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Reduction of wastewater pollution using the technologies for heat recovery from wastewater in buildings – a review of available cases

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ABSTRACT

The rise in living standard and the rapid development of the economy have led to an increase in the daily production of domestic wastewater. Environmental policies aim to reduce pollution, and appropriate technologies in the field of wastewater heat recovery could contribute to this goal. Technologies such are heat pumps and heat exchangers enable wastewater heat recovery and contribute to reduction of wastewater thermal pollution at the source. Also, using the recovered heat can meet some of the energy needs of buildings and reduce CO_2 emissions. This paper reviews the literature on wastewater heat recovery in buildings and the opportunities to reduce energy consumption and greenhouse gas emissions through the use of wastewater heat recovery technologies. Also, the paper presents the methodology for evaluating the effects of the potential of wastewater heat recovery in buildings, and gives an analysis of the key factors affecting the wastewater heat recovery potential. Given the constant potential of heat recovery and its widespread availability at the source, this study concludes that future strategies for creating more sustainable societies will rely more heavily on heat recovery from wastewater.

Keywords: Buildings; Domestic wastewater; Heat recovery; Thermal pollution

1. Introduction

The link between energy, greenhouse gas (GHG) emissions, water, and wastewater is becoming increasingly important in developing innovative solutions for technically feasible and socially desirable sustainable management for urban growth [1]. Cities require a continuous energy supply and they consume about 75% of global primary energy [2]. Because modern societies are highly dependent on fossil fuels [3], they account for more than 70% of GHG emissions [4]. To reduce the environmental impact, energy consumption and GHG emissions could be scaled back by increasing energy efficiency in cities [5]. In 2021 the operation of buildings accounted for 30% of global final energy consumption and 27% of total energy sector emissions [6]. Due to the problem of scarcity of resources and growing impacts on the environment, the European Union (EU) has set a goal to achieve a reduction in GHG emissions (compared to 1990 levels) by 55% by 2030 [7], and to increase the share of renewable energy to 32% of total energy production [8,9]. Also, the International Energy Agency (IEA) published a special report on the pathways to a global net-zero energy system by 2050. The report

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lists more than 400 milestones that need to be achieved to reach the goal of net-zero energy consumption and emission rates by 2050. In cities, the building sector is key to advancing net-zero energy consumption and emission rates [10] because buildings represent a source of substantial untapped efficiency potential [11]. Therefore, there is a need to change the building design and construction concept [12] or to improve the energy efficiency of existing buildings. The four predominant end-uses of energy, which together account for a total of 98% of residential energy consumption in 2019, are space heating (65%), water heating (14%), household appliances (13%), and cooking (6%) [13].

To reduce energy consumption and greenhouse gas emissions, governments of countries and regions should increase the amount of energy generated by renewable sources and/or reduce energy demand through improved building energy performance [12]. In this regard, the transformation and improvement of energy systems should aim at providing reliable and affordable energy services, decreased energy consumption, decreased impact on the environment, and reduced import dependency [14]. For this reason, renewable energy sources have received special attention in recent years. To support these goals, EU Directive 2018/2001 [15] specifies wastewater as a renewable heat source. Furthermore, the European Green Deal Investment Plan provides additional subsidies to member states to implement waste heat reuse measures [16]. Given that advances toward sustainable societies necessitate sustainable urban management [17], wastewater heat recovery could be one of the municipal responses to these objectives. Approaches that enable the use of waste heat sources are considered third-generation renewable energy technology [18]. Water and wastewater management in buildings offers significant potential for implementing the circular economy concept: from raw wastewater heat utilization to utilization of produced wastewater sludge (material and/or energy recovery) [19]. There are several places where hot water is used in buildings, including showers, bathtubs, washing machines, sinks, dishwashers, etc. Energy consumption, and therefore GHG emissions, are influenced by use of water in buildings. In countries with strong economic growth and a high standard of living, increased water consumption [20] leads to an increase in energy demand. Almost 14% of energy consumption in the household sector is related to heating water for various purposes [13]. On average, the energy required to heat water is eight times higher than the energy used to produce, purify and transport water [21]. Other estimates have shown that water heating require ten times more energy than water transport and water treatment combined. As a result, reducing hot water consumption and utilizing wastewater heat recovery contribute to further energy demand optimization [22]. Depending on the amount of available heat, thermal energy recovered in this manner can be used to pre-heat the building's cold water supply or for space heating.

Studies conducted in Switzerland [23] showed that 15% of the thermal energy supplied to buildings is lost through the sewage system; this value rises to 30% in well-insulated buildings with low consumption. Wastewater heat recovery minimizes energy demand, makes buildings more efficient, reduces the carbon footprint, and increases the share of renewable energy [24]. Therefore, urban wastewater systems need to be reviewed, planned, and built according to a new set of rules and performance expectations that deviate from current standard practices [25]. Heat can be recovered in buildings/within the house (small applications), in sewers (medium applications), or at wastewater treatment plants (large-scale applications) [26]. It means that wastewater heat recovery systems can be installed in buildings, sewage systems, or wastewater treatment plants. The last two options are easier to organize and arrange [21]. Wastewater heat recovery systems can be used in single family homes and dwellings, and non-residential premises with higher hot water consumption [27]. In contrast to solar technologies, whose efficiency is influenced by variations in solar intensity [28], household wastewater recovery potential is relatively constant throughout the year. This can be considered an advantage of the approach, especially during the winter months when the demand for heat is highest. The technology of wastewater heat recovery is not new, but it is still not largely applied. This technology is applied in United Kingdom, Norway, France, United States of America (USA), and Netherlands [27,29]. Europe has the greatest technological lead in the world on this subject, with 326 patent applications since 2010, which is 70% of all patent applications in the world. Together, wastewater heat recovery systems have already recovered 300 GWh corresponding to the annual domestic hot water consumption of 17,000 households [27]. Also, the transition to clean and renewable energy technologies within the sector is vital to bring down emissions and meet future energy needs [30]. The efficiency of these technologies is constantly improving [31].

Heat exchangers and heat pumps can be used for heat recovery, and they can be applied at different points in the sewer system (from end-user to water treatment). These locations and technologies have advantages and disadvantages concerning their energy, economic and environmental perspectives. Also, the variety of wastewater heat recovery devices enabling heat recovery in many situations [32].

Using the wastewater heat recovery technology in buildings creates the possibility [33]:

- To recycle already purchased energy for reheating living spaces and water (or cooling). For example, some systems for efficient wastewater heat recovery can take advantage of up to 95% of the thermal energy available in the property's wastewater. This corresponds to 20%–35% of the total energy consumption of a normal apartment building;
- To control energy (in and out) – modern heat recovery systems include control modules, which show data for energy use and optimize capacity;

Thus, there are:

- Economic benefits (profitable heat recovery) – heat recovery reduces the need for energy supplied and saves on the building's total energy cost;
- Environmental benefits – using wastewater heat recovery technologies reduces the climate impact and improves the key figures for the sustainability report and energy declaration.

Systems using sewage or wastewater as a heat source have already been extensively described in the literature.

This study aims to provide a comprehensive overview of the current state-of-the-art on wastewater heat recovery in buildings. Therefore, the review: (1) briefly focuses on the energy consumption in building sector and energy-related emissions coming from buildings; (2) explains the correlation between energy, emission, and wastewater; (3) presents the methodology for evaluating the effects of the potential of wastewater heat recovery in buildings; (4) gives the overview of different types of wastewater heat recovery technologies used in buildings; (5) presents examples of wastewater heat recovery technologies in buildings and possible energy savings and reduction of GHG from wastewater heat recovery; (6) presents the advantages of wastewater heat recovery in the building.

2. Energy, emission, water and wastewater in building sector

2.1. Energy use in building sector

In 2019, the building sector had the largest share of global total final energy consumption, amounting to 35%. An estimated 130 EJ, or about 30% of the total final energy consumption, was used in 2019 for building operations. An estimated 21 EJ, or about 5% of the total demand, was used for building construction. Global energy demand in buildings fell by 1% in 2020 to around 127 EJ, despite the sector's share of overall energy demand stands at 36%, compared to 35% in 2019 [26]. Taking this into account, as well as the average distribution of residential energy use presented in section 1, it is possible to deduce that energy consumed for water heating in buildings amounts to approximately 17.78 EJ, which corresponds to around 5% of global energy demand. For the first time since 2012, energy consumption in this sector was stable [34]. In 2021, construction activities rebounded back to pre-pandemic levels in most major economies, alongside more energy-intensive use of buildings. As a result, buildings' energy demand increased by around 4% from 2020 to 135 EJ (the largest increase in the last 10 y) [35]. Fig. 1 shows global final energy consumption by fuel type in the construction sector.

When analyzing buildings energy consumption, GHG emissions, and wastewater, it is necessary to classify buildings into residential and non-residential (commercial) sector. Many authors differ buildings by their use, but sometimes this can't be applicable because buildings can be mixed-use. Besides, there are different typologies and types of residential and commercial buildings by many parameters (offices, retail establishments, educational institutions, recreation centers, etc.) [37].

In 2010, buildings accounted for 32% (24% for residential and 8% for commercial) of global final energy use [38]. In 2016 energy use in buildings decreased to 17.5% (10.9% for residential buildings and 6.6% for commercial buildings) [39].

Space heating represented 32%–34% of the global final energy consumption in both the subsector in 2010, Fig. 2. Non-residential buildings usually use more energy to light the space, while residential buildings use more energy for cooling the space. There are no recent data on final energy distribution for residential and commercial buildings in the literature. It is necessary to study and analyze each facility individually, to obtain a realistic state of final energy consumption and GHG emissions.

Residential and non-residential buildings consume relatively large amounts of energy for heating, cooling, lighting, and other needs (Fig. 3) [40]. Constructed floor space in buildings worldwide has increased by about 65% since 2000, reaching nearly 245 billion m² in 2019 [41]. This progress, however, has not compensated for the growth in surface area, resulting in a steady increase in energy use. Between 2015 and 2019, the final energy intensity per m² of the

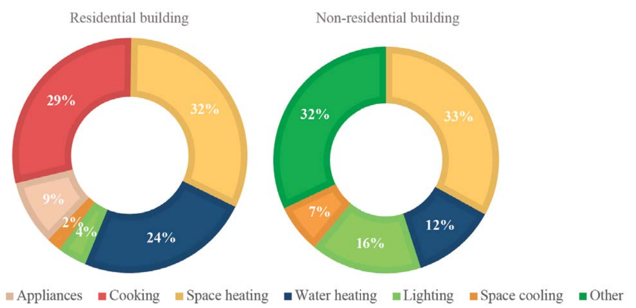


Fig. 2. World building final energy consumption by end-use in 2010 [38].

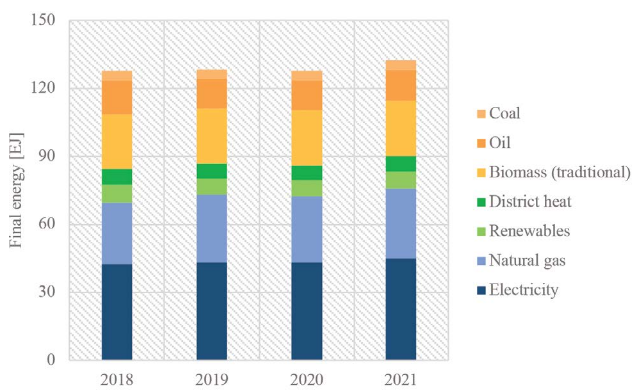


Fig. 1. Global buildings sector final energy use by fuel type, 2018–2021 [26,36].

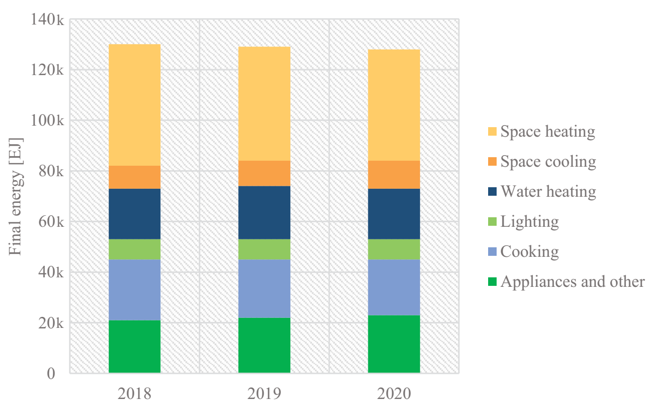


Fig. 3. Global share of buildings and construction by end-use [26].

building changed from 330 to 320 kWh/m². It is expected to further decrease up to 300 kWh/m² by 2025 [42].

Although the classification of energy services varies between sources, this paper classifies them into heating, ventilation, and air conditioning (HVAC), domestic hot water (DHW), lighting, cooking, and other equipment, mainly appliances and other plug-in devices. Their share of the world and the countries with the highest consumption is shown in Fig. 4, according to the latest available and reliable data.

Buildings go through several stages during their lifetime including design, construction, operation, and reconstruction. At each stage, there are opportunities to improve energy efficiency and reduce emissions.

2.2. Emissions from the building sector

The building sector is a leading contributor to GHG emissions, accounting for about one-third of all energy-related emissions [41]. Total energy-related emissions from buildings operations and construction declined by 10%, from 13.1 Gt of CO_2 in 2019 to 11.7 Gt in 2020. Energy-related emissions from buildings and construction account for 37% of the global total in 2020, a slight decrease from 38% in 2019.

Total operational emissions from the global buildings sector (direct and indirect emissions related to heating, cooling, preparation of domestic water, lighting, etc.) fell by 10% in 2020, from around 9.6 Gt of CO_2 in 2019 to 8.7 Gt, reflecting the shift in energy use patterns caused by the pandemic. In 2021 direct and indirect emissions from buildings operation rebounded to about 10 Gt, or 2% higher than in 2019 and about 5% higher than 2020 (Fig. 5) [36]. Direct energy-related emissions for building operations fell to just under 3 Gt of CO_2, and indirect emissions related to electricity use total 5.8 Gt of CO_2 in 2020, down 13% from 2019. Taking this into account, as well as the average distribution of residential energy use presented in section 1, it can be deduced that domestic water heating accounts for approximately 1.4 Gt of global CO_2 emissions, representing approximately 5% of global emissions share.

These emissions are caused in part by direct use of energy from fossil fuels in buildings, and in part by generation of electricity and heat energy for use in buildings. From another point of view, fossil fuels are usually used to meet hot water needs [45], which has a clear carbon footprint and contributes to GHG emissions. In 2021 about 8% of global energy-related and process-related CO_2 emissions was caused by the use of fossil fuels in buildings, with another 19% caused by generation of electricity and heat used in buildings, and an additional 6% related to the manufacture of cement, steel and aluminum used for buildings construction [36].

Space heating and cooling, as well as the preparation of domestic hot water, represent the largest share of energy consumption in residential buildings. Analysis of data from commercial and stable agglomerations showed that half of the GHG emissions are produced in the building sector, mainly in residential buildings [21].

Despite the expected rebound in emissions in 2021, buildings are still far from being carbon neutral by 2050. To meet this target, all new buildings and 20% of the existing building sector would need to be zero-carbon-ready as soon as 2030 [26].

2.3. Correlation between energy, emission and wastewater

To achieve the EU's overall 55% emissions reduction target by 2030, the construction sector would have to reduce its emissions by 60% [46].

Wastewater heat recovery leads to a reduction in GHG emissions by reducing the use of primary energy. However, to analyze the overall sustainability of wastewater heat recovery, it is vital to consider the life-cycle assessment (LCA) of applied technology [47].

Considering the growing portion of total building energy demand that hot water creates as buildings become more efficient, it is important to focus on reducing this demand alongside heating and cooling requirements, which are the focus of existing sustainable agendas. Looking at the system of wastewater recovery in a building, as a whole and integrating these new high-performance technologies, there is still great potential to increase efficiency and reduce fossil fuel demand and CO_2 emissions [12].

Water consumption in buildings is classified into two types of uses: cold water and domestic hot water. Domestic hot water implies additional consumption of electricity, because hot water accounting for about 18.9% of the final energy consumption of households [40]. When looking at the ratio of hot water demand compared to space heating and

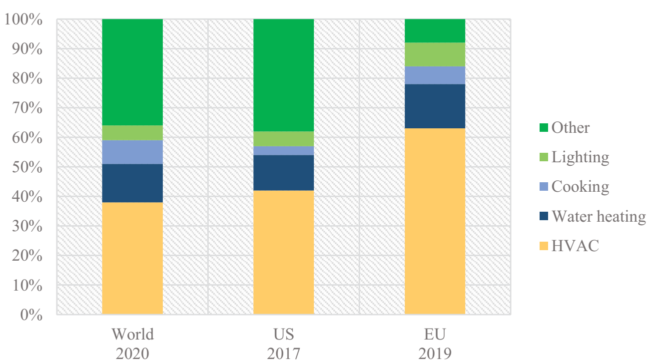


Fig. 4. Global share of buildings and construction by end-use [37,43,44].

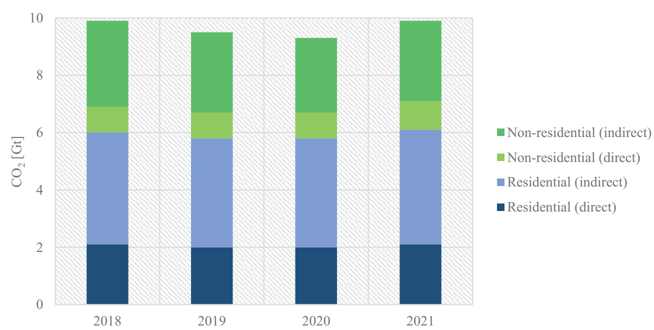


Fig. 5. Global buildings sector energy-related emissions by building type and indicator, 2018–2021. Direct emissions are those emitted from buildings, while indirect emissions are emissions from power generation for electricity and commercial heat [26,36].

other end-use of energy, it is typically only 10%–20% for a typical late 20th-century building [37,43,44]. Heat demand for hot water is rarely affected by performance improvements and becomes a significant part of demand in high-performance buildings. Hot water represents a significant energy demand, but the wastewater stream has an energetic value also [48], thus wastewater represents a concentrated source of heat.

Wastewater systems in residential and non-residential buildings are considered to be the systems with the highest rate of heat loss. Studies conducted in Switzerland showed that 15% of heat energy in residential buildings is lost through the wastewater system (Fig. 6). This heat loss could be even higher.

Water temperature plays a crucial role when considering the water-energy nexus [49].

3. Wastewater heat recovery in building

There are several options to recover wastewater heat: within houses/buildings (small-scale applications), from the sewer (medium-scale applications), or at wastewater treatment plants (large-scale applications), Fig. 7.

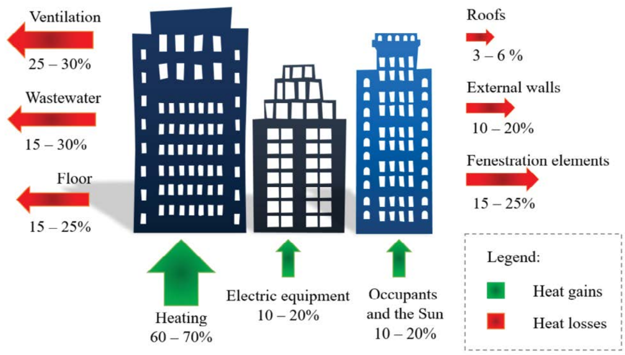


Fig. 6. Heat balance in residential building [19].

Choosing the most suitable location for heat recovery is a design choice based on specific project conditions. This paper analyzes heat recovery within buildings, and below, the factors that affect the potential of heat recovery in buildings will be analyzed.

3.1. Factors affecting heat recovery in buildings

Wastewater is a limited energy source, and its recovery potential is determined by the use of water in buildings. To fully utilize it as an energy source in buildings and to reduce energy consumption, CO_2 emissions and pollution, it is necessary to analyze the parameters that affect energy recovery. Based on the literature review, Fig. 8 presents the methodology for evaluating the effects of the potential of wastewater heat recovery in buildings.

A few steps for evaluating the effects of the potential of wastewater heat recovery in buildings are explained in this chapter, and other ones are explained in the next chapter.

Step 1: Determining the environmental impact of wastewater after the process of heat recovery on the wastewater treatment plant (WWTP)

The prerequisite for using wastewater in buildings to obtain heat is to check the impact of the wastewater after heat recovery on the wastewater drainage system and the operation of the WWTP. There is a limited number of papers dealing with wastewater characteristics after the process of heat recovery. These papers analyze wastewater temperature and its influence on the efficiency of biological and chemical wastewater treatment (nitrification). The rate of biological and chemical reactions in some elements of wastewater treatment is strongly dependent on temperature [51]. If the temperature of the wastewater drops too low, the limit values of the pollutant concentration in the treated wastewater can no longer be guaranteed. For this reason, in Switzerland, the daily average temperature

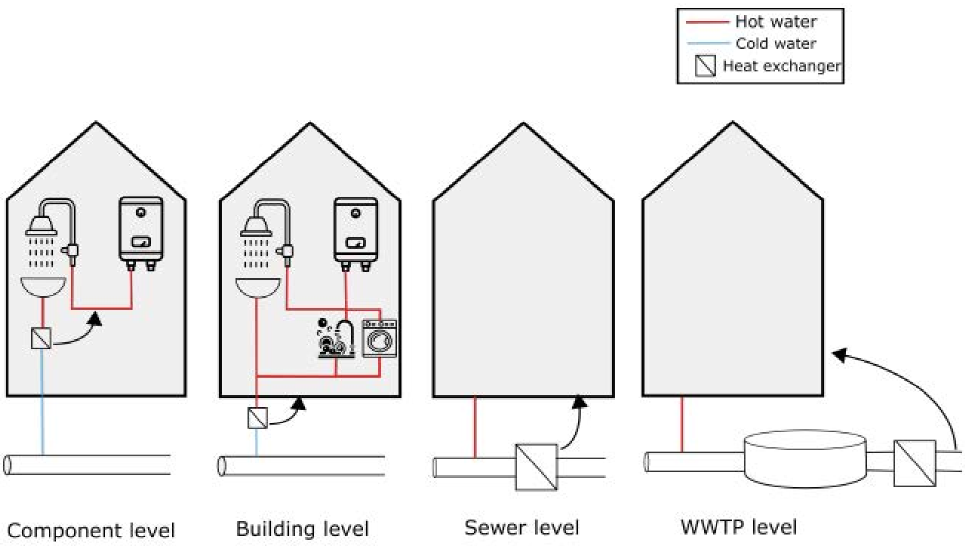


Fig. 7. Possibilities for energy recovery from wastewater [50].

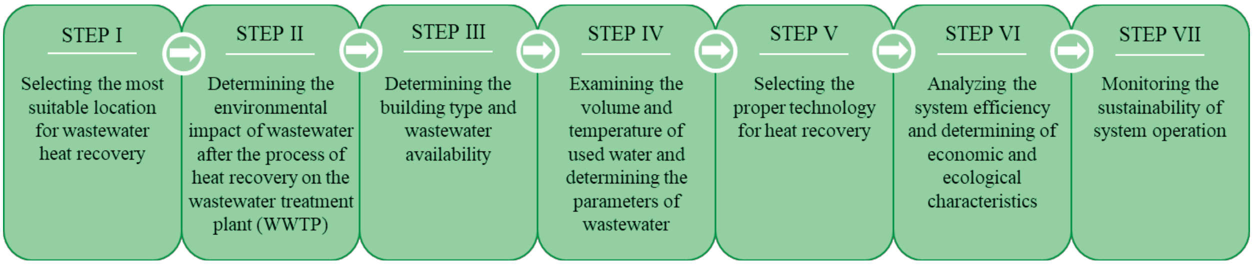


Fig. 8. Possibilities for energy recovery from wastewater.

of wastewater should not be lower than 10°C, and the total cooling should not be higher than 0.5 K [23].

Step 2: Determining the building type and wastewater availability

Hot water consumption, flow characteristics, and wastewater temperatures differ for different building types. In residential buildings, there are immense variations in the temperature and amount of wastewater flow on a daily, monthly and annual level. Thus, it is difficult to predict the possibility of thermal energy recovery [23]. For residential buildings, measurements and estimates are available from variety of studies dealing with wastewaters. Non-residential buildings have a higher potential for heat recovery because their wastewater volumes are higher. The possibilities for using heat recovery are concentrated in places where wastewater is both continuous and available in large quantities: buildings with large volumes of wastewater (hospitals, sports centers, public showers, schools, etc.).

Step 3: Examining the volume and temperature of used hot water and determining the parameters of wastewater

The amount of hot water consumed is entirely dependent on the human factor. The standard indicator used to describe water consumption is the average water consumption per person [47]. One of the most frequently used indicators in the world as a parameter of hot water consumption is the number of inhabitants in residential buildings or users in non-residential buildings. The consumer's water consumption pattern is related to work activities and habits, typically diurnal cyclical characteristics, an increase in temperature and flow in the morning and evening, with a decrease at night. This cyclical variation in temperature throughout the day means that the recovered heat would not have the same amount; therefore, heat recovery technology necessitates heat storage to compensate for variations in flow and temperature [47]. The household size, consumer number, the number of rooms, seasons, etc. affect water consumption. Therefore, the temperature, flow rate, frequency, and capacity of wastewater flow at a specific location depends on the consumer's water consumption pattern as well as seasonal and daily influence.

Regardless of the type of technology used for heat recovery, process design requires reliable information on hot water consumption as well as the wastewater characteristics. Appropriate input data must be generated or obtained from highly variable water use statistics [51].

For heat recovery, it is necessary to know the time of water consumption, wastewater generation, and its duration so that the recovery can be precisely modeled and analyzed during the year in residential and non-residential buildings. Analyzes of wastewater heat recovery potential have been conducted in Sweden, but the number of residential buildings covered by the study was limited, so the data are not nationally representative [12].

To determine the wastewater heat recovery potential, it is necessary to analyze:

- The end-use of water and its temperature;
- Flow rate and loading;
- Frequency and duration of hot water use.

Temperature and flow rate of wastewaters are closely related to the temperature and flow rate of end-use water. If end-use hot water data are available, then wastewater flow rate and temperature can be estimated. Domestic hot water consumption by end-use is described in Table 1.

Volumetric flow data for hot water end-uses in Europe are summarized for residential and non-residential buildings in Tables 2 and 3 (the only available data). For domestic hot water flows, a common value seems to be around 0.13–0.14 L/s for showers. For bathtubs, the volumetric flow rate depends on the volume considered. The volumetric flow rate of the sink is about 0.1 L/s, although lower and higher values are reported. The bathroom sink volume flow data shows the highest variance, with values between 0.03 and 0.1 L/s.

Similar tables can be found for the water use duration and frequency [5].

Obstacles limiting successful application of these technologies are the lack of data and scattered information indicating a wide range of values of key parameters, for example, flow, temperature, etc.

Impurities in the wastewater can also be an obstacle for effective heat recovery as they affect the quality of heat exchange process between the wastewater and the refrigerant used.

3.2. Review of wastewater heat recovery in buildings – technologies, examples, and benefits

3.2.1. Wastewater heat recovery technologies in buildings

Heat exchangers (HE) and heat pumps (HP) are used for wastewater heat recovery in buildings. Heat exchangers as passive heat recovery technologies are suitable for

Table 1
Domestic hot water consumption by end-use

End-use	Residential buildings				Non-residential buildings
	Water temperature (°C)				Water temperature (°C)
Sink/hand washing	40.06	60	–	60	60
Dishwasher	49	60	65	60	60
Shower	40.06	60	–	60	60
Bath	40.06		–		–
Washing machine	49	60		60	60
References	[52]	[5]	[53]	[54]	[54]

Table 2
Domestic domestic hot water volumetric flows, in L/s [5]

References	Koiv and Toode	Thorsen and Kristjansson	Schramek	Widen et al.	Blokker et al.	Neunteufel et al.	Neunteufel et al.	Gutierrez-Escolar et al.
Pub. year	2006	2006	2009	2010	2012	2012	2014	–
Country	Estonia	Denmark	Germany	Sweden	Netherlands	Austria	EU	Spain
Bathrooom sink	–	–	0.05/0.08	–	0.04	0.03	–	0.07, 0.1
Kitchen sink	0.2	0.1	0.1/0.17	39 L	0.08/0.13	0.03	–	0.1, 0.13
Shower	0.2	0.14	0.14	0.13/0.2	0.12, 0.14	0.13	–	0.17, 0.25
Bathtub	0.3	0.21	0.11/0.17	100 L/bat	0.2	76 L/bat	150 L/bat	250 L/bat

Table 3
Lodging domestic hot water volumetric flows, in L/s [5]

References	Koiv and Toode	Thorsen and Kristjansson
Pub. year	2005	2011
Country	Spain	Netherlands
Building type	Hotel	Hotel, nursering home
Bathrooom sink	15.26 L/d·guest	0.08
Showering	13.03 L/d·guest	0.12/0.14/0.37
Bath filling	–	0.2

pre-heating domestic hot water, and they are the most commonly used in residential construction [55]. Heat exchangers are used for transferring heat energy from warm media (wastewater) to a cooler (domestic water) in buildings. There are a number of wastewater heat exchanger available on the market for recovering wastewater heat [56]. There are four main types, available in the market: falling film tubular evaporator/gravity, concentric pipes, plates, shell and tube tank [24]. Heat exchangers can be orientated vertical or horizontal. Vertical heat exchangers are much more efficient compared to horizontal one. In horizontal exchangers, the fluid covers only half of the pipe circumference, while in vertical completely covers the pipe circumference, which results in lower efficiency of horizontal exchangers [24]. However, some type of vertical heat exchangers is not easy to use because of the lack of space [57].

In addition to heat exchangers, a wide variety of heat pumps are being developed for wastewater heat recovery in buildings [58]. Heat pumps are used to elevate a low-temperature heat source to a useful higher temperature [59]. There are various types of heat pumps with different efficiencies. Depending on the type of building (residential or non-residential) installed solution could be with or without a storage tank. On a building level wastewater is commonly collected in a storage tank, and heat is recovered using heat exchangers or a heat pump [50]. The main advantage of this system is a possible time gap between the production of wastewater and heat utilization. The storage tank is designed according to the wastewater flow in a drain pipe [60].

An option to reduce energy consumption in the building is to recover the heat from the various wastewater streams (in-building solution). In this regard, heat can be recovered at the component and building levels. At the level of individual components, heat is recovered immediately after the wastewater generation in specific activities in the operation of that component (showering, cooking, food processing, etc.). The heat exchanger recovers heat after the end-use of water consumption. Building-level heat recovery refers to the heat recovered from the collective discharge of wastewater from an entire building. The characteristics of the wastewater flow and the temperature of this discharge depend on the type of building. Energy savings at the building level can be higher than the level of individual components due to the consistent amount of wastewater and the accumulation of multiple hot water activities. Table 4 summarizes different wastewater heat recovery technologies in respect to components and buildings.

Heat is recovered through the use of heat exchangers and heat pumps [50].

At the level of residential buildings, due to the small volumes of wastewater flow and the high economic costs, heat pumps are not a viable option for heat recovery. Heat pump technology can be expensive and may not be financially suitable for single-family housing. Furthermore, wastewater flow is insufficient and contains too much variation within individual housing units to make such a system economically efficient [61].

It is feasible to use a heat pump in buildings with large amounts of wastewater discharge, such as public showers, sports centers, commercial kitchens, residential areas, etc. Over 500 wastewater heat pumps are operating worldwide [9]. A heat pump system that uses wastewater as a heat source enables the use of cheap electricity. The sewage water is cooled and discharged into the drain, while the extracted heat is used via a heat pump to prepare hot domestic water. The use of heat pumps has a colossal energy-saving effect [62]. But their use is suitable for non-residential buildings with a constant wastewater flow.

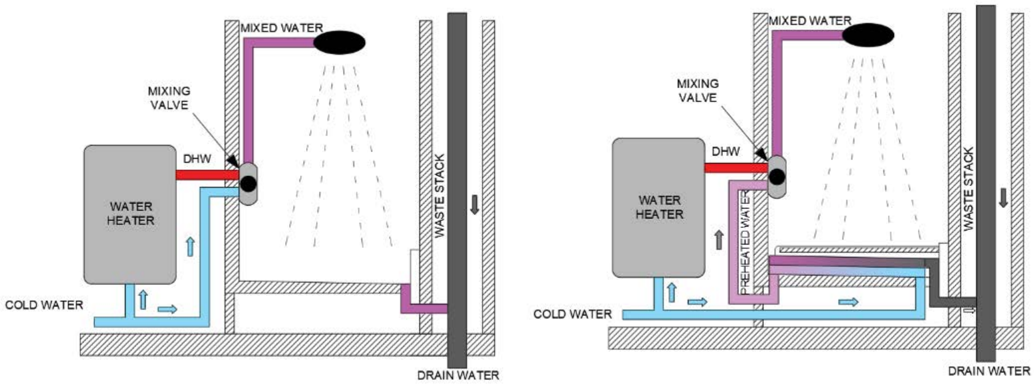
Heat exchangers are used for installations with a consistent amount of wastewater. A heat exchanger is a device that facilitates the process of heat exchange between two fluids that are at different temperatures. Usually, the fluids are separated by a heat transfer surface without mixing or crossing [25]. The heat exchanger is in direct contact with wastewater. The quality of wastewater has an influence on the contamination of heat exchangers. It is necessary to carry out analyzes on the influence of wastewater quality on the operation of the exchanger. When these devices are installed in sewers or within WWTP, the higher temperature recovery value is not utilized and is only available close to the point of use [62]. And, their use is suitable for wastewater heat recovery within residential and non-residential buildings.

A significant number of studies describe wastewater heat recovery during showering and the use of showers. Namely, with these systems, there is a continuous simultaneous flow of wastewater and the supply of cold water for showering. High efficiency can be achieved with these systems because there is no time lag between the available wastewater and the need for shower heat. In this way, the need for heat storage is eliminated, and thus the occurrence of losses is prevented [54]. In practice, heat exchangers are installed in a vertical configuration for the first floor and a horizontal configuration for the ground floor, Figs. 9 and 10.

Most research and technologies focus on showers although heat exchangers are equally useful to basins, sinks, dishwashers, and washing machines [24].

Table 4
Wastewater heat recovery technologies [54]

Technology	Scale	Characteristics
Vertical wastewater heat exchanger	Component	- Can be used for preheating shower water; - Higher space requirements; - Higher efficiency due to the higher contact surface area.
Horizontal wastewater heat exchanger	Component	- Suitable for preheating shower water; - Low space requirements; - Less efficient due to the lower contact surface area.
Heat exchanger with wastewater storage tank	Building	- Hot water is stored in the storage tank; - Higher cost of the device due to the additional storage tank; - More feasible with a heat pump.
Heat pump with heat exchanger	Building	- Higher energy recovery; - Less economic feasibility for individual dwellings.



(a) (b)

Fig. 9. Installation example of a heat exchanger mounted under the floor shower drain: (a) installation without and (b) installation with a shower heat exchanger (DHW—domestic hot water) [63].

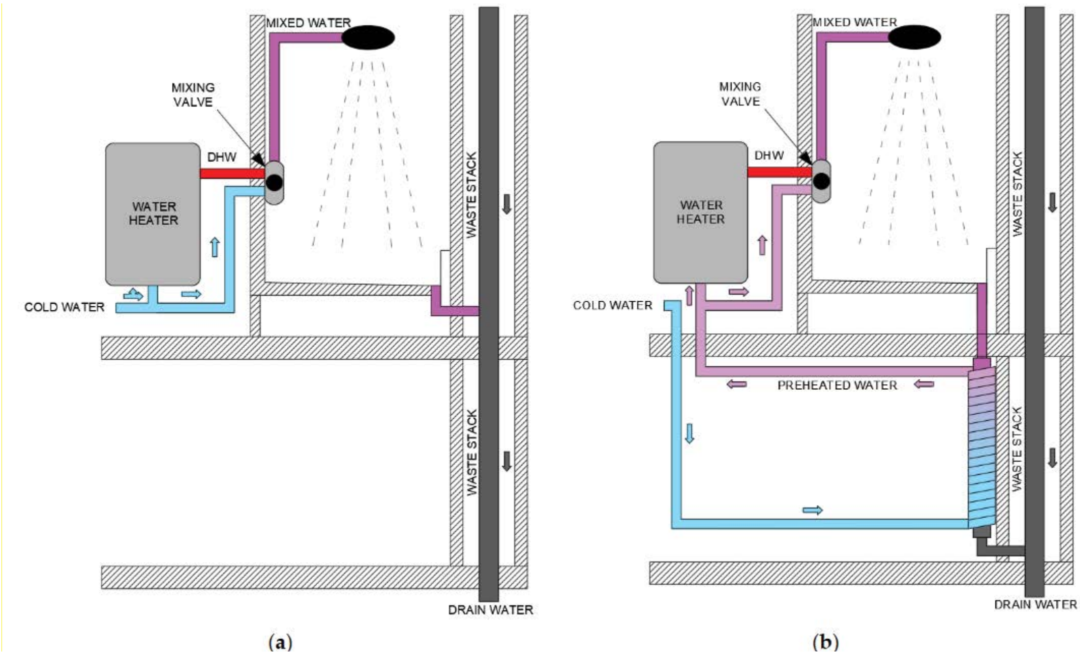


Fig. 10. Installation example of a vertical heat exchanger: (a) installation without and (b) installation with a shower heat exchanger (DHW—domestic hot water) [63].

There are three options for the connection of heat exchangers at the building level:

- Preheated water can flow to both the storage and appliance – the balanced condition;
- Preheated water flows only to the storage – unbalanced condition;
- Preheated water flows only to the appliance – balanced condition [24].

A combination of heat pump and heat exchanger is another option for heat recovery. The challenge for the coming years is to choose solutions of all possibilities to meet the demand for energy.

A brief review of the wastewater heat recovery technologies reported in the literature is given in a tabular form in Table 5 according to the type of buildings and technologies.

Tables 6 and 7 provide a literature overview on wastewater heat recovery technologies in residential and non-residential buildings. Tables present the data on possible energy savings and reduction of GHG by utilizing wastewater heat recovery technologies.

3.2.2. System efficiency, energy saving, and emission reduction potential

The primary benefit of harvesting energy from buried infrastructure lies in the provision of abundant low-carbon heat. As well as any financial benefit, this will come with more significant carbon emissions reductions [77].

To achieve the at least 55% European emissions reduction goals for 2030, the EU must reduce GHG in the building sector by 60% and thus the energy consumption of heating and cooling by 18% [78]. After the literature overview, wastewater heat recovery technologies were identified as a promising technology to unlock the potential in reducing emissions and increasing buildings energy efficiency.

The energy saving and emission reduction potential are mainly influenced by:

- Efficiency of heat exchanger device or heat pump;
- Hydraulic connection of heat exchanger;
- Wastewater temperatures;
- The constancy of wastewater flow.

The higher the flow rate of wastewater, the higher the efficiency and the higher the performance. Efficiency, as a percentage of energy gained, varies by technologies used up to 70% [27]. If heat pumps are used for wastewater heat recovery in buildings, it is possible to expect emissions reductions. Some studies demonstrated that the use of heat pumps in buildings obtained 3 times more thermal energy compared to the consumed electrical energy [79].

If every renovated or newly built building in Europe were to be equipped with wastewater heat recovery technologies starting in 2023, it could be expected to achieve 25% of 2030 goals in the warm water sector. If the total current building sector would be equipped with the described technologies by 2030, a significant consumption drop could be observed, and the energy conservation goals for hot water would be surpassed by wastewater heat recovery technologies only [80]. Wastewater heat recovery technologies could make a significant contribution to the 2030 goals by contributing 3.07% (1.54 Mtoe) to the final energy savings goals and 1.52% (4.20 Mt) to the GHG emissions saving goals (based on the assumption that half of the existing residential buildings and half of newly built dwellings will deploy these technologies by 2030) [27]. Using these technologies

Table 5
Review table of paper studied wastewater heat recovery in buildings

Type of building		Type of technology				References
Residential building	Non-residential building	Heat exchanger type		Heat pump	Heat pump with heat exchanger	
		Plate	Shell and tube tank			
	☑			☑		[64]
☑				☑		[65]
	☑				☑	[25]
☑		☑				[66]
☑			☑			[67]
☑			☑			[67]
	☑		☑			[67]
	☑		☑			[67]
☑			☑			[68]
☑			☑			[69]
☑					☑	[70]
	☑			☑		[71]

Table 6
Residential building wastewater heat recovery examples

Residential building examples					
Country	Building type	Technology	Energy analysis	Emissions analysis	References
Sweden	Multifamily house (141 apartments, one pre-school and two small stores)	HE	- Extrapolated annual heat recovery 16.26 MWh; - Heat recovery rate/meter heat exchanger 0.31 kW/m; - Heat recovery ratio 19%; - Average heat exchanger effectiveness 0.5.	–	[67]
Sweden	Multifamily house (300 student apartments)	HE	- Extrapolated annual heat recovery 39.59 MWh; - Heat recovery rate/meter heat exchanger 0.08 kW/m; - Heat recovery ratio 42%; - Average heat exchanger effectiveness 0.42.	–	[67]
–	Residential (Shower in the building)	HE	The heat exchangers efficiency is 8% for a flow of 8 L/min and shower temperature of 37°C.	–	[72]
–	Residential (Shower in the building)	HE	Analysis of a survey on the use of heat exchangers in showers.	–	[53]
–	Residential (Shower in the building)	HE	The shower water heating energy consumption can be reduced by approximately 16.13% and 24.69% by mounting the helical coil heat exchanger horizontally and vertically. The saving rates reach 20.62% and 27.34% for brazed plate heat exchanger.	–	[72]

GHG emissions related to domestic hot water and space heating in building can be reduced by 7.6% to 22% [81].

In France, the national energy efficiency standards recognize the contribution of wastewater heat recovery in buildings as a source of heat from renewables. In the Netherlands, these technologies are included in the calculation software for new construction projects as they have a positive bearing on the energy performance of a building. In the United Kingdom, these technologies are recognized as one of the most cost-effective available energy efficiency technologies, and under the new regulations, wastewater heat recovery technologies will have a bigger impact on the building sector [27].

The effectiveness, cost efficiency, and optimum payback are strongly dependent on several parameters:

- Cost of specific integration of wastewater heat recovery technologies into the building;
- Location and position of the wastewater heat recovery units;

Table 7
Non-residential building wastewater heat recovery examples

Non-residential building examples					
Country	Building type	Technology	Energy analysis	Emissions analysis	References
Germany Berlin	Swimming pool	HE	539 MWh/y of energy savings.	89 t/y of CO_2 reduction	[73]
Poland	Swimming pool	HP	Reduce the energy demand by 34% up to 67% for pool water preheating and domestic hot water.	Reduction of CO_2, NO_X, SO_X emissions and dust and ensure a significant reduction of these pollutants in range of 34% to 48%.	[74]
Switzerland	Burgerbad is the biggest alpine thermal spa in Europe	HE	Energy recovered: approx. 450 kW.	–	[75]
Serbia	Hotel	HP	100% of energy provided for heating sanitary water. Besides, it enables the possibility of central heating of the building in the transitional period, as well as 100% of the energy needed for air conditioning (cooling).	–	[76]
Sweden	Commercial building with a rentable area (offices, hotel, and a supermarket)	HE	- Extrapolated annual heat recovery 13.10 MWh; - Heat recovery rate/meter heat exchanger 0.12 kW/m; - Heat recovery ratio 32%; - Average heat exchanger effectiveness 0.74.	–	[67]
Sweden	Commercial building with a rentable area (offices and five restaurants)	HE	- Extrapolated annual heat recovery 106.29 MWh; - Heat recovery rate/meter heat exchanger 1.01 kW/m; - Heat recovery ratio 38%; - Average heat exchanger effectiveness 0.41.	–	[67]

- Distance of heat exchanger/heat pump from the heat recovery point;
- Price of electricity/gas.

Table 8 compares advantages and disadvantages of performing in building wastewater heat recovery.

Additional benefits of using wastewater heat recovery technologies in buildings are:

- No behavioral change: the wastewater heat recovery technology works due to basic physical processes and does not require any interaction with the end-user and does not need any complex control system [82];
- No loss of comfort: because wastewater heat recovery doesn't have any impact on the flow or the desired temperature, the end-user doesn't have any loss of comfort [82];
- Constancy: the temperature and the amount of wastewater are almost consistent throughout the year, regardless of the atmospheric conditions making the system predictable and reliable [24];
- Wastewater heat recovery potential is quite significant, especially in commercial buildings [24];
- Wastewater heat recovery units (heat exchangers and heat pumps): units are diverse and can be efficiently integrated into conventional plumbing systems; most wastewater heat units have passive technologies, limiting maintenance and operational costs; these units extend the life of domestic water heaters, as their usage decreases [83];
- Reducing running costs: the system can be designed smaller [27];
- Circular construction: systems have a long lifespan and contain easy-to-recycle and highly recycled materials (copper, stainless steel) [82];
- Real-time production: the recovery and generation of energy adapt continuously and in real-time with the usage, without over or under-production (no storage and control system necessary) [82];

Table 8
Advantages and disadvantages of performing in building wastewater heat recovery [72]

Advantages	Disadvantages
- High water temperature - Short heat transport (Low losses) - Producers = Consumers - No impact from supplement water	- High fluctuations - Difficult to match peak demand - Decentralized system, high operative expenses

- Aesthetics: systems can be hidden [82];
- Societal benefit (employment): innovative manufacturing companies of wastewater heat recovery units are based in the EU, and it is expected that by 2025 direct employment in France alone may reach 1,000 persons. More importantly, the installation of these units in both new build and renovation sectors requires a local workforce [27].

Wastewater heat recovery technologies also have disadvantages. These include the capital expenditures linked with the cost of purchasing a heat exchanger and/or heat pump. Disadvantages of technologies also include possible significant fluctuations in the temperature and flow rates of the warm medium. During a year differences in the temperature of wastewater may exceed 10°C, which poses a technological challenge and may reduce the effectiveness of an installation [84]. Heat exchangers may be a maintenance-free and cost-effective solution within a multi-dwelling building, but the inconstant user behavior still limits their efficiency [80].

4. Conclusion

To achieve a more sustainable world, one of the significant factor is energy recovery from otherwise wasted sources. Wastewater contains a large amount of thermal energy, which can be recovered at various points in the water cycle and used to reduce heating needs. The use of wastewater heat recovery is environmentally and economically acceptable due to the reduction of heat emissions into the environment, lower energy consumption, and lower operating costs. Although the potential, concept, and motivation exist, wastewater heat recovery systems are yet to be a component of every building. The purpose of this paper was to provide an overview of wastewater heat recovery in buildings and present the main factors affecting wastewater heat recovery, as well as the potential for reducing energy consumption and pollution coming from the building sector. Thermal energy is extracted using heat exchangers and heat pumps. The ability to correctly select the type of technology for wastewater heat recovery in a building improves the efficiency of wastewater heat recovery, as well as a potential to reduce energy consumption and GHG emissions. At the level of residential buildings, due to the small volumes of wastewater flow and the high economic costs, heat pumps are not a viable option for heat recovery, but they are suitable for use in non-residential buildings. Non-residential buildings that generate a large amount of wastewater hold significant potential for wastewater heat recovery, and as a result, more research should be dedicated in this direction. From an environmental point of view, the coverage of the thermal energy of wastewater results in the reduction of CO_2, NO_X, and SO_X emissions in the range of 34% to 48%. Also, wastewater heat recovery technologies could make a significant contribution to the 2030 goals by contributing 3.07% towards the final energy savings goals and 1.52% towards the GHG emissions saving goals.

To encourage wastewater heat recovery in buildings, governments of countries and regions can introduce wastewater heat recovery in their respective building codes and guidelines aimed at improving energy efficiency and reducing energy consumption and emissions.

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