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SCIENTIFIC PAPER

OPPORTUNITIES FOR WASTEWATER HEAT RECOVERY IN HUNGARY AND ITS ROLE IN THE CIRCULAR ECONOMY

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Abstract: *Most of the energy content of wastewater can be found in wastewater heat, however, its recovery is limited. In this article, the current situation, future opportunities of wastewater heat recovery are presented based on secondary data collection, mentioning the constraints and main influencing factors of sustainable implementation of heat recovery systems in Hungary. Besides, the already existing systems are described. As regards the capacities of treatment plants, 103 of the 574 domestic plants have a capacity of over 20,000 Population Equivalent (PE), of which 25 plants have a capacity of over 100,000 PE. According to our calculations, in big cities/capitals (20.000 – 100.000, and over 100.000 inhabitants), it may be possible to recover wastewater heat sustainably in several places. In small towns (5.000 – 20.000 inhabitants), wastewater heat recovery can be technologically and economically sustainable only in the presence of agricultural or industrial plants with high and continuous wastewater feed into the pipeline system. Taking into account the temperature conditions at each place of use and their estimated fluctuations, it can be said that proper, careful planning, sizing and implementation have a crucial effect on the efficiency of microbiological activity in the treatment plants. In bigger cities, of course, the effect of the temperature drop of one main collector may be minimal, however, in smaller and medium-sized settlements, excessive heat extraction may result in complete inhibition or cessation of nitrification. In Hungarian case studies, the maximum acceptable temperature drop is approx. 2-3 °C. It can be stated that energy recovery from wastewater may be very promising considering the size and temperature limitations. Therefore, the rational recovery of wastewater heat can be an important part of the implementation of circular economy and sustainable energy utilization in wastewater management, resulting in significant energy savings and pollutant reduction.*

KEYWORDS: wastewater treatment; circular economy; energy management; heat energy; nitrification
JEL CODE: Q25

INTRODUCTION

The transition of the European economy to a greener, more flexible circular model is an emerging concept (Németh et al., 2020) in which redesigning products and production processes help to minimize waste and turn unused materials into resources. According to Osztovics (2018), global megatrends — resource scarcity, technological breakthroughs, and the emergence of new generations — are now creating an environment in which waste and by-products end up in landfills. Companies and service providers that recognize the untapped potential of extending the life cycle of products and materials can enter new markets, save costs and increase consumer confidence while significantly reducing their environmental footprint. Thus, environmental challenges also mean economic opportunities; economic development does not necessarily go hand in hand with the deterioration of the environment.

Nowadays, the amount of water used is constantly increasing due to the growth in population and living standards. At present, agriculture is responsible for 70% of global water use, while urban and residential use accounts for 11% and industrial water demand for 19% (UNESCO, 2017). Another tendency is that an increasing proportion of the population moves to big cities; the proportion of the urban population exceeds 50% globally, while in Hungary it is close to 70% (KOVÁCS, 2017). The problems of wastewater management in villages and towns and the possibilities of the applied technology differ greatly, not only due to the different size and regional tasks to be performed but also due to the different income levels and wastewater quality. In the villages, therefore, smaller and semi-natural, less efficient treatment solutions are characteristic, while in the big cities - because of the more concentrated, higher amount and industrially polluted wastewater production - large-scale, automated wastewater treatment plants with mainly activated sludge technology are typical (BODÁNÉ KENDROVICS, 2018).

According to FAO (2018), nearly three hundred billion m³ of wastewater is generated on Earth in one year. However, in terms of treatment, the proportion of treated water is favourable (70% on average) in developed, economically prosperous countries, while in developing and underdeveloped, poor countries it is only one-third or a quarter on average (SATO et al., 2013). Accordingly, it is estimated that approximately 80% of the wastewater produced worldwide is released into the environment without proper treatment and purification (UNESCO, 2017). However, the energy and nutrients it contains are of great value, and their utilization can be important regarding not only waste management but also emissions. One of the greatest potentials for energy recovery is to use wastewater temperature to produce heating or cooling energy.

In our article, we present the current situation and the legal and technological environment influencing the direct recovery of wastewater heat, we describe the best practices that have already been implemented and we also cover the limiting factors that mostly influence the prevalence and efficiency of wastewater heat recovery in Hungary.

1. LITERATURE REVIEW

In the European Union, overall waste generation is stable, but the amount of sewage sludge is still increasing (EC, 2019a). The purpose of Directive 91/271/EEC is to protect the environment against the harmful effects of urban and certain industrial wastewater discharges. To achieve this, the Directive requires member states to collect and treat urban wastewater as a mandatory obligation above 2,000 population equivalents (PE).

According to European policymakers, there is a need to develop an energy sector based mainly on renewable energy sources, aspiring to the rapid phasing out of coal and decarbonizing gas (EC, 2019b).

The European Union Heating and Cooling Strategy (EC, 2016) states that in some industries, a much larger proportion of heat as a by-product could be recycled within the plant or sold to nearby buildings. The wastewater heat recovery we examined is also closely included in this issue.

1.1. Energy content of wastewater and its usability

According to MCCARTY et al. (2011) and GUDE (2015), energy is present in three forms in the average wastewater generated in the USA and their theoretical specific energy is as follows:

1. energy of organic pollutants: ~ 1.79 - 1.93 kWh/m³
2. energy of plant nutrients (N and P): ~ 0.70 - 0.79 kWh/m³
3. thermal energy: ~ 7.00 kWh/m³

The values were determined by MCCARTY et al. (2011) by using the COD (Chemical Oxygen Demand) value (500 mg/l) for the organic compounds present in the wastewater, assuming a theoretical COD energy potential of 3.86 kWh/kg. In Hungary, this value is slightly higher as the wastewater is more concentrated due to the lower water consumption per capita. The energy value of wastewater is also larger in the case of higher agricultural sludge content, because of the higher N and P ratio in animal manure (Ladányi and Szűcs, 2016). WETT et al. (2007) describe that wastewater contains more energy than is sufficient to use electricity for the treatment plant, and with appropriate technology, the treatment activity in the plant can be self-sustaining, while FILLMORE et al. (2014) suggest that wastewater contains up to five times the energy required to treat it.

Most of the energy content of wastewater is found in wastewater heat, however, its recovery is limited. According to DULOVICS (2012), theoretically, 1.16 kWh of thermal energy can be obtained by cooling 1 m³ of wastewater by 1°C. The reason for the significant heat content is that the wastewater coming from bathing, washing and washing-up leaves our home at a temperature of 35-65°C and then flows underground to the treatment plant. In this regard, the following recovery methods are available by extracting the heat energy with a heat exchanger and then increasing it to the required temperature with a heat pump: (1) from the sewerage of the building at the place of generation; (2) from the sewer; (3) heat recovery from treated water leaving a wastewater treatment plant. The energy efficiency values (COP - coefficient of performance) of the wastewater heat generated in large quantity at relatively constant temperature are significantly more favourable than that of ground heat and aquifer water:

- heating (COP): 5.0-6.5, taking into account auxiliary energy approx. 4.5,
- cooling (EER1): 7.5-8.5, taking into account auxiliary energy: approx. 6.5.
- the COP value of natural gas combustion in this context is 2.9-3.2.

The favorable recovery and COP value of wastewater compared to other heat sources lie in its constant temperature.

According to Dulovics (2012), sustainable and economical heat energy generation in Hungary is primarily ensured by the following factors:

- at least 15 L/s (1,296 m^3/day) flow in the sewer,
- adequate temperature of the wastewater at the wastewater treatment plant,
- minimum heat demand of 150 kW,
- usually, 100-300 m distance between the sewer and the buildings; 300 m in non-built-up areas.

1.2. Relationship between wastewater heat recovery and wastewater treatment efficiency

Although directly recoverable heat energy represents the largest proportion, it cannot be extracted entirely due to wastewater treatment considerations.

WONG (2014) and NEDOROST (2018) draw attention to the careful and thoughtful planning of the heat recovery of the inflowing wastewater, mentioning that excessive extraction of wastewater heat before reaching the plant may cause problems in terms of treatment efficiency - due to low water temperature -, and may also lead to increased energy consumption.

The biological nutrient removal process in wastewater treatment plants released N2O as a main content. The process of the elimination of nitrogen contains two steps. These two-steps of nitrogen bio-elimination from wastewater consist of nitrification under strict aerobic conditions followed by denitrification under anoxic conditions (Thakur and Medhi, 2019). Nitrification according to Lydmark et al. (2007) is characterized in two consecutive steps by two chemolithoautotrophic groups of bacteria, called ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB). During this process, ammonium is oxidized to nitrate, via nitrite.

Furthermore, in the first step aerobics bacteria known as Nitrosomonas, converts ammonium to nitrite while another group of aerobic bacteria called Nitrobacter finish the conversion of nitrite to nitrate (Trygar, 2009). Regarding denitrification, it is the biological process by which nitrate is converted to nitrogen and other gaseous end products.

The basic and crucial factor influential for the efficiency of the removal of nitrogen and carbon compounds from wastewater containing de-icing agents is the temperature.

Nitrification is a very delicate process regarding water temperature whether cold or hottest temperature. It reaches a maximum rate at liquid temperatures between 30 and 35 degrees C (86°F and 95°F). Moreover, with the increase in temperature above 40°C its rates fall to near zero. On the contrary, the cold water temperature has an impact on the nitrification rate as well. As water temperature decreases the nitrification process slows down (Trygar, 2009). According to Antoniou et al., (1990) and Hepbasli et al., (2014), wastewater temperature is depending on the season however the effective maximum specific growth rate of nitrifying bacteria is ranged between 15 and 25°C, whereas a decrease in the temperature affects the ongoing process of the specific growth rate of nitrifying bacteria. In the study of Gnida et al. (2016), the WWTP operation was analyzed during the wintertime and it shows that the activated sludge was sensitive during the decline of temperature. The nitrification efficiency is decreased under 16°C and presumably, at 10°C, the nitrification would be inhibited completely.

1.3. Case studies in Hungary

In Hungary, in recent years, 540 million m^3 of municipal wastewater is treated annually at public wastewater treatment plants, according to the records of the Central Statistical Office (KSH, 2020). The records of Municipal Wastewater Information System (TESZIR, 2019) state that out of the 574 Hungarian plants, only 25 have a capacity of over 100,000 PE (population equivalent), however, these plants still represent more than half of the total treatment capacity. In general, the vast majority of wastewater is treated by larger treatment plants, typically based on activated sludge technology.

According to estimates, the investment cost of the applicable technology, developed in Hungary, is approx. EUR 1 million (two-thirds of which is the installation of the conventional energy generating capacity, i.e., the implementation cost is higher by a third of the total cost). The technology has a lifespan of 15 years. When an existing system is converted, the return is 8-10 years (savings of 120,000 EUR/year), while new constructions take 3-4 years due to the annual savings of 20-40% in energy costs of the end-user. The solution optimally provides full energy supply (cooling and heating) to commercial units and office buildings near larger main collectors (above 600 mm in diameter).

The most significant projects implemented in Hungary (with a total installed capacity of 8.4 MW) are the following (Table 1).

In the table, we can see the Hungarian examples implemented so far, and their characteristics, all of them in the capital city, Budapest. We can observe that each of them clearly exceeds the theoretical water flow limit values, which are approx. 1 300 m^3/day or 15 l/sec. In chronological order,

1 EER: Energy Efficiency Ratio.

Table 1: Wastewater heat recovery references in Hungary

Project site	Water flow (m^3/day)	Water flow (L/sec.)	Average temp. of wastewater	Capacity	Year
MOM Cultural Center and Larus Event Center	2 160 m^3/day	25 L/sec.	15-17°C	1.0 MW	2011
FCSM Kerepesi Road WWTP and headquarters	3 360 m^3/day	39 L/sec.	17°C	1.0 MW	2012
MH EK Military Hospital	11 520 m^3/day	133 L/sec.	17°C	3.8 MW	2014
University of Szeged JATIK building	3 264 m^3/day	38 L/sec.	17°C	1.5 MW	2015
FCSM Ferencváros lifting/pumping station	5 760 m^3/day	67 L/sec.	17°C	1.2 MW	2015

Source: own editing based on KISS (2016)

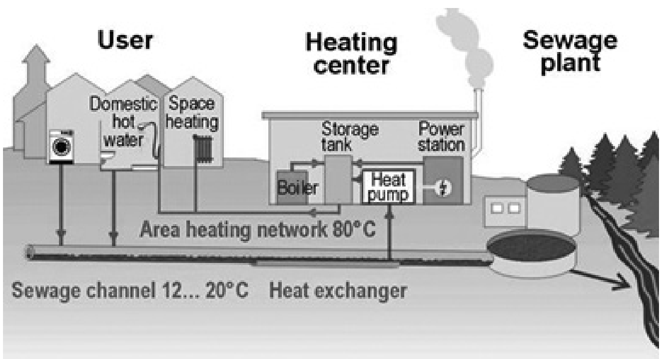
first was the Larus Event Center, while the biggest one is the system implemented for ensuring a significant part of the heat supply of the Military Hospital.

2. MATERIALS AND METHODS

In our work, after secondary data collection, we describe the current situation, opportunities and potential of wastewater heat recovery, as well as its characteristics on both the "supply" and "demand" sides.

Figure 1. shows the design of a theoretical system, which consists of the following: on the left: the users (or wastewater producers), below is the sewage channel and the built-in heat exchanger. The heating center and heat pump are at the bottom, which is responsible for the distribution of the heat. The wastewater treatment plant is on the right side, at the end of the process.

Figure 1. Design of a theoretical wastewater heat recovery system



Source: REHVA, 2012

In our calculations, we used the following data and correlations related to the supply side:

- Register of the Municipal Wastewater Information System of Hungary on wastewater treatment plants and their capacity (TESZIR, 2019).
- Domestic average wastewater production data: 130 liters/person/day (Kárpáti, 2016).
- Domestic references for wastewater heat recovery (Table 1).
- The heat obtained by using the heat exchanger and the associated temperature change (Formulas (1) and (2)).

Regarding the possibilities of wastewater heat recovery, we used the following formula by Cecconet al. (2019) and Kretschmer et al. (2016):

$$P_{RS}=Q_{RS}\cdot c\cdot \Delta T_{RS}\cdot \rho \quad (1)$$

where: P_{RS} : available heat potential (kW)

Q_{RS}: wastewater flow diverted at the recovery site for heat exchange (L/sec)
c: specific heat capacity of wastewater (4.18 KJ/kg/°C) (Funamizu et al., 2001)
ΔT_{RS}: temperature difference or decrease due to heat recovery (K)
ρ : wastewater density (1000 kg/m^3)

The temperature change in the sewer after wastewater heat recovery is described by Formula (2) below:

$$\Delta T_{SEWER}=(Q_{RS}\cdot \Delta T_{RS})/Q_{SEWER} \quad (2)$$

where: ΔT_{SEWER}: change of temperature in the sewer
Q_{RS}: wastewater flow diverted at the recovery site for heat exchange (L/sec)
ΔT_{RS} : temperature difference or decrease due to heat recovery (K)
Q_{SEWER}: flow rate in the sewer in the proximity of the building (L/sec)

Basic data related to the demand side, i.e., the user side of wastewater heat:

Specific heating energy demand (primary energy consumption by heating) (ÉMI-NFM, 2015):

- Office buildings: 86-240 kWh/m^2/year (average: 163 kWh/m^2/year)
- Commercial buildings: 146-258 kWh/m^2/year (average: 202 kWh/m^2/year)
- Healthcare and social services buildings: 151-308 kWh/m^2/year (average: 229.5 kWh/m^2/year)
- Cultural buildings: 70-198 kWh/m^2/year (average: 134 kWh/m^2/year)
- Educational buildings: 113-238 kWh/m^2/year (average: 175.5 kWh/m^2/year)

Based on this data, the calculated average demand is 180 kWh/m^2/year, which means an average power demand of 45 W/m^2 assuming a heating period of 4000 h/year, which is greatly influenced by the method of recovery.

The formula used to estimate the (peak) heating load, considering the nature of the building and the heated $m^{3,}$ for an average insulated building (Internet1):

Required (peak) load = Heated floor area * Ceiling height * Specific heating demand * 1.1 (3)

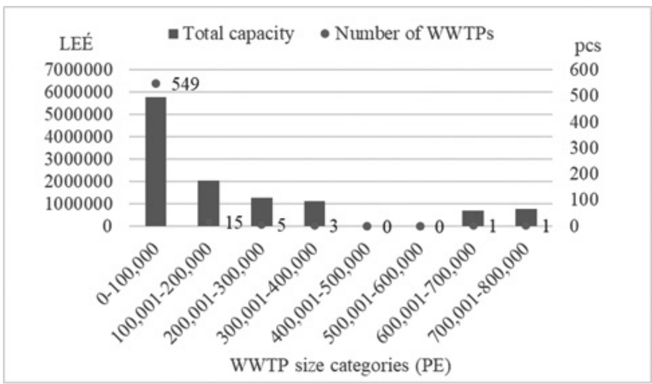
The National Building Energy Performance Strategy (2015) proposes a value of 30-40 W/m^2 as the specific heating demand. Based on the previous data, we use 35 W/m^2 in our calculations.

3. RESULTS AND DISCUSSION

When mapping the municipal wastewater heat recovery possibilities in Hungary, the size and capacity of the wastewater treatment plant of the given settlement are of paramount importance. This value is always closely related to the amount of wastewater flowing in the sewer system (main collector(s)) before reaching the plant.

The register of TESZIR (2019) helps to discover the possibilities of heat recovery. Based on the register, forming different size categories, we can find the characteristics shown in Figure 2. below. It can be observed that while 95% of the domestic wastewater treatment plants is below 100,000 PE, they are responsible for less than 50% of the treated wastewater volume.

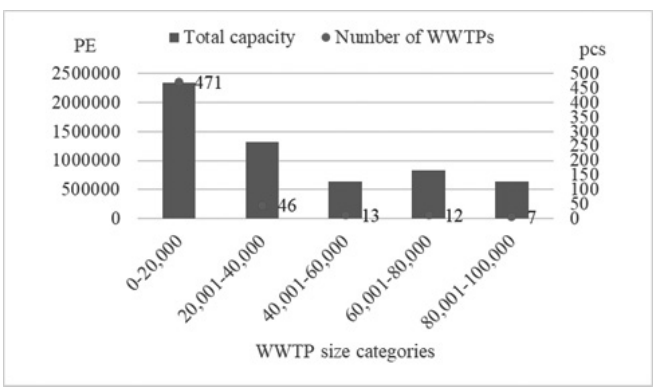
Figure 2: Number and the total capacity of wastewater treatment plants by different size categories in Hungary



Source: Own editing based on TESZIR (2019)

As the wastewater flow available in the given sewer section can be a significant limitation in terms of wastewater heat recovery, we also examined the distribution and characteristics of the first size category (plants between 0-100,000 PE) (Figure 3).

Figure 3: Number and the total capacity of wastewater treatment plants by different size categories (0-100,000 PE)



Source: Own editing based on TESZIR (2019)

On the figure, we can see the plants with less than 20,000 PE are in the vast majority (471). If we look at the contribution of plants above 20,000 PE, above 50,000 PE and above 100,000 PE, we get 80%, 65% and 50%, respectively, for the proportion of total treated wastewater.

Although our calculations show that the previously mentioned wastewater flow of at least 15 L/sec (or 1,296 m^3/day) indicated by Dulovics (2012) may theoretically be available in the sewer section of a 10,000 PE plant, this is influenced by several factors in practice, including the following ones.

Limitations on the supply side:

- only the wastewater collected in sanitary sewer pipes can be used for heat recovery (usually there is a significant amount of suction and transportation involving vacuum trucks)
- in order to avoid the negative effect of the heat extraction outside the plant on nitrification and denitrification processes, the appropriate wastewater flow rate is crucial.

Limitations on the demand/user side:

- in smaller settlements, a public institution, office building, community space or catering unit, etc. with a significant, continuous heating or cooling demand is less likely to be available in the vicinity (within a maximum of 300 m) of the main collector with the appropriate flow.

Using the data of Hungarian references, assuming a residential wastewater production of 130 liters/day/person, we calculated the wastewater flow of each plant, referring to PE (Population Equivalent). Subsequently, applying the formulas by Cecconet et al. (2019) and Kretschmer et al. (2016), we determined the temperature drop in a given sewer section assuming different recovery rates (Table 2). The following is the calculation for the first plant (MOM Cultural Center and Larus Event Center) in order:

Basic formula and calculation:

$$P_{RS}=Q_{RS}\cdot c\cdot \Delta T_{RS}\cdot \rho \text{, after rearranging}$$
$$\Delta T_{RS}=P_{RS}\,/Q\_(RS\,)/\,c\,/\,\rho \text{, substituted:}$$
$$\Delta T_{RS}=1000\text{ kW}/25\text{ L/sec}/4.18\text{ KJ/kg/°C/kg/L}$$
$$\Delta T_{RS}=-\,9{,}6\text{ °C}$$

In the next step, the actual temperature drop in the channel section was calculated based on the formula (2):

Basic formula and calculation for a 10% recovery rate:

$$\Delta T_{SEWER}=(Q_{RS}\cdot \Delta T_{RS})/Q_{SEWER}\text{, substituted}$$
$$\Delta T_{SEWER}=(25\text{ L/sec}\cdot 9{,}6\text{ °C})/250\text{ L/sec}$$
$$\Delta T_{SEWER}=0{,}96\text{°C}$$

In terms of recovery rates, the percentage of wastewater flowing in the sewer used for heat exchange is extremely important for changes in temperature conditions. The possible outcome is illustrated in the five columns on the right side of the table.

Table 2: Characteristics of domestic references and calculated temperature drop for different recovery rates

Project site	Water flow (L/sec.)	Capacity	Avg. temp. of wastewater	Size in P.E.	Change in temperature by different share of wastewater usage (°C)				
					100%	75%	50%	25%	10%
MOM Cultural Center and Larus Event Center	25 l/sec.	1.0 MW	15-17°C	16,615	9.6	7.2	4.8	2.4	1.0
FCSM Kerepesi Road WWTP and headquarters	39 l/sec.	1.0 MW	17°C	25,846	6.1	4.6	3.1	1.5	0.6
MH EK Military Hospital	133 l/sec.	3.8 MW	17°C	88,615	6.8	5.1	3.4	1.7	0.7
University of Szeged JATIK building	38 l/sec.	1.5 MW	17°C	25,108	9.4	7.1	4.7	2.4	0.9
FCSM Ferencváros lifting/ pumping station	67 l/sec.	1.2 MW	17°C	44,308	4.3	3.2	2.1	1.1	0.4

Source: own calculations based on KISS (2016

As shown in Table 2, assuming an average wastewater production of 130 liters/person/day, the smallest system has 16,600 PE, while the largest system contributing to the energy supply of the Military Hospital has a wastewater capacity of nearly 90,000 PE.

It can be observed that the proportion of wastewater use in the given sewer section has a significant effect on the temperature drop. If all the wastewater flowing in the given sewer section were to be used, the temperature would drop by 4.3 to 9.6°C. In contrast, if heat is extracted only from 50% of the total flow, the drop is by 2.1 to 4.8°C, while at 10% this value decreases to 0.4 to 1.0°C, depending on the amount of wastewater used for heat recovery.

Taking into account the temperature conditions at each place of use and their estimated fluctuations - according to the months and seasons, approx. 12-20°C in the range of 8°C (Cipolla and Maglionico, 2014, Wanner et al., 2005, and Kretschmer et al., 2016) -, it can be said that proper, careful sizing and design have a crucial effect on the efficiency of microbiological activity. In bigger cities, of course, the effect of the temperature drop of one main collector reaching the site may be minimal, however, in smaller and medium-sized settlements, excessive heat extraction may result in complete inhibition or cessation of nitrification.

After considering the limiting factors and characteristics of the supply side, we also performed calculations on the demand/user side, taking into account the min. 150 kW heat demand determined by Dulovics (2012).

Based on the formula applied to calculate the (peak) load required for heating, assuming a specific heating demand of 35 W/m^3 and a ceiling height of 3 m:

Required (peak) load = Heated floor area * Ceiling height * Specific heating demand * 1.1, after rearranging:

Heated floor area = Required (peak) load / Ceiling height / Specific heating demand / 1.1, substituted:

Heated floor area = 150 kW / 3m / 35W/m^3, so:

Heated floor area = 1300m^2

Combining the demand and supply sides, we created a table with several possibilities, which can help to assess and determine the possibilities of sustainable heat recovery that does not endanger microbiological activity, considering the temperature conditions of the given sewer section (Table 3).

Table 3: Temperature drop in terms of water flow and heating system capacity

Capacity required for heating (kW)	Water flow (L/sec.): 15	30	50	100	150	200	300	500
150	**2.38**	**1.20**	**0.72**	**0.36**	**0.24**	**0.18**	**0.12**	**0.07**
300	4.77	**2.39**	**1.44**	**0.72**	**0.48**	**0.36**	**0.24**	**0.14**
500	7.95	3.99	**2.39**	**1.20**	**0.80**	**0.60**	**0.40**	**0.24**
1000	15.90	7.97	4.78	**2.39**	**1.59**	**1.20**	**0.80**	**0.48**
1500	23.85	11.96	7.18	3.59	**2.39**	**1.79**	**1.20**	**0.72**
2000	31.80	15.95	9.57	4.78	3.19	**2.39**	**1.59**	**0.96**
3000	47.70	23.92	14.35	7.18	4.78	3.59	**2.39**	**1.44**
5000	79.50	39.87	23.92	11.96	7.97	5.98	3.99	**2.39**

Note: Values to the right and down of the second column and row indicate the temperature drop in °C.

Source: own calculations

Table 3 shows how wastewater heat recovery reduces temperature under different conditions. The cells marked in bold are considered to be less risky combinations for efficient microbiological activity in the wastewater treatment plant based on the presented Hungarian case studies, while the faded cells contain the cases resulting in a significant decrease. The latter is only relevant to wastewater with much higher temperatures. In Hungarian case studies, a maximum temperature drop of 2-3 °C can ensure the efficient course of the denitrification process. A facility with a floor area (to be heated) of about 1,300 m2 has the lowest (150 kW) heating power demand, which is, of course, greatly influenced by its thermal and energy consumption properties. In the domestic case studies (assuming a maximum temperature drop of 2.39 °C), they can supply 300-1500 kW of power, which can enable heating of 2.6-13 thousand m^2 each, reducing energy costs and the associated emissions.

Our list of wastewater treatment plant sizes (Figures 2 and 3) based on the records of TESZIR (2019) and our analysis described above show that 103 of the 574 domestic plants have a capacity of over 20,000 PE, of which 25 plants have a capacity of over 100,000 PE. In the former group, sustainable wastewater heat recovery can be achieved only in an ideal case and under the right conditions, while the sewer sections in front of the treatment plants above 100,000 PE can provide a good opportunity to extract the heat content of wastewater, resulting in significant energy savings and pollutant reduction.

Based on professional experience we can say that although the collectors with the highest wastewater flow are generally located in densely populated areas, due to the size of the sewer network and the maximum size of the collectors in medium and big cities/capitals (20,000 - 100,000, and over 100,000 inhabitants) it may be possible to recover wastewater heat sustainably in several places. In small towns (5,000 - 20,000 inhabitants), however, considering the supply side we regard wastewater heat recovery as technologically and economically sustainable only in the presence of agricultural or industrial plants with higher wastewater discharges into the sewer network. In the latter case, another important condition is the availability of a place of use within a reasonable distance and with appropriate heat demand.

Careful planning and implementation are necessary for economic efficiency and sustainability and in order to avoid adverse effects on biological processes (especially nitrification and denitrification). Therefore, not only the supply side (adequate amount, flow and temperature of wastewater) but also the demand side, i.e., concentrated and possibly continuous heating and/or cooling demand must be present. The possible return in each case depends on the investment and operating costs of the given system and the magnitude of savings provided by the system (such as the cost per unit of energy, etc.). In principle, the overall efficiency of the process could be increased by converting the thermal energy extracted from wastewater into cooling energy (by solving its recovery during summer), but the additional electricity demand required for this could only result in economical operation in case of particularly large (much higher than domestic) capacity. Such examples are public institutions that are in use all year round (e.g., community house, cultural center, shopping center, office building) or possibly cold stores, warehouses.

It can be stated that energy recovery from wastewater is extremely promising and considered as a future prospect. Therefore, the rational recovery of wastewater heat can be an extremely important complement to the implementation of circular economy and sustainable energy management in wastewater management.

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