The potential of the heat recovery from urban sewage wastewater for use in residential and commercial buildings

S. Farman Ali* and A. Gillich

School of the Built Environment and Architecture, London South Bank University

103 Borough Road, London SE1 0AA, United Kingdom

*Corresponding author's mail: alis133@lsbu.as.uk

Abstract

The pressing need of implementing climate change act and a commitment to increase renewable energy has led to the identification of number of secondary heat sources in UK (1). This paper focuses on heat recovery from urban sewage wastewater - a secondary heat source. The heat that is added by the consumer when it is heated, used and dumped in the sewer systems. The technique is not new and have been successfully implemented in many cities around the world with many others considering its deployment. In UK there is a growing interest to explore this new technology specially after the successful sewage heat recovery demonstration project at Borders College, Galashiels, Scotland - a joint venture between Scottish Water Horizons & SHARC Energy Systems (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 (LSBU) was created to address this evidence gap. The current paper is third in series of output on wastewater heat recovery in UK and is motivated by the need to introduce the research done to the industries where the data pertaining to sewage wastewater heat recovery is scarce and there is a lack of understanding of the flow behaviour of urban sewage. In this paper we present some measured data from a location in London, monthly variations in sewage wastewater temperature and the heat potential along with policy implications for UK heat strategy.

Keywords Sewage heat recovery; Urban wastewater heat recovery, Wastewater temperature, Wastewater treatment plant, Heat pump, Sewer, Heating of buildings, space heating and hot water.

1. Introduction

Billions of litres of heated water end up in the sewers every day and its heat content is completely lost. When this heated water is discharged from dwellings all year round, its temperatures is in the range of 30 to 25°C and by the time it reaches to wastewater treatment plant (WWTP) its normally between 12 to 10°C. This sewage wastewater heat could be reuse that is lost to environment before it reaches to WWTP. However once in WWTP, the treatment processes done on wastewater within plant to clean it can again raise its temperature by 2 ~ 3 °C from that of its entrance value, thus providing another opportunity to recover heat. Each of the recovery options have their own further advantages and disadvantages (discussed in later section) and the final choice depends on the local specific conditions. Nonetheless because wastewater (influent or effluent) temperature is lower than that provided by conventionally used heater/boiler, thus this heat cannot be used directly and requires heat pump to raise its temperature for heating application with an additional advantage of reversing its use in summer to provide cooling. In case of large capacity central heat pump raised hot water can be used in heat network or with smaller heat pump can fulfil the heat requirements at building scale. Previous works in this area have (3,4,5) found that average temperature of sewage wastewater in sewers remains relatively steady throughout the year (when compared to other low temperature sources (secondary heat sources) e.g. ambient air, fresh water, ground etc. Therefore, in comparison to other low energy sources heat pump using wastewater heat can give a stable energy supply throughout the year along with simpler and smaller dual purpose system with lower operational costs. Additionally, the recovered heat counterbalances the fossil fuel use and results in raising the share of renewable energy. This energy recovering via heat pump is already a viable source of heat recovery in some of the coldest countries of the world e.g. Switzerland, Canada, Japan and Scandinavian countries (6) and many others are considering its deployment or increasing it numbers to recover thermal energy.

By itself, heat pump has been around for almost long time now but have been in latency due to the cheaper conventional fossil fuel. However, during this time, the technology has matured in terms of its delivery temperatures, rating, reliability and cost with now being used with wastewater combination from few kW to MW ratings (7). In many countries around the world this wastewater-heat pump combination (from few kW to MW) has shown greater carbon savings and contributing to their carbon reduction targets, e.g. (8) reported 34% reduced energy consumption alongside of 68% reduction in CO_2 and 75% in NO emissions. In Vancouver, Canada, Seven35 Condo – a residential estate reduced their GHG emissions by 150 tonnes and now recovering 80% of its wasted energy through SHARC wastewater heat recovery system (9). Another project in Canada, Okanagan College in Kelowna, British Columbia has been operating since 2004 using treated wastewater (effluent) covering 60% heating requirements and offsetting more than 800 tons of CO_2 emissions per annum. A sustainable swimming pool, Waterboard Groot Salland, Raalte, Netherlands uses hot water heated from the treated wastewater employing four 59 kW heat pumps. The project has resulted in reducing 137 tons of CO_2 per annum, 33% less use of gas and saving of € 25.000 per year on gas (10). Another project in Binningen, near Basel, Switzerland was able to reduce its CO_2 emission to 675 tonnes per year by substituting its 200 tonnes oil consumption with heat from wastewater. A multifamily residence of 52 flats in 3 buildings, Seeblick, Uster, Switzerland avoided 157 tonnes oil and 172.000 Nm^3 gas by using heat from wastewater for its space and water heating thereby reducing its emission to 340 to 412 tons CO_2 (11). Half of energy used in Sandvika, Oslo (Norway) offices and residential buildings is supplied from wastewater treatment plant where heat is recovered by four heat pumps. As a result of this, CO_2 emissions are reduced by 6000 tons per annum (12).

In UK also there is a growing interest to explore this innovative technology specially after the successful small pilot sewage wastewater heat recovery project at Borders College, Galashiels, Scotland - a joint venture between Scottish Water Horizons & SHARC Energy Systems. The system started working in December 2015, consisted of 2 heat pumps of 400kW (800kW, COP = 4.8) (Winter/Summer intake temperature = 7.5°C/14.5°C, delivery temperature 50-60°C) producing 1.9 GWh annually providing around 95% of the heat demand of the college with no negative impact on the operation of the local sewer network. 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 boilers heating (2).

This paper will present; an overview for this sewer heat recovery technology with examples of heat recovery systems worldwide, its context in UK, brief discussion on the HE4T small catchment case study focused on recovering heat from the upstream of the WWTP, its heat recovery potential, limitations and possible itineraries to address them. The work presents useful information for the first time on variation of flows and temperatures encountered in the sewers of the UK's capital allowing researchers to have first ever information UK sewage systems.

2. Sewage Characteristics

The primary factors in quantifying the potential heat recovery are; flow capacity, temperature of sewage and the impact of lowered sewage wastewater temperature on the downstream WWTP. The temperature and flow capacity of the sewage 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 cyclical daily characteristics; increase in temperature and flow in mornings and evenings, with drop in temperature and flow in nights (3,4). Because of this cyclical variation, same amount of heat may not be recovered at all the time hence the heat recovery technology require storage (usually a buffer tank) to offset the variations in flow and temperature. Note this is also required as the demand of the heat (space heating & domestic hot water use) occurs prior to these supply peaks. The situation is more complicated because of the condition of sewer i.e. if the sewer is old drainage system or combined sewer and any rain (or snow melt) related event occurs causing dry weather flow to be increased by a factor up to 10, such scenarios require careful evaluation of the amount of water (3) and its temperature drop. The general practice is to consider dry weather flow conditions. Additionally, it is more appropriate that the interested sewer network is located in densely populated area to offset the lowered temperature after extraction. Sites in the populated areas, apart from the domestic such as hotels, restaurants, indoor swimming pools, leisure centres, hospitals etc. 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.

3. Sewage heat recovery system

The sewage heat recovery system either uses direct recovery i.e. sewage waste water sent directly to heat pump's evaporator side after screen and filtering OR to a heat exchanger installed in and/or near the sewer (Figure. 1) that indirectly supply 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 buffer tank. After upgrading low grade heat through heat pump to a higher temperature, it can be delivered to a heating system. In order to raise the temperature of 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 comes in contact with the working fluid (clean water or refrigerant) in the heat pump system and the recovered energy is reused for heating and cooling purposes. The heat pump works economically and efficiently under low temperature conditions and offers flexibility of integrating within existing and new system. The recovered energy is best for use in range of domestic and non-domestic heating loads; district network, office buildings, apartments, hospitals, sport facilities, swimming pools, industrial complexes, universities, schools, shopping & leisure complexes, hotels, estates etc.

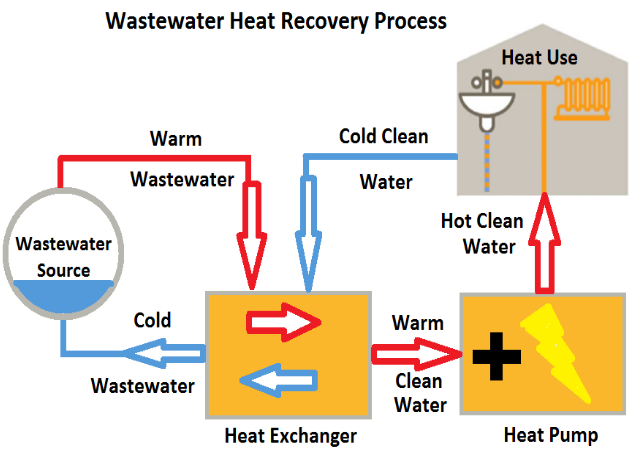

Figure 1 – Wastewater heat recovery process - adapted (13, 14)

The heat recovery (thermal energy) from urban wastewater can be performed; before WWTP from the untreated / raw wastewater / **influent** in the sewer network i.e. before it reaches WWTP (locations upstream in sewer network) or from after the WWTP (downstream) from the outlet / **effluent** of the wastewater cycle.

The **upstream** heat recovery (from the influent) has an advantage of higher temperatures with demand and supply nearby but severely influenced by limited temperature drop due to uncertain impact on WWTP performance, effects of seasonal diurnal, fouling and biofilms growth on heat exchanger surfaces, solid handling and constant periodic maintenance (3). Different arrangements of heat recovery system are available for **upstream** heat recovery i.e. the wastewater flowing in populated area sewer network. The heat recovery can be done (**1) close to heat source** i.e. within the premises of the household / building referred as **in-house** (Figure. 2a). Close to the heat source the sewage temperature is higher with no mixing with other drain water. Producers are also consumers of heat so more extraction is possible close to the home but flow is relatively low and varies in time, hence requires a buffer tank for storage and smaller scale. **(2) recovery from adjacent to the source or side stream** (Figure 2b), i.e. the wastewater flow from the nearby sewer diverted to a collector or well containing screens (to maintain clear intakes) than to specially designed large diameter shell and tube heat exchanger. The advantages include; high sewage temperature, wastewater is little cleaner due to screening/filtering, can be installed in existing and new developments but disadvantages are flow is relatively low, requires periodic maintenance, and its installation requires considerable space. In the other type heat recovery system known as **(3) In-sewer,** heat exchanger in form of plates, panels, built-in internal tubes is directly installing in the base/ inner circumference of the sewer pipe within the sewer system (Figure 2c). The advantages include higher and more stable flowrates but lower wastewater temperatures, installation of the heat exchanger requires space and may not be possible in all cases (short length of straight runs or too great a slope) (3,15). Further in case of combined sewers and weather/ natural events like snow melt, rainfall, flood, ground water leakage etc. could alter the temperature significantly effecting the performance of heat recovery equipment's.

In the d**ownstream** heat recovery after WWTP (outlet) from the effluent before discharge in large water body (Figure 2d), a cleaner, constant stable flow with similar or slightly higher temperature is achieved with no impact on the performance on WWTP allowing higher energy potential. Thus majority of sewage wastewater heat recovery plant are using plant effluent /treated wastewater as heat source. However, WWTPs are often located quite remotely (outside the urban boundary) where no or few heat consumers are available (3) and recovered energy can only be used; by WWTP itself or is fed to the heat networks. Further details of these options can be found here (6,7).

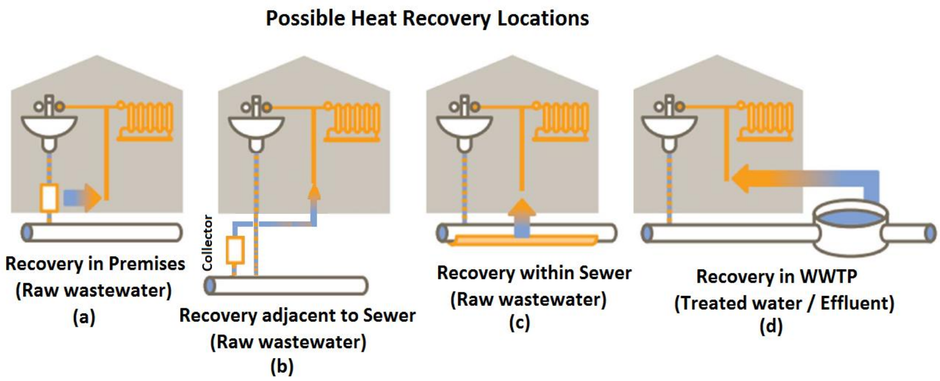

Figure 2 – Wastewater heat recovery locations - adapted (13)

4. Viability conditions for sewage heat recovery

A significant barrier in picking up this technology is lack of data and scattered existing information indicating wide ranges of values of the major parameters e.g. flowrates, temperatures, pipe sizes, heat recovery capacity etc., a general framework was put together (6) adapted from different sources (3, 15, 16 and 17) so that any future work on this technology can follow the pathway and make further progress. Briefly; **(i)** the potential heat recovery site to be located in densely populated area (around 5000 – 1000 PE) corresponding 15 to 30 l/s of wastewater to the minimum dry weather flow (3,15 and 16), **(ii)** minimum sewer pipe diameter for existing network should be no less than 500mm and above 800mm in newer developments to allow sufficient flow, placement of heat exchanger and its maintenance (3 and 16). Further, **(iii)** this potential heat recovery site should be in the close proximity to heat consumers approx. 100 to 300m (maximum 500 m) (3,15 and 16). to avoid heat losses. **(iv)** The minimum heating load/ requirement should be ≥ 100 kW (3 and 16). Additionally, **(v)** in the surveyed literature no definite minimum heat extraction temperature is defined except (17) who used a value of 5 °C in his modelling work. However, **(vi)** regardless what value is used; it should be ensured that the influent WWTP temperature should not be below 10°C. This limiting value is to ensure that that wastewater treatment activities at WWTP are not compromised by sewer heat recovery upstream, thus restraining the sewage wastewater temperature at WWTP inlet not to be less than 10°C (3 and 18). This could have avoided by having dense population past the heat recovery point to ensure the temperature at inlet to WWTP is higher than 10°C.

5. Examples of wastewater heat recovery from around the world

Swiss are considered to be the pioneer in sewage wastewater heat recovery technology with their first wastewater heat recovery application via heat pump dating back to eighties (3 and 19) Currently, many raw sewage wastewater & effluent/treated wastewater heat recovery plants using more than 500 heat pumps are in operation across the world (3, 16 and 20). Table 1 and Table 2 presents 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 under 1MW while treated wastewater/effluent heat recovery systems are higher capacities. As evident from these tables, the technology has progressed from small scale and now being used at large/ commercial scale.

Table 1 – Raw wastewater heat recovery examples from around the world

City / Country	System Supplier	Arrangement	HP capacity / COP	Purpose	Scale / year
Southeast False Creek, BC, Canada	IWS Sewage SHARC	Raw wastewater, Screened, passed to shell & tube heat exchanger	2.7 MW	Heating + Hot water	Large (2010)
Wintower, Winterthur, Switzerland [2]	Huber Technology RoWin	Raw wastewater, screened and passed to collector with heat exchanger	1.5 MW, COP 5 - 6	Heating + Hot water + Cooling	Pilot (2011)
Leukerbad, Switzerland	Huber Technology RoWin	20°C Raw wastewater, screened and passed to collector with heat exchanger	2 x 225 kW	Heating + Hot water at 51°C	Small 2018
Bavaria, Switzerland	Huber Technology ThermWin	Raw wastewater, screened and passed to collector with heat exchanger	2 x 280 kW + 2 x 500 kW	Heating + Hot water	Small 2018
Dietikon (Zürich), Switzerland	Huber Technology ThermWin	Raw wastewater, screened and passed to collector with heat exchanger	1 x 4.0 MW COP 5.50	Heating + Hot water NH_3 supply 40°C	Small 2018
Sandvika, Oslo, Norway	Friotherm AG	10°C Raw wastewater, Screened, passed to shell & tube Heat exchanger	2 × 6.5 MW + 2 × 4.5MW, COP 3.10	Heating R-134a supply 68°C + Cooling	Large (1998 & 08)
Sköyen Vest, Oslo, Norway	Hafslund Fjernvarme AS	10°C Raw wastewater, screened, passed to shell & tube heat exchanger	28 MW, COP 2.8	Heating R-134a supply 90°C	Large (2005 and 2008)
Budapest Military Hospital, Hungry	Thermowatt Ltd.	Raw wastewater screened passed to collector with heat exchanger	3.8 MW + 3.4 MW, COP 6 - 7	Heating / Cooling	Large (2014)
Budapest Sewage Works, Hungry	Thermowatt Ltd.	Raw wastewater screened passed to collector with heat exchanger	1.23 MW, COP 4.5	Heating / Cooling	Large (2012)
Újpest - City Hall & Buildings, Hungry	Thermowatt Ltd.	Raw wastewater screened passed to collector with heat exchanger	1.6923 MW, COP 4.0	Heating / Cooling	Large (2012)
Mülheim, Cologne, Germany	Cologne Sewerage Company, Stadt Köln, Rhein Energie,	In-sewer heat recovery	150 kW	Heating only	Pilot project under CELSIUS
Wahn, Cologne, Germany	Cologne Sewerage Company, Stadt Köln, Rhein Energie,	In-sewer heat recovery	200 kW	Heating only	Pilot project under CELSIUS
Nippes, Cologne, Germany	Cologne Sewerage Company, Stadt Köln, Rhein Energie,	Pumped directly into evaporator of HP	3 × 150 kW	Heating only	Pilot project under CELSIUS

SinTec Technology Park, Singen, Germany	**GVV Städtische**	**In-sewer heat recovery**	**200 kW + 243 kW COP 3.5 – 3.9**	**Heating / Cooling**	**Pilot project under ReUseHeat**
Lübeck, Schleswig-Holstein, Germany	**Uhrig Kanaltechnik GmbH**	**In-sewer heat recovery Therm-Liners**	**147 kW**	**Heating only**	

Table 2 – Effluent heat recovery examples from around the world

City / Country	System Supplier	Arrangement	HP capacity / COP	Purpose	Scale / year
Postal office of Muelligen/Schliern, SwitzerlandDH	**EWZ utility**	**8 to 102C Effluent pumped into evaporator of HP**	**5.5 MW**	**Heating + Cooling, uses NH_3, hot water supply 65°C**	**Large (2006)**
Whistler Athlete's Village, Canada	**IWS Sewage SHARC**	**Effluent pumped into evaporator of HP**	**3.5 MW**	**Heating + Cooling**	**Large (2009)**
Beijing Olympic Village, China	**Skandinavisk Termoekonomi AB**	**Effluent with plate Heat Exchanger**	**4 × 5.4 MW + 4 × 5.25 MW, COP 3.85**	**Heating + Cooling**	**Large (2008)**
Suomenoja Espoo, Finland	**Fortum Energi**	**Effluent pumped into evaporator of HP**	**2 × 20 MW + 2 × 14.5MW, COP 3.0**	**Heating + Hot water**	**Large (2014)**
Katri Vala, Helsinki, Finland	**Friotherm AG**	**10°C Effluent pumped into evaporator of HP**	**3 × 30 MW + 2 × 30 MW,COP 3.5**	**Heating + Cooling, uses R-134a, hot water supply 88°C**	**Large (2006)**
Kakola, Turku, Finland	**Friotherm AG**	**10°C Effluent pumped into evaporator of HP**	**2 × 10 MW + 2 × 30 MW,COP 3.3**	**Heating + Cooling, uses R-134a, hot water supply 78°C**	**Large (2006)**
Ryaverket, Gothenburg, Sweden	**Göteborg Energi**	**Effluent pumped into evaporator of HP**	**2 × 50 MW + 2 × 30 MW, COP 3**	**Heating + Hot water**	**Large (2009)**
Hammarbyverket, Stockholm, Sweden	**Fortum Energi**	**Effluent pumped into evaporator of HP**	**5 HP producing total 131 MW, COP 3.0**	**Heating + Hot water**	**Large (1986, 91 & 97)**
Jönköping, Sweden	**Fortum Energi**	**Effluent pumped into evaporator of HP**	**25 MW, COP 3.0**	**Heating + Hot water**	**Large (1986, 91 & 97)**
Lund, Sweden	**Lund Energi**	**8 to 16°C Effluent pumped into evaporator of HP**	**1 × 13 MW + 2 × 40 MW, COP 3.3**	**Heating + Hot water + Cooling uses R-134a, hot water supply 80 to 90°C**	**Large (1984 and 2003)**
Helsingborg, Sweden	**Öresunds-kraft**	**8 to 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)**
Gothenburg, Sweden	**Göteborg Energi**	**12°C Effluent pumped into evaporator of HP**	**2 × 30 MW, COP 3.3**	**Heating + Hot water+ Cooling, uses R-134a, hot water supply 80°C**	**Large (1984 and 1986)**
Sundbyberg – Solna, Sweden	**Norrenergi**	**8 to 12°C Effluent pumped into evaporator of HP**	**2 × 60 MW, COP 3.2**	**Heating + Hot water + Cooling, uses R-134a, hot water supply 83°C**	**Large (1985)**
Borås, Sweden	**-**	**16°C Effluent pumped into evaporator of HP**	**1 × 10 MW + 1 × 510 MW , COP 3.5**	**Heating + Hot water + Cooling, uses R-134a, hot**	**Large (1984 and 1985)**

				water supply 72°C	
Uppsala, Sweden	**-**	**9-18°C Effluent pumped into evaporator of HP**	**3 × 12 MW, COP 3.0**	**Heating + Hot water + Cooling, uses R-134a, hot water supply 70°C**	**Large (1982)**
Västerås, Sweden	**MälarEnergi**	**9-20°C Effluent pumped into evaporator of HP**	**2 × 13 MW, COP 3.5**	**Heating + Hot water, uses R-134a, hot water supply 70°C**	**Large (1992)**
Kalundborg Denmark	**Kalundborg Forsyning A/S**	**20°C Effluent pumped into evaporator of HP**	**10 MW, COP 3.6 to 4.0**	**Heating + Hot water, uses R-134a, hot water supply 79°C**	**Large(2017) under INNERS project**

6. The United Kingdom

In 2017, UK's space and water heating was the second largest energy consumer after the transport and was also the cause of one third of UK's greenhouse gas emissions (3 and 21). Most of this energy utilized in space heating (64%) and for domestic hot water heating (17%) ultimately ending in the sewer with all of its thermal energy (roughly still containing 80% thermal) lost to the environment. Recovering this thermal energy added by the consumer from the sewer systems could result in offsetting the fossil fuel used, reducing greenhouse gas emissions and decarbonizing the UK's major energy consumption sector.

With daily average discharge of 16 billion litres of sewage wastewater across UK in more than 624,200 kilometres of sewer pipes to leading to 9,000 WWTPs (22) with typical sewage wastewater temperature reported from 7 to 25 °C (5 and 7), the potential of heat recovery is significant. Theoretically, if this daily discharge is cooled by 3 degrees 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 effected 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 wastewater, 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 constraints, economics and carbon savings.

7. London Case study - Theoretical Potential

According to (4) in 2016, 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 9 million, the UK's largest city London is working on exploring pathways for transition to low carbon heating (London 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. (1) published London's Zero Carbon Energy Resource 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). The Figure 3 below shows the areas within and around London with a potential for recovering heat from sewers as well as from industrial sources (24). Some of the associated work of the GLA report by boroughs (25) across London have also identified the potential customers near to these heat sources in order to make the secondary heat recovery technologies viable via heat networks. However, here it would be appropriate to point out that while there are heat/cooling network infrastructures available in many cities that have adopted this technology (e.g. Oslo, Helsinki, Stockholm, Budapest, Berlin and Amsterdam etc.), in UK and specially in London such networks are scarce. Currently only 2% of UK space and water heating demnds are met heat networks (26). While this seems to be barrier under current scenario impeding this technology adoption, it is not! In fact, this is a perfect opportunity that can be availed promptly by developing the necessary infrastructure and decentralising the energy supply that would assist in meeting UK carbon emission targets. Many Urban developers' in and around London have started to adopt this approach of decentralized energy centres in form of community based energy centres supplying domestic hot water at these new developments. If these heat networks are encouraged to use alternative energy sources, it could facilitate the transition towards near-zero carbon heat making secondary heat recovery technology become viable. It is anticipated that this move from fossil fuel (i.e. natural gas) will likely be replaced by alternative energy sources, with heat pump (26) playing a very important role. It is therefore expected that in future heat pumps will be retrofitted in existing buildings as well as form major part of new developments energy centres.

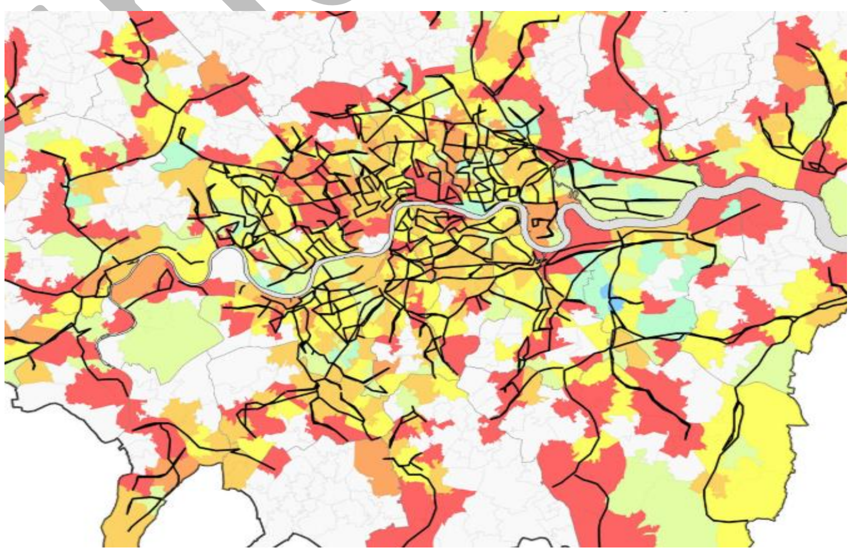

Figure 3 – London Heat Map indicating waste heat potential (sewer + Industrial) (27)

7.1 Raw Sewage wastewater potential

According to an estimate by Thames water (27), the approximate total length of London sewers is about 55,000km. The early research on sewage in southern England (28) reported minimum temperature of 11°C in February and the maximum 19°C in August as representative temperatures in Thames water treatments plants in and around London. In early 2000 (5) found the typical average sewage temperatures from 12°C to 20 °C in winter and summer affirming it a potentially viable source of heat pump. More recently, (7) found average temperature of 22°C in summer and 12°C in November 2018 with lowest average temperature of 7.5°C in last few days of February 2018 recorded during an unusual cold wave 'Beast of East' (when outside ambient temperature was -1.5°C) around central London area. The work was performed as the part of the Home Energy 4 Tomorrow (HE4T) project at London South Bank University (LSBU) along with a clean-tech firm (ICAX Ltd.), as well as two utility partners (Thames and Anglian Water) as part of their ongoing energy innovation work. As part of this project, temperature and flow monitoring was performed at various sites across London. The data analysed here belongs to a small monitoring site in one of borough in central London and is for period between June 2018 to January 2019. This period includes the summer, autumn and winter period and dry weather period (free of the influence of stromwater runoff on the flow and temperature measurements). The site considered is 1450mm combined sewer system, gravity driven lying approx. 6.5m beneath the ground. The sewage wastewater belongs to an upstream catchment area consisting of houses business and commercial activities, mainly restaurants, high streets shops etc. with common main sewer collectors given in Figure 4. Since the sites are nearby homes, restaurants, high streets shops, continuous flow with higher temperatures are expected throughout the day. The measuring data sites are also shown in Figure 4. The average dry weather flow at the downstream end is around 778 m^3/day. The Figure 5 shows the average monthly temperatures in the collector sewer, i.e. 19°C in May increasing to 23°C in July and dropping down to 17.5°C in January. The calculated average energy potential for this location is between 90 to 100MWh per month. The annual average domestic gas consumption in this borough 12.7MWh/yr (29), hence it is possible to supply heat to around 90 homes annually.

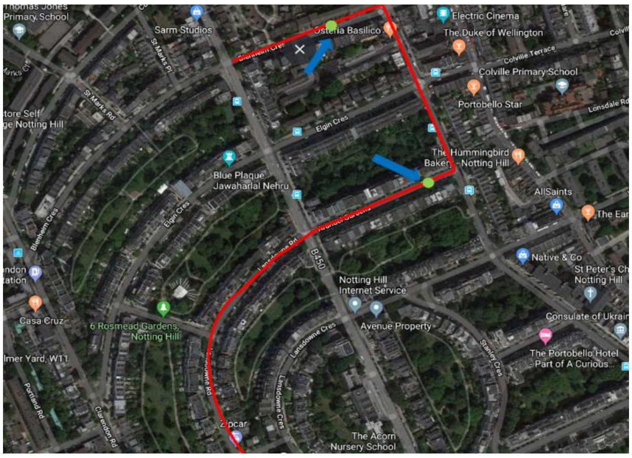

Figure 4 – Sewage network site in Borough of Kensington and Chelsea, London (30)

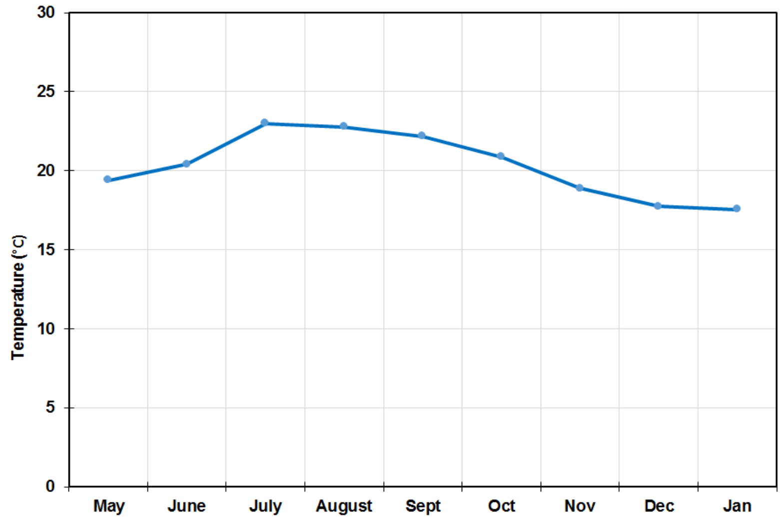

Figure 5 – Monthly average raw sewage wastewater temperatures near central London area.

7.2 Treated effluent potential

Another heat recovery option available is to recover heat is from effluent/ treated sewage wastewater. As limitation of unstable flow, low temperature and uncertain impact on WWTP does not exist anymore hence this option is very favourable. As indicated in Table 2, this heat recovery option is very popular throughout EU and some of the biggest capacity heat pumps are installed across the world recovering heat in mega-watts range. Currently there are eight wastewater treatment plant across the capital, London treating the sewage wastewater of about 9 million people, see Table 3 for their names and their daily average capacities, see Figure 6.

Table 3 – Sewage wastewater treatment plant in London. (Thames Water, 2018)

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

If considering heat recovery from the treated sewage wastewater / effluent of above sewage treatment works situated across London based on their daily average dry weather flows and cooling it by 3°C, then it is possible to recover approximately 4TWh of heat annually, see Figure 7. Considering an average domestic gas consumption of 13000kWh a year based on BEIS data of London boroughs gas consumption (29), this value is enough to heat more than 250,000 homes. From the above figure, it also obvious that the Thames Beckton treatment works in East London, the largest WWTP in 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 treatment work plant. In this regard, this plant is most suitable for effluent heat recovery system and recoverable amount of energy is enough to provide space heating and hot water to more than 100,000 homes alone. However, this does not mean that the rest of sites cannot be used, in fact the other sites also have great potential for smaller scale effluent demonstration heat recovery project.

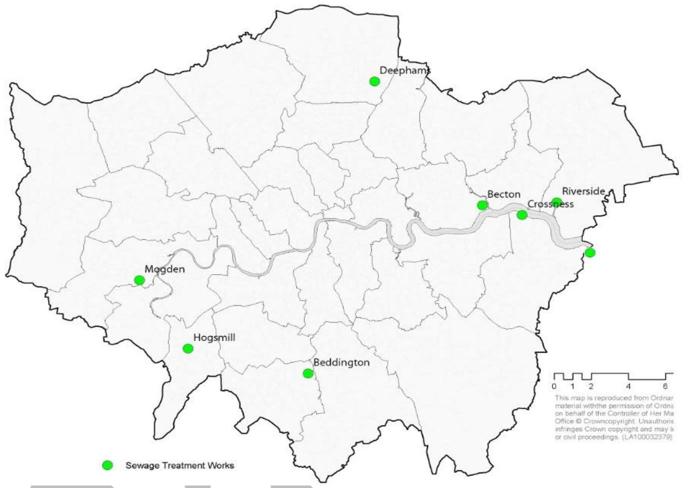

Figure 6 – Sewage treatment works across London (1)

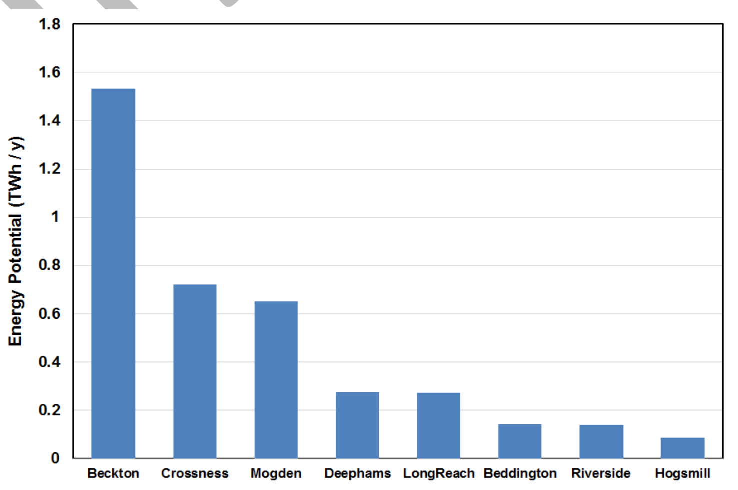

Figure 7 – Treated sewage wastewater/effluent heat potential at eight WWTPs in London based on their average flow capacities.

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 London to Net Zero objective. 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 e.g., 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 currently a largely untapped resource.

8. Conclusion

Simple analysis presented here indicate that raw sewage and treated sewage wastewater both has potential to be viable. The amount of energy available could add to London energy demand and thus can help in closing the gap of GHG emission target of London to net zero plan.

Current obstacle for progression of this technology is less technical but more economic and social barrier; cheaper cost of fossil fuel in UK, barrier in implementation of heat pump technology in UK and public perception. In spite of these barriers, the economic scenario is expected to improve in future due to the government's commitment to climate change act through their positive measures like RHI etc.

This work leads us to the second step i.e. implementation of a pilot scale trial in or around London that can demonstrates the thermal energy recovery from the sewer network and/ or from the effluent at sewage treatment plant with the energy being utilized at nearby buildings establishing a reduction in carbon dioxide emission compared with a conventional gas boiler.

ORCID Id of authors

Farman Ali, Shazia – 0000-0002-2301-7441
Gillich, Aaron – 0000-0002-4132-4824

Acknowledgement

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. The Authors wishes to thank for their support.

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