In-house waste water heat recovery

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Introduction

A measurement-based analysis of the energetic potential of waste water within six buildings in Germany shows the high temperature level of the so far widely unused resource waste water. The waste water has an average temperature of about 21 to 26°C. Due to measurements of the consumption of drinking water the estimated amount of waste water for a weekday is in average 113 to 133 litres per day and person in residential buildings, 184 litres per day and room in hotels and 327 litres per day and bed in hospitals. The usage of thermal energy from waste water provided by heat pumps leads to high seasonal performance factors enabling economical as well as ecological use of the in-house heat recovery systems. To ensure the efficiency of the system the biofilm that grows on the sewage-sided heat exchanger, as a result of the nutritional richness of the waste water, has to be removed regularly.

Research approach

About 5% of the total delivered energy consumption in Germany is used for water heating [1]. Referring to buildings, the percentage of the delivered energy consumption for domestic hot water is about 11% [2]. Due to continuous efforts to reduce the heating demand of buildings the percentage of energy used for hot water supply will increase decisively during the upcoming years. This tremendous amount of energy in the waste water is usually discharged unused in the sewage system.

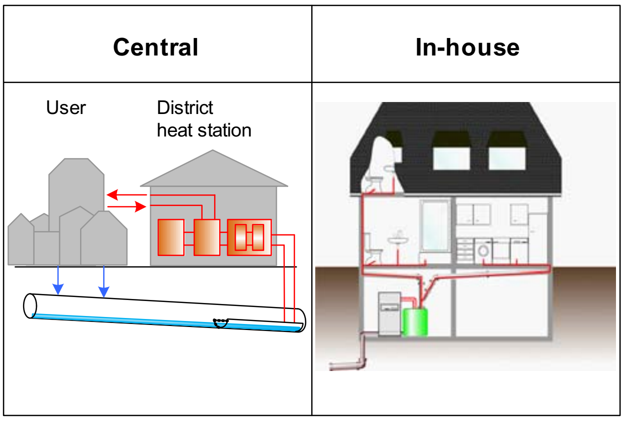

Figure 1. Concepts of waste water heat recovery.

In order to achieve the European objectives of climate protection waste water heat recovery provides an enormous and for the most part unexploited potential to develop resource-efficient heating devices in buildings.

The idea of heat recovery from waste water with heat pumps is certainly not new. Since the 1980s centralized systems in Germany, Switzerland and in the Scandinavian countries make use of the heat in waste water (**Figure 1**), either in the sewage system or in the effluent of sewage treatment plants [3]. The temperature of waste water is about 10 to 15°C throughout the whole year and even up to 20°C during summertime that guarantees an adequate heat source for the operation of heat pumps [4]. During the winter months with high heating demand waste water temperatures of only about 10°C are available that leads to decreasing heat pump efficiency.

In contrast to this technology, the aim of the project supported by the German Federal Ministry of Transport, Building and Urban Development called "In-house heat recovery of domestic waste water to increase the energy efficiency of buildings", which is compiled by the Chair of Construction Business and Building Services of RWTH Aachen University, is different [5]. Here the main objective is the decentralized use of thermal energy of all waste water flows before having entered the sewage systems within buildings to prevent the emission of energy to the surrounding soil. That's how to explain the waste water temperatures of about 23 to 26°C on average, which are substantially higher compared to the temperatures in centralized systems. As a consequence, the efficiency and cost-effectiveness of the heat pump systems can be increased decisively. Thus, a heat cycle is built up, in which the thermal energy of the waste water can be used by means of a heat pump to produce domestic hot water directly within the building.

In the context of the research project metrological potential analysis of the energy source waste water within buildings, as well as the simulative investigation of different system concepts, is conducted in order to evaluate the efficiency of the system compared to conventional energy generation.

Monitoring concept

In order to determine the energetic potential of waste water flows the consumption of cold drinking water, as well as the temperature of the waste water, has to be measured in the monitored objects. Here, the consumed amount of drinking water is equal to the estimator for the amount of waste water. The waste water temperature is measured redundantly with respectively two temperature sensors on each sewer. The measuring points are situated on the main sewers on the back of all internal sewers and before the waste water flow enters the sewage system (**Figure 2**).

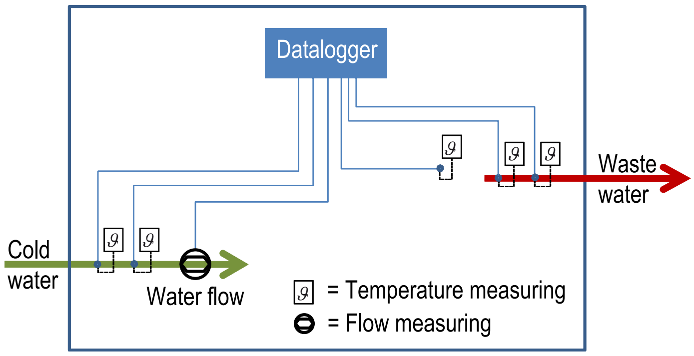

Figure 2. Monitoring concept.

The six monitored objects include a multiple-family house with 19 residents in the city of Düren, another multiple-family house with 49 inhabitants in the city of Pforzheim, two student residences with 244 and 208 occupants, a business hotel with 150 rooms and a hospital with 348 beds in the city of Aachen.

Monitoring results

Figures 3 and 4 show the representative daily variations of the consumption of drinking water and the waste water temperatures for a weekday based on arithmetic averages for one of the multiple-family houses and one of the student residences.

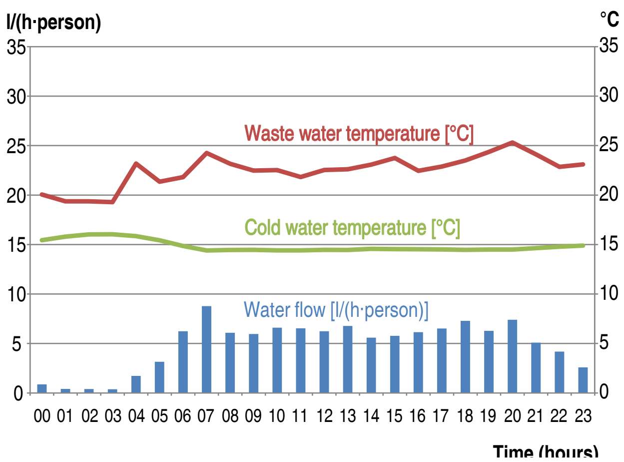

Figure 3. Multiple family house with 19 residents, hydrograph for a weekday.

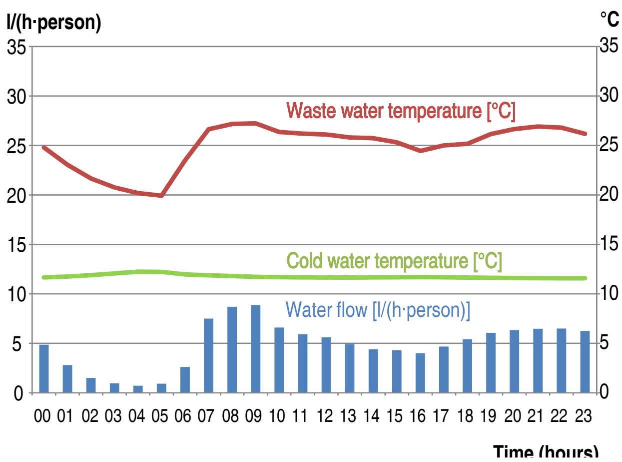

Figure 4. Student residence (TKH) with 244 residents, hydrograph for a weekday during the lecture period.

Derived from the measurement data for the multiple family house in the city of Düren with 8 accommodation units and 19 residents from May 2012 to July 2012 the average flow on weekdays results in 117.0 litres per day and person or rather 2.2 cubic metres per day. The average waste water temperature is 22.5°C while the average temperature of cold drinking water is 14.8°C during this period. **Figure 3** shows the daily fluctuation of water flow and waste water temperature. It can be noticed that the consumption of drinking water starts at 4:00 am and reaches its maximum of 8.8 litres per hour and person between 7:00 am and 8:00 am. Afterwards during the day, the flow is on a constant level between 5.6 (2:00 pm to 3:00 pm) and 6.8 (1:00 pm to 2:00 pm) litres per hour and person. During the night hours the flow increases slightly until 9:00 pm whereupon a steady decrease follows. The waste water temperature reaches its maximum average hourly value of 24.3°C (7:00 am to 8:00 am) and 25.3°C (8:00 pm to 9:00 pm) during the morning and the evening peak. The profiles of the curves are different on Saturdays and Sundays (not to be seen in the chart). The early consumption peaks begin with a three-hour delay on both days of the weekend. It is remarkable that the average consumption is with 133.9 litres per day and person higher on Sundays.

The results derived from the measurement data for the student residence in the "Theodore von Kármán" building (TKH) with 244 residents from May 2011 to February 2012 are the following: on a characteristic weekday (Monday to Friday) during the lecture period the average consumption of drinking water is 116.9 litres per day and person respectively 28.53 m³ per day while the average waste water temperature is 24.9°C. The average temperature of cold drinking water is around 11.8°C during the measurement period. **Figure 4** shows the representative daily variations of the water flow and the waste water temperature. It is obvious that the drinking water consumption starts at 6:00 am in the morning and reaches its daily maximum of about 9 litres per hour and person between 8:00 am and 10:00 am. During the afternoon hours between 4:00 pm and 5:00 pm the consumption is slightly lower. Between 10:00 pm and 11:00 pm there is a second consumption peak with 6.5 litres per hour and person. The curve of the waste water temperatures shows a similar trend: The maximum hourly value of 27.2°C can be observed during the early consumption peak between 9:00 am and 10:00 am while the temperature falls to 19.9°C between 5:00 am and 6:00 am. The shape of the curve shows that during periods with much flow water the waste water temperature is higher than in periods with less flow water. On Saturdays and Sundays the profiles are slightly different (not to be seen in the chart): The consumption peaks in the morning begin with a one-hour delay on Saturdays and with a two-hour delay on Sundays.

Evaluation of the performance

Due to the high temperature level of waste water it can be described as an ideal heat source for a heat pump system, as shown in **Figure 5**. The waste water storage compensates the fluctuating amount of incoming waste water in the course of a day and serves at the same time as an installation site for the sewage-sided heat exchanger, which absorbs heat from the waste water. The heat pump supplies the required rise in temperature and distributes the heat on a higher temperature level to the domestic water heating. In bivalent designed systems the heat pump accomplishes a preheating of the drinking water, whereupon a second generator (a conventional gas boiler for instance) rises the temperature from the preheating-level to the drinking water temperature of 60°C. This is done in order to keep Legionella bacteria from growing and to ensure a hygienically unobjectionable supply system.

In the context of the research project [6] different system concepts are analysed concerning their ecological and economic advantages by simulation calculations, where the hydrographs of the waste water energy profiles serve as input quantities for the simulation. In the following the simulation results are presented for a heat pump system wherein the heat pump provides a preheating of the domestic hot water to a 45°C-level and a gas boiler rises the temperature up to 60°C using the example of the student residence TKH with 244 occupants. Further constraints are:

- ensuring the domestic hot water temperature $\vartheta_{DHW} = 60°C$
- preheating of domestic hot water through heat pump $\vartheta_{pre} = 45°C$
- domestic cold water temperature $\vartheta_{\mathrm{DCW}} = 10°C$
- volume of water heater $V_{water\ heater} = 5\ m^3$
- volume of waste water storage $V_{waste\ water\ storage} = 5\ m^3$
- heat output of heat pump is 24 kW
- thermal disinfection of water heater once daily using the gas boiler

Because of the nutritional richness of the medium waste water the formation of biofilms on all contact surfaces is expected. Here, the biofilm formation on the sewage-sided heat exchanger is of particular interest because the biofilm has a low thermal conductivity and thus

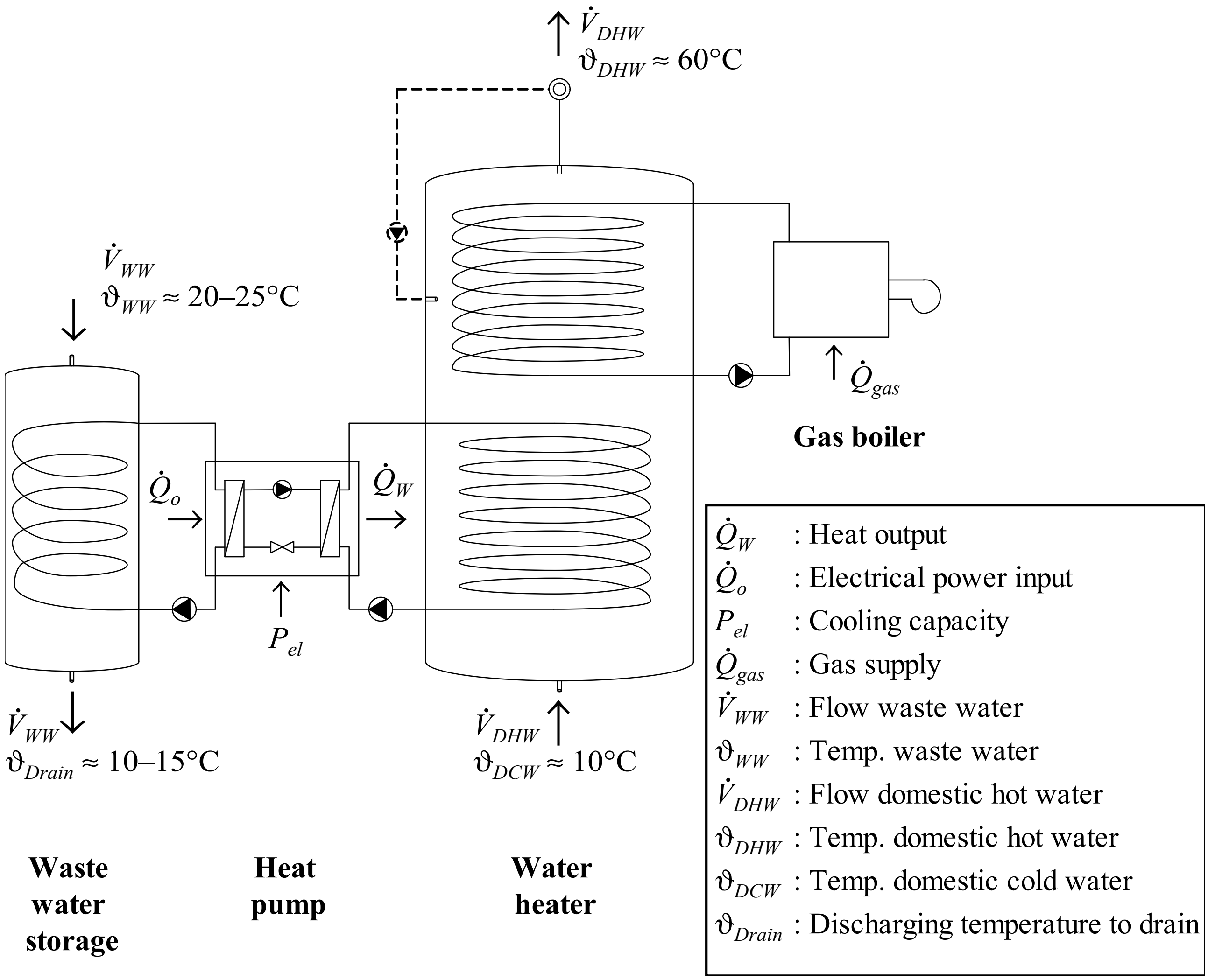

Figure 5. Possibility for using waste water energy to heat up drinking water by means of a heat pump.

has an insulating effect and can significantly impede the heat transfer of the heat exchanger. In the simulation a biofilm with an average thickness of 1 mm is applied, which requires regular cleaning of the sewage-sided heat exchanger in one-day-intervals:

- thickness of biofilm on sewage-sided heat exchanger d_{bio} = 1 mm
- thermal conductivity of biofilm λ_{bio} = 0.5 W/m·K

For the simulated system, a delivered energy demand for domestic hot water of 991.2 kWh/a·person is calculated, from that the heat pump provides 475.5 kWh/a·person and the gas boiler 515.5 kWh/a·person. The performance factor of the heat pump is extrapolated on company data to 5.5 with a heating coverage of 48.0%. On average, the heat pump operates with a temperature rise from 17.7°C to 44°C. Based on the calculations, the waste water is cooled down to 18°C on average. Thus, no damaging effects on downstream waste water cleaning processes in the sewage treatment plant have to be expected. For detailed results, reference is made to other publications that were compiled within this research project, see [6].

The reduce of biofilm formation on the sewage-sided heat exchanger, for example with the help of highly innovative and automated cleaning methods, is essential for the efficiency of the system. The main objective of the research project is the expansive use of waste water as a heat source. The in-house waste water heat recovery can be considered as a forward-looking technology that can increase the energy and resource efficiency of heating devices in buildings. ■

References: See the complete list of references of the article in the html-version at **www.rehva.eu** -> REHVA Journal