

SWEET HEAT: MODELLING WASTEWATER TEMPERATURES FOR EFFICIENT WASTEWATER HEAT RECOVERY

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ABSTRACT

A measurement campaign of wastewater temperatures was carried out in a section of the Berlin wastewater network. These results were used to carry out a temperature simulation using the EPA SWMM-Fork SWMM-HEAT. It was shown that a good agreement between measurements and simulations is possible for predominantly residential areas, even if the network was only moderately thermally calibrated ($MAE \leq 1 \text{ }^\circ\text{C}$).

Keywords: Wastewater heat recovery, hydraulic simulation, case study

INTRODUCTION

Germany's commitment to the "Energiewende" (energy transition) has been formalized since 2010. This national strategy aims to shift the country's energy sources away from fossil fuels towards more sustainable and renewable energy sources [1]. In this context, making effective use of untapped energy sources, is of crucial importance. One example is the thermal energy embedded in urban wastewater systems, also known as wastewater heat recovery (WWHR). In Berlin alone, the installed capacity of WWHR systems is approximately 7.5 MW, with the capacity expected to increase. The total technical potential is estimated at around 275 MW, which could supply about 5% of the city's heating demand [2].

However, the deployment of WWHR presents several challenges. There is a trade-off between the amount of recoverable energy and the required investment, as well as a critical operational constraint: the temperature of the wastewater entering treatment plants must not fall below approx. 12 °C in order to preserve the biological processes that are essential for effective treatment. Therefore, a thorough understanding of heat dynamics in sewer systems is essential for designing optimised, feasible recovery strategies.

In this context, temperature modelling is a valuable tool. It enables the simulation of temporal and spatial variations in wastewater temperature by considering factors such as residential and industrial discharges, weather conditions and soil temperature. As the hydraulic dynamics of the sewer network also influence heat transport, it is essential to use a model that integrates thermal and hydraulic processes.

Unfortunately, many existing modelling approaches are not well suited to predicting wastewater and stormwater temperature dynamics at the network scale due to limited accuracy, a lack of flexibility or high computational costs [3].

To address this issue, the SWMM-HEAT tool [4] extends the EPA SWMM [5] by thermal components, enabling temperature evolution to be simulated in urban drainage networks under dry and wet weather conditions alongside traditional hydrodynamic modelling. As an additional benefit, the SWMM and SWMM-HEAT toolchain is completely open source and thus easily accessible without a financial hurdle or running costs.

This paper presents the SWEET-HEAT project conducted by the water utility of the City of Berlin (BWB) alongside the Berlin Centre of Competence for Water (KWB), which aims to assess the WWHR in Berlin through hydrodynamic and thermal simulation using SWMM-HEAT.

In the scope of the project it is planned to:

- i. Transfer the hydraulic model from InfoWorks ICM to SWMM(-HEAT)
- ii. Use the monitored data to calibrate the thermohydraulic model
- iii. Perform extensive temperature simulations under varying conditions

METHODOLOGY

The monitoring program was conducted in one sub-area of the Berlin sewer network with 49 km conduit length and a dry-weather inflow of 60 LPS. The area has a separate sewer system in the dry-weather case and is only connected to surrounding networks under rain conditions. Temperature logging started at the end of May 2024 until February of 2025. In total, 14 loggers that recorded temperature data on a 5-minute basis were installed on a string fastened underneath manhole covers. It was ensured, that the sensors were always in contact with the waste water. The logged data was brought to a common timestep by averaging the data in 5-minute intervals. Besides that, no cleaning steps were deemed necessary to achieve sufficient data quality.

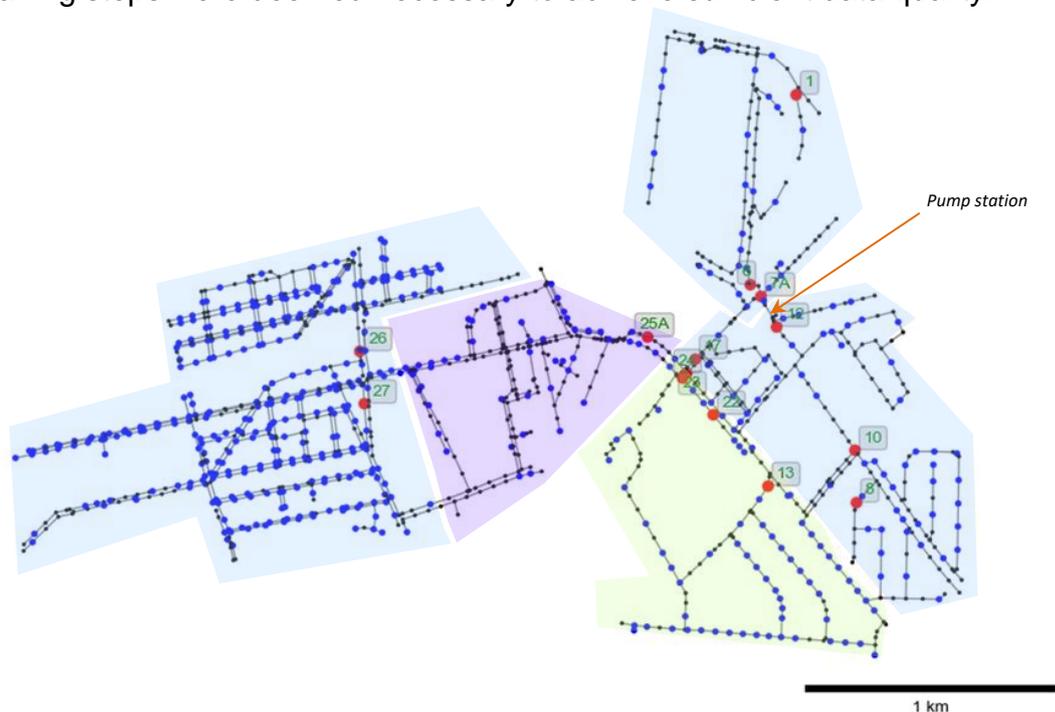


Figure 1. Model area (blue: modelled inflow, red: measured temperatures)

Figure 1 shows the graph representation of the model area. Red nodes with labels are the sensor positions where temperature was logged. Blue nodes indicate locations where an inflow is available in the hydraulic model. The

background colour indicates the kind of discharges, where blue is predominantly residential, green is predominantly commercial/industrial and purple is mixed.

The hydraulic model provided by BWB contains dry-weather flow (DWF) patterns for the different discharge points and was calibrated beforehand in the daily business. To model the pilot zone, the first step was to export the original model from InfoWorks ICM (ICM). The model was exported to an INP file. ICM provides a tool specifically for this purpose. However, errors are generated when the INP file is loaded in EPA-SWMM.

The main issues are as follows:

- The geometry of the custom conduit shapes is not imported, even though these shapes are referenced in the conduits.
- Conceptually, ICM and EPA-SWMM represent subcatchment information differently. In InfoWorks, residential and industrial discharges (inflows) are embedded within the subcatchment itself. In contrast, EPA-SWMM requires inflows to be defined at the node level. Furthermore, EPA-SWMM only allows one time series to be associated with each node, meaning two distinct inflow time series patterns cannot be linked to the same node.

To overcome this limitation, the network was exported in CSV format using the function available in ICM to access all network elements as originally structured in ICM. Using the information extracted from the CSV files, the INP file generated by ICM was post-processed using the Python package “swmm_api” [6] to:

- Create global patterns for each node by merging the different inflow patterns associated with all subcatchments connected to that node.
- Import the customised shape geometries into the original model.

Once the network has been properly imported and post-processed, simulations can be run successfully in EPA-SWMM, yielding results that match those obtained using the original ICM model.

In addition to the hydraulic calibration, the simulation module required a thermal calibration. Conduits on the model need to be supplied with additional parameters, including the thickness of the conduit, the thermal conductivity of the conduit material and soil as well as the density and the specific heat capacity of the surrounding soil. Since none of these were measured or readily available, in this first stage default assumptions were used to establish the workflow for the thermal-hydraulic modelling. All inflows in the thermal-hydraulic model also need a temperature pattern or timeseries. Since only 14 locations were measured, a default pattern was created by averaging the temperatures of the measured locations. In addition, the framework requires soil and air temperature patterns, none of which were included in the measurement campaign. For a general idea, the soil temperature was approximated by the monthly mean temperature in 100 – 255 cm soil depth [7]. To estimate the sewerage air temperatures, historical measurements from the H2020 project Digital Water City [8] in combination with the outside air temperature [7] were used to build a simple multiple linear regression model (MLR) that predicts the air temperature at the measurement locations. In this project sewerage temperatures were measured in parallel both in the fluid and gaseous phase.

RESULTS

An overview of the collected data split by predominant discharge type is shown in Figure 2. Some interesting irregularities catch the eye: For mainly residential flows there are significant temperature drops for sensor 27 that stay for a few days, which are also visible for the downstream sensor 17 and thus not explainable by faulty data. The predominantly industrial flows show approx. 10 °C higher average temperatures on weekends, with additional irregular events.

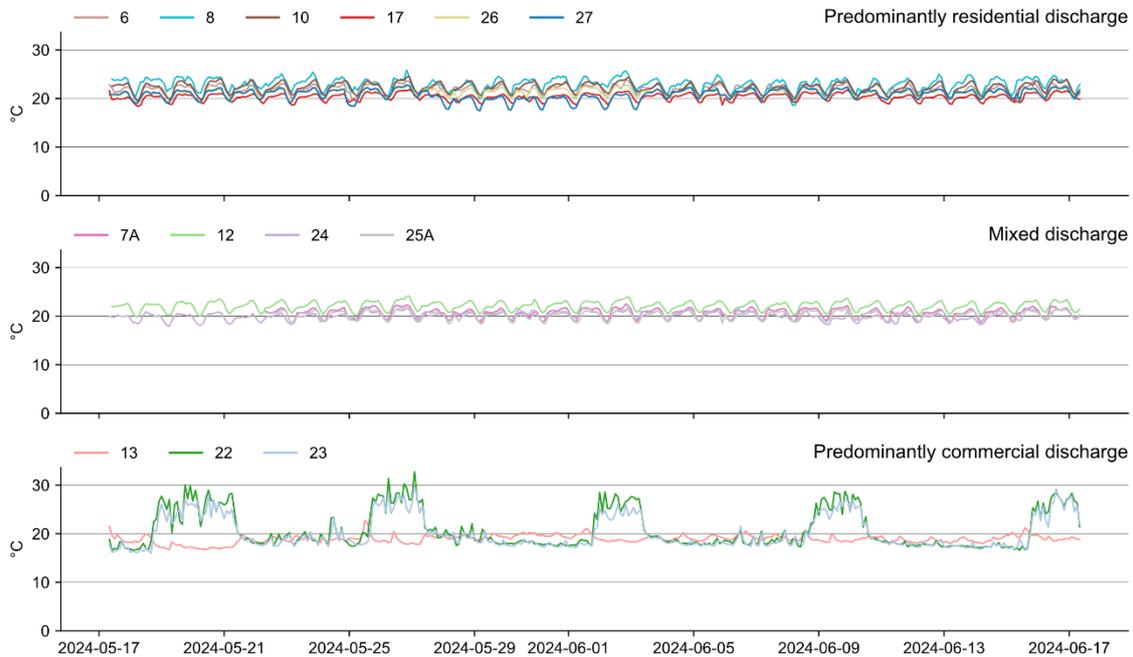


Figure 2. Collected data by assumed discharge composition

Using the average hourly weekday and weekend temperature patterns from the measured values as default discharge temperatures for all nodes where no measurements were made and measured temperatures for the 14 known locations yields the results depicted in Figure 3. The simulation was DWF-only and did not contain any surface run-off.

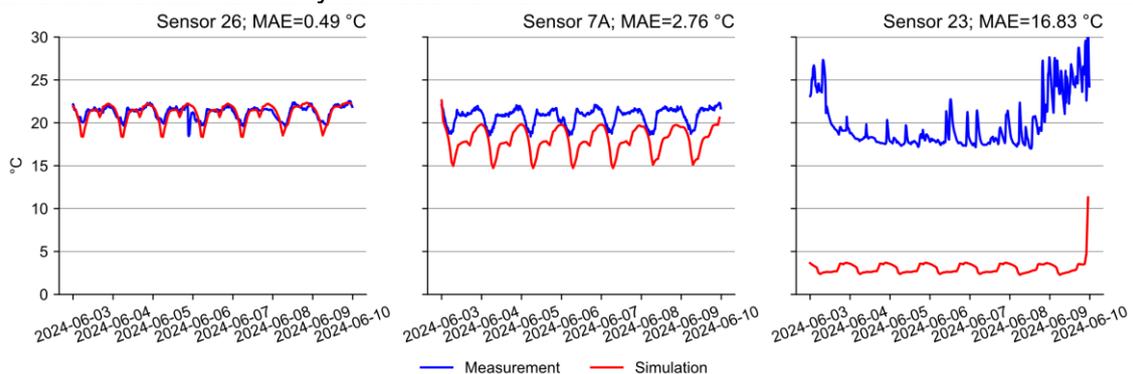


Figure 3. Comparison of simulation and measurements for three sensors

The results indicate a high sensitivity of the simulation to the quality of the thermal and hydraulic calibration. While for Sensor 26 the simulated temperature pretty much follows the measurements, for sensor 23 the simulated temperatures are way too low and also do not follow the highly irregular course of the industrial discharge.

The mean absolute errors of the measurement locations are summarized in Table 1.

Table 1. Mean absolute errors (MAE) per sensor, one week of simulation (R=residential, M=mixed, I=industrial)

Sensor	26	12	27	10	1	8	25A	6	7A	17	24	13	23	22
Kind	R	R	R	R	R	R	M	R	M	R	M	I	I	I
MAE	0.49	0.64	0.69	1.13	1.41	1.46	1.6	2.57	2.76	2.79	5.31	9.59	16.83	18.15

DISCUSSION

From the simulation results it becomes evident, that irregularities in the waste water generation as they occur in the industrial context highly effect the quality of the model results. While predominantly residential discharges at the edges of the network yield satisfying results with MAEs below 1 °C (26,12, 27), at the predominantly industrial nodes (13, 22, 23) the simulated temperatures are severely below the measured values. Since the boundary conditions (air temperature, soil temperature, generic inflow temperature for unmeasured nodes) are the same as in the rest of the system, as of now this behaviour cannot be explained and needs further investigation/calibration. The central nodes with mixed input also show effects due to the poor calibration of the industrial inputs, because the error propagates deeper into the system. Near the pump station (7A) the MAE is around 2.8 °C, indicating that the much higher residential flows compensate those effects to some degree.

While the model performance is generally promising, it might be difficult to replicate measurements and thus yield exact enough simulation results to predict the amount of energy that can be extracted from the system via heat pumps. The amount of energy is not just tied to the temperature but also the volume flow of the discharge – if both are not measured at the same location and the same time, the resulting heat flow will stay a rough estimate. For residential areas, this can be enough, but intermittent industrial discharges that might have a higher temperature are hard to model precisely using default inflow patterns.

EPA SWMMs way of providing patterns and time series allows for more or less arbitrary inputs, but the same methods are not implemented for the SWMM-HEAT plugin (yet). In the historic measurements used to create the MLR model for the sewerage air temperature prediction it was evident, that the fluid temperature plays a huge role. In SWMM-HEAT only a one-dimensional pattern (e.g. only hourly or only monthly values) is accepted as a valid input for air and soil temperature. This makes the simulation cumbersome, since for high precision simulations can only be done in 24h intervals before needing to reconfigure the input file. Nonetheless this tool yields exceptional results, considering the non-proprietary nature.

Choosing a smaller pilot area with a higher spatial resolution of measurements or doing network graph analysis before conducting the campaign to chose locations with high betweenness centrality can help to improve the simulation results.

CONCLUSIONS & FUTURE RESEARCH

It was shown, that it is generally possible to use the open source EPA SWMM fork SWMM-HEAT to simulate temperatures in a WWN exported from InfoWorks ICM. In the process, multiple impracticalities were identified and partly addressed.

For residential inflows, the simulation yielded satisfying results that can be improved by calibrating the boundary conditions. In the industrial case it became evident, that modelled irregular inflows that do not match the measurements cannot replicate the measured temperatures. Therefore, it is advised to not only monitor industrial temperatures but also discharges, which might come with additional expenditure. Regarding the collected data it is important to carefully pick the locations of the sensors. Bottlenecks in the network graph are a first point of orientation. The low-cost sensors that were used yielded a more than adequate temporal resolution and data quality for the purpose. Additional data that should be recorded optionally includes the sewerage air temperature as well as the surrounding soil temperature. Providing a detailed asset list for the thermal calibration of the conduits will also make the simulation more precise.

After the next iteration of the network calibration, a sensitivity analysis will be performed to identify the most important parameters in the thermal simulation and serve as a guide for the bare minimum of data that is required to simulate sewerage temperatures to an acceptable degree. After that, non-DWF periods will be included in the simulation and heat extraction scenarios will be tested.

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