Guidelines for the replicability of the Cologne Wahn Demonstrator

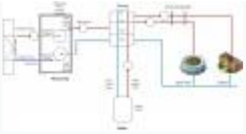
Introduction

Sewage heat recovery consists of a heat exchanger integrated into a sewage pipe, and a heat pump to increase the heat exchanger’s exhaust temperature to a level usable for indoor heating. The average water consumption in Germany lies at 122 litres for personal hygiene, cooking or cleaning. About 61 litres are heated up over 20°C by electric resistances inside washing machines, dishwashers, showers and bathtubs. Although the total quantity of available heat will generally be limited on a city-wide scale, the temperature of sewage is high, relative to ambient temperatures throughout the year: sewage temperature lies around 10°C in winter and 20°C in summer in average. Industrial sewage has often higher temperatures than the communal one.

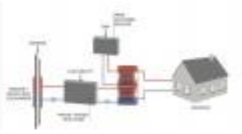
The heat potential is not limited to the sewage itself, the surrounding also has an important impact. In Germany the sewage lies at 2 to 4 metres deep. In Cologne’s region the temperature is nearly constant between 12°C and 15°C. Therefore, the sewage provides a relatively stable source of heat, allowing the heat pumps to achieve high performance figures. Depending on the exhaust and network temperature levels, the reclaimed and boosted heat can either be used locally or fed into a low temperature district heating network. Heat can be reused within dwellings, tapped from larger sewage pipes and pumping stations, or reused from sewage treatment plants (although most of the waste heat from the latter will have been generated at the plants themselves as part of the treatment process).

CO1 demonstrator description

The CO1 demonstrator consists of three different operation sites, in which sewage network heat recovery systems are installed. The demonstrator site in the district Porz - Wahn has been operated and monitored since October 2013 and so far, it is the demonstrator on which more experience has been gained. Therefore, the analysis of possible design improvements has been carried out with respect to the aforementioned site.

- 

Parameter list

- 

Scheme of utility Cologne Wahn

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Simplified tubescheme

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Potentials

Suitable locations for the implementation of such a system can be identified by overlaying a map of the sewage pipes and their diameters on the heat demand within the city. Pumping stations provide a concentration of sewage flow, thus pumping stations could be the most favorable locations for replication. This does however depend on sewage temperature, as this may have cooled down too much during transit from its sources. Therefore, data on local temperature fluctuations is required. The experience with the demonstrators validates the decision of using water as the heat pump working fluid. It is worth noticing that the heat pump manufacturers recommend to take glycol as working fluid to avoid problems connected with freezing, but this advice was not implemented because it would have required a permission of the environmental department and delayed the start of the project. However, the advice is to use water or glycol according to the weather conditions of the location.

Key Steps for replicability - An example from Cologne

Ecologic and Economic analyses of the technology

From the environmental point of view heat recovery from sewage water has a better energy balance as common oil/gas heater or air conditioner and it has lower emission of greenhouse gases. The plants are using heat from sewage water and emit around 44% fewer emissions as oil fired heaters. Crucial for the ecologic calculation is the current consumption, the Coefficient of Performance (COP) of the pump, the seasonal efficiency ratio and the relation between heat pump operation and gas fired peak boiler operation.

In Cologne, the following CO_2 emissions savings have been achieved since 2014

CO_2 Emissions [ton]CO_2 Emissions savings Source: Deliverable 4.3 *There is still no data available from 2017CO1 WahnCO1 Mülheim20142015201620170102030405060Highcharts.com

The Economic analyses have several different aspects that must be considered. First of all, the operational concept of heating or cooling is depending on the application. Three different applications are possible:

Monovalent operating mode
This mode foresees to use as much sewage water for heating purposes as possible, to save primary energy resources the most.
The heat is only distributed by the heat pump.

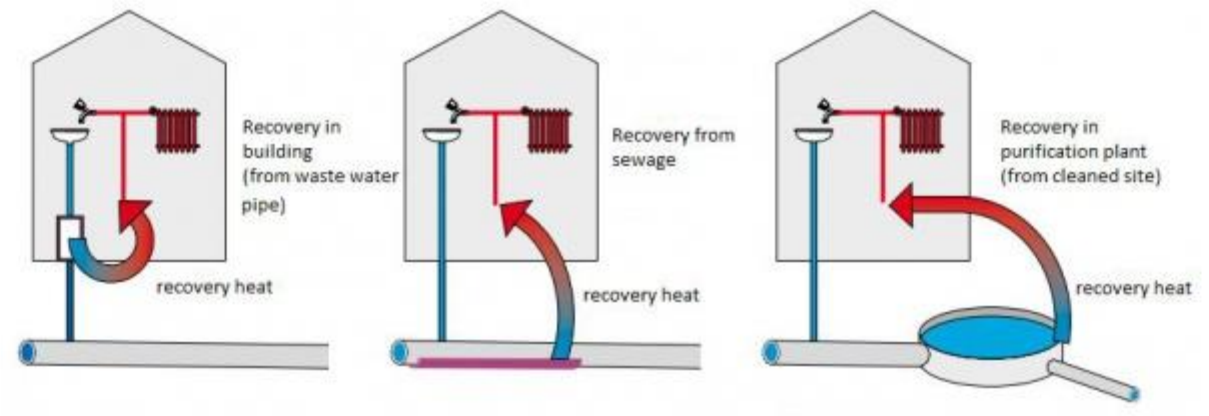
Bivalent operating mode
The gas fired heater is used as a peak boiler. It is recommended for existing buildings because a heat source already exists, which usually can be used in peak loads especially in wintertime.
It is the most common method because of economic benefits and reliability of the system.
Normally the heat pump is providing the base load which increases the COP of the entire system.
In case of failure the supply is ensured by the peak boiler. Heat pump and peak boiler can be managed in that way that even in peak demand periods the heat pumps are used to heat up the water beforehand.

Multivalent operating mode
The third mode combines a sewage heat pump system with a combined heat and power generator to run the heat pump. Throughout the process the method spends the fewest amount of primary energy. Furthermore, this method can be used as an emergency backup generator. This method is commonly used in projects with a very high heat demand.

Location of the energy recovery system

Further investment costs are implemented in the location of the heat recovery system. The heat exchanger is the main part of the energy recovery system. A very important criterion for installation of a heat recovery system is the location of the heat exchange plates as well as the distance to the sewage pipe. The biggest part of the investment takes the underground engineering and the connection of the secondary circle to the plates and absorber (Absorption).

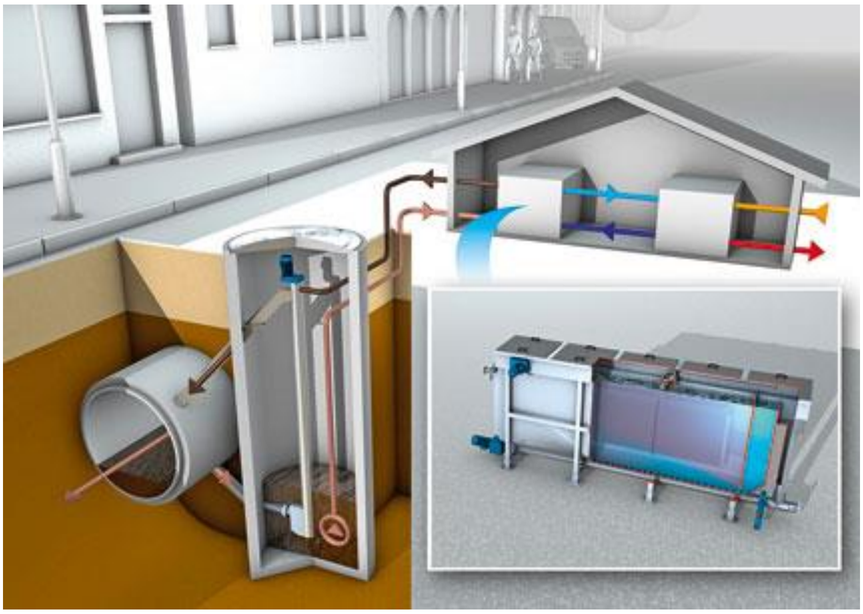
The energy recovery system can be installed in different properties.



Location for energy recovery system

Energy recovery in buildings

Buildings with a huge amount of waste water like hospitals, industry and public buildings can recover the energy from the waste water within the building.



Schematic view of a shaft construction

For this purpose the waste water is stored in storage or a shaft construction where the energy is recovered. With a heat pump the recovered energy is distributed back to the building for heating or domestic hot water purposes. To avoid big pollution of the storage or shaft a filter is installed in front of it. The dirt is forwarded directly to the sewage pipe. An important requirement is a high waste water flow rate per day.

Energy recovery in sewage

The heat exchanger plates are installed directly in the sewage pipe or installed subsequent. The waste water flows over the plates and exchange the heat with the circulating fluid inside the plates. That guarantees among other things that the contaminated water remains in the waste water pipe. The heat recovery system is implemented in main the sewage pipe or as a bypass solution. Furthermore, there are solutions were plates are implemented in the sewage tube directly at company site on such which are installed afterwards.

Heat exchanger in a sewage

Another placement of the plates (KASAG LANGAU AG)

Main pipe

If the heat recovery system is installed in the main pipe the heat exchanger plates are commonly placed at the footer in the sewage pipe. The plates are stacked together in a row along the sewage pipe. Technically the waste water flows across the plates. Inside the plates a thermo-conducting fluid absorbs the heat from the waste water. Through a secondary circle the thermo-conducting fluid distributes the heat directly to the absorber. It is also possible to place the heat exchanger plates on the sides of a pipe. An advantage is an easier service of the heat exchanger.

Furthermore, the cross-section of the pipe is not significantly shorted. On the other site the investment cost rises due to challenging installation. Here it has to bear in mind that enough waste water is flowing through the pipe to ensure an efficient work of the heat recovery system. In general, it can be said that due to robot technology heat exchanger can be placed in pipes with a diameter of 300 mm. Walkable and therefore cheaper in investment are pipes up from 600 mm. Recommended diameters for heat exchanger plates are up from 800 mm. In those the plates can be installed more easy.

Crucial for an efficient operation of the heat exchanger is the total surface area of overflowed plates in dry periods. This is a significant parameter for implementing a heat exchanger in sewage. In literature, mean flow rates up from 15 l/s are required for installation. If the heat demand is lower mean flow rates of 10 l/s would be sufficient, too. The implementation of a heat exchanger in a main sewage pipe is linked with requirements. In Germany the requirement foresees that system components in the pipe do not disturb the operation security and the disposal of sewage.

Those requirements are:

- Hydraulic efficiency
- Reliability of operation
- No more waste deposits
- Accessibility
- High pressure stability (in case of cleaning)
- Ability for renovation
- No damages due to implementation

The hydraulic performance capability in the canal section, where the exchange plates are placed, must be ensured. This parameter is a key factor which can be discerned from the sewage disposal plan. All implementations and modifications should be designed in that way that a zone would be created where particular materials could settle. The used material should be suitable for a use in sewage.

The amount of heat exchanger plates is depending on the required heat or cooling power. Thus, the number of plates can be adapted. Especially dirt inside the waste water has a significant influence on the system performance

Biofilm (KASAG LANGAU AG)

Microorganisms build a biofilm matrix on surfaces even on the heat exchanger plates. They create a millimetre-thick film on the surface. Those sewer films decrease the system performance. To approach this problem two scenarios are possible:

1. Regular cleaning of the plates by high pressure or by flushing the pipe
2. To oversize the heat exchange plates to compensate the sewer film degradation

The first option increases the operating costs and lowers the investment costs but under constant conditions the sewer films is reproducing within 2 weeks. Therefore, the second option is used the most although the investment costs are higher. The heat exchanger is oversized by the factor 1.5 than calculated.Daily routine has shown that this oversizing is sufficient enough. Furthermore, the system has some reserves.

The exchange plates are connected by the "Tichelmann" principle. Generally, this principle is used to avoid pressure losses and therefore guarantee a constant flow within the plates for prime operation. Beside subsequent installation the heat exchange plates can be implemented directly at company side. That combines synergies and minimize the investment costs. Those direct implemented solutions are used for new build pipes in dwelling areas, due to renovation of sewage or for bypass solutions.

Bypass pipe

If an implementation in a main pipe is not possible a bypass solution could solve the problem. Therefore, a part of the main flow is separated, filtered and forwarded to the absorber. Afterwards the sewage water is been led back into the main pipe. As mentioned before the flowrate should take minimum 15 l/s per day, too. The main difference here, the waste water itself is lead through the absorber. Therefore, a filter system should separate the solids from the sewage water to guarantee higher performance and operation time.

In Germany especially a bypass solution differs from the intended purpose of sewage permissions. In past the German law did not foresee another purpose for sewage than disposal. If a bypass solution is desired the public site have to check on communal level the possible environmental pollution risks. Further requirements are mentioned above. Moreover, it has to be clarified if anyone else is not affected by the bypass solution. Especially if the public authority has to deal with a heat recovery system for the first time, the permission process can take longer than expected.

Energy recovery in purification plant

The concept of heat recovery from waste water in a purification plant works similar to a bypass system. A part of the cleaned water is separated and leaded to an absorber. The benefit using the outlet water from purification is that the pollution in the heat exchanger plates is much lower. Fewer pollution of micro-organism like sewer film etc. is the result. Otherwise in most cases the near surrounding of a purification plant does not have adequate heat consumers. Therefore, in most cases the purification plants use the recovered heat for own purposes.

Individual location possibilities

Heat distribution can be done with a one or two pipe system. Furthermore, the connection to

Location of recovery system	Pros	Cons
Inside a building	• Relative high water temperatures • Short distribution lines • Operator=Consumer • No influence of rainfall water • Network independent operation	• Slightly drain with high variation during a day • Disturbing ingredients inside the water • Local operation with high expenditures
Inside a sewage pipe	• High flow rates • Mean heat distribution lines • Surveillance and operation security appropriate	• Dependence on grid operator • Installation requires surveillance • Influence on water disposal
After the purification plant	• No influences environmental pollution due to waste water • High and relative constant flow rate therefore biggest heat potential • Outlet of purification plant • Cooling effect for waste water which in favor of running water	• If no heat consumer in the near surrounding, long heat distribution lines • Dependency on purification plant operator

a district heating or cooling grid can be enabled which would increase the system efficiency much more.

The following criteria have to bear in mind while planning a system

- Distance between end users
- Space on offer for energy supply
- Integration of existing system (boiler, surplus sources, trunk lines)
- System temperatures of any heat users
- Proprietary rights
- Finance and operation (Contracting)

Temperature levels of sewage water

A crucial requirement for technical adequate use of the heat recovery system is the temperature level of sewage water. Technically and economical well recommended is a low temperature level operation for district heating grid by using heat pumps. Especially new build dwelling areas suits to these two conditions. Even in existing properties it is possible to get a yearly COP around 3 while heating up to 70°C. Heat pumps which are operating in bivalent modes or are combined with CHP systems can be used to heat water above 70°C. For really big system and heat pumps from 2.5 MW on, can reach outlet temperatures around 90°C. While the heat demand of end users differs around a year it has to be clarified in which temperature level the heat pump has to operate to run efficiently most of the time.

Localization of heat sources in sewage network

The localization of potential heat sources within the sewage grid should be done under several different points of views. Even the order of key steps can variate from case to case. The most sufficient way to localize heat sources is an analysis of the sewage grid in order to find the preferably best technical and economic solution. Therefore the waste water conditions has to be analyzed as well as potential end users in the near of the pipes. The first step is to set frame conditions. Possible conditions are:

- The system COP has to have an COP higher than 3 to run economical
- A low inlet temperature for heating
- A high heat source temperature (in sewage pipe)
- High heat demand of end user
- Upcoming modernization of a system/ building in existing or new build properties
- A positive influence on the economic part has the distance from pipes to end user
- A bivalent use of the system
- Upcoming sewage modernization or new construction

Indispensable for an analysis is the data structure. In Cologne the analysis was done by GIS program. The ArcGIS desktop provides several software products. ArcCatalog and ArcMap had been used for the Cologne analysis. Three main steps mapping, collection of data and analysis of geological data where done. The data from sewage came from the municipal sewage company (StEB). The baseline situation started with an entire sewage grid model of Cologne. A hydraulically calculation beforehand was done to analyze the grid situation in case of a heavy rainfall. For the recovery system in dry conditions assumptions where done but even these contains some difficulties. The influence of small trade properties and infiltration water was difficult to expect. The values can be influenced by pump stations, too. **Therefore, it is recommended to make several flow rate measurements at least during a feasibility study.**

Concerning the influence of the parameters following data where used in due consideration of the selected criteria:

- Only combined waste water (waste water + rainwater)
- Daily mean water flow [l/s] in dry weather condition
- Pipe diameters
- Allocation to purification plant

Heat consumer

After analyses of the sewage system Data from heat consumer should be collected to compare both information to find the possible sites for heat recovery systems. In Cologne the responsible grid operator had collected data from his grid. The operator is responsible for reliable distribution of electric energy, gas, water and district heating (DH). Furthermore, the grid operator gives all market opponents the same access. Depending on the influence factors and frameworks conditions following data were listed:

- Profiles (Standard load profile, registered power measurement
- Heat demand [kWh]
- Heat power requirement [kW]
- Energy source
- Year of construction of building
- Type of use

Construction

After analyses of the sewage grid system and information about the heat demand all relevant points are signed in within the map. The framework conditions and potential heat sources are overlaid in the GIS map. Furthermore, around the potential heat sources puffer zones of 100m, 200m, 300 m are signed in within all relevant information about distance, heat consumer, heat demand etc. Thereby all relevant locations are summarized and extracted into a table.

Every single location contains following information

- Building, construction date
- Type of use
- Post code
- Address of heat consumer
- Main energy sources of heating system W[kWh]
- Calculated heat demand P[kW] (can be selected into dwelling house, industry, trade/service, communal sector)
- Distance to sewage pipe Dist. [m]
- Pipe profile (high and width) [mm]
- Dry weather flow rate Q[l/s]

Out from that table location can be chosen under economical, ecological best circumstances within a city.

Lesson learnt

Following awareness occurred within the project:

- The operation of the system was not optimal, because the boiler operation was prioritized instead of the heat pump operation. A new management control system was installed and optimized the system operation. The gas boiler now supports the thermal energy production in times of higher demand
- Due to customers request the boiler capacity was 1 MW sized and thus oversized.
- The heat generators should be sized according a heat simulation test so that optimal heat production can be achieved.

- In order to modificate the sewage pipe system a bypass solution was implemented in the Cologne Nippes site Nippes. A bypass to the heating room had to be built, because the heat of the sewage is recovered in there. This is out of the intended purpose of sewage permissions which leads the local authorities to a permission procedure.

This modification led to a time delay, as some extra permission(s) had to be complied. In the past, the law in Germany did not foresee another purpose to operate sewage pipes than disposal. The city authority had checked the risks of environmental pollution due to e.g. leakages etc. Furthermore, it was checked if anybody else could be affected by the bypass construction.

It has to be taken into consideration, especially when it’s the first time for the appropriate authority to approve the modification(s) in the sewage system that the permission process could take longer.

Recommendations from other German experiences

Further recommendations can be found from other case studies outside the CELSIUS project. In the federal state Bavaria some energy utilities installed sewage water heat recovery systems. The following recommendations are given by the Bavarian Government:

- The role between all involved parts (e.g. property owner, the energy supplier, the sewage management company) should be clarified.
- The annual energy demand from wastewater is around 45 kWh per square meter. In order to force the regenerative energy process a heat pump should be operated with two steps compressor to resign fossil fuels.
- The costs should be distributed between all participants. In one case in Bavaria the costs for a conventional heating system were divided between public works service and the housing society.

Conclusion

The key steps for guideline for heat recovery of sewage water shows what aspects have to bear in mind the most. The order in the document can be changed. In some cases, especially for cities who consider an installation it would make sense first to analyse the sewage grid if any pipes/sectors are suitable for the project. Local specifications have to be considered, too. Different ecological aspects and laws in different European cities are neglected. Therefore, it has to be taken into account that delay could come through a project due to complications which are not mentioned here. In Cologne case the law did not foresee a different use of sewage water than disposal. The permission act took longer than expected which was caused by another effect. For the public authority it was the first time they dealt with such a project. Potential environmental pollution had to be checked and leaded into further restrictions which were mentioned, no environmental pollution caused by the bypass system, no interference cause by the system.

Other restrictions in different countries could have a similar effect than that one in Cologne. Some cities have different sewage pipe diameters which lead maybe into more complex installation of the heat exchange plates. Also, climatic differences and different end user behavior have an effect on the feasibility study which might could results into contrary conclusion of the study in Cologne. The cologne solution could not be suitable in other cities for 100%. Most points of the mentioned order of work will stay the same but differences can appear. All in all, even if there are some differences in several cities the installation of heat recovery from sewage water is still a sufficient system in ecological and social point of view. Primary energy is been saved and the carbon dioxide emission is lowered. The economic aspect has to be analysed for its own. But compared to the billions of subsidies for conventional energy generation the heat recovery from sewage is an easy solution, cheap and smart.

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