Marcia Rojas
University of California Berkeley
August 29, 2016

Preliminary Study of Heat Recover from Wastewater in Urban Water Infrastructure

Abstract

Supplying drinking water, treating wastewater, and heating water are energy intensive processes. Heat recovery from wastewater is a key opportunity to reduce costs, energy use and greenhouse gas emission. This preliminary study focuses on two locations for heat recovery: the wastewater treatment plant, Robert Hite Wastewater Treatment Plant in Denver, CO and a sewer leading to the facility. The two locations will be compared to understand their potential for heat recovery technology implementation. Due to project time constraints, the results are preliminary; not all aspects of their potential were evaluated. Heat recovery potential, subject to a constraint of an influent temperature of 13C to the wastewater treatment plant was calculated. The sewer displayed a higher heat transfer rate. Lowering the sewer temperature substantially will not have a negative effect on the treatment process.

Introduction

The 2013 ASCE Report Card rated the U.S.’s water infrastructure a D+ for both drinking and wastewater. Drinking water and wastewater infrastructure has a long service life, up to 100 years. Many systems are nearing the end of their service lives and show limited technological advancement from their initial implementation (Kiparsky et al. 2013). The deteriorated state will require a more than trillion dollar investment (ASCE 2013), an ideal opportunity for adapting energy saving systems. The long service lives mean that decisions made today about how to upgrade or replace these facilities will be affecting the cities they serve for decades to come. Considering sustainability, innovation and flexibility at the forefront during planning can have positive long-term consequences.

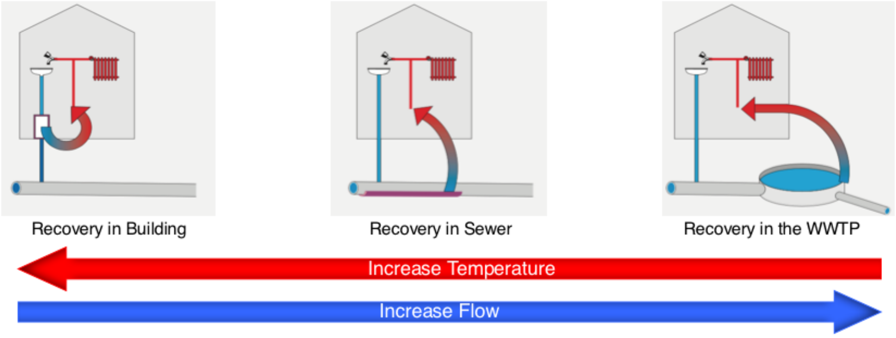
Water heating is the largest energy consumer in urban water systems. An Australian study found that residential water heating consumes more than 10 times the energy needed to supply drinking water and almost 10 times more energy than wastewater processing (Kenway et al. 2015). A key opportunity for offsetting the energy associated with water heating is recovering energy and resources from the waste itself. There are two major ways of recovering energy: biogas recovery and heat recovery (HR) from wastewater. Biogas co-generation is the easiest waste energy recovery method to implement in urban water systems (McCarty et al. 2011).

Wastewater HR is not as widely adopted as biogas recovery, though the technology is certainly not new. The first installations are over 25 years old; in 2008, researchers estimated there were 500 wastewater HR systems in place, including systems in Switzerland, Norway, Japan and other countries (Schmid 2008, Mo and Zhang 2013). In domestic, business, and industrial buildings, water is typically warmed for use and then disposed. In the U.S., water heating consumes almost 20% of the average household energy use (EIA 2013). This results in a loss of at least 15% of the building’s thermal energy down the drain. As a result, wastewater is typically much warmer than water in drinking water pipes (Schmid 2008). Additionally, wastewater is warmer than the air in the winter and cooler than the air in the summer, making it ideal for heating and cooling buildings. This thermal energy in wastewater could be harnessed to heat water or manage building temperature.

Energy recovery is an important reason for implementing HR, but is not the only one. In some cases, regulatory standards require that the discharged water from WWTPs be in a defined temperature range to protect ecosystem health. This environmental requirement, in conjunction with the energy and monetary benefits, may motivate some utilities to consider HR.

HR from wastewater can be implemented in three ways: in buildings/homes, in sewers, and in WWTPs. The method for buildings and sewers, is categorized as a decentralized method of HR. HR in the WWTP is known as a centralized HR system. Figure 1 outlines the considerations and tradeoffs between implementing HR at each scale (adapted from Schmid 2008).

Figure 1: Scales of Heat Recovery from Wastewater Systems



	Recovery in Building	Recovery in Sewer	Recovery in the WWTP
Environmental	Daily fluctuations	Seasonal and daily fluctuations Rainwater	Seasonal and daily fluctuations Rainwater Access to consumers
Regulatory	Responsibility for maintenance Effects on WWTP performance	Effects on WWTP performance Company is responsible for the system	Company is responsible for the system Regulations on effluent temperature
Economic	Cost per heat recovered?	Cost per heat recovered?	Cost per heat recovered?
Technical	Maintained by building owner How many buildings would have to be involved in order for this to be a viable option against HR at WWTP?	Maintained by company	Maintained by company Competes with energy recovery from biogas (can the utility sell excess energy?)

Modified from EnergieSchweiz 2005

The more concentrated heat in the decentralized scenario can improve HR efficiency. In wastewater that blended with other sewage in the sewers and WWTP, the heat is less concentrated and potentially less valuable, but the larger volumes of water can provide efficiency due to economies of scale. Decentralized systems may also experience efficiency challenges due to improper maintenance or other human factors. Anecdotal evidence indicates that in Switzerland, where HR is common, has removed so much heat from the water that WWTP processes are made ineffective. This may be a further reason to prefer centralized HR over decentralized systems.

Though WWTP HR technology seems a promising choice, it has not been widely implemented due to the complexity the systems themselves. Each facility is unique, with different unit processes, service areas, influent characteristics, and effluent requirements. For example, a WWTP could have anaerobic digestion of their sludge instead of aerobic, use ozonation to rid of pathogens and bacteria as opposed to UV treatment, or use a hybrid anaerobic/aerobic process (Metcalf & Eddy 2003, Shahabadi et al. 2009). The need for and preservation of heat will depend on the unit processes used. Therefore, to maximize treatment performance and energy recovery, it is necessary to know where heat can be removed and where it is needed. The most commonly cited uses of heat are for anaerobic sludge digestion, sludge drying, and nutrient removal but heating needs depend on how these processes are implemented (Schmid 2008).

In this study we compared sewer and WWTP HR in the Delgany Commons sewer line scale and at the Robert Hite WWTP in Denver, CO, considering the tradeoffs outlined in Figure 1. As a result of time constraints, the following preliminary data are presented with recommendations that further work be completed. For the “Technical” considerations, it was only possible to calculate the energy produced subject to the required 13C influent water temperature. This is the minimum temperature for the WWTP processes to continue uninterrupted. We hypothesized that it was possible to obtain a total influent of 13C while removing heat from the sewage line, or from the WWPT flow, due to the large wastewater flow.

Methods

In general, due to time and location constraints it was not possible to collect data directly from the WWTPs ourselves. Data was collected via communications with the utility. Temperature and volumetric flow rates at the influent and effluent of the plant and for a several sewer lines, including the Delgany Commons (DGC) sewer, were collected. General knowledge about the plant and location were also conveyed (Figures 2 and 3). The DGC line was used in the sewer HR calculations due to its proximity to a sports complex, the potential end-user of the heat. Except for the plant loading and influent and effluent temperatures of the WWTP, data was provided only for the months of December 2015 and January 2016. The data provided for daily plant loading was from December 2014 and January 2015. It was assumed that the flow data is consistent enough yearly to use the previous year's data.

Figure 2. "Version 1" presents given information by WWTP, "Version 2: Simplified System" is the simplified version in order to solve only for aspects important to the research

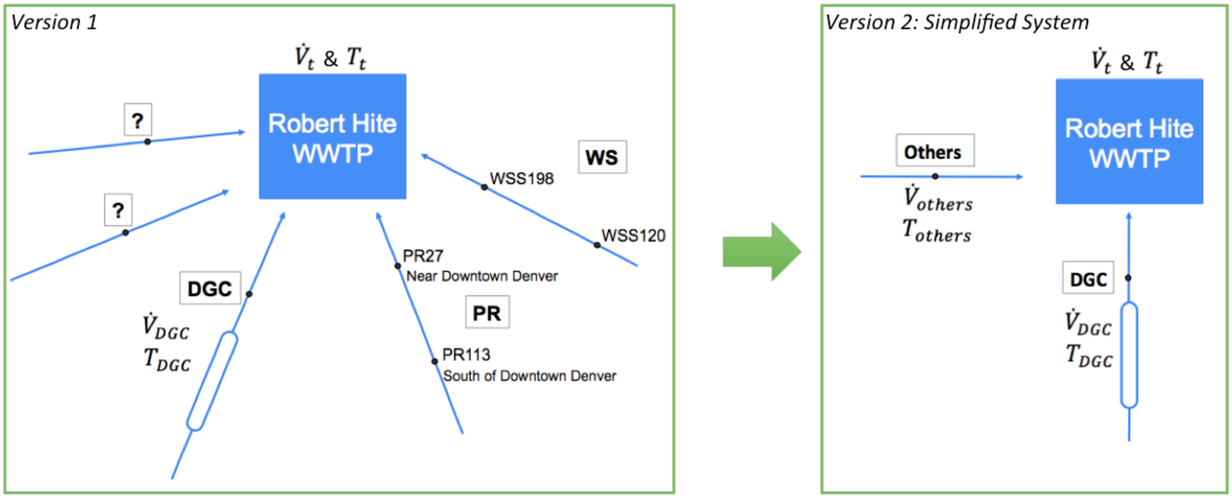


Figure 3. DGC line runs parallel to South Platte River and passes National Western Stock Show on its course to the Robert Hite WWTP.

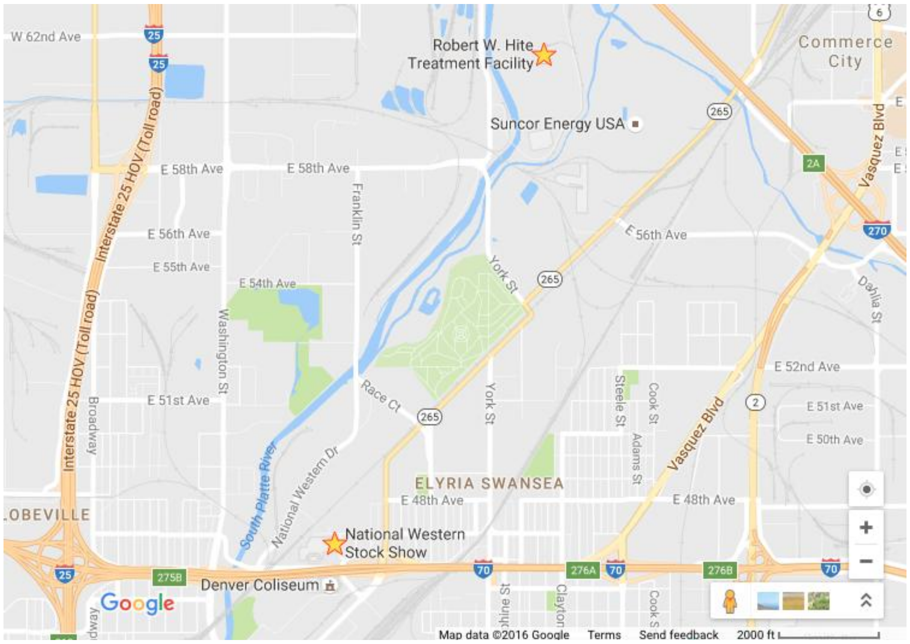


Table 1 below shows the proposed findings and calculations. Only the bolded section was explored in depth, due to project time constraints. The theoretical heat transfer was calculated for both scales, maintaining the requirement that the total influent temperature be 13C at the minimum. Heat recovery calculations were obtained from (Thulukkanam 2013). Data on heat exchangers was also necessary (DeltaT Heat Exchangers). There was no data for total influent and effluent temperature at the WWTP, therefore it was assumed that North Influent and Effluent Temperature data was representative of the totals.

Table 1. Considerations for Sewer and WWTP HR Comparison

Environmental	• Reusable heat form recovery: calculate heat transfer rate (q) and looking at exergy versus energy calculations • Greenhouse gas emissions avoided
Regulatory	• Effluent requirements (from Metro Wastewater Reclamation District) ○ *Segment 15 (Warm Stream Tier 1)* Summer (Mar-Nov): Chronic 24.2 and Acute 29 Winter (Dec-Feb): Chronic 12.1 and Acute 14.5 *Segment 1a (Warm Stream Tier 2)* Summer (Mar-Nov): Chronic 27.5 and Acute 28.6 Winter (Dec-Feb): Chronic 13.8 and Acute 14.3
Economic	• Cost benefits based on capital cost, maintenance and energy savings
Technical	• **Influent temperature requirement of 13C minimum** • Efficiencies of different technologies

Results

The following results are for a plate heat exchanger of surface area 4645 m^2 and a heat transfer coefficient (U) of 2500 $W/(m^2K)$. This U value was the average between the min and max presented in the U coefficient PDF (DeltaT Heat Exchangers). The surface area reflects a possible load of 30,000 gallons per day, about the same flow as the sewer line but less than the WWTP (Standard Xchange 2013).

After calculations, the DGC line and the WWTP showed heat transfer rate values in the range of 750-1250GW and 17-44GW respectively.

We found that, even with the requirement that the total influent wastewater be 13C, there is an immense amount of energy, on the order of GW, available at both the DGC and WWTP. The value for the theoretical wastewater temperature out in the WWTP is 13C. In the DGC the temperature of the wastewater out based in a theoretical temperature of 13C of total wastewater influent to the WWTP ranges from -8.5C to 4.5C. Freezing wastewater is not desired, therefore all theoretical temperatures less than 2C were set to be 2C for the heat transfer rate calculations. Calculation procedures can be found in the appendix.

Figure 4. DGC Hourly Heat Transfer Rate from 12/04/2015 – 01/29/2016

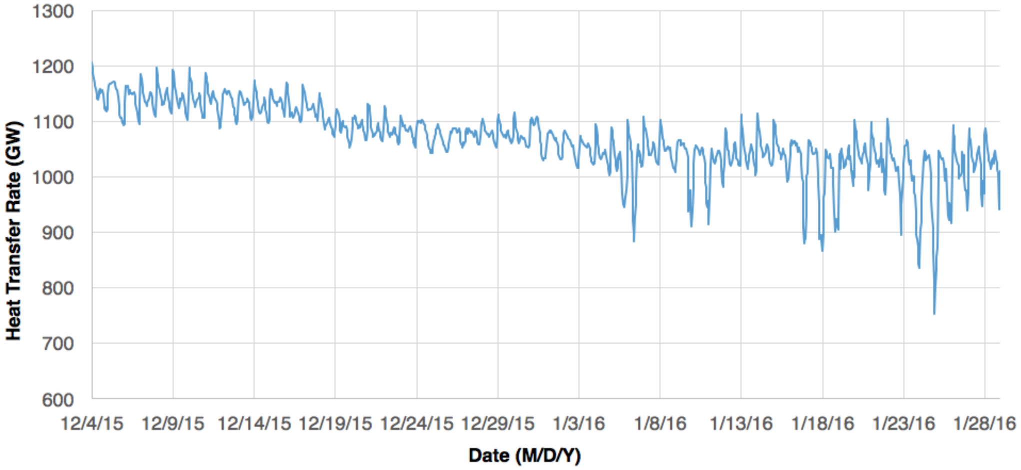
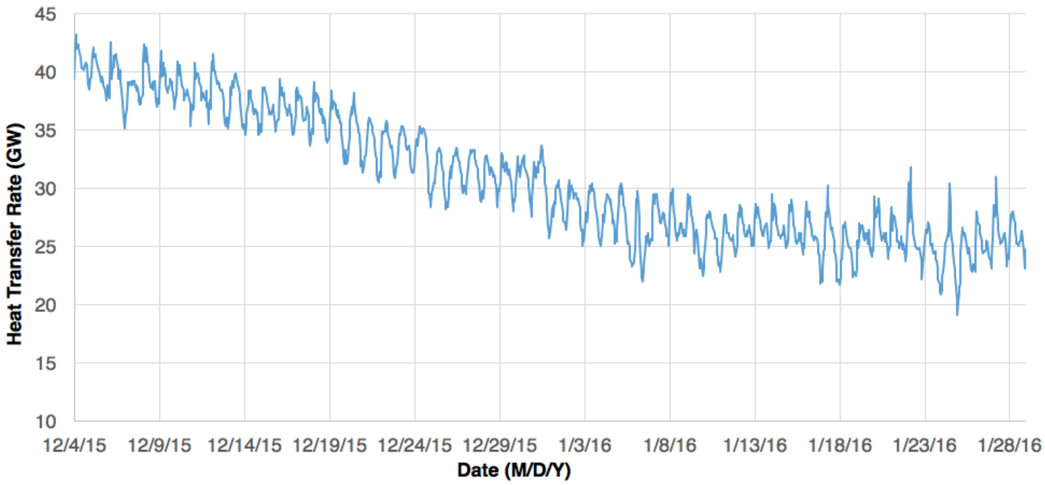


Figure 5. WWTP Hourly Heat Transfer Rate from 12/04/2015 – 01/29/2016



Discussion

Initially it was suspected that heat transfer values on the order of GW were improbable. However, a thermodynamics expert confirmed this to be an appropriate scale.

The DGC has much higher heat transfer rate values than the WWTP. WWTP HE scenario had a larger flow of wastewater, yet in the end the driving factor was the temperature difference between the influent ($T_{DGC,in}$, $T_{WWTP,in)}$ and the effluent ($T_{DGC,out}$, $T_{WWTP,out}$) wastewater that affected the outcome of which system would have more theoretical HE.

The extremely low $T_{DGC,out}$ is the result of the energy balance between the wastewater and the working fluid, T_{CW}. The working fluid being heated up was a cold water form a building. Because the goal was for T_{total} influent to be 13C, when calculating T_{DGC} out the result were very low, and even negative at times. It is not useful to have wastewater be negative and physically improbable, therefore we set a temperature constraint. The lowest temperature allowed was chosen to be 2C, keeping in mind that the only goal was for the WWTP influent temperature to stay above 13C. This still very low temperature produced a high temperature differential.

It is understood that in order for the total influent temperature to the WWTP to be affect negatively, the DGC line would at times need to be frozen. Lowering the temperature of the line to physically optimal heat exchange (HE) temperatures would be fine. In order to achieve optimal HE more research would need to be performed on the process itself such as materials used and needs of the user rather than just the thermal circumstances. Therefore, based on temperatures, we can say that maximum practical heat removal from the DGC line is possible.

Still, the area requirement of an appropriate heat exchanger may also be a reason for the low values for the WWTP. In which case for a back of the envelope calculation, the area can be multiplied by the ratio of the sewer and WWTP flow; 128MGD/27MGD = 4.7. The heat transfer rate for WWTP scenario from this calculation is the range of 89-205GW. This is still lower than the DGC line HE. It would be interesting to find all the factors that lower the WWTP temperature and in what situation it would have larger values.

We present the rest of the considerations related to our project in Table 1 as potential further research. The bolded bullet on the technical section is the consideration we investigated. Further research into economic and environmental considerations for HR at the sewer require additional energy and water use information at the National Western Stock Show facility. This information must include the demand volume of heated water by the facility or the need for heating and cooling of the buildings in order to find the heat transferred that is beneficially used.

More research and review of the calculations for the LMTD should be done to understand the reason for negative values of LMTD.

Process

This project was done in a transdisciplinary manner, which was a benefit and a challenge. Generally, the logistics and emails required waiting time, which for an 8-week project was significant and therefore only the preliminary stages of the project were completed; the results and analyses are not final. However, given more time, the value in communicating directly with people of different fields is invaluable. Through listening in on their perspective of the issue at hand, I was able to obtain a deeper understanding of the problem. We worked in collaboration with the wastewater utility, thermodynamics experts at Princeton University, and with a similar project group at Colorado State University (CSU). These were three very different interactions: industry, academia, and peer.

I learned from our interactions with the utility how to appropriately communicate with industry and that not every piece of data is readily, or at all, available. Getting a fuller context of the utility's situation from someone on the ground is extremely valuable in our making of strategic assumptions to address data barriers.

Working with experts in the field of thermodynamics was highly useful not only as an undergraduate engineering student but also as a researcher. Though there was not enough time to evolve the calculations more in their accuracy, the concept of looking at our actual heat transfer using exergy analysis, especially when moving towards looking at heat pump systems, is an idea that was offered by him, and something that I would have liked to arrive at. Another potential in this transdisciplinary project would have been the GHG calculations and possibly some LCA perspective by my mentor on the issue when it came down to both the environmental and economic considerations.

The collaboration with my peer at CSU was perfect in our development of ideas and sharing knowledge useful to both of us. Her project was on residential wastewater HR. With more time it would have been possible to compare her results, also in Denver, with ours and get an analysis for the three different wastewater HR systems.

All of these perspectives would provide a deeper analysis of the potential for HR from wastewater. It would include considerations at a grander scale that in the end would result in a more holistic view, allowing for cities and towns to benefit from this knowledge.

Acknowledgements

This work was funded by NSF Sustainability Research Network (SRN) Cooperative Agreement 1444758. I would like to thank the Urban Water Innovation Network and Prof. Arpad Horvath at UC Berkeley for accepting me in this project; at UC Berkeley, Dr. Jennifer Stokes-Draut for mentorship in this project and PhD student Eric Bell for his advice and communication with Metro Wastewater Reclamation District; at Princeton University, Dr. Forrest Meggers and PhD student Hongshan Guo for thermodynamics expertise and guidance; and at Metro Wastewater Reclamation District, Chief Innovation Officer Jim McQuarrie for the data used in this preliminary study.

Literature Cited

American Society of Civil Engineers (ASCE). 2013. "Wastewater". *2013 Report Card for America's Infrastructure*. http://www.infrastructurereportcard.org/wastewater/

American Society of Civil Engineers (ASCE). 2013. "Drinking Water". *2013 Report Card for America's Infrastructure*. http://www.infrastructurereportcard.org/water-infrastructure/

DeltaT Heat Exchangers. "U Factor for Heat Exchangers". 1674 Hyde Park Rd., Suite 206, London, ON, Canada. http://deltathx.com/uploadsdocs/u.pdf. Accessed: 6/19/2016.

Kenway, S.J., Binks, A., Lane, J., Lant, P.A., Lam, K.L., and Simms, A., . 2015. “A systemic framework and analysis of urban water energy”. *Environmental Modelling & Software* 73 (2015): 272-285

Kiparsky, M., Sedlak D.L., Thompson, B.H. Jr., Truffer, B. 2013. “The Innovation Deficit in Urban Water: The Need for an Integrated Perspective on Institutions, Organizations, and Technology”. *Environ. Eng. Sci.* 30 (2013): 395-408

McCarty, P.L., Bae, J., Kim, and J. 2011. “Domestic Wastewater Treatment as a Net Energy Producer – Can This be Achieved?” *Environ. Sci. & Technol.* 45 (2011): 7100-7106

Mo, W., and Q., Zhang. 2013. "Energy–nutrients–water nexus: integrated resource recovery in municipal wastewater treatment plants." *Journal of environmental management* 127 (2013): 255-267.

Shahabadi, B.M., Yerushalmi, L., and Haghighat F. 2009. “Impact of process design on greenhouse gas (GHG) generation by wastewater treatment plants”. *Water Research* 43 (2009): 2679-2687

EnergieSchweiz. 2005. “Heizen und Kühlen mit Abwasser – Ratgeber für Bauherrschaften und Gemeinden”. Bundesamt für Energie BFE, 3003 Berne. http://www.infrawatt.ch/sites/default/files/2005_EnergieSchweiz_Heizen%20und%20Kühlen%20mit%20Abwasser_Ratgeber%20für%20Bauherrschaften%20und%20Gemeinden.pdf

Schmid, F. 2008. “Sewage Water: Interesting Heat Sources for Heat Pumps and Chillers”. SwissEnergy Agency for Infrastructure Plants, Zürich, Switzerland.

Standard Xchange. 2013. “Plateflow® Plate & Frame Heat Exchnagers: Efficient Heat Transfer. Compact Design.” 175 Standard Parkway, Cheektowaga, NY, USA. http://www.standard-xchange.com/Tools/Portfolio/Upload/Project58/Docs/Plateflow_Plate_and_Frame_HX%20104_75.pdf

Thulukkanam, K. 2013,”Heat Exchanger Design Handbook”. 2nd ed. CRC Press

US Energy Information Administration (EIA). 2013. “Heating and cooling no longer majority of U.S. home energy use”. Residential Energy Consumption Survey (RECS) U.S., Department of Energy. (2009). http://www.eia.gov/todayinenergy/detail.cfm?id=10271

Appendix

Heat Transfer Rate Equation: $q = UA\Delta T_{lm}$

where U is the heat transfer coefficient for the type of heat exchanger being used, and A is its surface area between the two heat exchanging mediums. ΔT_{lm} is the Logarithmic Mean Temperature Difference (LMTD) and accounts for the asymptotic approach of the temperatures between the two values.

The LMTD is calculated by:

$$\Delta T_{lm} = \frac{(T_{ww1} - T_{cw2}) - (T_{ww2} - T_{cw1})}{\ln\left[\frac{T_{ww1} - T_{cw2}}{T_{ww2} - T_{cw1}}\right]}$$

Solving for $T_{cw2} = cold\ water\ out\ after\ heat\ exchange$

$$\dot{Q}_{ww} = \dot{m}_{ww} C_p (T_{ww2} - T_{ww1}) = \dot{m}_{cw} C_p (T_{cw2} - T_{cw1})$$

$$\dot{m}_{ww} = \dot{V}_{ww}\rho$$

$$C_p = 1000\,\frac{m^3}{kg}$$

$$T_{ww2} = minimum\ temp\ for\ treatment\ process$$

Referring to Figure 2., Version 2: Simplified System:
T_{others} was found using given inlet DGC values from data. This T_{others} data was then fixed and T_t (Total WWTP influent temperature) was set to 13. The varying value now was DGC. The result being the T_DGC out after heat exchange.

$$\dot{V}_{DGC} T_{DGC} + \dot{V}_{others} T_{others} = \dot{V}_t T_t$$

$$\dot{V}_{DGC} + \dot{V}_{others} = \dot{V}_t$$

The $T_{cw2} = cold\ water\ out\ after\ heat\ exchange$ is then calculated in the same way as for the wastewater calculations above