The theoretical versus practical potential of existing and emerging wastewater heat recovery technologies

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1.Project Summary

- Utilising secondary heat sources can play a critical role in meeting the UK's carbon targets.
- Recovering waste heat from sewage is an attractive option as it can help UK move towards its climate change targets while decarbonising the heating sector & reducing the reliance on fossil fuels.
- In UK, wastewater as energy source has so far been ignored because of the uncertain impacts of lowering sewage temperatures on WWTP efficiency, heat pump operational costs, relatively low cost of natural gas and longer payback period of heat recovery systems.
- LSBU along with project lead ICAX Ltd. are working on a new design of heat pump.
- The work is also supported by Anglian Water and Thames Water, as part of their ongoing energy innovation work.
- It is the aim of **H**ome **E**nergy **f**or **T**omorrow **(HE4T)** project to explore heat recovery potential in urban water cycle. It will look at how water systems (both mains & waste water) can be connected to the heat pump to boost efficiency - turning the water utilities into energy carriers.
- This part of HE4T project focuses on assessing the viability of heat recovery systems operating elsewhere in the world and use this information to promote this technology in UK that's emphasizes on sustainability.

2.Sewer Heat Recovery

- Everyday about 25 to 30% of energy used in heating water ends up in the sewers – but not all of this energy should be lost!
- Thermal energy contained in sewage is described as low grade heat and can be recovered and used for heating & cooling purposes by heat recovery system consisting of a heat pump and a heat exchanger installed in and/or near the sewer, **Figure 1**.
- The recovered energy is ideal for use in district network, office buildings, apartments, hospitals, sport facilities, swimming pools, universities, schools, shopping & leisure complexes, hotels, estates etc.
- Moreover, the recovered energy is cheaper and environmental friendly as it results in the reduction of greenhouse gas emissions, resource conservation and in increase share of renewable energy.

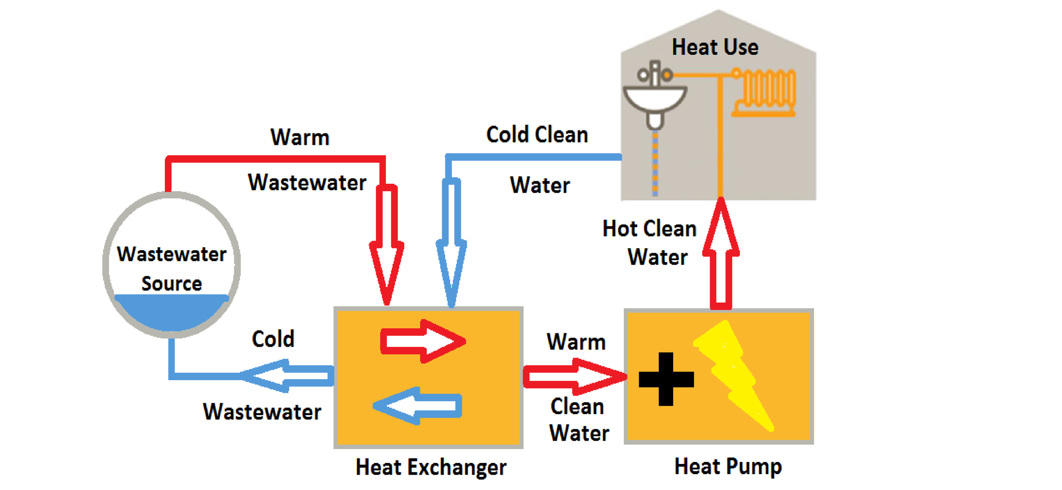


Figure 1. Wastewater Heat Recovery Process (Adapted from [20])

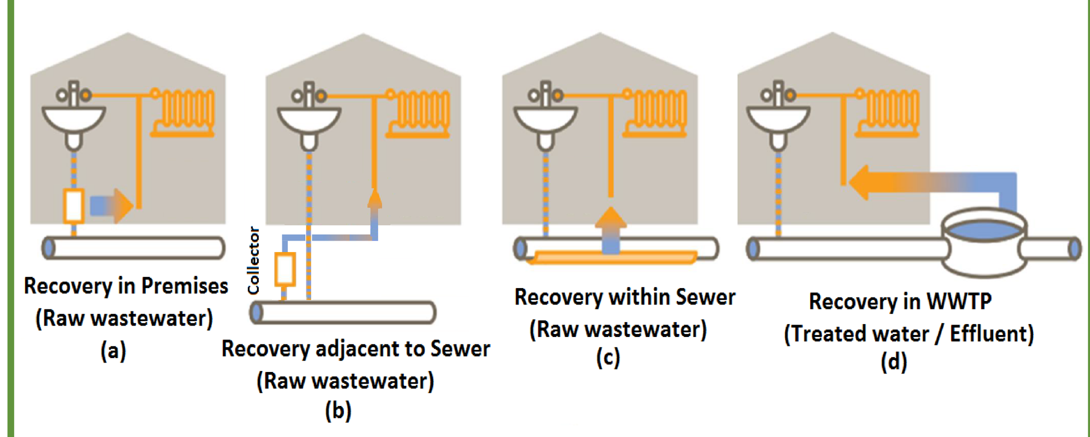
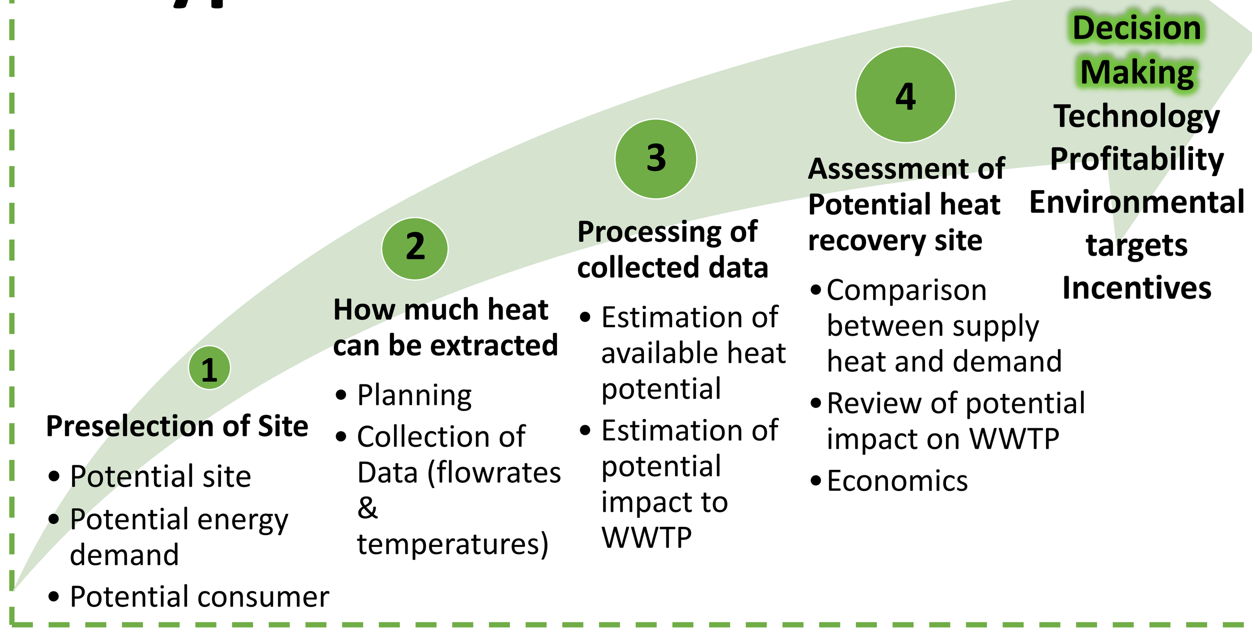


Figure 2. Possible Heat Recovery Locations (Adapted from[21])

3.Typical Framework



4.Heat Recovery Locations

- The heat recovery can be done either before it reaches WWTP (upstream) or after WWTP (downstream) in the wastewater cycle.
- **Before WWTP**, heat recovery can be done close to heat source i.e. within the premises of the household / building referred as **in house**, **Figure 2(a)**.
- The wastewater flow from the nearby sewer can be diverted to a custom made collector / pit / well containing screens and heat exchanger **adjacent to the source, Figure 2(b)**.
- **In-sewer,** directly installing heat exchanger in the base of sewer pipe by placing heat exchanger plates, panels or installing heat exchanger pipes with built-in internal tubes and external tube heat exchangers within the sewer system, **Figure 2(c)**.
- Alternatively, heat can be recovered **after WWTP** from the discharge / treated water / effluent, a much cleaner and stable flow, **Figure 2(d)**.

5.Advantages & Disadvantages

Figure 2(a) - Close to the heat source (Raw wastewater)

- Producers are consumers of heat.
- Sewage temperature is high, more extraction is possible but flow is relatively low & varies in time requiring storage.
- Small heat recovery systems may just employ a heat exchanger requiring lower investment to users.
- Heat recovery systems are modular, can be installed in existing & new premises easily.
- Fouling of heat exchanger surfaces.

Figure 2(b) - Adjacent to heat source (Raw wastewater)

- Sewage temperature is high and wastewater is cleaner.
- Construction of storage pit nearby sewer and equipment installation require space.
- A sieve at the inlet to the pit is necessary to prevent particle accumulation in the pit.
- Periodic backwash of the sieve is also necessary to prevent total or partial clogging.
- Sewage accumulation and biofilm growth on screen requires continuous monitoring, periodic maintenance and permissible oversizing.
- Can be installed in existing and new developments.

Figure 2(c) - In sewer /trunk lines (Raw wastewater)

- Higher & stable flowrates but low sewage temperatures due heat lost to the environment.
- Installation of the heat exchanger may not be possible in all cases e.g. length of straight runs, slope etc.
- Sewers can be combined sewers and weather/ natural events like snow melt, rainfall, flood, ground water leakage could alter the sewage temperature significantly.
- Fouling / biofilms growth on heat exchanger surfaces of varying degree requiring continuous monitoring, periodic maintenance and permissible oversizing.

Figure 2(d) - Heat recovery from the WWTP effluent (Treated water /Effluent)

- The effluent temperature is slightly higher than influent with steady and cleaner flow.
- Since it takes place downstream of WWTP it can be cooled down much more than upstream allowing higher energy potential than raw wastewater.
- This option cannot be used in many locations as WWTPs are located remotely where no heat consumers are available and recovered energy can only be used by WWTP itself.

6.Typical conditions for viability

Criterion 1 - Flow requirements: Potential in-sewer heat recovery site should be a densely populated area with minimum upstream population rate of 5000 - 10000 p.e, this corresponds to the minimum dry weather flow of 15 to 30 litres per second of wastewater [1,14,15].

Criterion 2 - Sewer: For new developments sewer pipe, minimum diameter 400 to 500 mm [14] and for existing sewer pipe minimum diameter 800 mm [1, 15]. In-sewer heat exchanger; the water-covered surface at the base of the sewer needs to be at least 0.8 m^2 [1].

Criterion 3 - Short distances: Potential heat recovery site should be in close vicinity to major heat consumers. There should be relatively short distance between sewer heat exchanger and heating system (heat pump), approx. 100 to 300 m (maximum 500 m) [1,14,15].

Criterion 4 - Heating requirement: Minimum heating load/ requirement should be ≥ 50 - 200 kW [1,14].

Criterion 5 - Legal requirement: Under no condition, activities at WWTP are to be impaired by upstream sewer heat recovery, limiting the sewage temperature at WWTP inlet not to be less than 10°C. This is to minimize the negative effects of transformation and biodegradation of pollutants particularly biological or bio-chemical processes, which may result in higher loads of pollutants exiting the WWTP (in the effluent) if no further action is taken [1].

Note that some countries also impose limit on the temperature of discharge-to-sewer and on the temperature of effluent from WWTP to protect habitat in inland waters, estuaries, streams, rivers and sea so that receiving waters stay at natural conditions [14].

7.Barriers & Promoting factors

Barriers	Promoting factors
• Limited awareness • High upfront cost • Poor perception • High Electricity prices & Low gas prices • Slow Technology upgrade	• Improve image of utilities • Existing infrastructure can be utilized • Chances of renovations, expansions could provide opportunity for sewage heat recovery system. • Profitability of investment improving with increase energy costs • Fuel saving alternative with lower carbon emissions

8.Best practice examples from around the world

City / Country	System Supplier	Arrangement	HP capacity / COP	Purpose	Scale / year
Glarus, Switzerland [1]	Huber Technology RoWin	Collector, Screened Heat Exchanger	30 kW COP 3.8	Heating + Hot water	Pilot (2004)
Swiss Concordia, Lucerne, Switzerland [1]	Huber Technology ThermWin	In-Sewer	n.a	Heating + Hot water + Cooling	Small (2007)
Wintower, Winterthur, Switzerland [2]	Huber Technology RoWin	Collector, Screened Heat Exchanger	1.5 MW COP 5 - 6	Heating + Hot water + Cooling	Pilot (2011)
Bavaria, Switzerland [2]	Huber Technology RoWin	Collector, Screened Heat Exchanger	2 x 280 kW + 2 x 500 kW	Heating + Hot water	Small (2010)
Mülheim, Cologne, Germany (CELSIUS project) [3]	Uhrig Kanaltechnik GmbH Therm-Liner	In-Sewer	150 kW	Heating	Pilot (2014)
Wahn, Cologne, Germany (CELSIUS project) [3]	Uhrig Kanaltechnik GmbH Therm-Liner	In-Sewer	200 kW	Heating	Pilot (2014)
Nippes, Cologne, Germany (CELSIUS project) [3]	n.a	Screened & Pumped into evaporator of HP	3 × 150 kW	Heating	Pilot (2014)
Hasteststraße, Hamburg, Germany [4]	Uhrig Kanaltechnik GmbH Therm-Liner	In-Sewer	4 HP (2000 MWha)	Heating / Cooling	Pilot (2009)
SinTec Technology Park, Singen, Germany [4]	Uhrig Kanaltechnik GmbH Therm-Liner	In-Sewer	200 kW + 243 kW COP 3.5 - 3.9	Heating / Cooling	Large (2004)
Lübeck, Schleswig-Holstein, Germany [5]	Uhrig Kanaltechnik GmbH Therm-Liner	In-Sewer	147 kW	Heating	Small (2014)
Leverkusen, Germany [5]	Rabtherm AG Rabtherm - Liner	In-Sewer	170 kW	Heating + Cooling	Pilot (2003)
Ryaverket, Gothenburg, Sweden [6]	Göteborg Energi	Effluent at WWTP	2 × 50 MW + 2 × 30 MW, COP 3	Heating + Hot water	Large (2009)
Solnaverket, Sweden [6]	n.a.	Effluent at WWTP	4 HP (total 75-100 MW) COP 2.6 - 3.1	Heating + Hot water	Large (1985)
Hammarbyverket in Stockholm, Sweden [7]	Fortum Energi	Effluent at WWTP	7 HP with 225 MW COP 3.5	Heating + Cooling + Electricity	Large (1986, 91 & 97)
Espoo, Finland [8]	Fortum Energi	Effluent at WWTP	2 × 20 MW + 2 × 7.5MW, COP 3.0	Heating + Hot water	Large (2014)
Esplanade, Helsinki, Finland [8]	Helen	Effluent at WWTP	2 × 11 MW + 2 × 7.5 MW	Heating + Hot water	Large (2014)
Katri Vala, Helsinki, Finland [8]	Friotherm AG	Effluent at WWTP	3 × 30 MW + 2 × 30 MW, COP 3.5	Heating + Cooling	Large (2006)
Sandvika, Oslo, Norway [1]	Friotherm AG	Screened, passed to Shell & Tube Heat exchanger	2 × 6.5 MW + 2 × 4.5MW, COP 3.10	Heating / Cooling	Large (1998 & 08)
Sköyen Vest, Oslo, Norway [6]	Hafslund Fjernvarme AS	Screened, Shell & Tube Exchanger	28 MW, COP 2.8	Heating	Large (2005)
Kalundborg Denmark [4]	Kalundborg Forsyning AS	n.a	10 MW	Heating	Large (2017)
Leuven, Belgium (INNERS project) [9]	Vlario	Collector Plate Heat Exchanger	250 kW COP 4.5	Heating + Hot water	Small (2014)
Budapest Military Hospital, Hungry [10]	Thermowatt Ltd.	Collector, Screened Heat Exchanger	3.8 MW + 3.4 MW, COP 6 - 7	Heating / Cooling	Large (2014)
Budapest Sewage Works, Hungry [10]	Thermowatt Ltd.	Collector, Screened Heat Exchanger	1.23 MW, COP 4.4	Heating / Cooling	Large (2012)
Eco-district Nanterre, Paris, France [11]	Suez Ltd. Degres Bleus	In-Sewer	2 × 400 kW, COP 2.7	Heating + Hot water	Medium (2015)
Beijing Olympic Village, China [12]	Skandinavisk Termoekonomi AB	Effluent with plate Heat Exchanger	4 × 5.4 MW + 4 × 5.25 MW, COP 3.85	Heating + Cooling	Large (2008)
Whistler Athlete's Village, BC, Canada [13]	IWS Sewage SHARC	Screened & Pumped into evaporator of HP	3.5 MW	Heating + Cooling	Large (2009)
Southeast False Creek, BC, Canada [13]	IWS Sewage SHARC	Shell and Tube Heat Exchanger	2.7 MW	Heating + Hot water	Large (2010)

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9.UK- a future case study

- There is a keen interest in UK to explore this new technology after the successful sewage heat recovery demonstration project at Borders College, Galashiels, Scotland - a joint venture between **Scottish Water Horizons & SHARC Energy Systems**, utilizing two 400 kW heat pump system (COP = 4.8) that deliver 95% of space heating and hot water requirements of campus. The retrofitted system provides 1.8 GWh of annual heat, saving 150 tonnes of CO_2 emissions per annum with no impact on the local sewage network [18].
- With daily discharge of 16 billion litres of sewage in more than 624,200 kilometres of sewer pipes to pass over to 9,000 WWTPs across UK - the potential of heat recovery is significant [16]. Typical, sewage temperature in UK sewers vary from 10 to 25 °C with a yearly average of 17.5 °C [17].
- Theoretically, if above daily discharge is cooled by 3 degrees for heat recovery, it is possible to recover up to 20 TWh heat energy annually, enough to heat 1.6 million homes.
- Similarly, considering heat recovery from the effluent of the largest WWTP in UK, with daily average DWF of 1207 million litres [19] and cooling it by 3 degrees, the recoverable heat potential is approximately 1.5 TWh heat energy annually, enough to heat more than 100,000 homes.
- **Note in practice the total amount of heat is a function of wastewater/effluent flow rates, initial temperature of the wastewater/effluent, minimum temperature requirements for the wastewater/effluent & efficiencies of the heat exchanger and the heat pump etc.**
- As shown above, there is much theoretical potential along with significant opportunity for future energy recovery and emissions reduction in the longer term but UK needs to overcome major practical constraints; limited awareness of heat pump technology, low cost of gas and a lack of energy networks infrastructure.

10.Next Steps

- Currently the HP is being developed & tested by ICAX Ltd. in the laboratory at LSBU.
- Thames water and Anglian water are performing sewage temperature and flowrates measurements at various potential locations across London and Midland area.
- Based on these measurements, sewer heat recovery model will be developed and various simulation will be performed, estimating potential heat recovery through the sewer pipe network at above locations within the HE4T project.

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