARIO launches a project involving a heat exchanger and heat pump directly supplying thermal energy to 100 nearby situated households.

1.1 Main goals and objectives of the demonstration project

Work package 2 demonstrates the thermal energy recovery from the sewer and its application in residential buildings. The following objectives were set:

- Demonstrate the use of sewage heat for pre-heating the domestic hot water from +/- 10°C to 20°C and further till 55°C with a heat pump.
- Demonstrate the use of sewage heat to produce heating water of 45-55°C with an average COP of 4,5.
- Demonstrate the use of sewage heat recovery in a renovated building.
- Half the CO_2 emissions compared with a standard gas boiler.
- Demonstrate the seasonal variation in sewer temperature and COP of the heat pumps.

Recovering thermal energy is a key to a sustainable urban water cycle because it is the energy source with the highest recovery potential. Work package 2 will demonstrate the advantages of recovering thermal energy from the urban water cycle and its use in several applications. To achieve the overall INNERS goal of optimizing energy use in the urban water cycle, the partners will develop new ways of producing sustainable energy so that the energy consumption in the whole urban water cycle can be reduced. With the outcomes of work package 1, locations will be selected where thermal energy can be reused. The results of the demonstration projects will be further used (work package 4) to show that thermal energy can be recovered, usefully applied and act as a brick.

1.2 Guideline through this report

The report gives an overview of the planning, the technical realization and the results of the demonstration project. Special attention is paid to the challenge of finding a suitable location, the formal procedures, the installation of an external heat exchanger on the public sewer and the results observed from temperature measurements.

2 Set up of the project

2.1 Screening potential residential buildings

Residential buildings were screened according to the following criteria in order to match a sewage heat recovery system:

- number of buildings, hospitals, etc. connected to the sewer passing the residential building,
- If the house / building is located at the beginning of the sewerage it will not be suitable for a heat recovery system due to a limited flow of wastewater,
- existence of a central heating system for the units,

- number of units are connected to the central heating. A minimum of 80 units was set as a criteria because of the feasibility of the techniques and the value as a demonstration project.

2.2 Feasibility study

The following questions were taken into account within the study:

- Can the installed heat recovery system cover the residential heat demand by utilizing the available sewerage heat?
- Can a low temperature heating regime (45/35°C-20°C) satisfy the heating comfort of the residents, at least during autumn and spring?

2.3 Tendering

A tender request was sent in order to find a contractor who can offer full engineering-procurement-construction-and maintenance services. The following details enabled the contractors to prepare a final tender:

- the distribution of the primary energy demand of the building over the year
- the sewage characteristics (temperature variation, flow ….)

The tender request gave the addressed contractors the opportunity to demonstrate different installation layouts of their technology (for example: heat exchanger in- or outside the sewer) and to inform us if they can quote for the full engineering-procurement-construction and maintenance services. With this tender request we require the estimation of the performance of their system and budget. If necessary, additional information would be asked.

2.4 Building specifications

The heating systems consist of one back-up gas-condensing boiler and one liquid/liquid heat pump extracting heat from the sewer. The building is recently renovated including insulation of the building and therefore feasible for low temperature heating.

2.5 Monitoring

The installation of the sewage heat recovery system was finished at the beginning of July 2014. The system was monitored from the starting of the heating system in October until the end of January.

3 Main results

3.1 Feasibility study

In accordance to these selection criteria in 2.1, a block of apartments in the Monseigneur Van Waeyenberghlaan (Leuven, BE) has been found. The public sewer in the street collects the wastewater from the city hospital, discharging 1000-1500 m³ wastewater per day with a temperatures above 15°C . The city hospital itself was not interested in heat recovery because they could not find an application for low temperature heat as the temperature of their heating water is > 60°C and the use of hot water is negligible compared to the disposed volume. The apartment in the Mgr. Van Waeyenberghlaan is owned by a social housing department (Dijledal), consists of 93 units and is heated by a central heating system.

During spring, i.e. between 19th of June and 27th of June 2014 a monitoring campaign of the sewer's wastewater temperature and flow rate was carried out. Wastewater temperature and flow rate was monitored and an hourly average was given for 9 days continuously. We measured an average flow rate of 45 m³/h and a temperature ranging between 15 and 22°C. Due to the discharge of the upstream city hospital the sewage temperature is higher compared to 'normal' sewers which varies between 7 and 25 °C across the year (See also: the paper 'Predicting wastewater temperatures in sewer pipes using abductive network models' for normal sewer temperatures.)

Based on the building scheme of the apartments (1980) the heating capacity of the radiators was calculated at a high temperature level [80/60°C-20°C]. Afterwards capacity of the radiators in the different apartments were measured and their heating capacity was determined at a low temperature regime [45/35°C-20°C]. At a high temperature regime the total heating capacity of all 93 apartments was 635 kW, at a low temperature regime the heating capacity was 176 kW.

J		I		H	
8,130	7,469	6,542		8,754	8,469
6,506	5,854	5,304	7,185	6,800	8,056
6,506	5,854	5,304	5,763	6,800	7,653
6,506	5,854	5,304	5,763	6,800	7,653
6,717	5,854	5,460	5,763	6,800	8,167
7,359	7,772	5,607	6,790	7,230	8,415

G		F		E		D	
8,653	7,680	6,754	7,525	6,038	7,598	7,194	7,570
6,781	5,873	6,203	5,910	6,166	5,726	5,708	8,066
6,781	5,873	6,203	5,910	6,166	5,726	5,708	7,552
6,781	5,873	6,203	5,910	6,166	5,726	5,708	8,139
6,965	5,873	6,194	5,910	6,377	6,304	7,204	6,909
7,910	7,570	6,699	7,258				

C		B		A	
9,158	10,442	8,919	9,213	7,846	10,452
8,984	8,350	8,488	7,726	7,965	9,387

totaal 635 kW

Table 1: Heating capacity of the radiators in the different apartments in blocks A-J at a heating regime of [80/60°C-20°C].The table gives a front view of the apartment block.

J		I		H	
3,613	3,320	2,908		3,891	3,764
2,892	2,602	2,357	3,193	3,022	3,580
2,892	2,602	2,357	2,561	3,022	3,401
2,892	2,602	2,357	2,561	3,022	3,401
2,985	2,602	2,427	2,561	3,022	3,630
3,271	3,454	2,492	3,018	3,213	3,740

G		F		E		D	
3,846	3,413	3,002	3,344	2,684	3,377	3,197	3,364
3,014	2,610	2,757	2,627	2,740	2,545	2,537	3,585
3,014	2,610	2,757	2,627	2,740	2,545	2,537	3,356
3,014	2,610	2,757	2,627	2,740	2,545	2,537	3,617
3,096	2,610	2,753	2,627	2,834	2,802	3,202	3,071
3,516	3,364	2,977	3,226				

C		B		A	
4,070	4,641	3,964	4,095	3,487	4,645
3,993	3,711	3,772	3,434	3,540	4,172

totaal 282 kW

Table 2: Heating capacity of the radiators in the different apartments in blocks A-J at a heating regime of [55/45°C-20°C]. The table gives a front view of the apartment block.

J		I		H	
2,258	2,075	1,817		2,432	2,353
1,807	1,626	1,473	1,996	1,889	2,238
1,807	1,626	1,473	1,601	1,889	2,126
1,807	1,626	1,473	1,601	1,889	2,126
1,866	1,626	1,517	1,601	1,889	2,269
2,044	2,159	1,558	1,886	2,008	2,338

G		F		E		D	
2,404	2,133	1,876	2,090	1,677	2,111	1,998	2,103
1,884	1,631	1,723	1,642	1,713	1,591	1,586	2,241
1,884	1,631	1,723	1,642	1,713	1,591	1,586	2,098
1,884	1,631	1,723	1,642	1,713	1,591	1,586	2,261
1,935	1,631	1,721	1,642	1,771	1,751	2,001	1,919
2,197	2,103	1,861	2,016				

C		B		A	
2,544	2,901	2,478	2,559	2,179	2,903
2,496	2,319	2,358	2,146	2,213	2,608

totaal 176 kW

Table 3: Heating capacity of the radiators in the different apartments in blocks A-J at a heating regime of [45/35°C-20°C]. The table gives a front view of the apartment block.

Further study of the building and renovation schemes gave us the information to simulate the average monthly primary energy demand of the apartment (EPB software- Flemish Energy Agency) and the heat demand at different outdoor temperatures.

EPB study of the complete building:

1. **Input parameters**

Type of structure	Orientation	Surface [m²]	U [W/(m².K)]
Wall	South	359	0,8
Wall	North	1168	0,27
Wall	East	524	0,27
Wall	East	126	0,8
Wall	West	524	0,27
Wall	West	126	0,8
Door	North	49	1,92
Window	South	942	3,5
Window	North	364	1,1
Ceiling under Roof		1606	0,74
Floor above basement		1606	0,77
Type of Heating	Efficiency of releasing heat [%]	Efficiency of producing heat [%]	Return temperature of heating system [°C]
Central	69	86	58
Type of Ventilation			
Free input, mechanical output			

2. **Software**

The input parameters above are introduced in the 'EPB Software 1.7.2' made available by the Flemish Energy Agency (VEA). This software gives the following output for heating the inner space in a Flemish climate:

1. Transmission losses (TL) [MJ]
2. Ventilation losses (VL) [MJ]
3. Internal gains (IG) [MJ]
4. Solar gains (SG) [MJ]

Using this output, the net energy requirements, gross energy requirement and the primary energy demand can be calculated with the following formulas:

$$Net\ energy\ requirements = TL + VL + IG + SG$$
$$Gros\ energy\ requirements = Net\ energy\ requirements * Efficiency\ of\ releasing\ heat\ (0{,}69)$$

$$Primary\ energy\ demand = Gros\ energy\ requirements * Efficiency\ of\ heat\ production\ (0{,}86)$$

Correspondingly the primary energy demand for sanitary water is calculated.
This software gives the primary energy demand for each month and gives no peak demand. In this project the peak energy demand will be measured on site by comparing the energy content of the departing and returning heating- and sanitary water (flow- and temperature measurement).

3. Results

Below you can find the monthly primary energy demand for the 93 apartments.

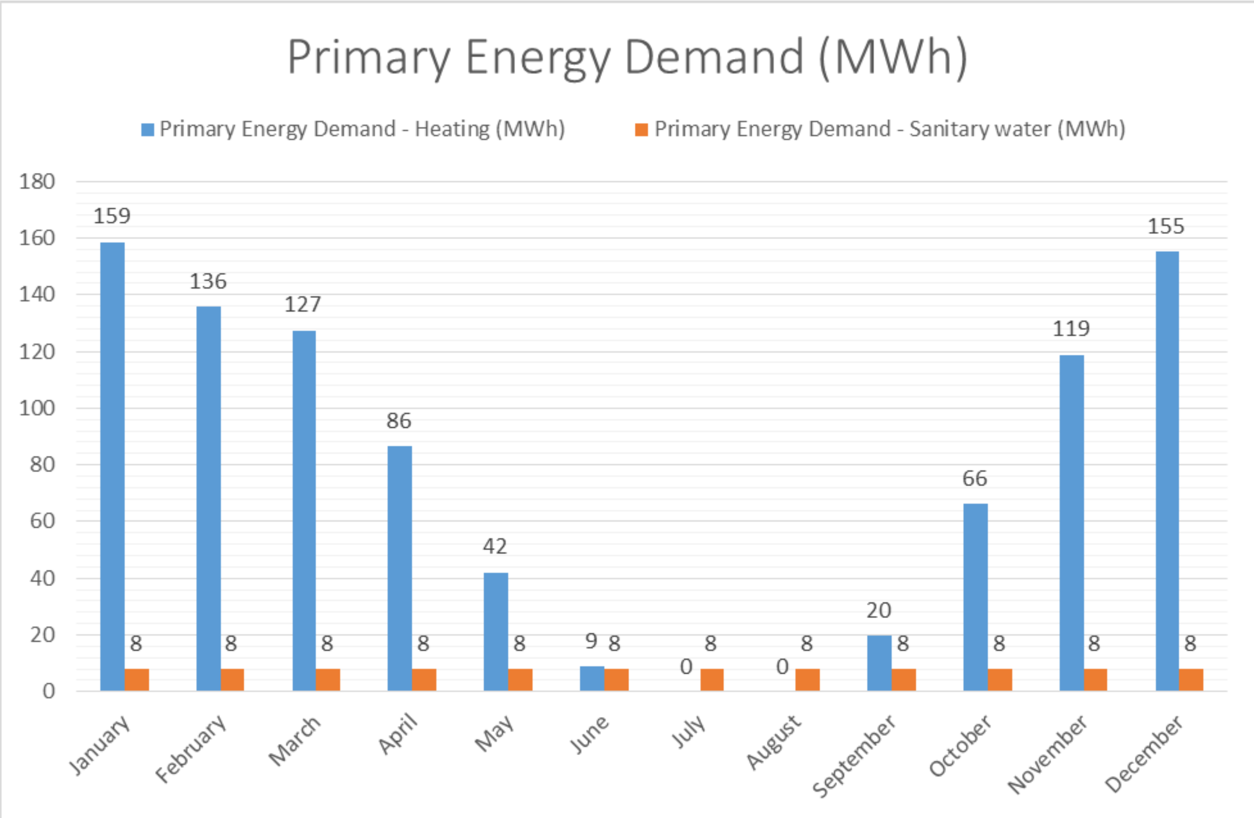


Figure 1: Distribution of the primary energy demand of the 93 apartments in the Van Waeyenberghlaan (Leuven), based on the EPB software of the Flemish Energy Agency.

These results give a yearly primary energy demand of 1015 MWh. While the primary energy of the heating oil that is yearly burned is 923 MWh. This software overestimates the primary energy demand, probably because it assumes that all the apartments are occupied and the average temperature is always 18°C.

Specific for an outdoor temperature of -10°C and an indoor temperature of 20°C we calculated for every apartment the heat losses, see the table below.

J		I		H	
5,566	5,684	4,566		5,566	6,396
4,254	4,027	3,585	5,430	4,254	5,903
4,254	4,027	3,585	3,882	4,254	5,500
4,254	4,027	3,585	3,882	4,254	5,500
4,528	4,027	3,800	3,882	4,528	6,435
5,486	5,788	4,843	5,459	6,076	7,231

G		F		E		D	
5,284	5,173	4,950	4,774	4,789	4,830	4,469	4,727
4,516	4,406	4,181	4,007	4,022	4,062	3,866	5,699
4,516	4,406	4,181	4,007	4,022	4,062	3,866	5,315
4,516	4,406	4,181	4,007	4,022	4,062	3,866	5,879
4,790	4,406	4,456	4,007	5,783	5,824	5,443	5,590
6,112	6,167	5,326	7,339				

C		B		A	
6,161	6,186	6,161	5,531	5,415	6,943
7,294	6,607	7,174	5,952	6,440	7,364

totaal 454 kW

Table 4: Heat loss of the different apartments in blocks A-J at an outdoor temperature of -10°C.

In severe winter conditions when the daily average outdoor temperature is -10°C we certainly need a high temperature regime and use the back-up gas condensing boiler. When daily average temperature is lower than 2°C we reach a cross-over point to a high temperature regime. This means the heat losses of the apartment equal the heating capacity of the radiators (282 kW). In Belgium there are on average 36 days colder than 2°C, therefore we predict that 36 days in a year the gas condensing boilers will deliver the heat for the heating circuit. (Ref. Belgian Measuring Point 'Herentals_ME', n°01ME10-011). Nevertheless we have to take into account the uncertainty of this result, as we are dealing with an old renovated building and the heating behaviour of the residents is unknown. Also the availability of sewage heat when meltwater flows in the sewer is unknown. Monitoring this demonstration installation will fine tune the model and optimize the feasibility assessment of new projects.

3.2 Tendering

The tender request was sent in order to find a contractor who can offer full engineering-procurement-construction- and maintenance services. This was addressed to five suppliers: Huber (Germany), Blue-synergy (Germany), Kasag Langnau AG (Suisse), Blue Heat (Belgium) and VDV Cleaning (Belgium).

In the table below an overview is given of the price estimations of Huber and the offers we received from Blue Synergy and Blue Heat. Kasag informed us that they are not in a position to quote for the entire energy system including service. They advised us to work with a local contractor. VDV Cleaning can only deliver the sewage heat exchanger and is therefore not withhold. Therefore, only 3 contractors remained in competition for the tender. The decision was based on the following selection criteria: completeness of the tender, COP of the installation, performance of the installation, location of installation (internal/external) of the heat exchanger and price.

1. **Completeness of the tender**

+ Blue Heat and Blue Synergy gave a complete tender.
- Huber only gave estimations of the price and the tender was not complete.

2. **COP of the installation**

+ Blue Synergy and Blue Heat claim a high COP for their installations.
- Huber gave a significantly lower COP than Blue Synergy and Blue Heat.

3. **Heat capacity of the installation**

+ Blue Heat has a higher heat capacity (293 kW) than Blue Synergy and also the size of the buffer is bigger. This will maximise the usage of sewage heat in apartments.
- Huber´s buffer tank is out of proportion (100 m^3)

4. **Location of the heat exchanger**

- Blue Synergy proposes a 66 m heat exchanger in the sewer, which will make it difficult to clean compared with a plate heat exchanger. Future deposits can decrease the efficiency of the heat exchanger.
+ Blue Heat and Huber suggest a plate heat exchanger outside the sewer because it is easier to maintain and the work inside the sewer remains minimal.

5. **Price**

Concerning the different price items and the total price, Blue Heat had the best score.

The contractor Blue Heat, obtained the highest score on performance and price for their full engineering-procurement-construction- and maintenance services. For that reason, Blue Heat was chosen as the contractor for this sewage heat recovery project. See attachment ‘Report- Tender request’ for more information. A detailed description for the different requirements and offers of the contractors are shown in the table below.

Color legend
Tender
Estimation
No Tender/ No Estimation made

	Explanation	*price*	*Explanation*	*Price*	*Explanation*	*price*
1. Contractor	Blue Synergy		Blue Heat		Huber	
2. Heat exchang	66 m, in sewer		No heat exchanger inside the sewer but three plate heat exchangers outside the		No heat exchanger in the sewer but plate heat exchangers outside the sewer	
3. Rewatering	bypass of sewage water during the installation of the heat exchanger		Not necessary		Not necessary	0
4. Connection to building	Connecting Pipe da 110, HD-PE between sewer and central heating place, length over all 30 m, civil engineering, incl. Data cable, Hand over Building inside, pressure tested,		Pump well with sieve and connection to the building		Pump well with integrated screening	
5. Heat Pump S	High-efficiency heat pump, expansion vessel and safety group, complete with installation, Dokumentation and start-up		2 heat pumps of 125 kW		Heat pumps and controllers.	
6. Buffer tank for energy storage	3 m³		5 m³		100 m³	Not included in the
7. Monitoring	Incl. Temperature sensors PT 1000 (incl transducer 0-20 mA) from sewer, suitable for MCR monitoring with optional flow indicator to the forwarding process for on-site representation		Electrical control panel with logging of the energy delivered		/	Not included in the tender
8. Connection of the heat pumps into the existing	Not included in the tender		Engineering		/	Not included in the
9. Maintenance	2 times a year with a local partner				/	Not included in the
Total						

Performance

	Blue Synergy	**Blue**	**Huber**
Power (kW)	250	293	100-200
COP - heating	5	4,5	3 - 4
COP - hot wate	5	5	

3.3 System installation

A plate heat exchanger outside the sewer turned out to be the most suitable heat recovery technology for this demonstration project as all the parts are placed outside the sewer.
The construction consists of a pumping sump in the street connected with the sewer and a heat recovery system (heat exchanger and heat pump) in the central heating place of the apartment. During the constructions, the street had to be blocked and partially opened. The pictures under chapter 6 show when the pumping well is submerged. The Blue Heat installation was completed in July 2014.

3.4 Monitoring

The overall COP of the heat recovery system was monitored from December 2014 to March 2015. A low average COP of 2,61 was obtained because the optimisations described below have only been implemented from mid-March 2015 onwards.

3.5 Data analyses

1. COP of the heat recovery installation

Data analyses with Blue Heat in January 2015 showed that the low COP was a result of the slowly opening of the expansion valves. By consequence during the night, when the heat demand is lower and the temperature of the heating water is low, a low COP was observed while we expected a high COP. As the heat pump turns on and off during the night, the expansion valve never opened completely resulting in a low COP.
Furthermore, the back wash of the heat exchanger wasn't operational and fouling of the heat exchanger occurred. This resulted in a low evaporation temperature and a low COP.
In February Blue Heat installed bigger expansion valves and incorporated backwash of the heat exchanger in the PLC.
Two additional optimisations of the heat pumps have been introduced in March 2015: incremental activation of the number of compressors (from 1 to 6) of the heat pumps in direct relation to the heat demand and increase of the circulation flow of hot water in the heating circuit (lowering the delta T of the circulation circuit and delivering more heat comfort to the dwellings farthest away from the heat pumps).
At the time of writing this report, we have only a few days of monitored results from these optimisations, but the results are promising: at low heat demand with only 1 out of 6 compressors working, we reached a COP of 3,39. With 2 compressors: 3,65, as the periphery (circulation pumps, sludge pumps,…) uses about 6 kW, independent of the heat demand. The COP will further increase with the increase of heat demand. If we don't take into account the electrical consumption of the periphery, the gross COP of the heat pumps reaches 5,08.

2. Delivered heat to the heating circuit

On January 31 2015, 88 MWh of thermal 'sewage' energy was delivered to the heating circuit and sanitary hot water at an average COP of 2,6. The heating water had a temperature of 50-55°C during daily average temperatures of 2°C without any complaints from the residents.
In February 2015 an additional 65 MWh of heat was produced with an average COP of 2,48 (lower heat demand without efficiency improvements of the heat pumps).
In March 2015 an additional 45 MWh of heat was produced. The COP for March was 2,71 but the optimisations only took place in the last week of March. For April 2015 the COP was 3,14.

4 Conclusions

Does the demo project indeed help to make the UWC more sustainable?

During winter the departure temperature of the heating water lay between 52-55°C which is lower than usual (70-80°C). The objective of lowering the heating water to 45°C in order to higher the COP wasn't possible for this renovated building during the winter of 2014-2015. During spring and autumn 2015 we expect to work with a lower depart.

5 Recommendations for follow up

The following problems occurred during the start-up and were corrected:

1. The sieve, lying in the sewer pipe, prevents the connection pipe between sewer and sump to block. Bigger pieces flowing through the sewer though can get stuck and can cause a total or partial clogging of the sieve. Adjusting the angle between the flow direction of the sewage and the surface of the sieve wasn't helping. The solution is a periodical backwash of the sieve depending on the waterlevel in the sump. When the waterlevel is lowering in the sump, it means the sieve is getting blocked and the sieve needs to be cleaned. This backwash systems works perfectly.
2. The sump can bog down as sand accumulates. By establishing a periodical flow or a low flow from sump to sewer, the sand flushes back. Sand, accumulated on the bottom of the sump, is pumped back to the sewer with a separate pump and direct circuit.
3. Sewage, pumped from the sump to the heat exchanger is further filtered (<2mm) preventing the heat exchanger to block.
4. The heat exchanger can foul as biofilm grows on the plates. Measuring the temperature difference between the two media flowing in counter current can predict the fouling. Up till now, a backwash of the heat exchanger prevented blocking or loss in heat exchanging capacity. No enzymatic or chemical agents were necessary to clean the heat exchanger.
5. During winter, meltwater cools down the sewage water and lowers the available heat and COP of the heat pump. A gas condensing boiler will always be necessary as a backup during severe winter conditions or during reparation of the installation.
6. Heat pumps make a constant background noise in the apartments near the technical room. Further isolation of the technical room is important for the comfort of the inhabitants who can hear the heat pumps.
7. Delay of expansion valves (heat pump) to open.

The constructions of the heating system of the building can be visualized by the following 2D and 3D drawings below. Figure A shows where the warm sewage water is cooled and the tap water and heating water is heated.

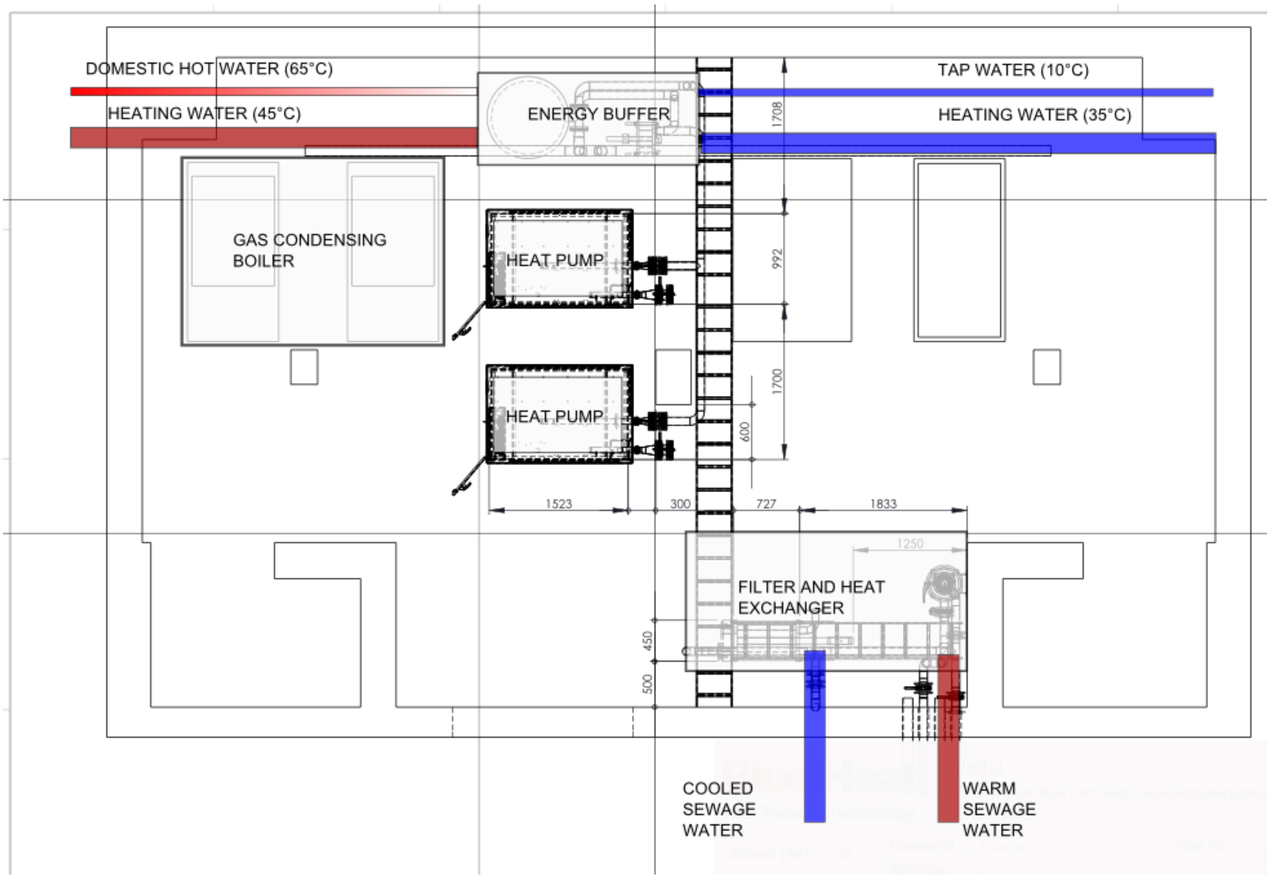


Figure A: 2D drawing of the implantation of the sewage heat recovery technology

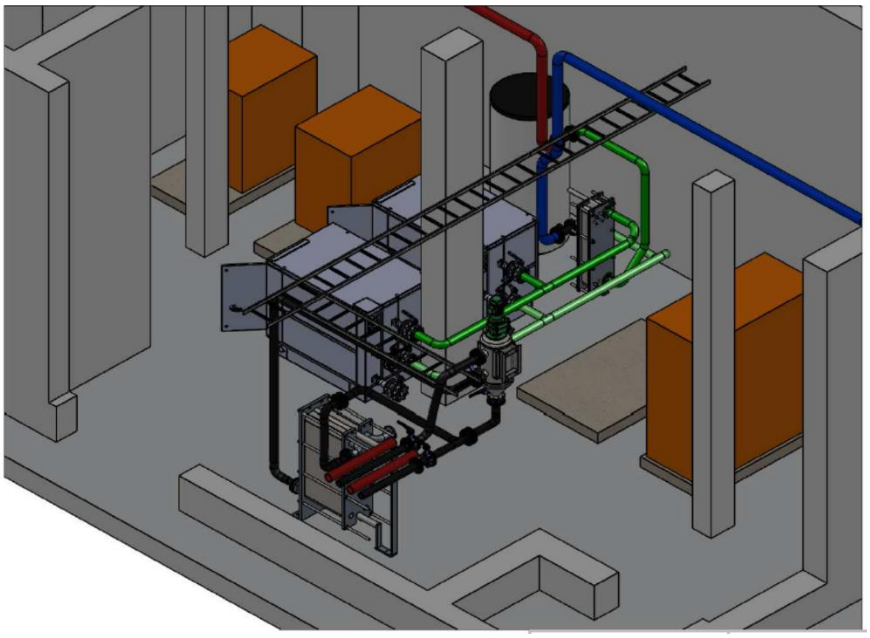
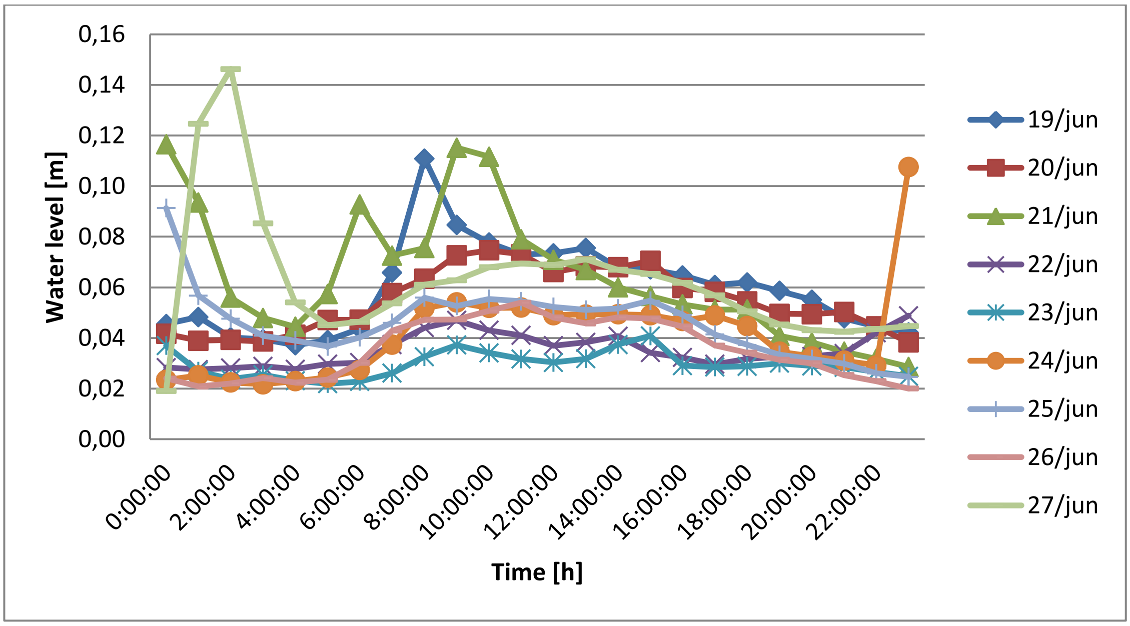


Figure B: 3D drawing of the implantation of the sewage heat recovery technology

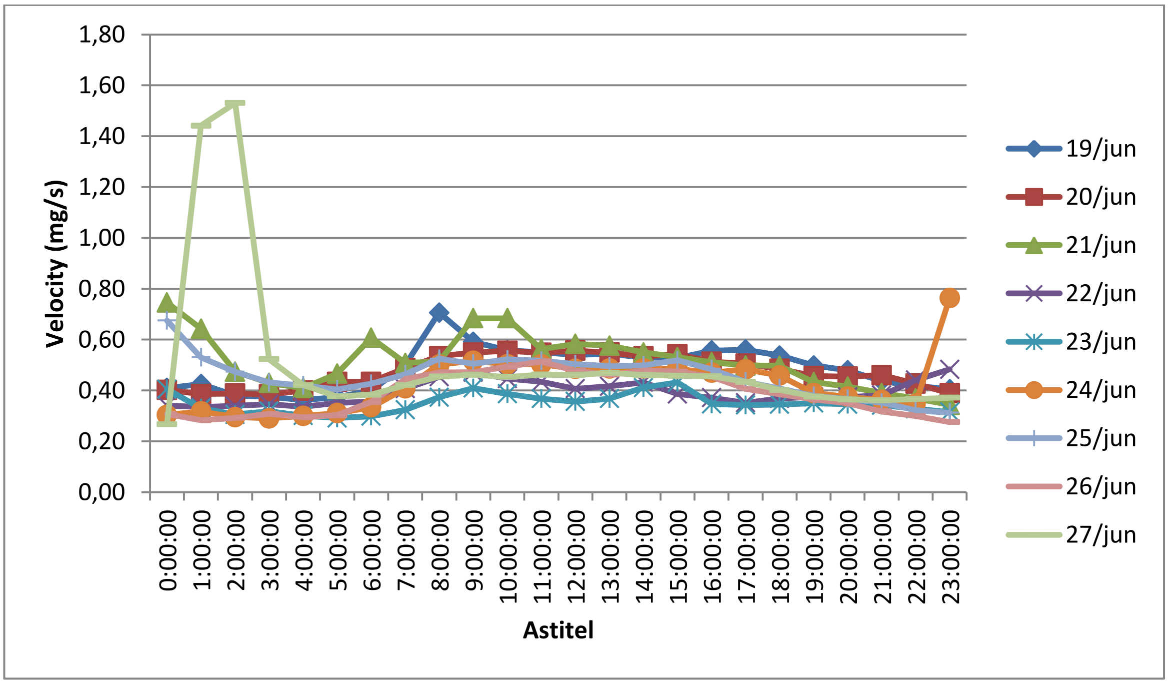
6. Graphics

The sewer characteristics were monitored in june 2013 and can be retrieved from figures 1 to 4:

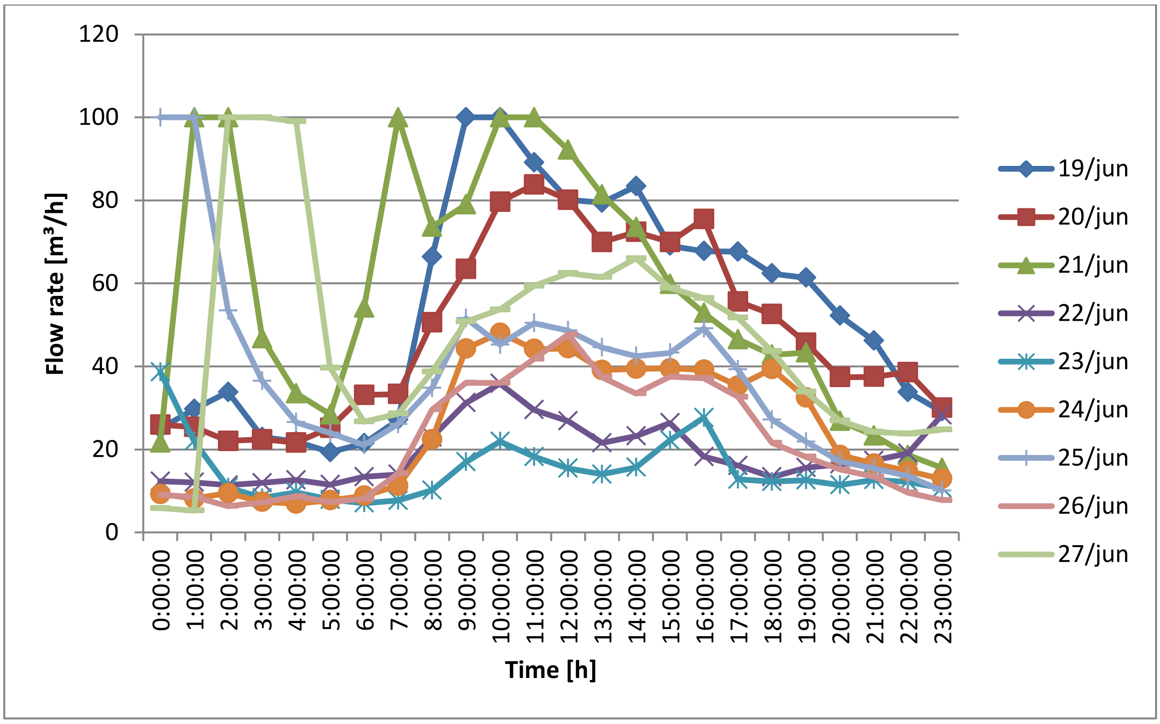
1. The water level ranged between 2 and 22 cm with an average of 5 cm



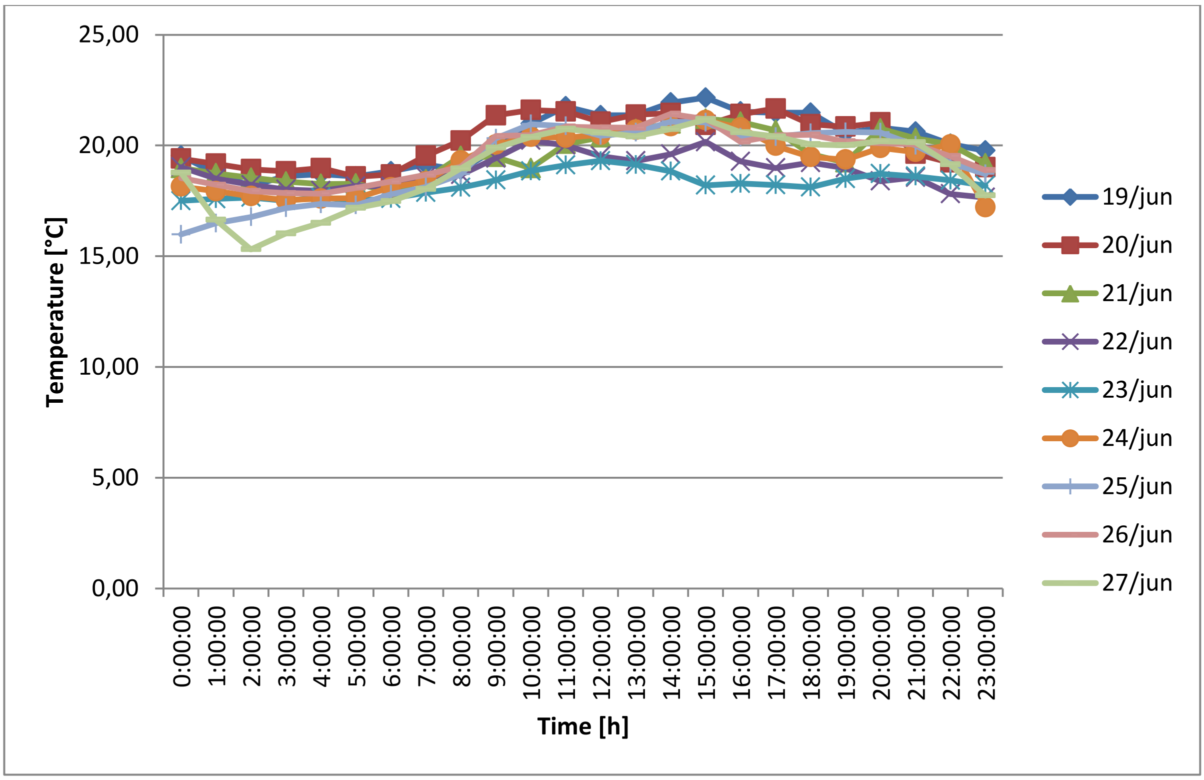
2. The velocity of the water ranged between 0,25 and 2,5 m/s with an average of 0,44 m/s



3. **The flow rate ranged between 4,6 - >100 m³/h with an average of 45 m³/h**



4. **The sewer temperature ranged between 15,2 and 22,5 °C with an average of 19,4°C**



5. **Submerging of the pumping well**

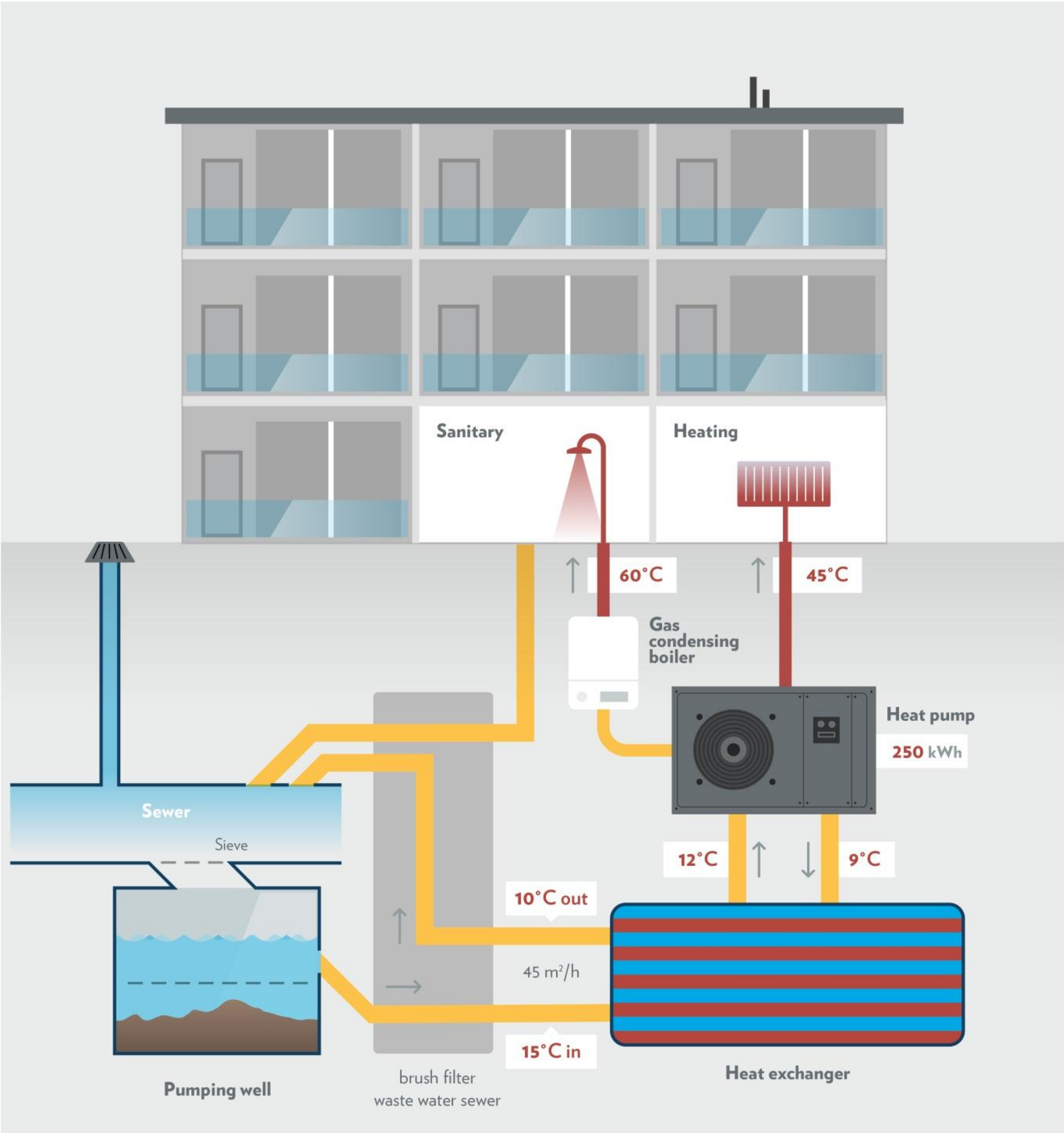
6. **Existing pumping well to the public sewer DN 1200 mm**

7. **Existing pumping well with connection**

PROJECT 5

HEAT RECOVERY FROM THE SEWER SYSTEM

Vlario



THE RESULTS