Waste heat recovery from sewage water in Cologne

Facts about this case

Annual thermal energy provided: 1109 MWh (Wahn) and 762 MWh (Mülheim)
Heat source: Excess heat from sewage water (at least 12 °C)
Energy efficiency: 116 % in Wahn and 128 % in Mülheim
Annual greenhouse gas savings: 214 tonCO_2e in Wahn and 150 tonCO_2e in Mülheim

Period: From 2012 to 2016
Support: FP7-supported CELSIUS-project
Link to web page: http://celsiuscity.eu/

Contact information:
CELSIUS project: Rhein Energie, Fachhochschule Köln, D'Appolonia

The main objective of Cologne's Demonstrator is to recover heat from sewage water and use it in decentralized local heating networks by supplying heat and DHW to local school buildings.

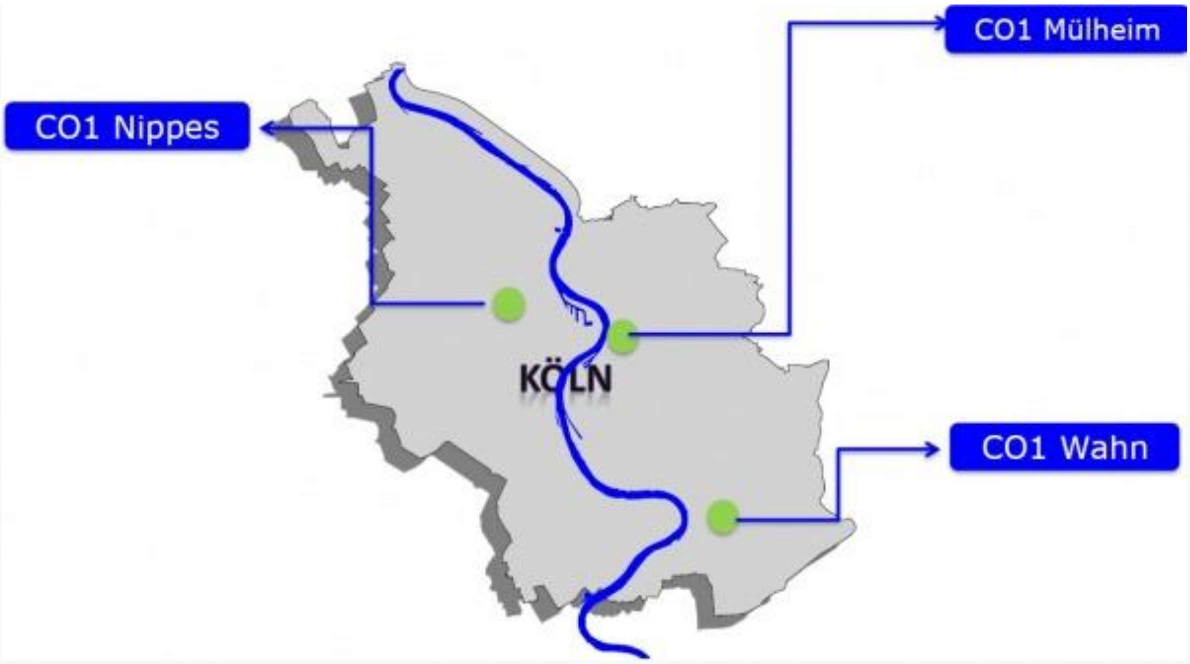

Fig.1. Three demonstrator sites in Cologne.

Idea and layout

The CO1 demonstrator consists of three different operation sites; Wahn, Mülheim and Nippes. In all sites, sewage source heat pumps recover heat from sewage water. The main components of the system are: heat exchangers, water-to-water heat pumps, gas boilers and heat buffer tanks. One innovative part of the demonstrator is the heat exchanger, which is installed inside the sewage pipe. This indirect heat extraction technique is used in two of the demonstrator sites (Wahn and Mülheim). In the third site, a direct heat extraction technique is used. This means, part of the sewage water is by passed and pumped direct to the evaporator of the heat pumps.

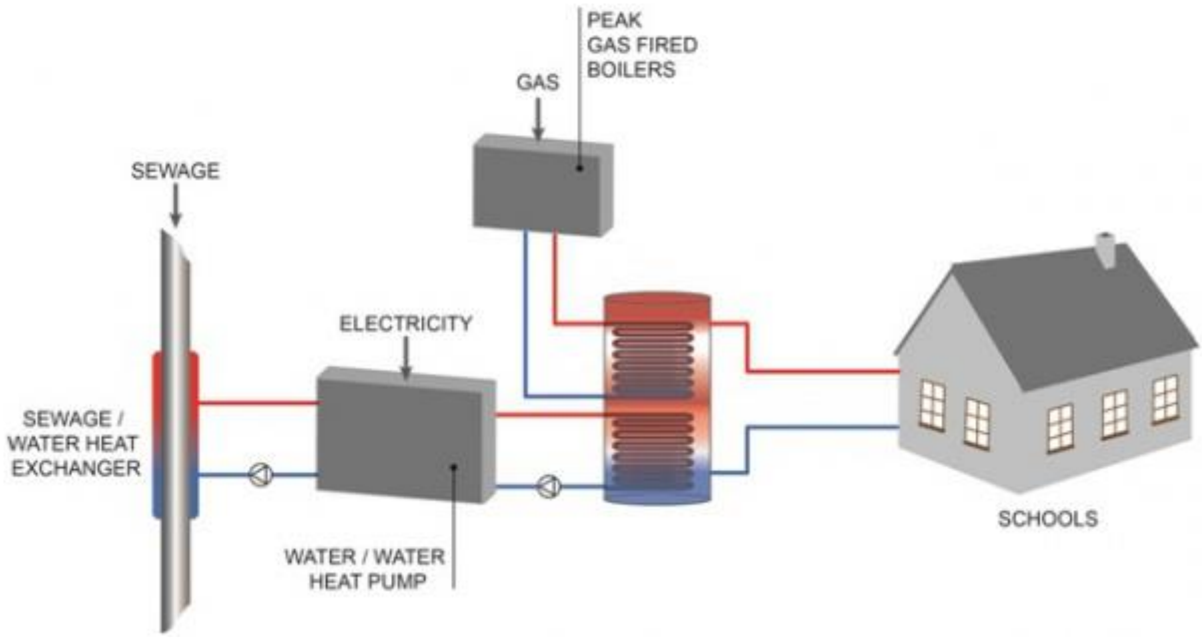

Fig.2. Main components of the system.

Impact

The overall demonstrator's performance is summarized in the following table according to 5 evaluation criterions. It can be noticed that the assignment of all the scores is directly linked to the values calculated for the Key Performance Indicators, except for socio-economic benefits where a qualitative assessment is carried out based on this cluster's indicators and on separate interviews.

Overall Impact	**Fair/Medium**				
Size [MWh/y]	1-100	100-1000	1000-5000	5000-10000	>10000
Primary Energy Savings	0-10%	10-20%	20-40%	40-60%	>60%
GHG Emissions Reduction	0-10%	10-30%	30-60%	60-90%	>90%
Pollutant Emissions Reduction	0-10%	10-30%	30-60%	60-90%	>90%
Socio-Economic Benefits	Low	Fair	Medium	High	Extrem

Replication Potential

The assessment of potential for replication of demo technologies is based on the results of the whole monitoring phase. General replication requirements for demo technologies are assessed through seven criterions including availability of the exploited source, adaptation to different climate conditions, ease of authorization, implementation and operation, required investment cost.

Overall replication potential	**Medium-High**				
Criterion	1	2	3	4	5
Availability of required conditions	Need for conditions currently not available in Europe	Conditions available in a small part of Europe(< 20%)	Fair availability of required conditions (20-60% of Europe)	Conditions available in a large part of Europe (60-90%)	Conditions available in all areas (> 90% of Europe)
Adaptability to different climates	Solution not compatible with European climate conditions	Solution applicable only in a small part of European climate areas (< 20%)	Solution fairly applicable to European climate areas (20-60% of Europe)	Solution applicable to climates of a large part of Europe (60-90%)	Solution compatible with all climate areas in Europe (>90%)
Ease of authorization	Lack of a normative framework	Long time needed for authorizati on (> 6 months)	Medium time required for authorizati on (3-6 months)	Short time needed for authorizati on (< 3 months)	No need for specific authorization
Ease of operation	Strong maintenanc e need and effort to guarantee operation	Significant time and effort needed for functionin g	Maintenan ce and operation effort in line with other suitable alternative s	Low effort required for technolog y operation	Almost no need for maintenance and very limited effort for operation
Integration of waste energy sources	Technology not allowing any recovery of waste	Solution allowing a limited waste energy	Technolog y relying on a fair share of waste	Solution exploiting a significant amount of waste	Technology relying almost only on waste energy sources (>80%)

	energy sources	recovery (<20%)	energy (20-50%)	energy (50-80%)	
Low CAPEX requirements	CAPEX needs much higher than conventional alternatives (> +80%)	Capital investment slightly higher than conventional solutions (+20-80%)	Capital investment in line with conventional alternatives (±20%)	Solution cheaper than conventional alternatives (–20-80%)	CAPEX requirements almost negligible compared to conventional alternatives (<–80%)

Considering the replication potential at European level, more than 84% of EU population is connected to a sewage network, share which increases if focusing the analysis on urban areas only; this means that the replication potential for the Cologne demonstrator is particularly high, also due to the adaptability to different climate conditions and the use of conventional technologies that are economically viable. According to the analyses carried out within other research projects (e.g.: Stratego), 5% of total heat demand could be covered with heat recovered from sewage systems in cities and towns with more

Technical requirements

The technology demonstrated in Cologne could be replicated in several places, within the city of Cologne and in other cities over the EU, provided that some minimal requisites are verified. To ensure the economic feasibility of heat recovery from sewage the following aspects are important:

- Low supply temperature (a 40 °C temperature leads to a COP of 5 whereas a temperature of 70 °C gives a COP of 3)
- High temperature of sewage (min. 12 °C)
- High heat demand to pay off the higher investment (min. 150 kW)
- New construction or refurbishment of the building to be heated
- Short distance between building and sewage pipe (max. 200 meters)
- Adequate sewage pipe (minimum diameter 800 cm; dry weather flow 15 l/s)

More information: Guideline for the replicability of the Cologne Wahn Demonstrator

Stakeholders

Stakeholders	Organization Name	Organization Type	Organization Domain	Benefits from demo
Multi-utility	Rheinenergie AG	Local energy supply company owned at 80% by the City	https://www.rheinenergie.com , http://www.smartcity-cologne.de/index.php/celsius.html	Practical experience in planning and building implementing heat recovery from sewage

		of Cologne		network. Investment, cost for use of energy and maintenance are recovered by the price of the heat.	
Municipal waste water company Cologne	Steb	Municipal sewage company	http://www.steb-koeln.de/	Wastewater grid screen to locate possible heat recovery sites.	
Technology supplier	UHRIG Straßen- und Tiefbau GmbH	Producer and Installer of the heat exchanger	http://www.uhrig-bau.de		
Research Institute	TH-Koeln	Educational	https://www.th-koeln.de	Technical knowledge about recovering heat from sewage network throughout compression heat pumps	
Municipality	City of Cologne/Coordination of Climate Protection	Public authority	www.smartcitycologne.de	Increased efficiency and sustainability of public buildings	

End-users	School head teachers and caretakers	Tenants	--	Increased efficiency of heating supply	

Finance

The financial model used in the project is *Energy Supply Contracting*. RheinEnergie AG planned and operates the heat recovery plant in the buildings. External companies, such as Vießmann) (Heat pump manufacturer) and URIGH (Heat exchanger manufacturer) installed the equipment. The return of the investment and the maintenance costs are recovered by the sale of heat.

Challenges & Risks

- Difficulties in getting permissions for using sewage network for different purposes rather than disposal.
- High investment compared to standard solutions (gas-boiler); heat price required for recovering the investment has to be higher than the heat price of standard-solutions (gas-boiler). Therefore, key factors are:
  - Optimal technical dimensioning to cut the investment to the inevitable.
  - Convincing the customer that the price for the sustainable solution is higher than the standard.
- Optimal location (sewage pipe nearby, good fill level, high flow rate, high heat demand, low temperature demand etc.) should be assessed. Thus, developing a cadastre map of the sewage network and the heat demand could be a strategic factor.
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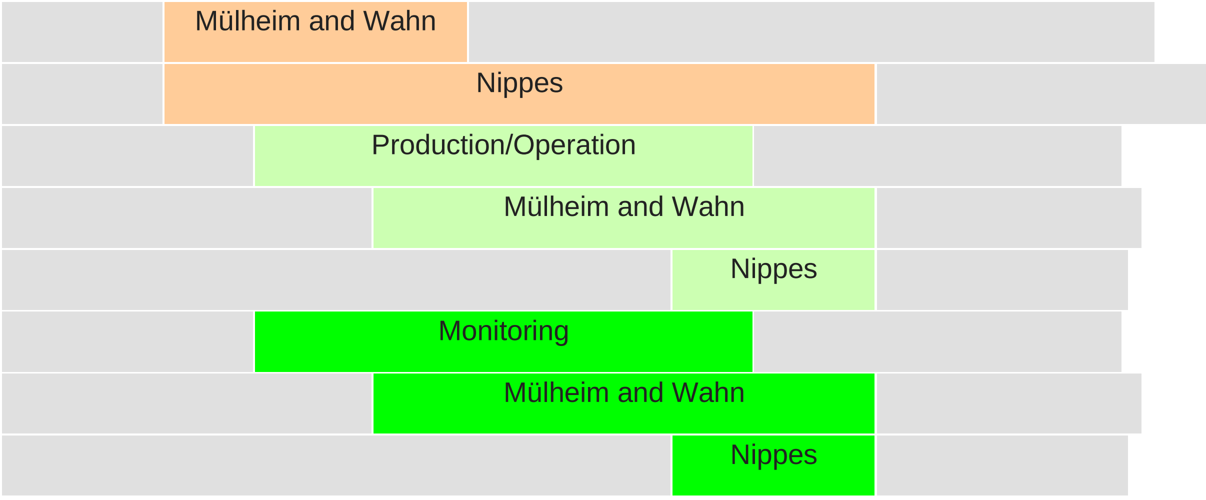
Demonstrator development

Cologne Demonstrator development

2012		2013				2014				2015				2016				2017			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Feasibility																					
Planing and design																					
Permitting																					
				Executive design																	
			Area preparation/Procurement																		
		Installation/Construction																			



Following awareness was gained 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 1MW sized and thus oversized. The heat generators should be sized according a heat simulation test so that the optimal heat production can be achieved.

- In order to modify the sewage pipe system a bypass solution was implemented in the Cologne Nippes site. To recover the thermal energy a bypass from the sewage network to the heating room had to be built. Being the purpose of this bypass, out of the intended purpose of sewage permissions. Some extra permission(s) had to be complied causing a delay in the demonstration realization process. In the past, the law in Germany did not foresee other purpose to operate sewage pipes than disposal. The city authority 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. Therefore, it must be taken into consideration, especially when it's the first time, some extra time for the permitting phase to allow appropriate authority approving the modification(s) in the sewage system.

Cologne Wahn

All project phases were successfully completed, and the system is in operation since October 2013. However, the measurement devices did not start operating until March 2014. For this reason, the data collection of this demonstrator site started in the before mentioned month.

The following challenges occurred during the operation phase:

- After the first monitoring period, a lack of data was detected. The malfunction of the measurement devices (sensors, communication equipment) caused this problem.

- The control system of the demonstrator was not working in an optimal way. It was prioritizing the operation of the gas Boiler instead of the heat pump operation. This means that the gas boiler was supplying most of the heat demand of the school and the heat pump was rarely operating. A new control system was designed for this demonstrator. The new control system was successfully installed, and it is in operation since July 2015.

Cologne Mülheim

All project phases had been successfully completed and the demonstrator site Mulheim started operation in November 2014.

- Some of the measurement devices have not been working properly, causing some missing data.
- From November 2015 to Feb 2016 the HP was out of operation due to a problem with the heat exchanger inside the sewage. Due to an overflowed in the sewer channel, the heat exchanger was damaged. The repairmen work lasted almost forth months as special permits have to be managed and no previous experience existed in this field.

Cologne Nippes

After some delay of the heat pump delivery, the operation site Nippes accomplished all project phases and started operation in February 2015. However, in May 2015 due to malfunctioning of some systems components the operation stopped. The demonstrator site in Nippes is not using any heat exchange, but rather the sewage water is been bypassed to a retention basin where a well pump sends the water to the evaporator. This variation in the layout has not been successful. The operation of the heat pumps has been very unstable. The following unexpected issues have raised:

- One of the two pumps had to be inspected due to high operation noise.
- The actual water flow rate is lower than expected.
- The pump gets easily clogged even if it is provided with a lattice and chopper.
- The heat pump manufacturer went bankrupt after many weeks of uncertainty and rescue attempts.

Several measures at the sewage pump seem to solve the problems so far, but there are few operating hours to prove that they work stably. Test and optimization of the evaporator will start in the next heating period (10/2017)

Demonstrator monitoring

Following the monitoring methodology set up to analyze the CELSIUS demonstrators, relevant key performance indicators are identified for this technology. The methodology aims to quantify the impact of the new demonstrators with respect to the specific baseline situation. The base line situation refers to the previous heating technology, in this case, gas boilers. The following table shows the calculated parameters for the baseline situation of the year 2014 for both demonstrator’s sites. This calculation changes every year, since each year the heat demand varies.

Baseline parameter	Wahn(2014) [1]	Mulheim(2014) [1]
Boiler power [kW]	1370	940
Gas consumption [m³]	1500	1000
Annual percentage of use [%]	85	85
Primary energy consumed [MWh/year]	1650	1100
CO_2-Emissons [t/year]	272	181
SO_2 [kg]	21	14
NO_x [Kg]	306	204
Particulate matter [kg]	12	8
Heat supply [MWh/year]	1220	850

Primary energy efficiency	1,35	1,29

Once the parameters for the baseline are calculated, they are compared with the measured parameters of the new technology in order to obtain the KPI's. The following table shows the calculated KPI's, since the demonstrator sites in Cologne went online.

KPI's	Unit	Wahn (2014) [2]	Wahn (2015)[3]	Mülheim (2015)[3]	Wahn (2016) [4]	Mülheim (2016) [4]
Energetic KPI's						
Yearly amount of thermal energy provided by the new system	MWh/year	704	1109	719	1015	762
Saved PE in comparison with baseline	MWh/year	118	289	216	411	166
Energy efficiency of the project	%	110	116	136	148	128
Energy recovery from waste/renewable sources	MWh/year	95	286	237	371	252
Environmental KPI's						
Yearly GHG savings in comparison with the baseline	%	5	14	16	22	8
Yearly GHG emissions related to the project	ton CO_2e/year	149	214	130	177	150
Yearly pollutant emissions related to the project	%	SO_2: 8 NO_x: 111 PM: 4	SO_2: 12 NO_x: 169 PM: 7	SO_2: 6 NO_x: 87 PM: 3	SO_2: 7 NO_x: 108 PM: 4	SO_2: 7 NO_x: 96 PM: 4
Yearly reduction of polluting emission in comparison to baseline	%	SO_2: 5 NO_x: 65 PM: 3	SO_2: 8 NO_x: 109 PM: 4	SO_2: 6 NO_x: 85.5 PM: 3	SO_2: 10 NO_x: 147 PM: 6	SO_2: 6 NO_x: 87 PM: 4
Carbon footprint	ton CO_2 /year	149	214	130	177	150
Ecological footprint	ha					
Economic KPI's						
Yearly depreciation rate per saved PE	€/kWh	.35	.14	.16	.1	.21

Yearly depreciation rate per ton of saved CO_2e	€/t CO_2e	5030	1238	1438	833	2672
Total cost (yearly depreciation rate + OPEX) per kWh of saved PE	€/kWh	.47	.19	.21	.14	.28
Total cost (yearly depreciation + OPEX) per ton of saved CO_2e	€/t CO_2e	6803	1675	1918	1127	3565
Social KPI's						
Number of users benefiting of the new project	-	1310		735	1310	735
End user complaints due to the implementation of new system	-	0		0	0	0
Surface area served by the new system	m^2	20650		11199	20650	11199

Video

[Cologne Waste Heat Recovery - a Celsius demonstrator]

References

1. Heat recovery from sewage. Feasibility study 2012. Rheinenergie
2. D4.3 progress and achievements on demonstrators_SC_London_Nov_2015
3. D4.3 progress and achievements on demonstrators_SC_Genoa_May_2016
4. D4.3 progress and achievements on demonstrators 2017