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Feasibility of small scale heat recovery from sewers

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Denewa

Waterbedrijf Groningen

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Feasibility of small scale heat recovery from sewers

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1 Introduction

1.1 Heat recovery from sewers

Warm wastewater enters the sewer system at many places. Most warm water discharges occur irregularly during short periods. All warm water used in homes ends up in the sewer system. Moreover, in many cities hot water is discharged into the sewer from for instance industrial water users. Examples are industrial textile laundry or food industry.

Thermal energy is an important factor in the total energy consumption related to the water cycle. Research has indicated that for domestic use (shower, bath, laundry machine, dishwasher etc.) the primary energy required to heat the water is about ten times higher than the operational energy for producing and distributing drinking water and collecting and treating wastewater (Sukkar et al. 2009a, Sukkar et al. 2009b, Kluck et al. 2011, Hofman et al. 2010). Using the average drinking water consumption at households (approximately 130 L per person per day) and the total heat used to produce warm water (60 $MJ_{primary}/m^3$ water), the average temperature of domestic wastewater entering the sewer system can be calculated. In the Netherlands this temperature is between 25 and 30°C.

When a modern isolated house is considered, the heat loss via the sewer is approximately 40 % (or higher) of the total heat loss of a house. When this heat is recovered and reused, less primary energy resources need to be used and emission of carbon dioxide (CO_2) can be reduced significantly.

Heat recovery from sewers is practiced already for some time in Switzerland. Also in Germany and Scandinavia projects exist. Nevertheless, heat recovery from sewers is not a mature technology. Design principles, operation and maintenance, and economic viability are uncertain.

1.2 Project setup

This project aimed at the development of a small scale system (20 - 50 houses) for heat recovery from the sewer system in a representative neighbourhood of the city of Groningen. This system should demonstrate the heat recovery from sewer water and reuse of that heat for the heating of houses and/or the warm water production in houses. However before realisation, a desk study was performed to proof the economic feasibility of this business case.

In this desk study two aspects were distinguished:

- The heat exchanger in the sewer system and the connected heat recovery system;
- The distribution and application of heat in(to) the houses including the heat pump facilities.

In this report each aspect is addressed including an estimate of the economic feasibility.

2 Sewer heat exchangers

2.1 Locations for heat recovery

Heat recovery from wastewater can be done on several locations in the water cycle. Close to the heat source (dwellings, apartment buildings) is the first option. At this location the sewage water temperature is still relatively high and only little energy content is lost to the environment. Opposed to this, the amount of wastewater – and therefore the heat content – is relatively low and varies considerably in time. A second option is heat recovery in the sewer system. In the sewer system more water is available and less variation is expected. On the other hand, the sewage temperature will be lower because heat is lost to the environment and cold water may enter the sewer (rainfall, groundwater). Heat recovery can also be done more downstream at main sewer pipes and transport sewers. In that case, it may be necessary to consider the temperature decrease of the waste water upon arrival at the wastewater treatment plant. Finally, heat recovery can be done from the WWTP effluent. At this point the temperature is the lowest, but a more or less constant water flow is available. Model calculations may be used to predict the potentially available heat in waste water and the optimum location to install heat transfer equipment.

2.1.1 Shower sink heat exchangers and local systems

Shower sink heat exchangers can directly use waste heat. The heat exchanger is installed in the shower sink. The warm used water is used to heat up the cold water flowing into the cold tap and the warm water boiler. Therefore the boiler uses less gas to heat the water and less warm water is used at the mixing tap to achieve the desired shower water temperature. A distinction has to be made between horizontal and vertical heat exchangers (Figure 1). Vertical systems can often be installed in vertical indoor sewer pipes. If less space is available, horizontal systems can be used, because they can be installed below a shower basin.

Waternet, the watercompany of Amsterdam, recently started a project in a student housing conmplex ('Uilenstede') in Amstelveen. Here 100 shower sink heat exchangers are installed. Ten of them will be monitored closely in the coming years to test their performance. Theoretically about 50% of the heat can be recovered from used shower water. This means that for a one-family home an annual saving of € 100,-- is possible. The pay-back time for the investment in a shower heat exchanger will be around 6 years.

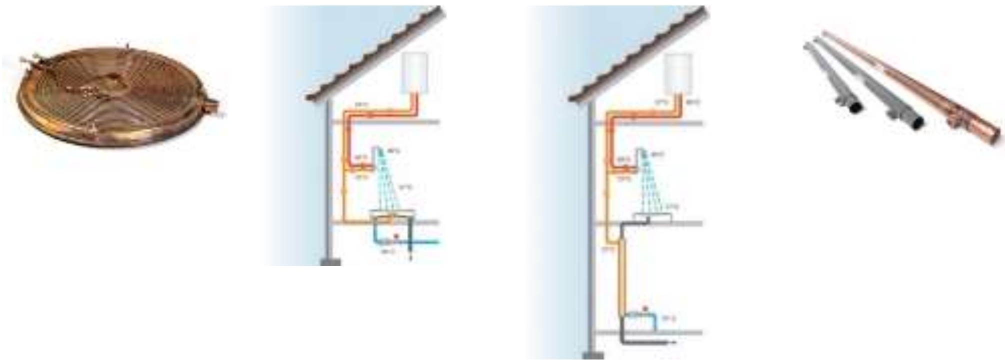

Figure 1. Examples and principles of shower sink heat exchangers. Left: horizontal system, right: vertical system. (source: www.technea.nl).

A second local system is heat exchanger that can be installed in a sewage pit near a building (Figure 2). The system is sold by FEKA[1], Switzerland. The heat exchanger is a fully integrated system. The wastewater from the pit is discharged by a siphon. A pump is installed to backflush the siphon. The heat exchanger is connected to a heat pump and a heat reservoir to increase the heat value.

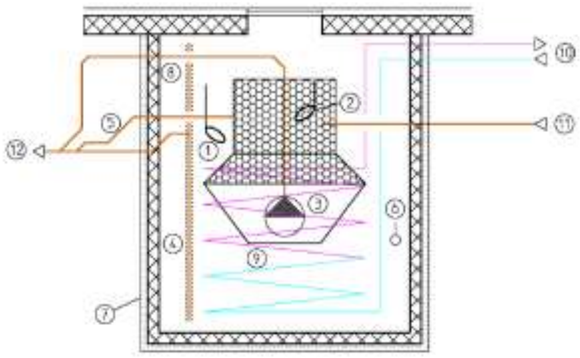

Figure 2. Heat exchanger in a sewer collection pit. Applicable at apartment buildings and flats. (source: www.feka.ch)

An example of this technology can be found in the zero-energy complex 'Eulachhof' in Winterthur, Switzerland. The complex consists of 132 dwellings. The wastewater from the wet rooms in the building is collected in the pit. The heat pump increases the temperature o 60 °C. The heat is sufficient for covering the total energy demand for the warm tap water use. The system can be used for waste water flows of 8.000-10.000 L/d with an average temperature of 23 °C (Wanner 2009).

2.1.2 Gravity sewers

Table 1 gives a good overview of gravity sewer heat exchanging systems that are available on the market nowadays. Three different ways of exchanging heat from the sewer can be distinguished. Firstly the heat exchanger can be built-in separately in the sewer pipe, mostly on the bottom of the pipe. Secondly the heat exchanger can be integrated in the sewer pipe wall. And thirdly the heat exchanger can be placed above the ground. In this situation only part of the water in the sewer will pass a screen and is pumped to the heat exchanger. Some of these systems will be described in more detail below.

TABLE 1. HEAT EXCHANGING SYSTEMS FOR GRAVITY SEWERS (ADAPTED FROM HEIJMANS)

supplier	**Wavin**	**Huber**	**Kroondehly**	**Uhrig Bau & Geveke**	**Berding concrete & LBn concrete**	**Frank GmbH**	**Frank & Socea & Heijmans**
Lifetime	unknown	15 years	unknown	15 years	unknown	50 years	1000 years
Type heat exchanger	integrated	above ground level	built-in	built-in	built-in	integrated	integrated
Drill pipe	no	no	no	no	no	no	yes

[1] FEKA-Energiesysteme AG, Elestastrasse 16, 7310 Bad Ragaz, Zwitserland

Rabtherm[2] supplies integrated systems that can be used during construction of new sewer mains. Furthermore they can supply systems that can be inserted in existing sewers (Figure 3). The heat exchangers are made of a special steel for optimal heat transfer. Moreover, a patented method for reduction of biofilm formation is applied, that makes use of copper strips in the heat exchanger surface.

The Rabtherm systems can be used in diameters of ∅400 mm. The minimum required wastewater flow rate is 12 L/s. According to the specification the system delivers 2-5 kW_{th}/m^2 after the heat pump. The heat transferred from the waste water is 2-6 kW/m^2, depending on the flow rate, the water velocity, the mains' slope and the fouling. At a filling level of 1/3 a heat transfer rate of 1 kW/m can be achieved. A comparable system is available on the market: ThermLiner, sold by Uhrig Bau [3].

Figure 3. Rabtherm heat exchangers: left integrated system, right: system for implementation in existing sewer mains. (source: www.rabtherm.ch)

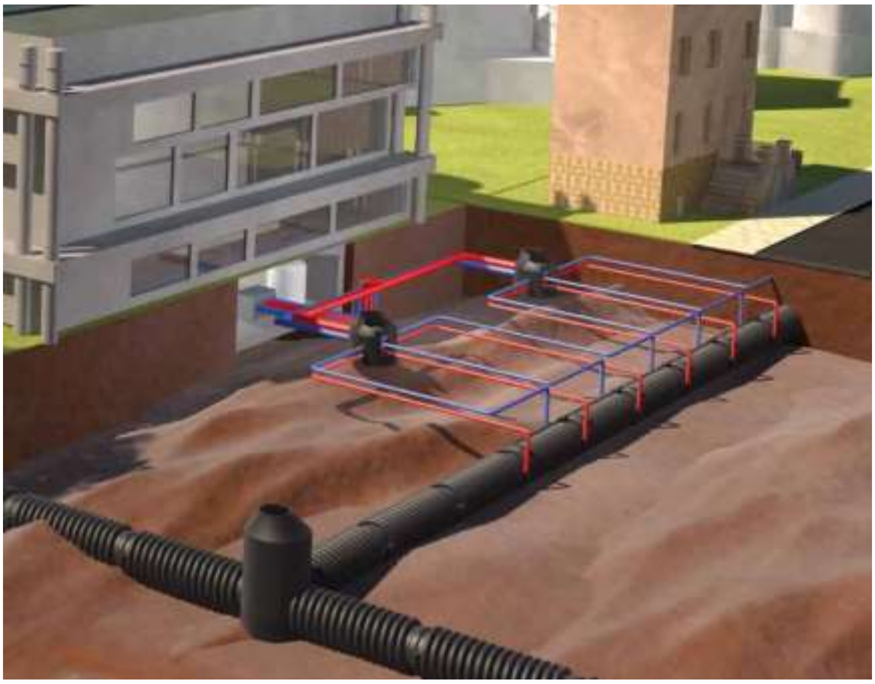

Figure 4. Example of a Thermpipe-PKS system (source: www.frank-gmbh.de)

[2] Rabtherm Energy Systems / RABTHERM AG, Buckhauserstrasse 40, CH - 8048 Zürich, Zwitserland
[3] UHRIG Straßen-Tiefbau GmbH, Am Roten Kreuz 2, 78187 Geisingen, http://www.energie-aus-abwasser.de/

Another system is developed by the German company Frank[4]. The system consists of a plastic (PE) mains with a small helical tube wound around it (Figure 4). A coolant is flowing through the helical tube, abstracting heat form the wastewater and also from the surrounding soil. The heat exchanger tubes are available in in diameters ∅300–1.800 mm. The heat recovery varies between 350 W/m for a ∅300 mm to 1810 W/m for a ∅1.800 mm.

Recently the Hydrea Thermpipe system was developed by Heijmans, Frank GmbH and Socea (Figure 5). In this system the Thermpipe-PKS is used as a basis and poured in a concrete mains. Pipe elements can be connected to a strain of 150 m and coupled to a distribution system the mains outer diameter is minimal ∅1.600 mm (1.000 mm inner diameter). The system can be installed by drilling.

Also Wavin is developing a plastic system (PP) with a double walled.

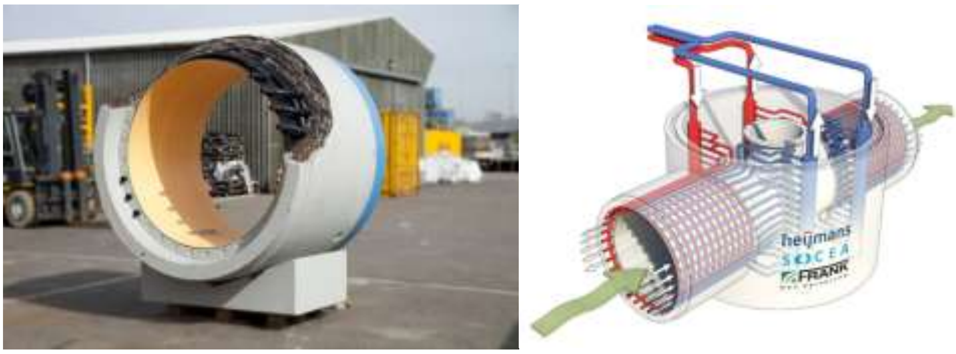

Figure 5. The Hydrea-Thermpipe system of Heijmans, Frank en Socea.

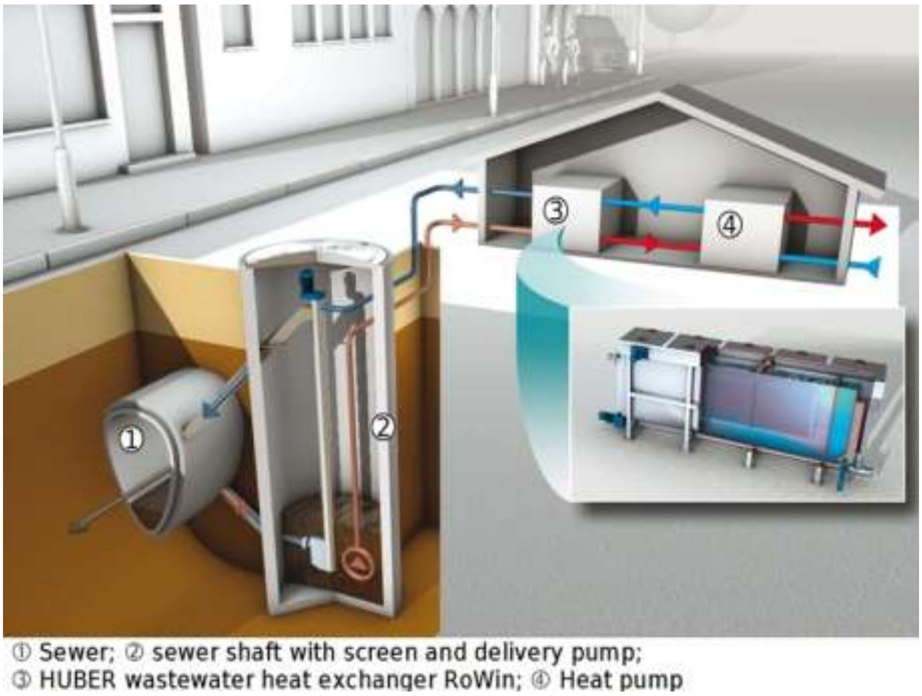

Figure 6. The Huber ThermWin® system.

[4] Frank GmbH, Starkenburgstrasse1, 64546 Mörfelden-Walldorf, Duitsland

A completely different system was developed by Huber Technology[5]: the ThermWin system (Figure 6). In this system a self-cleaning external plate heat exchanger is coupled to a heat pump. The warm sewage is pumped from the sewer mains into the heat exchanger. After abstracting the heat, the water is discharged again in the sewer mains. Additional to this Huber supplies the TubeWin system, a heat exchanger that can be inserted in existing sewer mains (diameter above 1.000 mm).

It is important to notice that all systems described are developed for bigger transport sewers, typically 800 mm or more. For example the Hydrea Thermpipe is available from Ø 1600 mm. The Huber system is economical feasible (according to the supplier) from a dry weather flow of 10 liters per second upward. Main reason is that under these conditions the system is less dependent on the flow dynamics in the sewer.

Conclusion: most available heat exchange systems for sewers are developed for bigger transport sewer pipes and not for small sewer pipes in residential areas (20-50 houses).

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[5] HUBER SE, Industriepark Erasbach A1, D-92334 Berching, Duitsland

3 Inventory of possible pilot locations in Groningen

3.1 Selection criteria

To find a possible pilot location several criteria have to be considered. First of all the available heat should cope with the local heat demand. So it is important to find one or more potential heat users. The distance between the heat exchanger and heat users should be as small as possible, as transport of heat over great distances is not feasible. As availability and demand of heat may vary in time, storage of heat in the underground should be considered. The design criteria and specifications of heat recovery systems available on the market must be known well so the right location can be chosen. There should also be enough space available to implement the system. As investments in the infrastructure appear inevitable, it seems logical to select a new to build neighbourhood as a pilot location.

The criteria can be summarized as follows:

- Presence of one or more potential heat users in the direct surroundings.
- The available heat from the sewer should match? with the heat demand.
- When supply and demand of heat vary in time / season, storage in the underground is necessary.
- Design criteria for the heat recovery system.
- Plans for new to build neighbourhoods.
- Available space for the heat recovery system.

Other preconditions:

- Small scale (20-50 houses) in a drain sewer.
- Substantial heat demand in the direct surroundings.

3.2 Acquisition of pilot locations

A list of new urban development projects in the city of Groningen was made with the help of information on the internet. Subsequent acquisition on these locations however did not result in a suitable pilot location. There were two reasons in particular why no suitable location was found. First of all the construction of residential houses was in deep recession at the time the acquisition was done so many development projects were ‘on hold’. Secondly those projects that were relevant could not meet the criteria mentioned above.

Conclusion: no suitable pilot location for a project concerning 20 to 50 new build houses could be found.

4 Design of small scale system

4.1 System layout

For setting up a business case the following fictional situation was used.

A project that consists of two streets (Figure 7):

- Street 1: 30 two-under-one-roof houses 500 m^3
- Street 2: 16 terrace houses + 4 corner houses 400 m^3

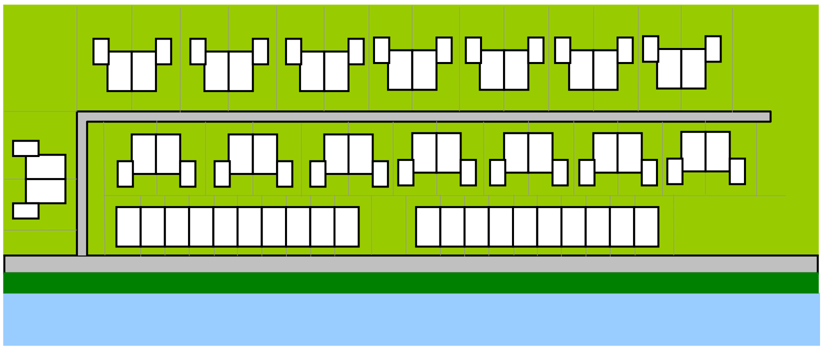

Figure 7. Hypthetical street layout.

In the normal situation the following (relevant) component are essential:

- Conventional sewer system
- Gas supply lines
- High efficiency combi system for warm water production and heating

In the planned situation with heat exchange from the sewer the following components are essential:

- Sewer system with heat exchanger
- Small facility with pump in the street
- Heat pump per house with water/glycol system connected to the heat exchanger in the sewer. The heat will be used for warm water production and heating.

4.2 Costs

It is obvious that the costs for the construction of a sewer heat exchanger will be higher compared to the conventional situation. It is estimated roughly that the extra costs for this construction (including the facilities in the street) will be compensated by the cost saving of the gas infrastructure. This means that the benefits should be made in the houses.

The average annual gas consumption for an average household (2,2 persons) in the Netherlands is 1.600 m^3 (www.milieucentraal.nl). This corresponds with a total heat consumption of 20.500 kWh as 1 m^3 of gas equals 12,8 kWh. When in the alternative situation a heat pump (hybrid high efficiency heat pump with electrical post heater) is used with a COP of 4, in that case (20.500 kWh/4 =) 5.125 kWh electrical energy must be used to get 15.375 kWh heat from the sewer.

TABLE 2. COMPARISON OF A CONVENTIONAL HEATING AND APPLICATION OF HEAT RECOVERY FROM SEWERS

Situation per household	**Conventional situation**	**Situation with heat recovery from sewer**
investment central heating boiler (24 kW CW4)	€ 1.500,-	-
investment heat pump (hybrid, high efficiency 15 kW)	-	€ 7.500,-
depreciation	10 years linear	10 years linear
gas price* € /m³	0,65	-
electricity* € /kWh	-	0,23
gas consumption m³/year	1.600	-
extra electricity consumption kWh/year	-	5.125
depreciation per year	€ 150,-	€ 750,-
energy costs per year	€ 1.040,-	€ 1.150,-
total costs per year	**€ 1.190,-**	**€ 1.900,-**

* *Source www.milieucentraal.nl price level 2013/2014*

The calculations show that for the present price levels for gas and electricity the use of heat from the sewer system via a heat pump per household is economically not feasible.

With a consistent electricity price, the gas price would have to rise to € 1.10 to reach a break-even point. Under the influence of political and social factors it is virtually impossible to predict the price development of gas and electricity in the near future. However, with the introduction of renewable (green) energy in the society and the gas reserves becoming smaller globally, on the long term the situation for recovering heat from the sewer system with the help of heat pump will become more favourable.

Conclusion: with current gas and electricity prices, heat recovery from the sewer on a small scale of 20-50 houses is economically not feasible

5 Conclusions and recommendations

5.1 Conclusions

This project aimed at the development of a small scale system (20 - 50 houses) for heat recovery from the sewer system in a representative neighbourhood of the city of Groningen. This system should demonstrate the heat recovery from sewer water and reuse of that heat for the heating of houses and/or the warm water production in houses.

Main conclusions:

- Most available heat exchange systems for sewers are developed for bigger transport sewer pipes and not for small sewer pipes in residential areas (20-50 houses).
- No suitable pilot location for a project concerning 20 to 50 new build houses could be found.
- With current gas and electricity prices, heat recovery from the sewer on a small scale of 20-50 houses is economically not feasible

5.2 Discussion and recommendations

A separate (still current) project ("*heat recovery from sewer and drinking water pipes*") performed within the joint research program for drinking water companies (*BTO theme Energy and Water*) looks into more practical aspects such as heat availability based on model calculations. The conclusion from this project is also that, although the highest temperatures were found in the streets near the houses, the realisation on a small scale is technically not feasible. This is mainly due to the big fluctuations and the very low efficiency for heat recovery as a direct result.

This information together with the findings of this desk study lead to the recommendation that heat recovery from the sewer should focus on projects on a larger scale, where the heat from larger transport sewers is recovered and reused in a suitable nearby location, e.g. a swimming pool, an office building or a hospital. This study made clear that most suppliers of these systems also aim at these kind of applications.

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Appendix 1

Overview project for new urban development in the city of Groningen

1. Source: http://gemeente.groningen.nl/nieuwbouw/nieuwbouwlocaties/
2. More information on Google Maps

Project	Info	Aantal woningen
CiBaGo Schots 6 en 7		?
Curacaostraat	http://www.lefier.nl/	55
Gordel van Smaragd (Molukkenstraat)	http://www.degordelvansmaragd.nl/	?
De Held 3	http://www.nieuwbouwgroningen.nl/	1500
De Velden (Merelstraat)	http://www.uw-thuis.nl/ http://www.pandomo.nl/	21
Eemskanaalzone	Gemeente Groningen Afdeling Wonen en Monumenten	1400
Froukemaheerd	http://www.dehuismeesters.nl/	11
CiBaGo 5	http://www.schotsenscheef.nl/	63
Oosterhamriktracé	Gemeente Groningen, Dienst RO/EZ	900
Oostersingel / Nieuweweg	?	?
Reitdiep fase 3 en 4	Gemeente Groningen; Afdeling Wonen	500
Trefkoel	http://www.nijestee.nl/	200
Woldjerspoorweg	Gemeente Groningen; Afdeling Wonen en Monumenten	20