Check for updates

Research Paper

BUILDING SERVICES ENGINEERING RESEARCH & TECHNOLOGY

Building Serv. Eng. Res. Technol.
2021, Vol. 0(0) 1–18
© The Author(s) 2021
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/01436244211034739
journals.sagepub.com/home/bse
SAGE

Opportunities to decarbonize heat in the UK using Urban Wastewater Heat Recovery

Shazia Farman Ali and Aaron Gillich

Abstract

By 2050, the UK government plans to create 'Net zero society'.[1] To meet this ambitious target, the deployment of low carbon technologies is an urgent priority. The low carbon heat recovery technologies such as heat recovery from sewage via heat pump can play an important role. It is based on recovering heat from the sewage that is added by the consumer, used and flushed in the sewer. This technology is currently successfully operating in many cities around the world. In the UK, there is also a rising interest to explore this technology after successful sewage heat recovery demonstration project at Borders College, Galashiels, Scotland.[2] However, further experimental research is needed to build the evidence base, replicate, and de-risk the concept elsewhere in the UK. The Home Energy 4 Tomorrow (HE4T) project at London South Bank University was created to address this evidence gap. This is the fourth article in the series of outputs on sewage heat recovery and presents some results using sewage data from the UK's capital London. These data are scarce and provide useful information on the variation of flows and temperatures encountered in the sewers of the UK's capital. Lastly, we discuss the recoverable heat potential along with policy implications for the UK heat strategy.

Practical application: This work focuses and accentuate that in order to meet climate change targets, substantial improvements can come by heat recovery from the raw (influent) and treated wastewater (effluent from wastewater treatment plant) that is still unexploited in the UK. The estimation presented indicates that there is much theoretical potential in the UK with significant opportunity for future energy and revenue retrieval along with GHGs emission reduction in the longer term to fulfil the 'net zero' objective. This work aims to raise awareness and seek support to promote pilot scale studies to help demonstrate technical and economic feasibility in the building industry.

Keywords

Wastewater heat recovery, raw wastewater, treated wastewater, wastewater temperature, wastewater treatment, wastewater treatment plant, heat pump, low carbon heat

Received 21 February 2021; Revised 5 July 2021; Accepted 6 July 2021

Introduction

By 2050, the UK plans to create 'Net zero society'.[1] To meet this ambitious target, the deployment of low carbon technologies is an urgent policy and a research priority. Recovering heat from wastewater

Net Zero Building Centre, School of the Built Environment and Architecture, London South Bank University, London, UK.

Corresponding author:
Shazia Farman Ali, Net Zero Building Centre, School of the Built Environment and Architecture, London South Bank University, 103 Borough Rd, London, London SE1 0AA, UK.
Email: alis133@lsbu.ac.uk

(often referred as domestic wastewater, sewage, sewer water or urban wastewater) is relatively new and an attractive low carbon option that alongside other renewable technologies can assist in reaching towards net zero target. Every day, in the UK billions of litres of heated water end up in the sewers and its heat content is completely lost. All year round, this heated water when discharged from dwelling is approximately around 30°C temperature. By the time this wastewater (referred as influent) reaches to wastewater treatment plant (WWTP), its average temperature is normally between 10 and 12°C, so much of its heat is lost to the environment. Additionally, once it reaches the WWTP, the treatment processes within the plant to clean this wastewater again raise its temperature approximately by 2°C from that of its entrance value,[3,4] providing a further opportunity to recover heat from treated wastewater (referred as effluent) that is much cleaner and stable flow. Whichever route is taken to heat recovery, once this energy is recovered, it can be used in providing heating in winters and cooling in summers to multiple users, for example, office buildings, community buildings and public facilities. The additional benefits are the recovered heat counterbalances the fossil fuel use, lowers gas and electricity bills, reduction in CO_2 emissions and increasing the share of renewable energy, hence playing a significant role in achieving near zero emission targets.

In the past two decades, many countries around the world have successfully implemented urban wastewater heat recovery (WWHR) technologies[5] and many others considering its deployment. Within the UK, there is a growing interest to explore this innovative technology, especially after the successful WWHR pilot project at Borders College, Galashiels, Scotland, by Scottish Water Horizons and SHARC Energy Systems. The system consisting of two heat pumps of 400 kW (800 kW, COP = 4.8) started working in December 2015, producing 1.9 GWh annually providing major share of heat demand of the college. The annual carbon saving are 170 tonnes of CO_2 with monetary savings of around £10,000 annually by college in their heating bills in comparison to conventional gas boiler heating.[2]

This work presents useful information for the first time on the variation of flows and temperatures encountered in the sewers of the UK's capital London allowing researchers to have first such idea of temperatures encountered in UK sewage systems. This article consists of four sections: an introduction, an extensive literature review, a London-based two case studies exploring heat recovering potential along with conclusion and recommendation. The vigorous literature review covers wastewater characteristics, WWHR systems, preferable installation locations, viability conditions and the wastewater heat recovery examples worldwide setting the context for London-based case study. Next, the article discusses two locations for exploring heat recovery: a small catchment in London recovering heat from upstream of the WWTP and the heat recovery potential from Thames Water's Beckton WWTP in East London. Lastly, we present some policy implications for UK heat strategy.

Literature review

Sewage characteristics and heat recovery system

The primary factors in quantifying the potential heat recovery of wastewater are the flow capacity, temperature at a particular location and the impact of lowered wastewater temperature on the WWTP located downstream. The temperature and flow capacity of the wastewater at particular location are dependent upon the consumer water consumption pattern as well as seasonal and diurnal influence. The consumer water consumption pattern is related to work activities and their habits, typically daily cyclic characteristics, increase in temperature and flow in mornings and evenings, with drop in temperature and flow in nights. This cyclical variation of temperature during the whole day means that same amount of heat may not be recovered at all the times; hence, the heat recovery technology requires thermal storage to offset the variations in flow and temperature. The situation is more complex if the sewer is a combined sewer as any rain (or snow melt) event causes dry weather flow to increase and its temperature to drop significantly. Additionally, it is more appropriate that the heat recovery sewer is located in densely populated area to offset the lower temperature after the heat extraction. The sites in the populated areas apart from the domestic such as hotels, restaurants, indoor swimming pools, leisure centres and hospitals may further add value of sewage heat because of their large capacity uses of hot water, more stable discharged into sewer with an additional advantage of utilizing the recovered heat in close proximity.[5–7]

The factor that favours this mode of heat recovery is the wastewater temperature being higher than other low temperature heat sources such as ambient air and fresh water. The previous wastewater heat recovery research by Schmidt[3] reported that the average temperature of wastewater in sewers remains relatively steady throughout the year. In early 2000, Hayley and Fenner[8] found the typical average sewage temperatures in England vary between 12°C and 20°C affirming it as potentially viable heat source for heat pump.

Currently, there are many WWHR technologies available, some established while others are still relatively new, each with their own advantages and disadvantages. The final choice depends on the local specific conditions. Regardless of the option chosen, the wastewater (raw or treated) temperature is lower than that provided by conventionally used heater/boiler and must be upgraded to a useful temperature by a heat pump. Using this wastewater recovered energy via heat pump is already a viable heat source in some of the coldest countries of the world, for example, Switzerland, Canada, Japan and Scandinavian countries.[5–7] Depending upon the quantity of wastewater, its temperature and hot water requirement, large capacity central heat pump can be used for heat networks or a smaller heat pump fulfilling the heating requirements at the building scale.

The WWHR system either uses direct recovery, that is, a part of wastewater bypassed and sent directly to heat pump's evaporator side after screening and filtering (Figure 1(a)), or to a heat exchanger installed in and/or near the sewer (Figure 1(b)) that indirectly supplies recovered heat via an intermediate fluid (R134a, R407, R410, R717, water/glycol and brine solution) to a heat pump located in the plant room with a buffer tank. After upgrading low grade heat through a heat pump to a higher temperature, it can be delivered to a heating system. In order to raise the temperature of the refrigerant, some input energy is involved in the form of electricity running the compressor. It is to be noted that the sewage (dirt) does not come in contact with the working fluid (clean water or refrigerant) in the heat pump system and the recovered energy is reused for heating purposes. The heat pump works economically and efficiently under low temperature conditions and offers flexibility of integrating within existing and new systems. The recovered energy can be used in a range of domestic and non-domestic heating loads: district networks, office buildings, apartments, hospitals, sport facilities, swimming pools, industrial complexes, universities, schools, shopping and leisure complexes, hotels, estates, etc.

The heat recovery from wastewater can be performed, before WWTP from the raw wastewater (i.e. untreated or influent) in the sewer network (Figure 1), that is, before it reaches WWTP (locations upstream in sewer network), or after the treatment in the WWTP (downstream) from the treated wastewater (i.e. effluent) flowing to the outfall (Figure 2). The selection of the most suitable location to recover heat is a design choice based on specific project conditions.[3,5–7] However, the general trend is as the heat recovery location moves away from the home towards the WWTP, the temperature of the fluid available will decrease and the flow rate will increase as more branches join the main trunk.

The upstream heat recovery from the influent to WWTP has an advantage of higher temperatures with the demand and supply nearby but severely restricted by the limit on the temperature drop or energy extracted due to negative impact on WWTP performance. This is due to the requirement of the WWTP as the wastewater treatment efficiency depends upon entering wastewater temperature. Some other issues reported are effects of seasonal diurnal variations, sewer requires continuous monitoring for solid handling, fouling and biofilms growth on heat exchanger surfaces and constant periodic maintenance.[3] Further details can be found elsewhere.[5–7]

The downstream heat recovery takes place after the treatment in the WWTP from treated wastewater (effluent) before discharging to a large water body (Figure 2). This heat recovery is more favourable as

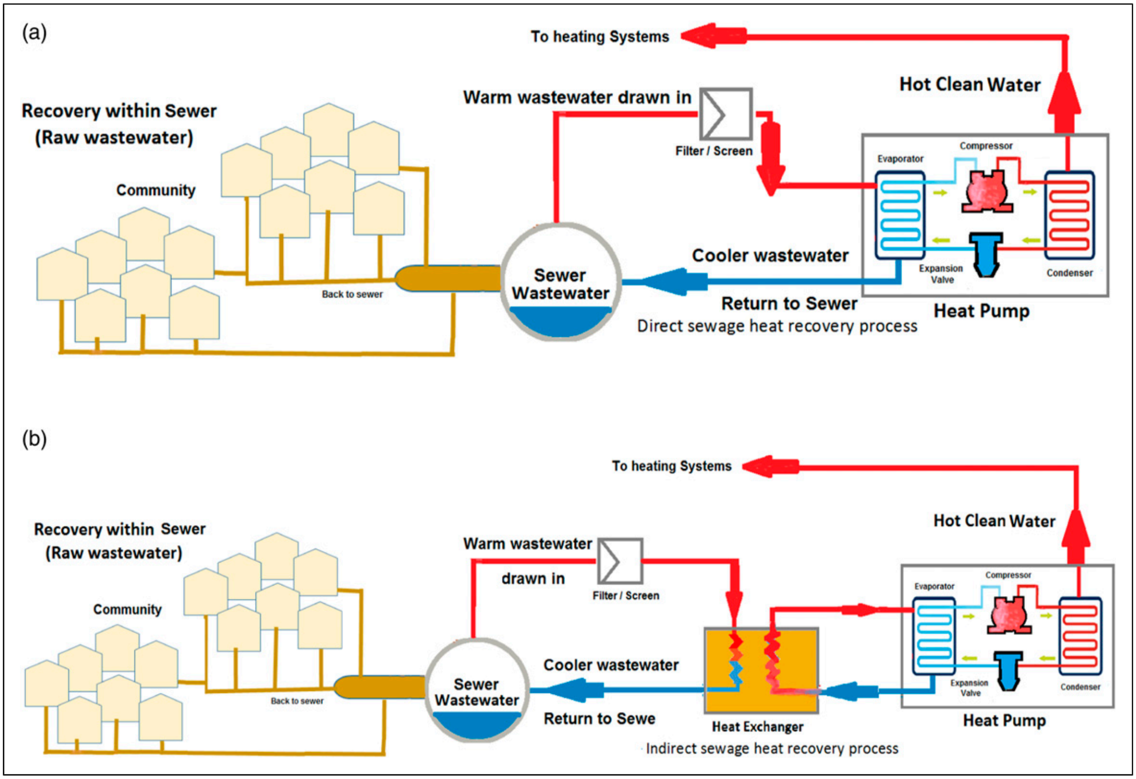

Figure 1. (a) Direct and (b) indirect wastewater heat recovery process from the sewer network before WWTP.

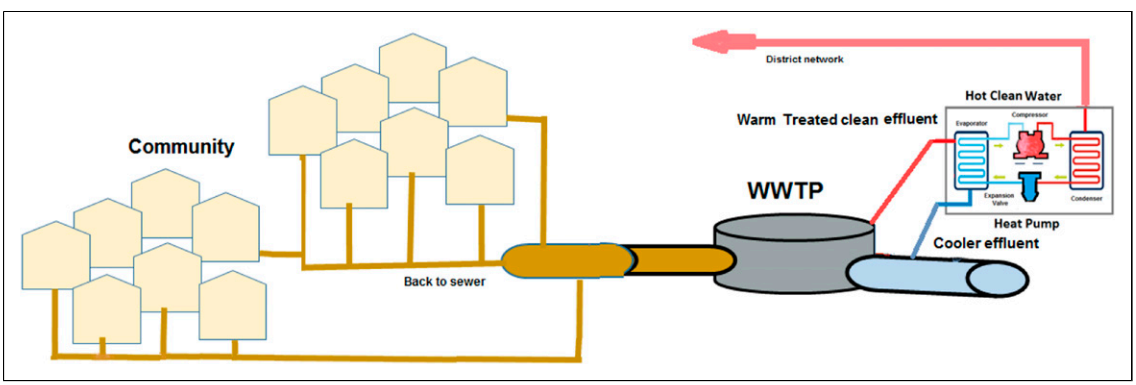

Figure 2. Heat recovery from the wastewater (effluent) after WWTP.

the limitations of the raw wastewater heat recovery do not exist. Moreover, this treated wastewater is cleaner, constant stable flow with similar or slightly higher temperature than entrance to WWTP with no impact on the performance on WWTP, thus allowing higher energy potential with lower maintenance requirement and higher reliability of heat recovery equipment. Still, further installation of equipment and accessibility are more straightforward, compared to raw wastewater heat recovery that can be expensive and challenging. Because of its advantages, majority of sewage heat recovery plants are using treated wastewater as a heat source and producing heat in megawatts.[7] Only limitations are that often WWTPs are located outside the urban boundary where no or few heat consumers are nearby[3] and in such cases recovered heat can only be used by WWTP itself in sludge drying and or in upgrading the biogas quality in the anaerobic digestion process.[8] Therefore, any opportunity to explore this option will require infrastructure setup in place to deliver the heat to domestic and non-domestic customer or taken into consideration at an initial assessment stage.

Viability conditions for sewage heat recovery

The significant barriers to successfully implement this technology are lack of data and scattered existing information indicating wide ranges of values of the major parameters, for example, flowrates, temperatures, pipe sizes and heat recovery capacity; because of this, a general framework was put together[5] adapted from different sources[3,9–12] for future work on this technology.

Briefly for upstream heat recovery (from the influent), following conditions should be met: (i) the potential heat recovery site to be located in densely populated area (around 5000–10,000 PE) corresponding 15–30 L/s of wastewater to the minimum dry weather flow,[3,9,10] (ii) minimum sewer pipe diameter no less than 500 mm for existing network and above 800 mm in newer developments to allow sufficient flow, installation of heat exchanger and its maintenance,[3,10] further, (iii) this potential heat recovery site should be in the close proximity to heat consumers approx.100–300 m (maximum 500 m) to avoid heat losses,[3,9,10] (iv) the minimum heating load/requirement should be ≥100 KW,[3,10] in the surveyed literature, (v) no definite minimum heat extraction temperature was found except a WWHR limit of 0.5°C, that is, the wastewater temperature drop should not be more than 0.5°C at the point of extraction,[11] additionally, (vi) the influent WWTP temperature should not be below 10°C to ensure that wastewater treatment activities at the WWTP are not compromised by sewer heat recovery upstream.[3,4,13] However, this could be avoided by having dense population past the heat recovery point to warrant higher than 10°C temperature at inlet to WWTP and lastly (vii) while for downstream heat recovery, previous constraints are not applicable; low discharge temperatures from WWTP much cooler than average water temperature of the water body are likely to disrupt the aquatic ecosystems[8]; hence, treated wastewater temperature after heat recovery should not be lower than the average temperature of water body.

Examples of wastewater heat recovery from around the world

Switzerland is considered to be the pioneer in wastewater heat recovery technology with their first wastewater heat recovery application via heat pump dating back to the 1980s.[3] Currently, many raw and treated wastewater heat recovery plants using more than 500 heat pumps are in operation across the world.[3,9,14] Tables 1 and 2 present some examples of wastewater heat recovery plants successfully operating around the world. It can be noted that raw sewage heat recovery systems are typically smaller with maximum rating of under few MW while treated wastewater heat recovery systems are higher capacities mainly used with district heat networks. As evident from these tables, the technology has progressed from small scale and now being used at commercial scale.

Wastewater heat recovery in the United Kingdom

In 2019, the UK's space and water heating alone were the second largest energy consumption sector after the transport and was also the cause of UK's one-third greenhouse gas emissions.[15,16] Figure 3 shows the UK domestic energy consumption[17] from 1991 to 2019 – a significant portion of this energy ultimately ended in the sewers and was lost to the environment. Recovering this thermal energy added by the consumer from the sewer systems could result in offsetting the fossil fuel use, reducing

Table 1. Some raw wastewater heat recovery projects from around the world.

City/country	Arrangement	HP capacity/COP	Purpose	Scale/year	References
Southeast False Creek, BC, Canada	Raw wastewater, screened, passed to shell and tube heat exchanger	2.7 MW, COP 3.2	Heating + hot water at 65–95°C	Large (2010)	[31,22]
Wintower, Winterthur, Switzerland	Raw wastewater, screened and passed to collector with heat exchanger	1.5 MW, COP 5–6	Heating + hot water + cooling	Pilot (2011)	[14,32–34]
Leukerbad, Switzerland	20°C raw wastewater, screened and passed to collector with heat exchanger	2 × 225 kW	Heating + hot water at 51°C	Small (2018)	[32]
Bavaria, Switzerland	Raw wastewater, screened and passed to collector with heat exchanger	2 × 280 kW + 2 × 500 kW	Heating + hot water	Small (2018)	[32]
Dietikon (Zürich), Switzerland	Raw wastewater, screened and passed to collector with heat exchanger	1 × 4.0 MW COP 5.50	Heating + hot water NH_3 supply 40°C	Small 2018	[33,34]
Sandvika, Oslo, Norway	10°C raw wastewater, screened, passed to shell and tube heat exchanger	2 × 6.5 MW + 2 × 4.5 MW, COP 3.10	Heating R-134a supply 68°C + cooling	Large (1998 and 08)	[35,36,29]
Sköyen Vest, Oslo, Norway	10°C raw wastewater, screened, passed to shell and tube heat exchanger	28 MW, COP 2.8	Heating R-134a supply 90°C	Large (2005 and 2008)	[34]
Budapest Military Hospital, Hungary	Raw wastewater screened passed to collector with heat exchanger	3.8 MW + 3.4 MW, COP 6–7	Heating/cooling	Large (2014)	[29,37,38]
Budapest Sewage Works, Hungary	Raw wastewater screened passed to collector with heat exchanger	1.23 MW, COP 4.5	Heating/cooling	Large (2012)	[34,37,38]
Újpest – City Hall & Buildings, Hungary	Raw wastewater screened passed to collector with heat exchanger	1.6923 MW, COP 4.0	Heating/cooling	Large (2012)	[37,38]
Mülheim, Cologne, Germany	In-sewer heat recovery	150 kW	Heating only	Pilot project under CELSIUS	[36,39,40]
Wahn, Cologne, Germany	In-sewer heat recovery	200 kW	Heating only	Pilot project under CELSIUS	[36,39,40]
Nippes, Cologne, Germany	Pumped directly into evaporator of HP	3 × 150 kW	Heating only	Pilot project under CELSIUS	[36,39,40]
SinTec Technology Park, Singen, Germany	In-sewer heat recovery	200 kW + 243 kW COP 3.5–3.9	Heating/cooling	Pilot project under ReUseHeat	[29]
Lübeck, Schleswig-Holstein, Germany	In-sewer heat recovery	147 kW	Heating only	—	[41]

Table 2. Some treated wastewater heat recovery projects from around the world.

City/country	Arrangement	HP capacity/COP	Purpose	Scale/year	References
Postal office of Muelligen from Werdhoelzli STP Switzerland	8–10°C effluent pumped into evaporator of HP	5.5 MW	Heating + cooling, uses NH_3, 65°C HW supply	Large (2006)	[14]
Whistler Athlete's Village, Canada	Effluent pumped into evaporator of HP	3.5 MW	Heating + cooling	Large (2009)	[42]
Beijing Olympic Village, China	Effluent with plate heat exchanger	4 × 5.4 MW + 4 × 5.25 MW, COP 3.85	Heating + cooling	Large (2008)	[43]
Suomenoja Espoo, Finland	Effluent pumped into evaporator of HP	2 × 20 MW + 2 × 14.5 MW, COP 3.0	Heating + HW	Large (2014)	[44]
Katri Vala, Helsinki, Finland	10°C effluent pumped into evaporator of HP	3 × 30 MW + 2 × 30 MW, COP 3.5	Heating + cooling, uses R-134a, 88°C HW supply	Large (2006)	[34,45,46]
Kakola, Turku, Finland	10°C effluent pumped into evaporator of HP	2 × 10 MW + 2 × 30 MW, COP 3.3	Heating + cooling, uses R-134a, 78°C HW supply	Large (2006)	[47,51]
Ryaverket, Gothenburg, Sweden	Effluent pumped into evaporator of HP	2 × 50 MW + 2 × 30 MW, COP 3	Heating HW	Large (2009)	[29]
Hammarbyverket, Stockholm, Sweden	Effluent pumped into evaporator of HP	5 HP producing total 131 MW, COP 3.0	Heating + HW	Large (1986, 91 & 97)	[13]
Jönköping, Sweden	Effluent pumped into evaporator of HP	25 MW, COP 3.0	Heating + HW	Large (1986, 91 & 97)	[48]
Lund, Sweden	8–16°C effluent pumped into evaporator of HP	1 × 13 MW + 2 × 40 MW, COP 3.3	Heating + cooling uses R-134a, 80°C HW supply	Large (1984 and 2003)	[48]
Helsingborg, Sweden	8–16°C effluent pumped into evaporator of HP	1 × 27 MW + 1 × 7 MW, COP 3.0	Heating + cooling, R-134a	Large (1996 and 1999)	[29]
Gothenburg, Sweden	12°C effluent pumped into evaporator of HP	2 × 30 MW, COP 3.3	Heating + cooling, uses R-134a, 80°C HW supply	Large (1984 and 1986)	[29]
Sundbyberg – Solna, Sweden	8–12°C effluent pumped into evaporator of HP	2 × 60 MW, COP 3.2	Heating + HW + cooling, uses R-134a, 83°C HW supply	Large (1985)	[48]
Uppsala, Sweden	9–18°C effluent pumped into evaporator of HP	3 × 12 MW, COP 3.0	Heating + HW + cooling, uses R-134a, 70°C HW supply	Large (1982)	[48]
Västerås, Sweden	9–20°C effluent pumped into evaporator of HP	2 × 13 MW, COP 3.5	Heating + HW, uses R-134a, 70°C HW supply	Large (1992)	[48]
Kalundborg, Denmark	20°C effluent pumped into evaporator of HP	10 MW, COP 3.6 to 4.0	Heating + HW, uses R-134a, 79°C HW supply	INNERS project (2017)	[29,49]

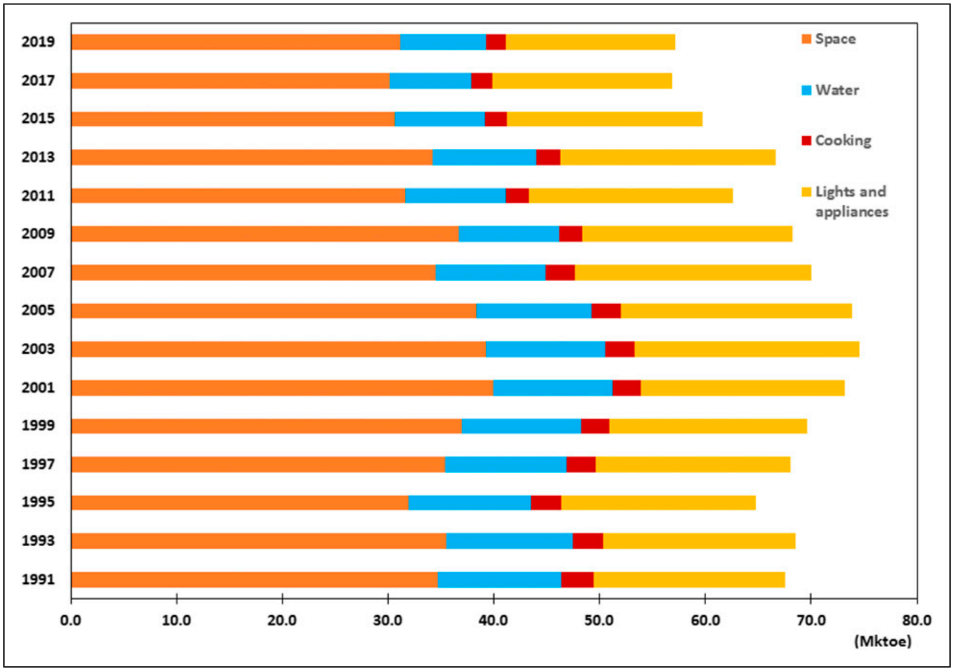

Figure 3. Domestic energy consumption by end use, 1991–2019.

greenhouse gas emissions and decarbonizing the UK's major energy consumption sector.

With daily average discharge of 16 billion litres of sewage across the UK in more than 624,200 km of sewer pipes heading to 9000 WWTPs[18] with typical sewage temperature from 7 to 25°C,[5–,8] the potential of heat recovery is significant. Theoretically, if this daily discharge is cooled by 3° for heat recovery, it is possible to recover more than 20 TWh heat energy annually, enough to provide space heating and hot water to 1.6 million homes. Although this simple calculation shows high potential (no heat loss), actual potential is affected by various other parameters. In practice, not all of this heat can be recovered because the total amount of heat recovered from wastewater is a function of initial temperatures and flowrates of the sewage, minimum temperature and flowrates requirements and by multiple other factors including uncertain impacts of lowering sewage temperatures to WWTP efficiency, appropriate heat recovery site, efficiencies of heat recovery system, demand for recovered heat, legal and economics constraints and carbon savings.

Case study – London's wastewater theoretical potential

According to GLA report in 2015,[16] London's domestic energy consumption was responsible for 37% of greenhouse gas emissions with 24% from gas use for space heating and hot water. With the population of approximately nine million, the UK's largest city London is working on exploring pathways for transition to 'Net Zero'. Thus, the identification of secondary heat sources and use of these to facilitate the transition of decarbonization has been a high priority. GLA published London's Net Zero report where secondary heat sources across London referred as 'London Heat Map' are identified – a spatial potential of various secondary waste heat sources (power station rejection, industrial sources, London underground, national grid electrical infrastructure, ground source, air source sewer heat, water and river source, etc.) in and around London areas.[1] Figure 4 below shows the areas within and around London with a potential for recovering heat from sewers as well as from industrial sources.[19] The map is the

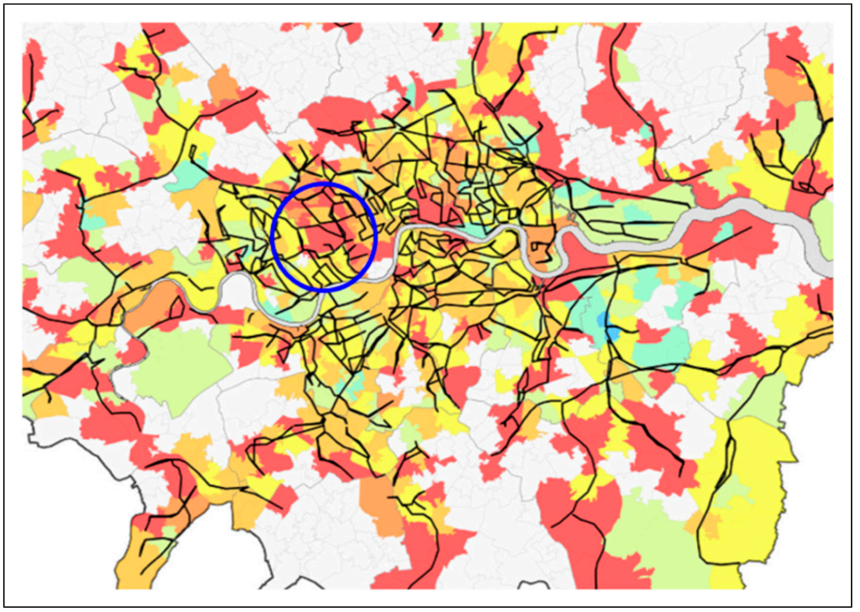

Figure 4. London Heat Map indicating waste heat potential (sewer + industrial).[20]

result of work done across boroughs of London[20] and identifies the potential customers near to these heat sources in order to make the waste heat recovery technologies viable via heat networks. It is the result of such finer level studies[1] that estimated total theoretical waste heat recovery potential from London sewers as 232 GWh/year. Noticeable here is while there are heat/cooling network infrastructures available in many cities that have adopted this technology, such networks are scarce in the UK and specially in London. Currently, only 2% of UK space and water heating demands are met by heat networks.[21] The current investment of £320 million via Heat Network Investment Programme to fill the gap of heat network technology by the government is a perfect opportunity to develop the necessary infrastructure to incorporate more waste heat recovery into heat network design. Many urban developers in and around London are now adopting the communal heat network approach (decentralized energy centres/community-based energy centres) supplying domestic hot water at new developments/estates. If heat networks at community level and district levels are encouraged to use secondary heat sources, it could facilitate the transition towards near-zero carbon heat making waste heat recovery technologies become viable. It is anticipated that this move away from fossil fuel will be replaced by secondary heat sources, with heat pumps[21] playing a critical role. It is therefore expected that in the future, heat pumps market likely to expand will be retrofitted in existing buildings as well as form major part of new developments energy centres.

Current work in wastewater heat recovery area is done under 'Home Energy 4 Tomorrow' (HE4T) project (https://www.lsbu.ac.uk/stories/he4t-project) to address Zero Carbon London plan. The work was performed at London South Bank University (LSBU) along with a clean-tech firm (ICAX Ltd.), as well as two utility partners (Thames Water and Anglian Water) as part of their ongoing energy innovation work to achieve net zero carbon emissions by 2030. Alongside developing and testing novel heat pump by ICAX Ltd., wastewater temperatures and flows were monitored near number of prospective energy centres sites across London by Thames Water during February 2018 to January 2019. During this period, wastewater discharges and its temperatures were recorded by flowmeters and temperature data loggers in the upstream and downstream manholes near the sites. The physical details of the sewer network were taken from Thames Water database. All the sites considered were collector sewers and trunk sewers collecting the domestic wastewater, rainwater, surface water, etc. Some data have been analysed by the authors forming the series of outputs[5,6,7] on wastewater heat recovery. Further detailed analysis is ongoing and is subject of future publications in this series.

Raw wastewater potential

A number of raw screened wastewater heat recovery schemes are successfully operating around the world to provide renewable heating adding weight to pursue development here in the UK. One such example is the Neighbourhood Energy Utility district energy system in Southeast False Creek, BC, Canada, producing 2.7 MW since 2010, using screened raw sewage (18–20°C) of the same area in two heat pump (COP = 3.2) evaporators, outgoing hot water 65°C in summer and 95°C in winter supplying heat and hot water to 33 high rise commercial and residential buildings. Currently, 70–80% of the demand is met from sewage heat recovery via heat pump and rest is supported by natural gas fired boilers at peak loads. A further expansion to this wastewater heat recovery project is underway to increase the capacity by 5.8 MW.[22] Some similar other examples can be found in Table 1.

The daily average discharge of three billion litres of wastewater in 55,000 km length of London sewers[23] with prevailing average temperatures of 11°C in February and 19°C in August at the entrance to Thames WWTPs in and around London[24] provides a good opportunity to extract waste heat. More recently in 2018, Ali and Gillich[7] reported an average wastewater temperature of 20°C–22°C in July and 12°C–16°C in January in some of the London sewers. They further reported lowest average wastewater temperature of 7.8°C in February 2018 found in one of the monitored boroughs in London during an unusual cold wave 'Beast from the East'.[6] Figure 5 shows this unusual cold weather and average wastewater temperature inside the sewer being less affected by average ambient air temperature (6.5°C) outside.

The current presented site shown in Figure 6 is from a borough in central London. The sewer is a combined sewer of 1450 mm, gravity driven lying approx. 6.5 m beneath the ground. The two data measuring sites are also visible in the figure. The wastewater belongs to an upstream catchment area consisting of houses, business and commercial activities, mainly restaurants, high street shops, etc., with common main sewer collector. Since the site considered is dense urban area, thus continuous flow with high temperatures range is expected throughout the day. The average dry weather flow at the downstream end is around 778 m^3/day. Figure 7 shows the average monthly wastewater temperatures in the collector sewer, that is, 19°C in May increasing to 23°C in July and dropping down to 17.5°C in January. Accompanied in the figure is outside average ambient air temperatures for the same period. It can be seen that in the monitoring period, average wastewater temperature inside the sewer is relatively stable, higher and less affected by mean ambient air temperature outside (5°C) corroborating previous works.[3,6,8,25,26] Considering the average monthly temperatures above and assuming a drop of 6°C after heat recovery, the calculated average energy potential for this site is around 1134.77 MWh/y based on dry weather flow period. The annual average domestic natural gas consumption[27] in this borough is 12.7 MWh/y (98% of this is for space heating and hot water); with this potential, it is possible to supply heat to around 90 homes. These 90 homes will annually displace 291 tonnes of CO_{2eq} emissions coming from natural gas-fired boilers as using sewer recovered heat only requires work input in form of electricity by the heat recovery system (with COP = 3.2). The estimated annual total CO_2 emissions in wastewater heat recovery case is around 83.3 tonnes of CO_{2eq}, almost 3.5 times less than natural gas-fired boilers.

Treated water potential

The other option to wastewater heat recovery is to reclaim heat from the treated wastewater (effluent) at the exit from WWTP. This is because the treatment

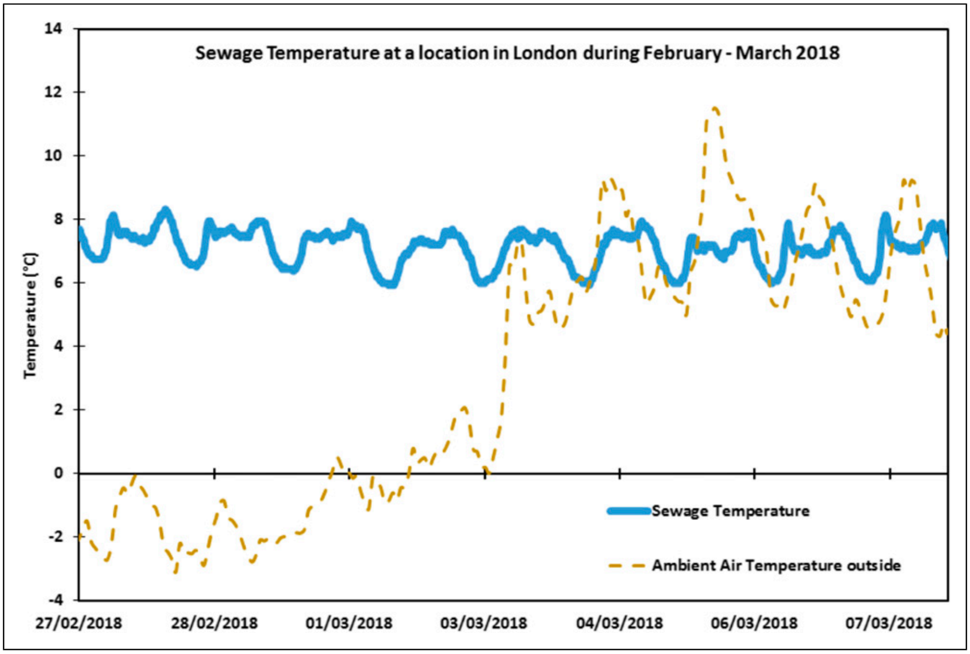

Figure 5. Sewage temperature within sewer during the 'Beast from the East' February 2018.

within the WWTP raises the temperature by few degrees Celsius from that of its entrance value, providing another opportunity to recover waste heat. Wanner et al.[4] found treated wastewater temperature higher by 2°C from that of raw wastewater in summer while in winter, it was higher by 0.72°C. A similar observation is made in current work when comparing the annual average wastewater temperature at the entrance and the exit of Beckton WWTP in London. Figure 8 shows that the annual average raw wastewater and treated wastewater temperatures are in agreement.

Due to the benefits mentioned earlier in the *Literature Review* section, the treated wastewater heat recovery via heat pump is more popular with some of the biggest capacity heat pumps installed across the world recovering heat in Mega-Watts range. One recent successful heat recovery example is of the city of Malmö, Sweden, using treated wastewater heat (14°C–8°C) from the Sjölunda WWTP in shell and tube evaporators of its four ammonia refrigerant heat pumps of 10 MW each (4 × 10 MW) for district heating and cooling. The outbound district heating water from the 4 heat pumps is at 60–72°C and is further heated in a waste incineration plant to 75–95°C before delivering heat to around 100,000 homes in the city. The setup annually saves around 50,000 tonnes CO_{2eq} while producing 200 GWh/y, fulling 8% of the Malmö's annual heating demand.[28] Another project is the Rya Värmepumpverk WWTP treated wastewater used in district heating network of Gothenburg, Sweden, since 1985. The project is using four heat pumps (COP- 3.0) of 160 MW (2 × 30 & 2 × 50 MW) to recover energy from the treated wastewater (12°C) and operate to support the base heat load in Gothenburg at hot temperature of 75–85°C. The only drawback is that the heat pumps are operating with R134a; however, no noticeable leakages have been reported. Till 2013, the heat pumps have covered 11,496 h of operation producing 443 GWh[29] (refer to Table 2 for other examples).

Currently, there are eight WWTPs across the capital (London) (see Figure 9) treating the wastewater of about nine million people. Table 3 summarizes the population served by each of these WWTP and their daily average capacities while

Figure 6. Monitoring site in central London, London.[50]

Figure 10 presents their annual average effluent temperatures around 12.5°C–20°C. If we consider heat recovery from the treated sewage of all these WWTPs situated across London based on their daily average dry weather flows and cooling it by just 3°C, then it is possible to recover approximately 4TWh of heat annually (see Figure 11). Considering an average domestic gas consumption of 13,000 kWh/y based on BEIS data of London boroughs gas consumption,[27] this value is enough to heat more than 250,000 homes. From Figure 11, it is also obvious that the Thames Beckton WWTP in East London, the largest WWTP in the UK and Europe, has the highest recoverable heat potential of about approximately 1.5 TWh heat energy annually. This is because there is strong relationship between the population equivalent and available energy from that WWTP. This wastewater treatment plant is most suitable for an effluent heat recovery system, and the recoverable amount of energy is enough to provide space heating and hot water to more than 100,000 homes alone displacing around 0.33 Mt CO_{2eq} emissions annually. All the other sites also have waste heat potential and thus can also be explored for small to medium scale effluent heat recovery. Depending upon the availability of space and accessibility to available infrastructure, the potential reduction in emissions is further expected.

Implications

The above simple calculations indicate that there is much theoretical potential along with significant opportunity for future energy and revenue retrieval along with GHGs emission reduction in the longer term to fulfil the Zero Carbon London objective.

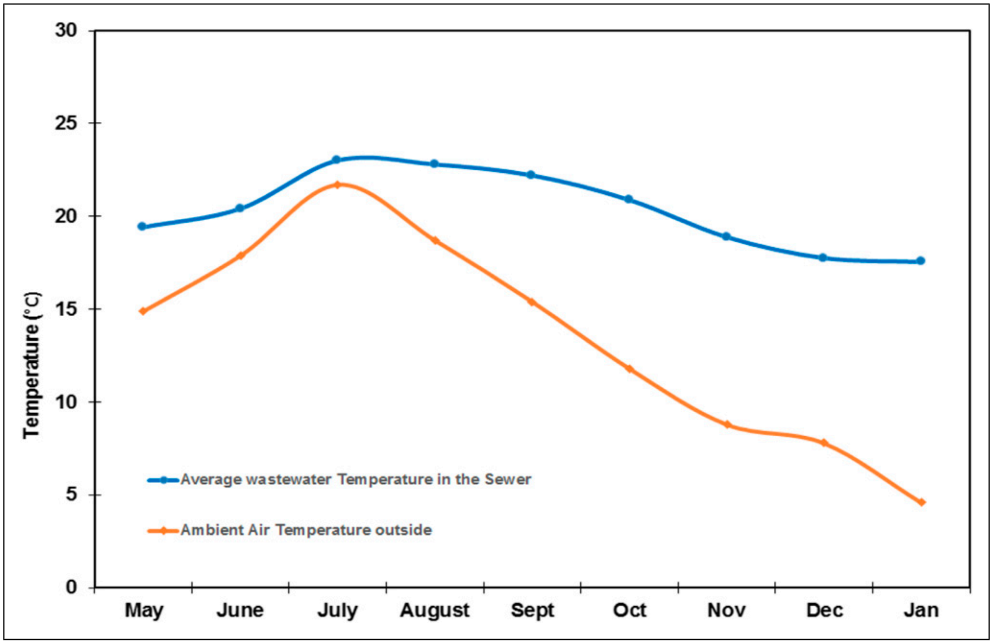

Figure 7. Monthly average raw wastewater temperatures near the site in a borough in central London in 2018.

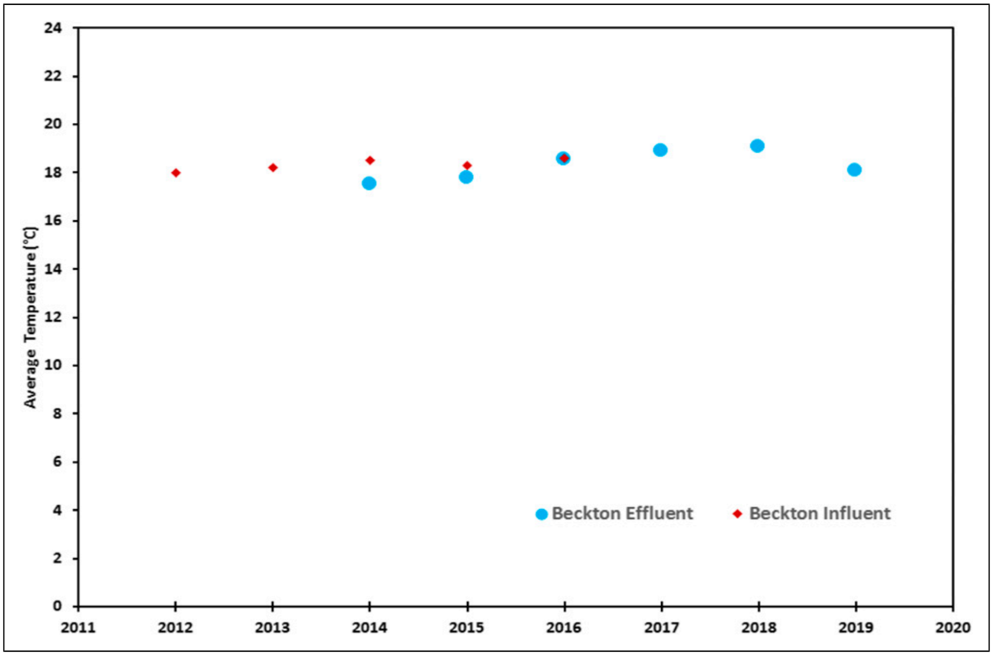

Figure 8. Annual average influent and effluent temperatures of Beckton Sewage Treatment Plant in London.

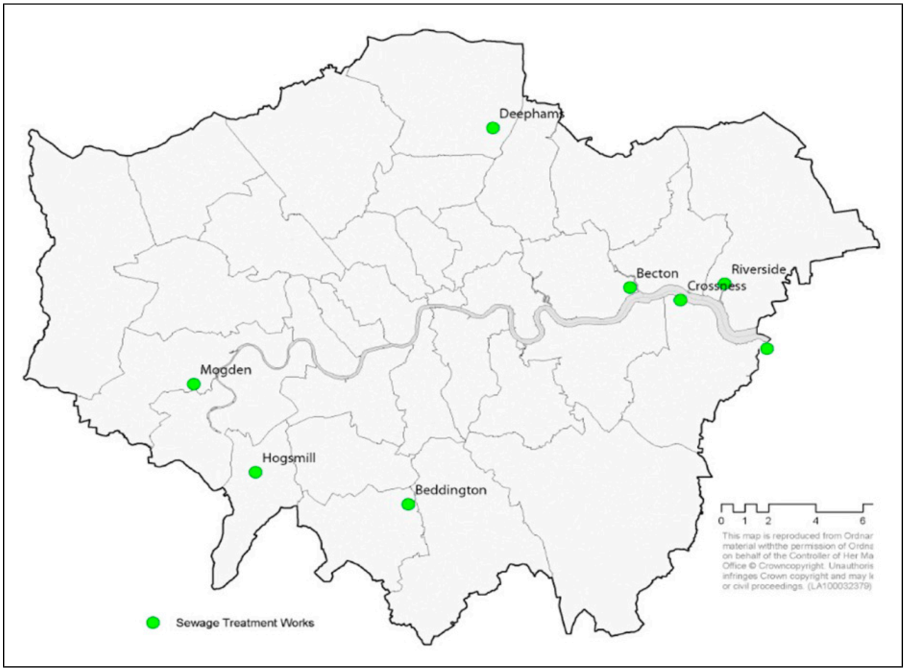

Figure 9. Sewage treatment works across London.[1]

Table 3. Sewage treatment plants in London.

Name	PE served	Avg. flow treated (million litres per day)
Beckton	3,760,000	1207.73
Mogden	2,010,000	512.95
Crossness	1,950,000	567.04
Deephams	910,000	217.30
Longreach	868,000	215.91
Riverside	423,000	109.04
Beddington	406,000	111.63
Hogsmill	394,000	68.52

However, work is needed to overcome major practical challenges: absence of heat networks, capital and operational cost of heat pumps, comparatively low cost of natural gas and high cost of electricity unit, longer payback period of heat recovery systems, perception of this technology and in some cases finding a suitable application (demand) for the low grade heat.

It is hoped that with government plans to support decarbonization through various funds and scheme, for example, Renewable Heat Incentive Scheme and Heat Network Development Unit, the demand for recovering heat will continue to grow as the potential for energy recovery from sewers is largely untapped resource.

The key drivers of the feasibility of this heat recovery technology are raw wastewater and treated wastewater temperatures and flowrates. While the raw wastewater heat recovery may still not offer large

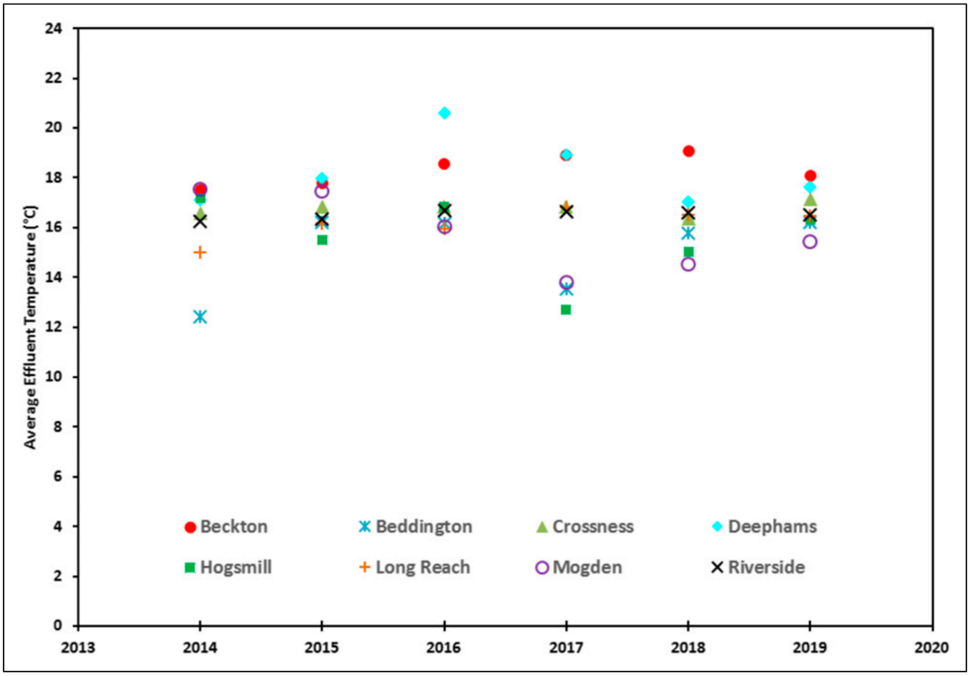

Figure 10. Average effluent temperature of eight WWTPs in London.

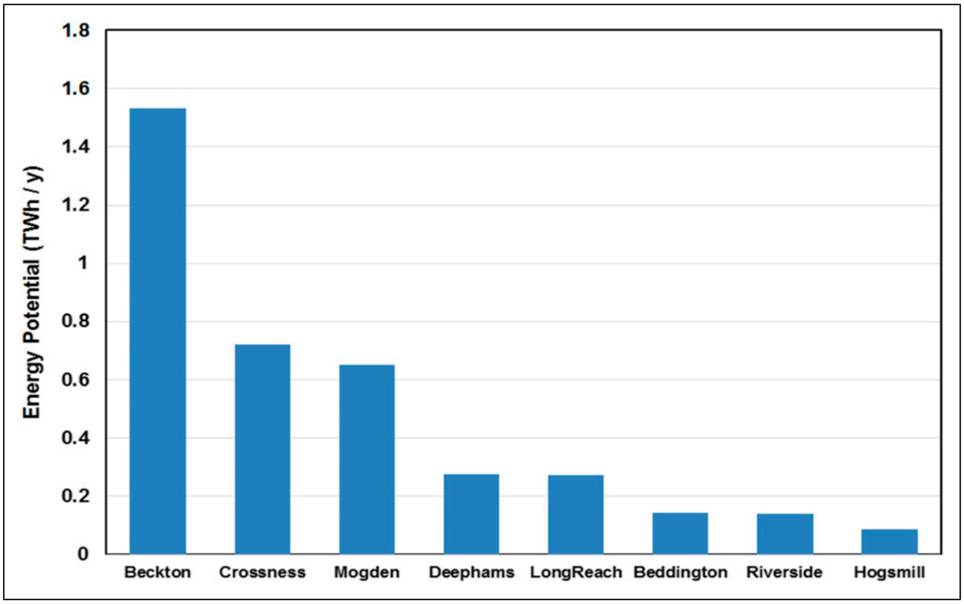

Figure 11. Treated water/effluent heat potential at eight WWTPs in London based on their average flow capacities.

financial benefits due to the high unit cost of electricity in comparison to natural gas unit cost, it is technically, economically and environmentally more viable to implement treated wastewater heat recovery in existing WWTPs for a low carbon future. This is supported by many examples of the large scale heat recovery systems installed in the Scandinavian countries that can be replicated.

The progression of this technology in the UK is currently restricted by the low cost of fossil fuel, barrier in implementation of heat pump technology and public awareness. In spite of these impediments, due to the political will to implement climate change act and the gradual withdrawal of fossil fuels for heating, the economic scenario is expected to improve in future.

This can lead us to the next step, that is, the deployment of a pilot wastewater heat recovery project around London that can exhibit the thermal energy recovery from the sewer network and/or from the treated wastewater WWTP with the energy being utilized for heating in the buildings. At the time of this writing, Hogsmill treated wastewater heat recovery project has been announced by Thames Water and Kingston council. The scheme is expected to supply 7GWh low carbon heat annually to more than 2000 homes in Cambridge Road Estate in Kingston upon Thames, southwest London, saving 105 kt CO_{2eq} emissions over 30 years. If this project is successful, it will create a vital evidence base upon which more and bigger future projects could be undertaken.[30]

Conclusion

Every day, a large amount of low grade heat in raw and treated wastewater is lost to the environment. In this article with the help of recently acquired raw wastewater and treated wastewater data from London sewer, its heat recovery potential is presented. It is highlighted that this low grade heat, that is, still unexploited, could be recovered and utilized from both the sources. This could result in meeting the London's energy demand in climate-friendly way as well as support in reaching Zero Carbon London.

Acknowledgements

The Authors wish to thank all the partners for their support.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work is a part of Home Energy for Tomorrow (HE4T) project – a collaborative project between London South Bank University and clean-tech firm (ICAX Ltd.) and is supported by two utility partners Anglian Water and Thames Water. The project is also part funded by the BEIS's Energy Entrepreneur's Fund.

ORCID iD

Shazia Farman Ali https://orcid.org/0000-0002-2301-7441

References

1. GLA. *Secondary Heat Study – London's Zero Carbon Energy Resource*. Greater London Authority, https://www.london.gov.uk/WHAT-WE-DO/environment/environment-publications/secondary-heat-study-londons-zero-carbon-energy (2013, accessed 11 April 2018).
2. Dunsmore I. *"Heat from Wastewater - UK Water Projects – Renewable Energy UK Water Projects*, http://www.waterprojectsonline.com/case_studies/2016/Scottish_SHARC_2016.pdf (2016, accessed 02 April 2019).
3. Schmid F. Sewage water: interesting heat source for heat pumps and chillers. In: 9th IEA heat pump conference, Zurich, Switzerland, 22 May 2008.
4. Wanner O, Panagiotidis V, Siegrist P, et al. Effect of heat recovery from raw wastewater on nitrification and nitrogen removal in activated sludge plants. *Water Res* 2005; 39: 4725–4734.
5. Ali SF and Gillich A. The theoretical versus practical potential of existing and emerging wastewater heat recovery technologies. In: Energy systems conference 2018, QEII Centre, London, London, UK, 19–20 June 2018.
6. Ali SF and Gillich A. Determining the UK's potential for heat recovery from wastewater using steady state and dynamic modelling - Preliminary results. In: Global conference on energy and sustainable development

2018, Edinburgh, Scotland, 18–20 December 2018. John McIntyre Conference Centre, The University of Edinburgh.
7. Ali SF and Gillich A. The potential for heat recovery from urban wastewater. In: CIBSE-ASHRAE virtual technical symposium 2020, Virtual, London: CIBSE, 2020.
8. Hawley C and Fenner R. The potential for thermal energy recovery from wastewater treatment works in southern England. *J Water Clim Change* 2012; 3(4): 287–299.
9. Culha O, Gunerhan H, Biyik E, et al. Heat exchanger applications in wastewater source heat pumps for buildings: a key review. *Energy and Buildings* 2015; 104: 215–232.
10. Kretschmer F., Simperler L. and Ertl T. Analysing wastewater temperature development in a sewer system as a basis for the evaluation of wastewater heat recovery potentials. *Energy Build* 2016; 128: 639–648.
11. DWA. *DWA-M114: Energie aus Abwasser - Wärme- und Lageenergie (Energy from Wastewater - Thermal and Potential Energy)*. Hennef: DWA, 2009.
12. Abdel-Aal M, Schellart A, Kroll S, et al. Modelling the potential for multi-location in-sewer heat recovery at a city scale under different seasonal scenarios. *Water Res* 2018; 145(15): 618–630.
13. Mikkonen L, Rämö J, Keiski L, et al. Heat recovery from wastewater: assessing the potential in Northern Areas. In: "Water research conference," Oulu, Finland, August 2013, Thule Institute, University of Oulu Finland., 2013.
14. Zogg M. *History of heat pumps: Swiss contributions and international milestone*. In Proceedings of Heat Pumping Technologies Conference; Bern Switzerland; 20 May 2008.
15. GLA. *Secondary heat study – London's zero carbon energy resource*. Greater London Authority, https://www.london.gov.uk/WHAT-WE-DO/environment/environment-publications/secondary-heat-study-londons-zero-carbon-energy (2013, accessed 11 April 2018).
16. GLA. *Cutting carbon in London*. Greater London Authority, https://www.london.gov.uk/about-us/london-assembly/london-assembly-press-releases/cutting-carbon-london-2015-update (2015, accessed 11 April 2018).
17. ECUK. *National statistics: energy consumption in the UK*. Department for Business, Energy & Industrial Strategy, https://www.gov.uk/government/statistics/energy-consumption-in-the-uk (2019, accessed 11 July 2020).
18. Water U. *Investment in waste and wastewater management*. Water UK, https://www.water.org.uk/policy-topics/managing-sewage-and-drainage/drainage-and-wastewater-management-plans/ (accessed 27 March 2018).
19. Cheshire J. *"London's wasted Heat*, https://mappinglondon.co.uk/2013/londons-wasted-heat/ (2013, accessed 22 August 2018).
20. Chris Grainger C. *Borough wide heat demand and heat source mapping*. London: BuroHappold Engineering, 2015.
21. ADE. *ADE market report. Heat networks in the UK*. London: The Association for Decentralised Energy., 2018.
22. Lee M. *"Innovative approaches to low-carbon urban systems: a case study of Vancouver's neighbourhood energy utility*. "Ottawa, Canada: Canadian Centre for Policy Alternatives, 2015.
23. Water T. *Thames water website*, https://sustainability.thameswater.co.uk/Delivering-efficient-operations/Sludge-as-a-resource/Energy-from-sludge (2018, accessed 02 May 2019).
24. Tassou SA. Heat recovery from sewage effluent using heat pumps. *Heat Recovery Syst CHP* 1998; 8(2): 141–148.
25. Cipolla SS and Maglionico M. Heat recovery from urban wastewater: analysis of the variability of flow rate and temperature. *Energy Build* 2014; 69: 122–130.
26. Togano Y, Ueda K, Hasegawa Y, et al. Advanced heat pump systems using urban waste heat "sewage heat". *Mitsubishi Heavy Industries Tech Rev* 2015; 52(4): 80–88.
27. BEIS. *Gas Consumption by Borough in London*, https://data.london.gov.uk/dataset/gas-consumption-borough (accessed 18 October 2019).
28. Hoffmann K. Large scale heat pumps for high efficiency district heating projects. In: *BRE innovation in community heating and cooling*. London: SIRACH Network Meeting, 2018.
29. Petersen BA. *Handbook: Experiences from other urban waste heat recovery investments: 25 cases of urban waste heat recovery*. ReUseHeat Project (D6.1), Denmark, 2017. [Online] https://www.reuseheat.eu/wp-content/uploads/2018/03/6.1-Other-experiences-25-case-studies.pdf (08/04/2018).

30. Pearson A. *"London's hidden energy source: recovering heat from sewage*, https://www.cibsejournal.com/general/londons-hidden-energy-source-recovering-heat-from-sewage/ (2021, accessed 01 May 2021).
31. Comeault C. *Integrated Community Energy System Business Case Study: Southeast False Creek Neighbourhood Energy*. Canada: University of British Columbia, 2011.
32. Huber. *HUBER Technology. Solutions for wastewater heat recovery from sewers*, http://www.huber.de/solutions/heating-and-cooling-with-wastewater/heat-from-wwtp-effluent.html (accessed 12 March 2018).
33. Arpagaus C and Bertsch S. *Industrial heat pumps in Switzerland application potentials and case studies*. Bern Switzerland.: Swiss Federal Office of Energy, 2020.
34. Bailer P and Pietrucha U. *District heating and cooling with karge centrifugal chiller - heat pumps*. Switzerland: Winterthur, 2006.
35. Friotherm. *Energy from sewage water – District heating and district cooling in Sandvika*. Winterthur, Switzerland: Friotherm AG, https://www.friotherm.com/wp-content/uploads/2017/11/sandvika_e005_uk.pdf (2005, accessed 05 August 2018).
36. Wiki C. Celsius project, https://celsiuscity.eu/energy-recovered-from-sewage-water-in-sandvika-norway/ (accessed 05 August 2018).
37. Kiss P. Heat recovery from wastewater for heating and cooling large buildings. In: Budapest water summit sustainable water solution expo, Budapest, Hungry, 28- 30 November 2016.
38. Kiss P. Efficient solution for large heat pumps: wastewater heat recoveryIn: 12th IEA heat pump conference, Rotterdam, The Netherlands, 15-18 May 2017. https://hpc2017.org/presentations/
39. Perez A, Stadler I, Janocha S, et al. Heat recovery from sewage water using heat pumps in cologne: A case studyIn: International energy and sustainability conference. IESC, Cologne, Germany, 30 June–1 July 2016.
40. Perez A, Stadler I, Janocha S, et al. *Excess heat recovery from sewage water in Cologne*. Germany: , https://celsiuscity.eu/waste-heat-recovery-from-sewage-water-in-cologne-germany/ (2018, accessed 01 September 2018).
41. U. Technology. *Therm-liner: Tackle the energy transition now!* UHRIG Technology, https://www.uhrig-bau.eu/en/division/heat-from-wastewater/technology/ (2015, accessed 23 November 2018).
42. Nagy B. *Wastewater heat recovery*. Toronto, Canada: Plumbing & HVAC Digital Issue, 2014.
43. Zan C and Shi L. Large-scale application of municipal reclaimed water Source heat pumps to a DHC system in the Beijing Olympic village. In: 9th international IEA heat pump conference, Zürich, Switzerland, 22 May 2008.
44. Friotherm. *Utilising waste heat from treated wastewater from Suomenoja wastewater treatment plant*, https://www.friotherm.com/wp-content/uploads/2017/11/E10-15_Suomenoja.pdf (2015, accessed 06 August 2018).
45. Friotherm. *Katri Vala combined district heating and district cooling plant*. Friotherm AG, https://www.friotherm.com/wp-content/uploads/2017/11/E11-15_Turku-Energia.pdf (2005, accessed 06 August 2018).
46. Karjalainen I. Heat from wastewater and other intelligent ways of harnessing and reusing energy. In: IRBC Conference "Smart Cities". Munich, Germany, 5–11 November 2014.
47. Friotherm. *The wastewater utilization in Kakola heat pump plant- ecologic district heating and district cooling from treated wastewater*. Friotherm AG, https://www.friotherm.com/wp-content/uploads/2017/11/E11-15_Turku-Energia.pdf (2017, accessed 05 August 2018).
48. Averfalk H, Ingvarsson P, Persson U, et al. Large heat pumps in Swedish district heating systems. *Renew Sust Energy Rev* 2017; 79: 1275–1284.
49. Wiki C. *Wastewater as heat source in Kalundborg, Denmark*. , https://celsiuscity.eu/waste-water-as-heat-source-in-kalundborg-denmark/ (2017, accessed 06 June 2018).
50. G. Maps. *Royal Borough of Kensington and Chelsea. London*, https://www.google.com/maps/place/Royal+Borough+of+Kensington+and+Chelsea,+London/@51.5037663,-0.2593262,12z/data=!3m1!4b1!4m5!3m4!1s0x48760ff7f26a3943:0x40eae2da2ec6730!8m2!3d51.4990805!4d-0.1938253?hl=en-GB (2019, accessed 22 October 2019).
51. Friotherm. *The wastewater utilization in Kakola heat pump plant- ecologic district heating and district cooling from treated wastewater*. Friotherm AG, https://www.friotherm.com/wp-content/uploads/2017/11/E11-15_Turku-Energia.pdf (2017, accessed 05 August 2018).