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T6614KA

# USAGE OF WASTEWATERS AS A HEAT SOURCE FOR A HEAT PUMP OPERATION

Bachelor's Thesis
Building Services Engineering

October 2016

MAMK
University of Applied Sciences

# DESCRIPTION

MAMK
University of Applied Sciences

**Date of the bachelor's thesis**

October 2016

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**Degree programme and option**

Double Degree Programme in Building Services Engineering

**Name of the bachelor's thesis**

Usage of wastewaters as a heat source for a heat pump operation

**Abstract**

A significant improvement in economic and environmental performance of production thermal energy can be achieved by using heat pumps. Whereas ground waters, an air and a ground itself are well-known and explored heat sources, the heat that residents return to the ground with sewage remains mostly unused. Meanwhile, sewages possess necessary characteristics (such as relatively high temperatures, widespread availability and an absence of necessity in costly drilling works) to serve as a low-potential heat source. Investigated technologies are interesting for a large number of customers: from the private-house owners, who use local treatment facilities, to the water treatment plants. Difference in initial conditions such as effluents temperatures, their flow rates and quality leads to variety of technical decisions.

The main aim of submitted thesis is to estimate the potential of utilizing wastewater as a source of low-potential heat for the heat pump operation in scale of a one-family house. The thesis starts with a technical review of existing technologies, which is based on results of the literature analysis. In the practical part, the feasibility analysis of implementation the wastewater source heat pump system for heating and hot water preparing systems in a one-family house is performed. Calculated and compared values of thermal energy that could be extracted from effluents by heat exchanger and the energy demand of heating and hot water systems in the building. Performed a simulation of heat pump operation with use of CoolPack program. Its results demonstrate which part of required low-potential heat could be obtained from sewage. Finally, assessed an energy efficiency of proposed wastewater source heat pump system and its economic validity.

Obtained results indicate that wastewater can be considered only as an additional source of low-grade heat for a heat pump operation into a heating mode in scale of a one-family house. The main precondition is unevenness of water use. Meanwhile, the heat of sewage is sufficient for preparing hot water for domestic use (with a heat pump application). Evaluation of the payback period of the proposed sewage source heat pump system revealed the inexpediency of its application in case of existing connection to the gas pipeline. From the standpoint of energy efficiency, the heat pump system proved to be the most efficient converter of primary fuel energy (with using natural gas as the main fuel on the power station).

**Subject headings, (keywords)**

Heat recovery, heat pump, sewage, energy efficiency, primary energy

| **Pages** | **Language** | **URN** |
|---|---|---|
| 45 | English | |

**Remarks, notes on appendices**

**Tutor**

Jukka Raisa

**Bachelor’s thesis assigned by**

## CONTENTS

# 1 INTRODUCTION

An energy efficiency is one of the most crucial factors for HVAC (Heating, Ventilation and Air Conditioning) designers nowadays. An integrated approach to the system's design minimizes an energy consumption, reduces customer's operation expenses and usually have a positive effect to ecology by reducing the greenhouse gas emission. An integrated approach means implementation of an optimal set of measures for reduction the energy consumption of a building after an assessment of their collaborative impact.

Heating supply represents the biggest share of input energy in residential buildings. In Russia the 40% of utilized energy sources have being spent on the production of thermal energy /1, p.20/. While the share of centralized heat sources (CHP plants and large boiler houses) in Russia is 72%, the thermal losses in branching networks exceed 20% of the total thermal energy generation /1, p.21/. Wide spreading of the fossil fuel consumption is predicated by its accessibility. However, since the natural resources are finite, its wasteful use is careless. The transition to renewable energy sources must precede economic preconditions. Moreover, since the average level of gasification in Russia is only 65,4% (by 2014) /2/, there is a significant potential of development and implementation of autonomous heating systems using renewable energy sources in non-gasified regions.

A significant improvement in the economic and environmental performance of production the thermal energy can be achieved by using heat pumps (HP). The technology of utilization a low potential heat is widely implemented for the heating and cooling supply in developed countries. The submitted thesis aims to study a HP system using wastewater as a heat source. Whereas ground waters, an air and a ground itself are well-known and explored heat sources, the heat that residents return to the ground with sewage remains mostly unused. In the meantime, sewages possess necessary characteristics to become a heat source, and they are situated nearby the possible consumer. Considered technologies are interesting for a large number of customers: from the private-house owners, who use local treatment facilities, to the water treatment plants. Difference in initial conditions such as effluent temperatures, their flow rates and quality, leads to the variety of technical decisions.

Independent from boundary conditions, the heat of sewage should not be wasted. An implementation of wastewater source heat pump systems (WSHPS) is a promising measure to improve the energy efficiency of the building.

## 2 AIM AND METHODS

The main aim of this thesis is to estimate the potential of utilizing wastewater as a source of low-potential heat for the heat pump operation.

The thesis starts with a technical review of existing technologies, which is based on results of literature analysis. This part highlights the specific of utilizing sewage as a heat source. The following issues are covered:

- Difference in technical decisions depending on initial sewage characteristics (temperature, flow rate).
- Existing heat exchangers, their classification.
- Difficulties in the heat extraction from sewage and their relevant solutions.
- International experience in applying wastewater source heat pump systems.

In the second, practical part of the submitted thesis the feasibility analysis of implementation the WSHPS in scale of a one-family house is performed. Considering an unevenness of the main characteristics, the gross energy potential of the sewage is estimated, as well as the required power of the heating and hot water preparing systems. Furthermore, the simulation of heat pump operation is performed with use of the CoolPack program. Results of the simulations estimate the possibility of replacing traditional solutions for heating and hot water preparing systems by the proposed WSHPS. Eventually, an energy efficiency of proposed system is assessed, as well as its economic validity.

## 3 FEATURES OF SEWAGE-SOURCE HEAT PUMP SYSTEMS

### 3.1 Overview of the sewage heat recovery

Heating supply represents the biggest share of energy consumption in residential buildings /3/. Studies conducted in Switzerland /4/ report that the improving of buildings insulation and the reduction of energy consumption lead to increase the percentage of thermal energy lost through sewers from 15% to 30%. Taking into account that a quarter of global greenhouse gas emissions nowadays are generated due to burning fossil fuels for needs of power and heating supply /5/, the importance of the regeneration of wastewaters thermal energy is incontestable.

Secondary energy resources (such as ventilation emissions, sewage, waste heat of technological processes and etc.) are present on any residential or industrial facility, and disposal of their heat does not require additional geological surveys or drilling, the possibility of recycling heat contained therein should be considered as a possible measure to improve an energy efficiency of the building. The use of selected interventions is possible in the course of reconstruction, planned or major repair of the building.

Nowadays, heat contained in sewage is usually wasted. Meanwhile, it possesses advantages that make it a good source of low-potential heat for the heat pump system. The temperature of sewage is positive, commonly available and has high values (15-35°C depending on the point of extraction /6/). The heat pump in the meantime is characterized by the Coefficient of Performance (COP). COP is a ratio of the amount of generated high-potential thermal power (Ø, kW), gained from condenser, to the applied mechanical power (P, kW). Ideal lossless cycle of a vapor-compression heat pump is represented by the reverse Carnot cycle. The COP of that process depends only on absolute (unit is K) condensing and evaporation temperatures (T1 and T2). The COP of a real process is estimated considering the refrigerant properties and the quality factor of the compressor, which are included into the total Carnot efficiency ($\eta_{Ct}$). Thereby, the COP of a real process is:

$$\mathrm{COP} = \eta_{\mathrm{C}t} \cdot \frac{T_1}{(T_1 - T_2)} \tag{1}$$

where COP – Coefficient of Performance of a real process;
$\eta_{\mathrm{C}t}$ – total Carnot efficiency;
$T_1$ – condensing temperature [K];
$T_2$ – evaporating temperature [K].

The smaller the temperature difference between the low-grade heat source and the consumer's desired parameter, the higher the COP of the vapor-compression heat pump. In

/7/ authors demonstrate that with the temperature rise onto +2°C the COP increases on about 0,3. The temperatures convergence could be reached by implementing modern heating systems (with a preliminary improvement of structures thermal insulation). Thus, for modern floor heating systems design temperatures are 25..35°C, while traditional heating systems require coolant heating up to 70..100 °C /8, p.2/.

Since heat pumps are the most expensive equipment in the heat pump heat recovery system, it is advisable to pick up its power to the magnitude of the base load of the heating system. It ensures the maximum use of energy-saving equipment and stabilizes its operation modes. Furthermore, it is advisable to combine different types of sources in the system of low-grade heat collection. This contributes to the permanent security of the evaporator with thermal energy. Especially in case of utilizing heat of unstable source (as the sewage is), the use of hybrid heat pumps are the most promising. To cover peak loads the traditional sources of thermal energy could be used.

It should be noted that utilization of secondary energy resource's heat usually does not act as a complete replacement to traditional heating sources such as central heating or gas boiler in a private house. It is reasonable to take the decision to use heat pump systems in terms of technical and economic comparison of different options. The need for this justification is spelled out in the current regulations /9/.

The main design parameters of sewage source heat pump systems are the flow rate and the temperature of wastewater. The availability of reliable knowledge of these indicators is necessary for proper design of the system because they affect the performance and related costs /10, p.291/. The diurnal and seasonal fluctuations of these parameters are the main disadvantages of this source.

It is also worth to consider that the thermophysical parameters of wastewater before and after treatment are different. Untreated wastewaters have a higher temperature, and their possible source is situated closer to the possible consumer. It minimizes the length of transmission networks and thermal losses, in accordance. However, for the disposing of their heat problems of pipelines clogging and the fouling of heat exchanging surfaces have to be solved. Due to the wide variety of initial parameters, there are a big range of heat exchangers. Appropriate selection of heat extraction equipment significantly affects the whole system efficiency. Aspects of heat recycling from sewages are discussed more thoroughly in further subsections.

## 3.2 Technical decisions

Different operation modes of heat pump systems are illustrated on the Figure 1. Depending on the presence of supplemental heating sources, operation modes can be monovalent, bivalent and multivalent. In first case, the only HP meets all required thermal load of the building for heating or/and domestic hot water (DHW) systems. Being bivalent, the system contains the other heating equipment, which may as share the heat demand with a heat pump (parallel mode), as being used as an alternative heat source, when the heat pump cannot be used for some reasons (alternative mode). Whereas, the heating system called multivalent/monoenergetic presumes that an additional electric heater serves for increasing of the heated water temperature. At that, an important factor is an accurate design, so that an additional electric heater consumes power as little as possible. /11, p.6./

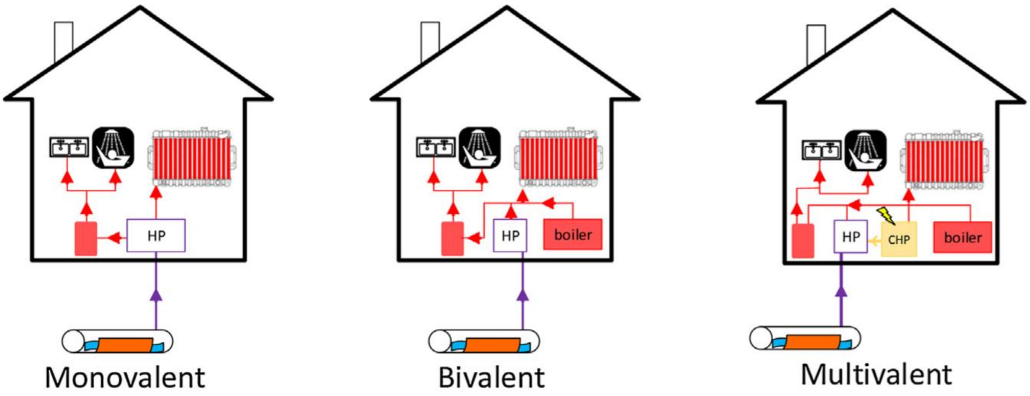


**FIGURE 1. Heat pump heating systems operation modes /12, p.216/**

Technical solutions to remove the heat embedded in the wastewater are different depending on the scale of the object. The following variants for recovering this heat can be highlighted: within houses (small scale applications), from the sewer (medium scale applications) and at wastewater treatment plants (large scale applications) /10, p.288/. Figure 2 illustrates the difference. Each case is specific.

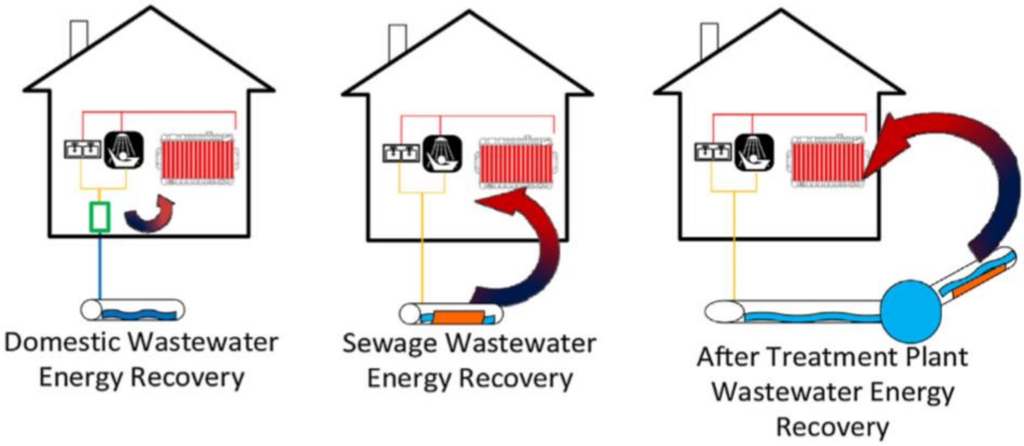


**FIGURE 2. Different locations of the heat extraction for the WWHPS /12, p.223/**

**Domestic utilization.** In this case, the flow and temperature of effluents are most exposed to daily fluctuations that determines the use of storage tanks. Due to the proximity to the source, the temperature of sewage is maximum. Heat losses during heat transfer to the HP are minimized. The scheme of a heat extraction system is simplified, hence the cost of a system is smaller. Depending on the heat exchanger, flows may be subjected to primary purification. Heat of the cleanest waste waters (from showers, washing machines and so one) via heat exchangers can be used to heat the incoming cold water without using the heat pump.

**Utilization from sewer** is characterized by continuously available sufficient quantity of wastewaters /12, p.218/, lower temperatures, along with the possible impact of rain and melt water in case of mixed drainage. Larger flow allows to supply heat to several buildings. Heat extraction requires greater interventions and, consequently, larger initial investment. In addition, the sewage temperature after heat extraction is limited by the value acceptable for a water treatment plant. Purification occurring there is based on bacterial activity and requires certain temperatures. If the temperature of the effluent is initially not high enough, the extraction of heat should be prevented.

**Downstream of the wastewater treatment plant** the effluents temperature is minimal. However, it can be maximally utilized. Unlike the previous case, lowering of the effluents temperature is favorable, since they are discharged into water bodies, the temperature of which is usually lower than the temperature of the effluent. Decreasing of the impact on the water bodies' thermal regime is even desirable for its fauna. The lower the water temperature, the higher the value of the solubility of oxygen in it. The flow rate on wastewater treatment plant is maximum and fluctuate minimally. There is no problem of the heat exchangers' fouling. The drawback of this source is that the plants are usually remote from the residential area, and therefore heat generated there is most effective can be used on place. If the station is located near the residential area, this heat recovery method is preferable.

## 3.3 Heat exchangers

Heat exchangers are generally grouped into two categories: direct (wastewater transfer heat directly to a refrigerant) and indirect (with an intermediate loop of recirculating water). As well, they can be grouped by the place of heat extraction.

**Effluents' heat utilization inside a house** can be performed to preheat cold water without heat pumps application. For this purpose heat exchangers shown on Figure 3 (a, b) are used. Heated water either flows directly to a mixer tap (with a thermostatic regulator), or fill up a storage water heater, thereby reducing its power consumption. These heat exchangers are suitable for flows from sanitary equipment. /13, p.83-84./

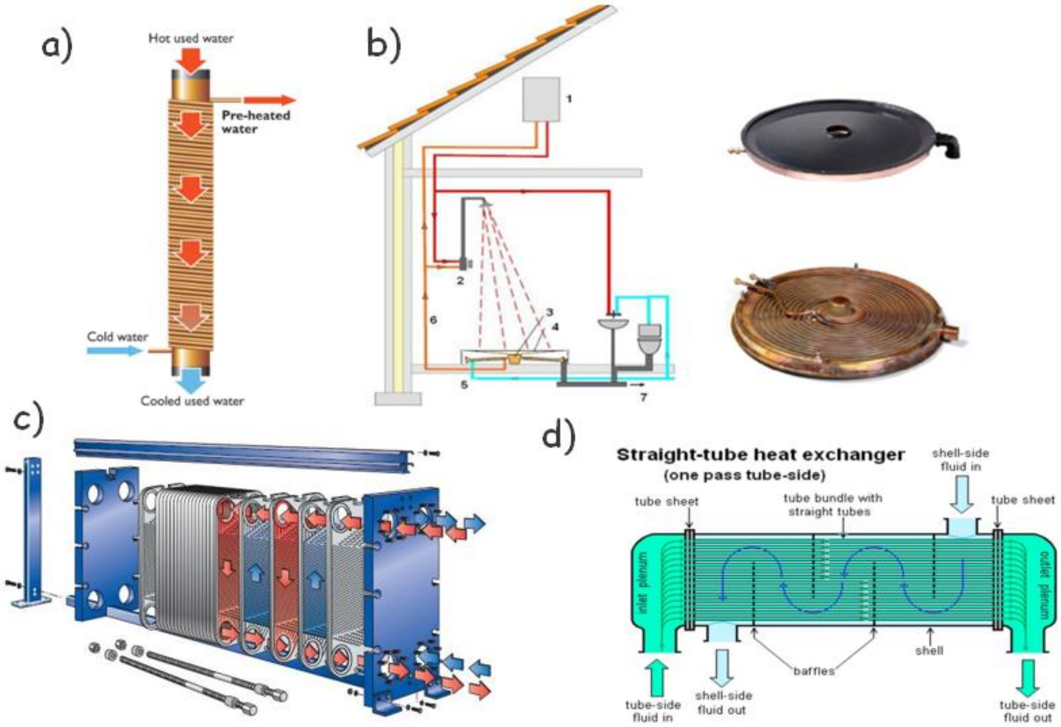


**FIGURE 3. Domestically utilized heat exchangers: a) gravity-film; b) spiral HE integrated into shower tray; c) plate; d) shell-and-tube /13, 14/**

For application of a heat pump, the constant flow of low-potential heat source is required. For this reason, the sewage arising from buildings is usually collected in a retention volume. The choice of heat exchanger is predefined by flow’s contamination. Thus, plate and shell-and-tube heat exchangers (Fig.3, c, d) identifiable by more intense heat exchange are used for liquids with low solid content. Thereby, the cleaning device should be added to the system. There are heat exchangers with built-in cleaning mechanisms (Fig. 4, a). The sewage flows through a coarse filter into a container with a defined retention volume, where the heat exchanger (cylindrical or flat) is pre-installed. The variant not requiring the prior filtering is a double-pipe heat exchanger (Fig.4, b). However, it is instantaneous, not cumulative. Figure 4 (d) illustrates a variant of its use with a storage tank. Meanwhile, helical models (Fig.4, c) can be immersed directly into a retention volume, but do not have high efficiency due to low liquids velocity.

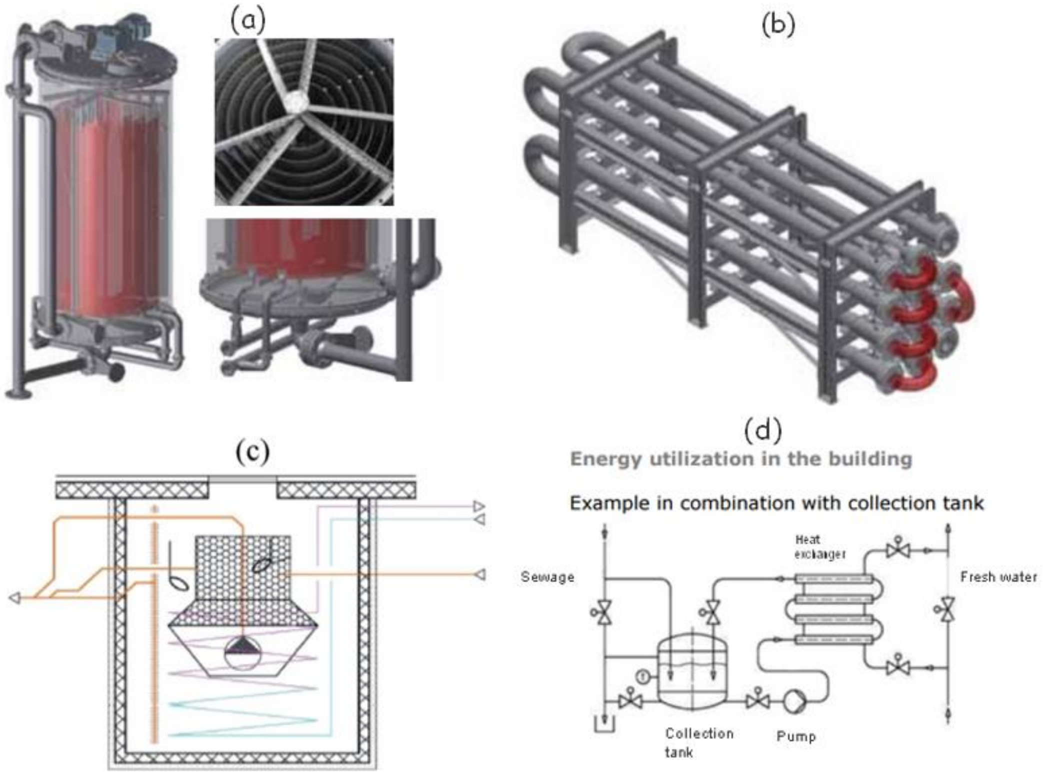


**FIGURE 4. Domestically utilized heat exchangers: a) cylindrical cleanable (provided by KASAG); b) double-pipe (by KASAG); c) immersed helical; d) example of energy utilization in combination with a collection tank /12, 15/**

In case of **heat extraction from the sewage collector**, a heat exchange can occur either “in-sewer’, or with a by-passed flow in the adjacent well/special device located above-ground. Heat exchangers for sewer heat recovery systems could be subcategorized as listed below:

1. “In-sewer”:
    a. In the casing;
    b. Embedded in the bottom of the sewer;
    c. As a casing;
    d. Internally.
2. External heat exchange with diverted previously filtered wastewaters.

**1.a.** ***«In the casing»*** implies that the sewage channel is surrounded with the thermal insulated jacket where piping distribution system is situated. Location of the pipes depends on whether the manifold is pressurized or not (before or after Wastewater Pumping Station). More heat is extracted from the pipes with bigger diameters and length. Figure 5 illustrates described heat exchangers.

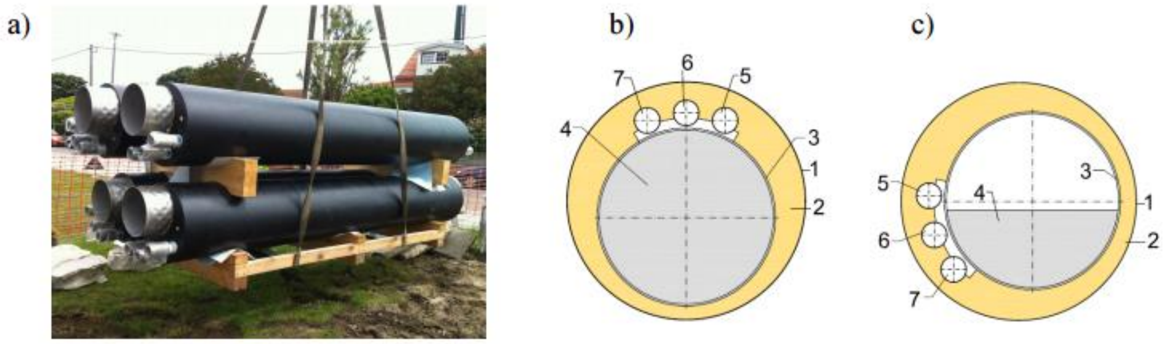


**FIGURE 5. Sewage pipe with special double jacket: a) prior to installation, b) pressure system, c) gravity system; 1 - outer jacket from polyethylene, 2 - heat insulation, 3 – sewage pipeline (heat exchanger), 4 - waste water, 5 - cold water supply to the heat exchanger, 6 - supply, 7 - output of the heated water from the heat exchanger /13, p.82/**

**1.b.** Heat exchangers ***embedded in the bottom of the sewer*** are mostly applied to new-build sewage lines, being a prefabricated component. Moreover, they could be installed in existent concrete, cast iron or plastic sewer. The distribution pipes are integrated in the walls. Such location complicates the accessibility for inspections. However, the stated minimum life span of the heat exchanger is 50 years. There are special requirements from the manufacturer (Rabtherm): minimum quantity of wastewaters should be in average 12 l/s; heat exchanger length is minimum 9 m, maximum 200 m /16/. The preliminary treating of the sewage is unnecessary due to the patented (Rabtherm) anti-fouling surface. Figure 6 illustrates heat exchangers.

**FIGURE 6. Integrated heat exchangers (Provided by Rabtherm) /16/**

**1.c.** The Profile Sewer System Thermpipe (PKS-Thermpipe) is a polyethylene pipe surrounded by circumferential loops. Heat transfer agent passing through ***the casing*** transfers heat from wastewater and surrounding soil to the boiler or heat pump. Polyethylene material provides greater durability than concrete pipe alternatives. Moreover, it allows to extract the heat from the surrounding soils; that makes the system less dependent on irregular wastewater discharges. The standard lengths of pipes is 20 feet (approximately 6 meters). Ideally, the dry weather wastewater flow should be minimum 240 gpm (approximately 18 l/s). However, the system can operate during lower flows due to ability of drawing heat from the surrounding soil. /17, p.12./ Figure 7 schematically demonstrates the heat exchanger.

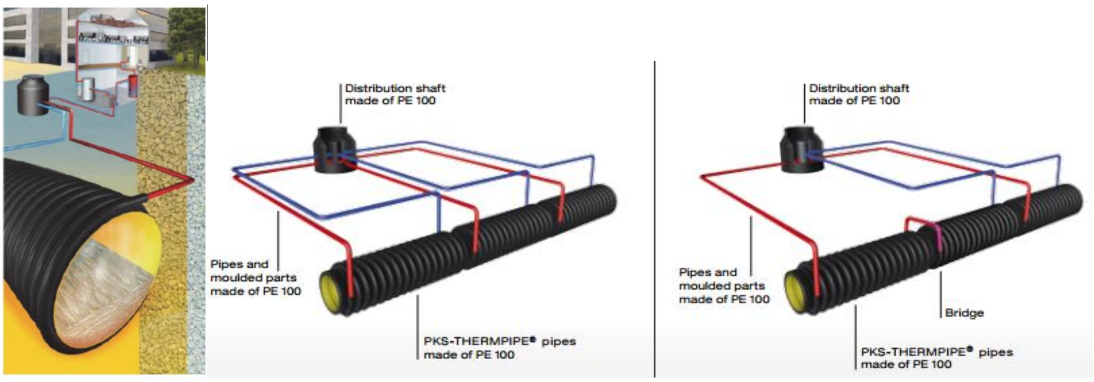


**FIGURE 7. Schematic of PKS-Thermpipe Heat Exchanger /17, p.12/**

**1.d.** Likewise, heat exchangers could be installed ***inside*** the existing sewage channel. They are designed according initial parameters of the channel such as cross-section, shape, flow quality and quantity of the sewage. The performance varies between 3,2 and 5,3 kW/m for the pipe diameters 1200 and 2000 mm respectively (KASAG manufactured). Distribution pipes located above the heat exchanger provide heat transmission to a heat pump. The cross sectional area is reduced. The bigger the diameter, the smaller the reduction. With applying of a TubeWin System provided by HUBER the reduction will be 2-15% /17, p.10/. The technology is relatively new, thereat there is a lack of information about a long-term use. Figure 8 illustrates a described heat exchanger manufactured by KASAG and Huber.

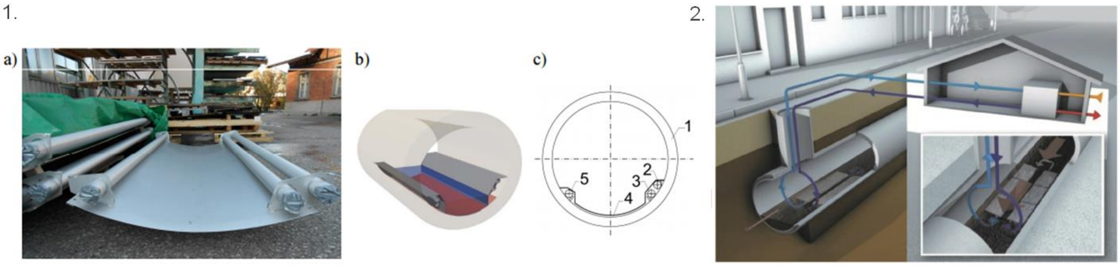


**FIGURE 8. 1. Stainless steel heat exchanger placed in the bottom of the sewage pipeline (Provided by KASAG): a) prior the installation; b) heat exchanger in the sewage pipe; c) cross-section; 1 – sewage pipeline, 2 – cold water supply to the heat exchanger, 3- supply, 4 – heat exchanger, 5 – output of the heated water from the heat exchanger /15/. 2. Schematic drawing of TubeWin System (Provided by Huber) /17, p.9/**

**2.a.** So-called ***“wet well” modular systems*** remove wastewater from the sewer to carry out their primary cleaning, and then pass through a heat exchanger. In HUBER ThermoWin system, screened wastewaters are pumped through the stainless steel tank, where the heat is exchanged with clean water in the tubes. Periodic cleaning for the biofouling prevention is performed automatically by a pre-built wiper system of the heat exchanger. An automation cleaning reduces maintenance costs, but wipers are recommended to be changed every 2 to 5 years. Required dry weather flow should be minimum 12,6 l/s. /17, p.7./ Figure 9 illustrates the schematic drawing of the described system provided by Huber.

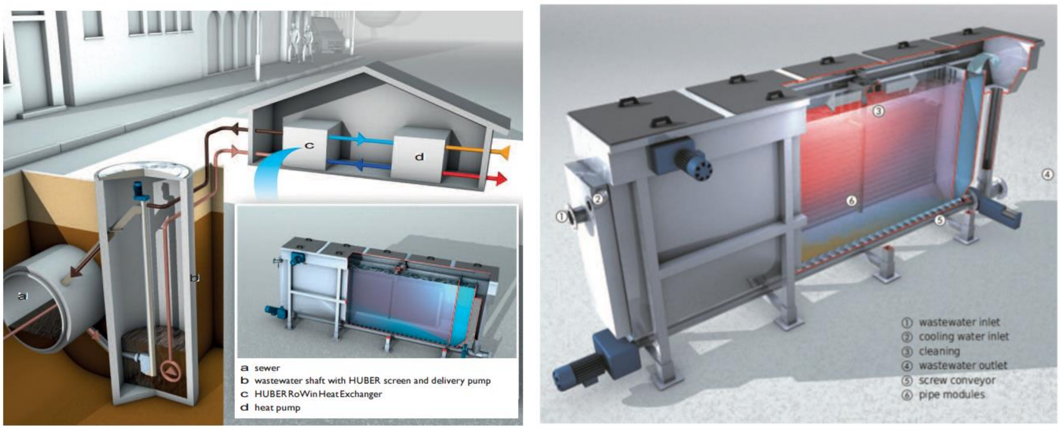


**FIGURE 9. HUBER ThermoWin system for the recovery of energy from wastewater (right), Schematic drawing of RoWin heat exchanger (left) (by Huber) /18, 17/**

**2.a.** Another pre-engineered packaged sewage heat recovery equipment that contains cleaning facilities is a SHARC system (produced by International Wastewater Systems). The SHARC system screens wastewater in a wet well adjacent to the sewer, and performs the heat exchange in the facility installed near the sewer /17, p.8/. Typical places of application of this technology are commercial buildings, multi-unit residential developments and industrial facilities.

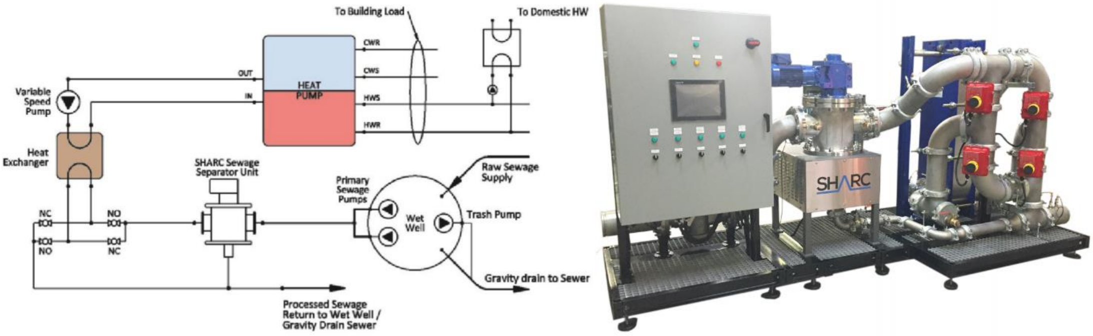
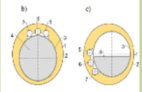
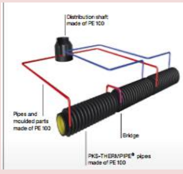
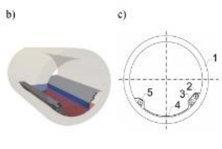
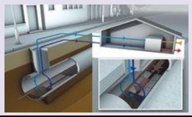


**FIGURE 10. Schematic of a typical SHARC System (left) and a real equipment (right) /17, p.8/**

Table 1 represented on the next page contains main characteristics of described heat exchangers suitable for Sewage Wastewater Heat Recovery. Data are taken from technical brochures of manufacturers. General requirements for implementing these equipment are:

1) minimum flow is 5-10 l/s;
2) distance to the customer < 500 m.

**TABLE 1. Characteristics of sewer heat exchangers**

| | Manufacturer, Model | Material | Performance | D, mm | Min q, l/s | +/- | Features |
|---|---|---|---|---|---|---|---|
| 1. “In-sewer” HE | | | | | | | |
| a. In a casing | KASAG Gravitytube<br><br> | Stainless steel, PE casing | 0,6-3,2 kW/m | 200-1200 | 10 | - | Segment length 2-6 m;<br>Sewage t > +13°C |
| b. Embedded in the bottom of the sewer | Rabtherm<br> | Surface of chromium ferritic steel | 2-5 kW/m$^2$ | > 800 | 12 | + applicated since 2000<br>+ claimed the life of 50 years | For new & existing sewers (cast iron, concret, plastic);<br>Max distance to a consumer 200 m;<br>patented surface preventing the biofilm formation |
| c. As a casing | FRANK, PKS-Thermpipe<br><br> | PE | 0,35-1,81 kW/m | 300-1800 | 15 | + high durability<br>+ claimed the life of 50 years | Heat exchange with the ground;<br>6 m segments;<br>From a point of extraction to a consumer 100-500 m |
| d. Internal HE | KASAG<br><br> | Stainless steel, PE | 3,2-5,3 kW/m | 1200 - 2000 | 10 | + section shape doesn’t matter, - 2-15% reduction of the cross-section | Suitable for any cross-section;<br>Segment 1-3 m;<br>Sewage t > +13°C |
| | HUBER, TubeWin<br> | Stainless steel | - | ОТ 1000 | 5 | + section shape doesn’t matter, - new enough | Min heat extraction 20 kW |
| 2. External HE | | | | | | | |
| a. Modular in a well | HUBER, ThermWin<br> | - | - | > 900 | 5 | - scrapes replacement every 2-5 years, + doesn’t require the sewer replacement | RoWIN HE locates in a special underground heat point |
| b. Modular | IWS, SHARC | - | - | - | 15 | + doesn’t require the sewer replacement | Modular unit containing chopper, HE, HP |

Analysis of the existing heat exchangers suitable for the heat extraction from sewers revealed the absence of similar Russian-made devices on the market. Meanwhile, publicly available information do not allow to reliable estimate the performance of the majority of equipment. Especially, it relates to the modular systems. Their performance depends on the specificity of a particular object.

Both «in-sewer» and external heat extraction possesses its strong and weak sides. While the first variant requires lower auxiliary power consumption, the second obtains higher technical flexibility.

It is worth to consider, that an implementation of «in-sewer» models entails organizational difficulties related to the need for extensive excavation works. The thermal capacity, meanwhile, directly depends on the amount of sections. Compared to traditional solutions, the cost of the sewer system arrangement significantly increases. The risk of clogging and/or significantly reduction in thermal efficiency does not contribute to a high probability of introduction of such technology without the implementation of the preliminary demonstration projects. According to data for 2013 /19, p.47/, these solutions do not have examples of application in the Russian practice.

When using modular units, there is no need for the reorganization of the existing network. They require only an arrangement of wells and underground heat points. In addition, to extract the required amount of heat is only necessary to select an extraction point, where there are sufficient flow rates. Channel geometry, the cross-section and the slope are unimportant to the power of heat exchanger /4, p.6/. Due to the integrated treatment system of sewage and heat exchanger surfaces, the sewer does not require regular inspections or cleaning. Required measures of scrapes replacement are carried out in the well and in a heat point.

With an appropriate system's organization, the wide range of heat exchangers could be implemented in schemes of different scales, from private houses to cleansed wastewaters on treatment plants. Examples of implementing double-pipe heat exchangers are represented on the Figure 11.

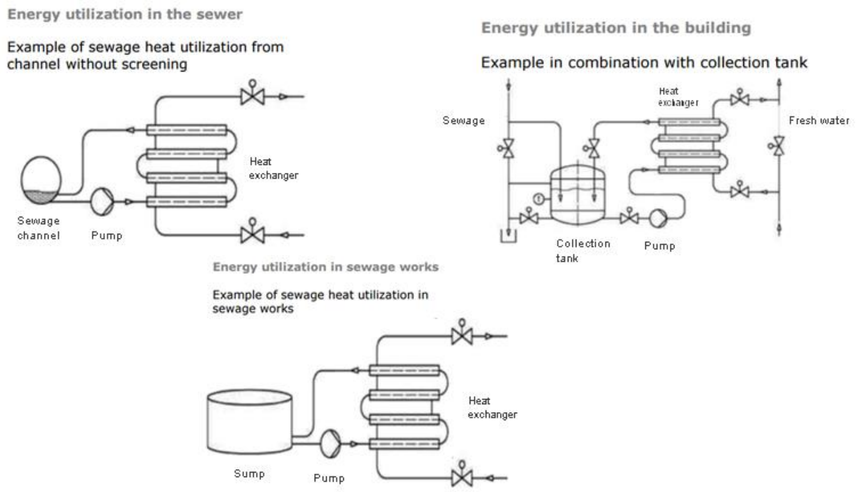


**FIGURE 11. Examples of heat utilization using a double-tube heat exchanger (left) /15/**

## 3.4 The biofilm formation on the heat exchanger surface

The main problem associated with specifics of wastewater is a biofilm formation. The biofilm matrix formation on a heat exchanger occurs when sewage's solids deposit near heat transfer surfaces, and microorganisms using nutrients settle in an aqueous medium on solid surfaces /12, p.224/. Biofilm has a low thermal conductivity, thus it has an insulating effect and provokes a significant reduction of the heat transfer coefficient of heat exchanger. The formation of biofilm and its thickness depends on flow rates and components of sewage flow.

In order to compensate the reduced heat exchange coefficient many heat exchangers are designed with an oversize surface /10, p.291/. Nevertheless, it does not overcome the problem of the biofilm formation. To prevent its formation the variety of flushing systems and periodic cleaning are applied. Since their effect is temporary, the automation systems or periodical manually cleaning should be implemented. If the first one enhances the initial systems cost, the second incurs larger operational cost. The common disadvantage is the necessity of the systems stoppage during the cleaning process. Besides that, the biofilm formation could be prevented with primary treatment of wastewater, the use of special heat exchanger surface materials or through the optimization of flow rates.

The research of the domestic wastewater heat recovery system in the study /20/ founds that if in first month of operation the maximum transporting capacity of wastewater pipes dropped seriously, in following months it decreased slowly (by 16,9% after the first month and by 20,1% after the fifth month) /20, p.442/. The authors conclude that a preliminary oversize design and a periodical cleaning will allow the system to keep an effective transfer capacity. Additionally, such precipitations as human hairs, staple fiber and so worth should be intercepted by the special filter.

### 3.5 Fluctuation of wastewater temperatures and flow rates

Knowledge of wastewater flow rates and temperatures allows to calculate the amount of thermal energy that can be obtained. It ensures an efficient system's design. The lack of reliable data for temperatures and flow rates in sewers represents a significant obstacle for designers.

The flow is exposed to daily, weekly and seasonal fluctuations depending on the number of residents, their water demand, lifestyle and weather conditions. In Switzerland, where compiled the wide database of sewage characteristics, the daily mean value during dry weather is taken as a basis for calculations with following application of the factor considering the daily variations. Preferable, if designers take into account the long-term perspectives of the available wastewater quantity. In countries with fast economic development the amount of utilized water is continually increasing. Nevertheless, in industrial nations the politic of the efficient water use has led to reduction of its volume.

Researches at a study /10/ demonstrate that the wastewater temperature in a sewer is more affected by variations in flow rates rather than the outside air temperatures. Just in case of combined sewer system, precipitations should be accounted. They increase the flow rates with a further temperature reduction /10, p.293/. During rainy periods the wastewater temperature drops by few degrees. The cleansed flow are virtually not exposed to variations. Figure 12 affirms it with graphs obtained in Zurich, Switzerland.

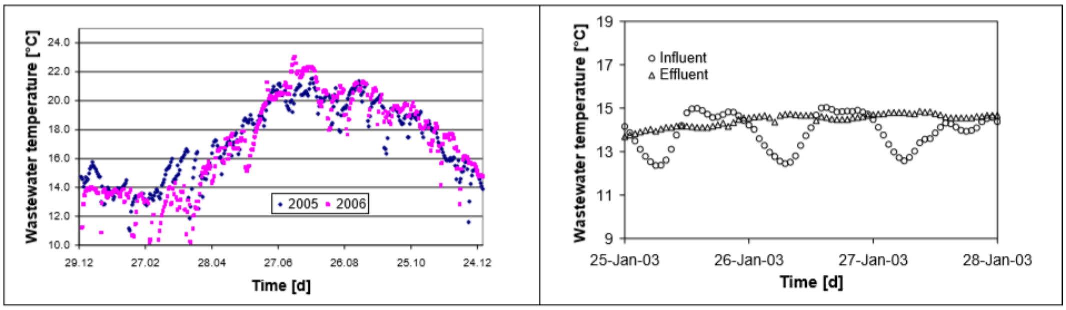
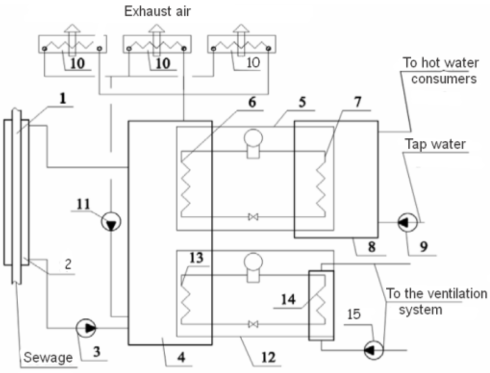


**FIGURE 12. Left: Wastewater temperatures at the input of the sewage treatment plant in Zurich (yearly average). Right: Daily variations in the input and output. (EAWAG 2006) /4, p.2/**

The field study /20/ compiles dependencies illustrating how the sewage temperature variations affect the COP of a domestic heat pump system. Among other, their experiments demonstrate the importance of the wastewater circulation inside the storage tank. Circulation alleviates the vertical gradient of temperatures; hence, the immersed evaporator (or other heat exchanger) is surrounded with warmer medium. At once, since the flow rate of wastewaters inside the tank is increased, the free convection appears to be more efficient.

Storage tanks are used for leveling uneven income flows of wastewaters and hot water consumption in domestic systems. Simultaneously, a storage accumulating an intermediate heat transfer medium before the evaporator provides a more stable operation of a heat pump. Moreover, it gives a possibility to connect other low-grade heat sources to the system in the future. Hybrid energy systems incorporating different energy sources are expected to be more prevalent in the future. In turn, the hot water storage tank helps to smooth consumption peaks /21, p.122/. Figure 13 schematically illustrates the described system.



1 - sewer;
2 - ground film HE;
3 - circulation pump for the intermediate coolant (sewage loop);
4 - accumulator of the intermediate coolant;
5 - heat pump for DHW system;
6, 13 - evaporators;
7, 14 - condensers;
8 - hot water storage tank;
9 - DHW circulation pump;
10 - exhaust air HE;
11 - circulation pump for the intermediate coolant (exhaust air loop);
12 - heat pump for the ventilation system;
15 - circulation pump for the ventilation loop.

**FIGURE 13. Schematic diagram of the hybrid sewage and air source heat pump system /21, p.122/**

## 3.6 International experience

Application of technologies for sewage heat utilization began in the late twentieth century. According to the data for 2013 presented in article /22, p.2/, there are more than 500 heat pumps utilizing the heat of wastewaters worldwide. The range of their heat output is from 10 kW to 20 MW. The government programs usually contributed to appearance of existing facilities. Thus, in 1993 the Swiss Federal Office of Energy initiated a campaign aiming to development and promotion of the wastewater energy resources utilization for heating and cooling /4/. The scope of campaign activities included support of related research projects, development on their basis of technical and economic tools with a further provision the builders, designers and local authorities with established guidelines. As a result of a comprehensive approach to the problem solving, Switzerland has become a pioneer in the international field of wastewater heat recovery. For instance, so-called wastewater use maps were compiled, informing where and to what extent the thermal resource of sewage can be used. At the legislative level, the utilizing of wastewater heat pumps is compulsory to new constructed buildings in areas where its economic justification was predefined /4/. In the European Union the target share of primary and final energy from renewables is 20% by 2020 /23, p.137/.

The use of combined heating and cooling machines is always especially economically interesting. In this case, space cooling and hot water production take place simultaneously on the same installation. There is a possibility of rearranging flows via valves. In Oslo, a whole quarter has been supplied with both heat and cold since 1984 /24/ by means of sewage source heat pump system. Such a decision has led to the non-necessity of the decentralized air-conditioning plants and individual air-conditioning installations. Two sewage heat pumps are located in a subterranean cavern next to wastewater sewer /4, p.6/. To meet peak loads an existing central heating with three oil-fired boilers and a conventional refrigeration machine was integrated in the energy network. The share of HPs energy production is 80%. The heating power station is shown on the Figure 14.

**FIGURE 14. Sandvika Wastewater energy central in Oslo (Friotherm) /4, p.6/**

Diversified energy utilisation (for cooling in summer and for heating in winter) from sewage with heat pumps application was demonstrated in the Beijing Olympic Village in 2008. Measured results show a reduction of $CO_2$ emissions by 3 105 t, and savings of 1,25 million RMB on operation costs /25, p.46/.

The sewer heat exchange systems are well established in such countries as Switzerland, Germany, Austria, Canada, Japan, South Korea and others. According to the data of 2014 /26/ there are approximately 50 facilities in Switzerland extracting heat from wastewater by means of heat pumps and heat exchangers installed in sewers. Simultaneously, Australian researches in a study /27/ simulated such a system for the particular site in Melbourne, estimated operation costs and concluded that this technology would not be presently commercially viable. Comparing their results with successful worldwide experience, authors highlighted two prerequisites for that. Firstly, the climate in countries where the sewage heat exchange systems operates successfully is significantly colder. The system operates for a longer period during the year that shortens the payback period of the initial investments. The second factor is a higher energy costs in those countries. Authors concluded that the idea of heat recovering from sewers is conceptually appealing in Australia for the objects with higher energy demand, in circumstances of continuously increasing energy costs.

The largest (as of 2006) heat pump plant in the world locates in Helsinki, Finland and produces district heat (90 MW) and cooling (60 MW) from purified wastewater and seawater. The sewage heat exchangers locates underneath the Katri Vala park, 35 meters below the ground level. The Katri Vala installation comprises five electric-driven vapor compression heat pumps. Winter and summer operating modes are operated by the automation system. The simplified functional diagram is illustrated on the Figure 15. In winter, heat pumps extract low-potential heat from sewage and transfer it (after multiplying) only to a district heating system (valves B, C, D are open, while A is closed). The district heating water is preheated to the 62°C that enhances the overall efficiency of district heating. The cooling load is completely covered by a "free" heat exchange with cold seawater (valves E, F, H are closed, while G is open). In summer the heat demand is considerably lower. Thus, the heat pumps meet the full heating demand. Periodically, when there is no heating load, the excessive heat is rejected to the sea (valves A, H, E, F are open, while B, C, D, G are closed). /28./

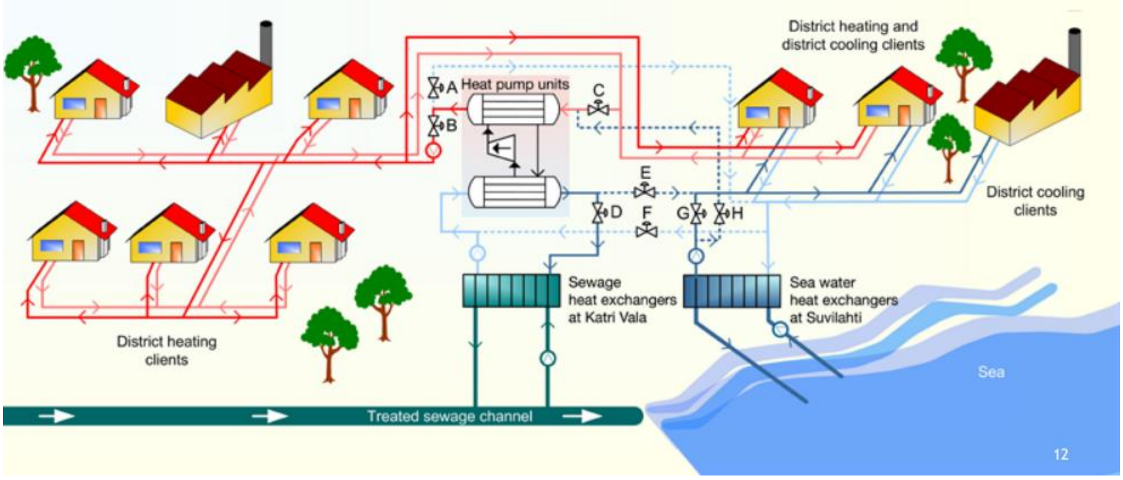


**FIGURE 15. Simplified functional diagram of the Katri Vala district heating/district cooling systems /28/**

Thus far, in Russia the use of sewage source heat pump systems was experimental in nature. Meanwhile, literature analysis gives evidence of conducting a lot of research and development works in the domain. In 2000, the heat pump system utilizing the heat of untreated wastewaters was developed and implemented at the municipal sewage pumping station in Perm. Trial run of the system during the heating season of the first year of operation showed that gained heat energy output fully meets the heating and hot water supply needs of a pumping station. Comparison with electric heating showed a decrease in the cost of 1 Gcal of heat in 4,6 times. The payback period was 1 year. /29, p.54./

Another experimental sewage source heat pump station was put into operation in 2004. It disposed raw sewage accumulated in the receiving tank on main sewage pumping station in Zelenograd. Generated heat was used to warm up tap water before boilers of the district heating station, which is located 0,5 km from the sewerage pump station. Untreated wastewaters with temperature +20°C pumped by fecal pumps to the heat exchanger shown in Figure 16, where their temperature was reduced to +15,4°C. The total flow rate was 400 $m^3/h$ that provided no formation of deposits on heat exchange surfaces. The temperature of an intermediate coolant, in turn, increased from +8°C to +13°C, and the tap water was heated from +23°C to +30°C. The value of thermal power achieved during the tests was 2,0 MW. The resulting energy savings amounted to 66%.

**FIGURE 16. The heat exchanger used in sewage-source heat pump system in Zelenograd, Russia /30/**

Wastewaters possess all the necessary characteristics to serve a low-grade heat source for the heat pump operation. There is a wide variety of technical solutions for objects of different scale. At this point, in Russia an implementation of wastewater source heat pump systems was only experimental. Moreover, application objects were only sewage pumping stations. Meanwhile, it is of interest to evaluate the potential use of this low-grade heat source directly for district heating of separate buildings. Benefits specific to this case are:

- maximum proximity to the consumer;
- maximum sewage temperature;
- no needs for costly excavation works;
- a promising source of low-grade heat for hybrid source heat pumps;
- low-rise buildings are characterized by a remoteness from the centralized thermal networks more often, that is promising for the development of decentralized decisions.

Besides the named benefits, domestic utilization has such difficulties for calculation of its performance and realization as: maximum fluctuation of the main parameters, an inability to predict the mode of water draw-off, high cost of basic equipment, lack of pilot projects and methods of calculation.

In the next section, the method of assessing the potential of using this source for private house heating is proposed. The solution is assessed from the standpoints of technological, energetic and economic feasibility.

# 4 WASTEWATER SOURCE HEAT PUMP SYSTEM FOR A ONE-FAMILY HOUSE

## 4.1 Selection of the heat exchanger equipment

At house with four residents, the long-term rhythm of water consumption is unpredictable. Meanwhile, the availability of reliable knowledge concerning flows and temperatures is a guarantee of qualitative design of a heat pump system. Changes in the rhythm of water consumption per capita significantly influence the gross potential of effluents. Smoothing of irregularities is a duty of a wastewater storage capacity. However, in this case it is inevitable that at hours with low water consumption, a liquid in a tank significantly cools down. Meanwhile, the heat of peak flows could be hardly fully used due to the fast refilling of a tank. In a big volume storage the peak flows become significantly diluted, that also reduces their thermal potential.

An implementation of the tank with bigger volume where sewage stay for longer periods duplicates functions of a septic tank. Placing of heat exchangers in there is possible and has been used in practice. Therewith, the effluents temperature in a septic tank is changing under the influence of anaerobic decomposition (goes with a heat release) and an inevitable dissipation of heat through septic’s walls. Figure 17 illustrates the results of a patent search of suitable heat exchangers. The following is the analysis of the advantages and drawbacks of the presented devices.

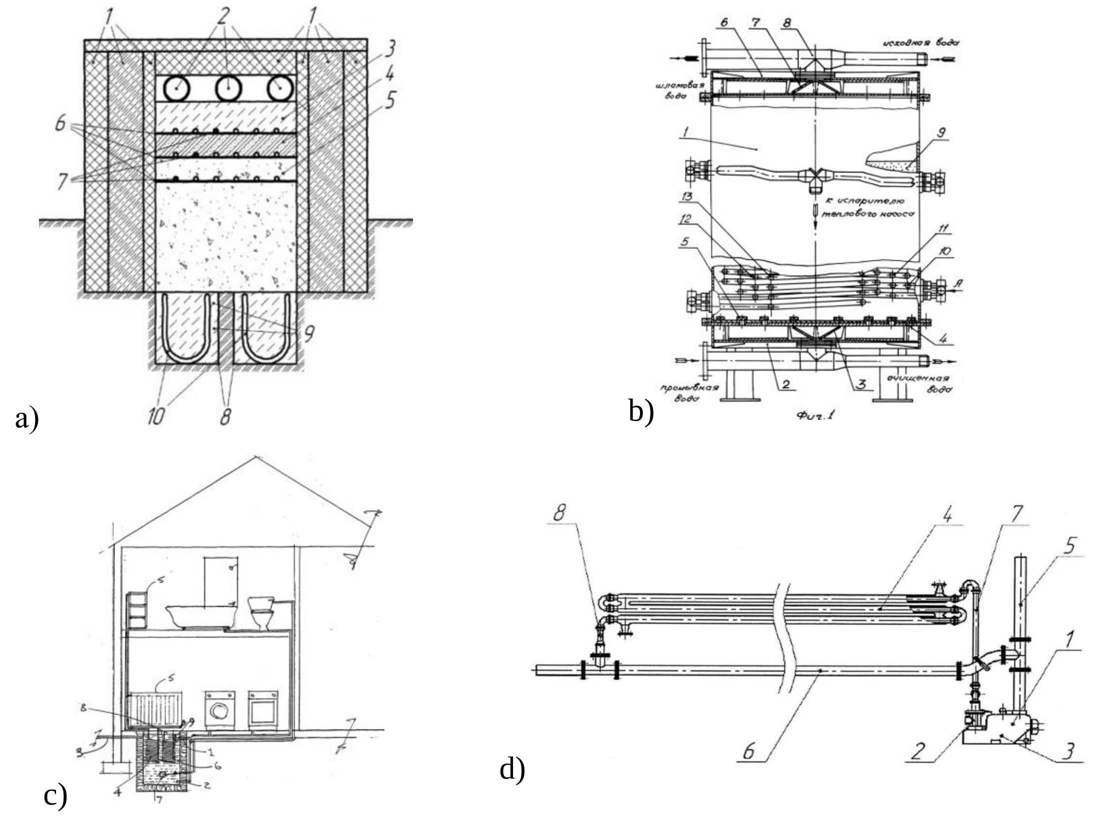


**FIGURE 17. Heat exchangers for domestic heat extraction from sewage, protected by patents /34-37/**

a) The presented device combines the functions of cleaning and heat extraction. Heat exchangers are located at the boundaries of the filtration materials layers that constitute the body of the heat-insulated mound. A film of a water-permeable material separates the layers. It promotes the formation by accumulated wastewaters the backwater on the boundary layers, which intensifying the heat transfer. The device is supposed to be used at the final stage of wastewater treatment in order to avoid using of additional filters. Designing requires a preliminary development and testing of the patented construction.

b) This filter-heat exchanger differs from the previous by the need for periodic cleaning by washing water that complicates the overall design. The device is a cylindrical casing filled with granular filter material, where tube heat exchangers are immersed. A relief-distribution device through which the wastewaters are fed into the body locates under the lid. A lower device discharges clarified waters.

c) In the presented device, a heat exchanger is immersed into a thermally insulated tank where effluents are accumulated. The most important disadvantage of this solution is the emergence of unpleasant smells, as well as the need for regular cleaning of heat exchange equipment.

d) In the installation, the effluents are pumped by fecal pump through a heat exchanger, with following discharging of cooled flows into a discharge line. An intended installation site is under the riser of the building's sewage system. The pump is started after the filling of the special tank to the certain level. This fact complicated the smooth heat transfer to an evaporator when there is insufficient flow of wastewaters. When the pump is turned off, the usage of water seal is provided to prevent emptying of the heat exchanger. However, exactly tribalization of the flow contributes to the thermal efficiency of the process. At certain flow rates the self-cleaning of heat exchange surfaces is declared.

In practice, such a method is used as an arrangement of heat exchanger's circuit in a septic tank. Septic serves as a cumulative capacity for stabilization of the load. A circuit of heat exchanger is advisable to place in top layers of a tank, where the cleanest and warmer effluents are. The volume of septic is designed with the purpose of at least three days of wastewater's staying there /38, p.9.2.13.3/. To maintain an effective for cleaning temperature conditions in a septic (to avoid its cooling), the heat pump's refrigerant boiling temperature is limited. Figure 18 illustrates described system, manufactured by SunDue (Kazakhstan).

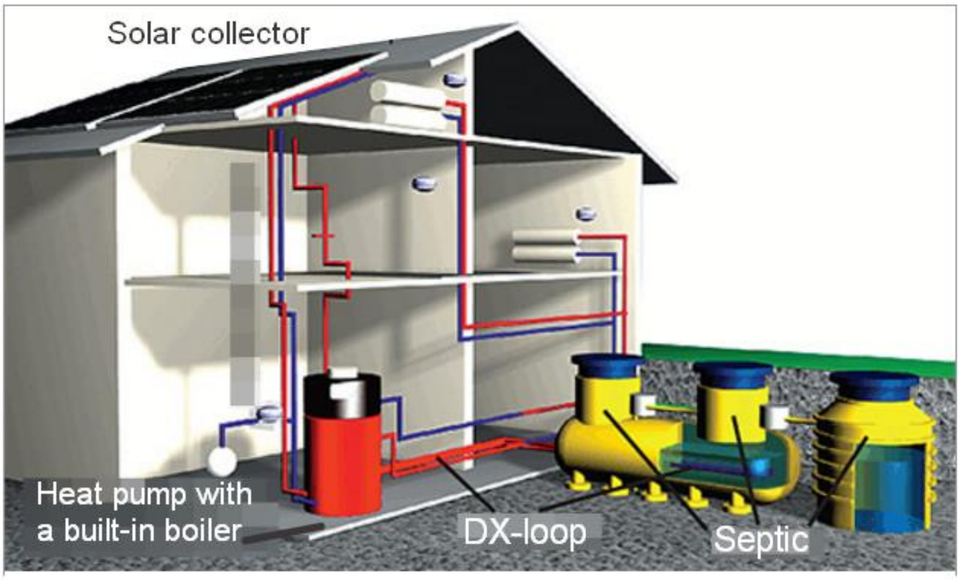


**FIGURE 18. Layout of DX-loop of the evaporator in a chamber of a septic tank /39/**

## 4.2 Calculations

To estimate the potential of the wastewaters heat utilization in a domestic scale, the integrated parameters were used. Initial data were taken from the project of a one-family house in St. Petersburg region. Initial climatic data are taken from /31/ and listed in Table 2.

**TABLE 2. Climatic data of the construction region**

| Parameter | Symbol | Unit | Design value |
|---|---|---|---|
| Climatic region of construction site | - | - | II B |
| Design outside air temperature | $t_{out}$ | °C | - 24 |
| Average outdoor temperature during a heating period | $t_{av\ h.p.}$ | °C | - 1,3 |
| Duration of a heating period | $z_{h.p.}$ | days/year | 213 |
| Design temperature of internal air | $t_{av.in}$ | °C | 20 |
| Day-degree of a heating period | $D_d$ | °C·days/year | 4537* |
| * $D_d = z_{h.p} \cdot (t_{av.in} - t_{av\ h.p.}) = 213 \cdot (20 - (-1,3)) = 4537$ °C·days/year | | | |

Detailed geometrical features of the cottage are not presented due to the fact, that in this work the thermal loads are calculated according to specific heat data given per unit area of a residential building. Initial data necessary for further calculations are listed below:

- Two-storey cottage for 4 residents (n=4);
- Living area S = 150 $m^2$.

In accordance with p.5.2 in /32/ the thermal loads for planned residential buildings are determined by specific thermal characteristics (Appendix B in /32/), when the number of floors and total area are known. This is the way of a heat load estimation, when the thermal losses calculation is impossible due to the lack of exact design data about materials and dimensions of the building. For the building constructed after 2015 in a region with a design outside air temperature -24°C, the specific value of the maximum thermal load on heating and ventilation for residential buildings is **66,4 W/$m^2$**. Thereby, estimated thermal load for the heating system is:

$$\Phi_\mathrm{h} = 66{,}4 \cdot 150 = 9960\ \mathrm{W} = 9{,}96\ \mathrm{kW} \tag{2}$$

Total energy demand for heating during the heating period is calculated with formula 3:

$$\mathrm{Q}_{\mathrm{h,an}} = \frac{\Phi_h \cdot D_d \cdot 24}{(t_{av.in} - t_{out})} \tag{3}$$

$$\mathrm{Q}_{\mathrm{h,an}} = \frac{9960\ \mathrm{W} \cdot 4536{,}9°\mathrm{C}{\cdot}\mathrm{day/year} \cdot 24\ h/day}{(20-(-24))°\mathrm{C}} = 24647{,}74\ \mathrm{kWh/year} = 24{,}65\ \mathrm{MWh/year}$$

To estimate an average daily flow of wastewater, the daily water consumption is calculated in accordance with Table A.2 in /33/. The specific average daily water consumption ($q'_w$) assumed equal to **210 l/day** per one person, including **85 l/day** of hot water. Temperatures of hot ($t_h$) and cold ($t_c$) water are presumed to be 60°C and 5°C respectively according to p. 5.1.2 in /33/. The daily flow of wastewater is:

$$q_s = q_{tot} = q'_w \cdot n = 210 \cdot 4 = 840\ \mathrm{l/day} = 0{,}84\ \mathrm{m^3/day} \tag{4}$$

Daily average hot water consumption:

$$q_{hw} = q'_{hw} \cdot n = 85 \cdot 4 = 340\ \mathrm{l/day} = 0{,}34\ \mathrm{m^3/day} \tag{5}$$

Daily average cold water consumption:

$$q_{cw} = q_{tot} - q_{hw} = 840 - 340 = 500\ \mathrm{l/day} = 0{,}5\ \mathrm{m^3/day} \tag{6}$$

A real water consumption diagram in a private house is variable. According to the most standard chart, the most active water consumption accounts for morning (6:00-9:00) and evening (18:00-22:00) hours. For further calculations, assume the daily water consumption equal to **7 h/day**. Thus, the hourly hot water consumption is roughly $\frac{340\ l/day}{7\ h/day} = 48{,}6\ l/h$. In a private house presumed an autonomous system of hot water heating. For preparing a hot water volume sufficient for the continuous usage during 4 hours, the storage tank of 48,6 l/h · 4 h = 194,4 l ≈ **200 l** is enough.

Calculation of the amount of energy transmitted to the body during heat exchange is calculated by the formula:

$$Q = m \cdot C_p \cdot \Delta T \tag{7}$$

where Q – thermal energy [kJ];
m – weight of a heated body [kg];
$C_p$ – specific heat capacity [kJ/kg·K] (assumed 4,2 kJ/kg·K for the sewage);
ΔT – temperature difference [K].

In accordance with the formula 7, an amount of heat required to heat hot water boiler (which volume accepted equal to 200 l, that corresponds to 200 kg):

$$Q_{dhw} = 200 \cdot 4{,}2 \cdot (60 - 5) = 46\ 200\ kJ = 12{,}8\ kWh \tag{8}$$

Wastewaters flow presumed to be equal to the water consumption. Effluents temperature is calculated as the temperature of the mixture:

$$t_s = \frac{t_c \cdot m_c + t_h \cdot m_h}{m_c + m_h} \tag{9}$$

where $m_c/m_h$ – cold/hot water mass flow.

Accordingly, the average temperature of the sewage depends on proportion of hot and cold water and being estimated as:

$$t_{sew,av} = \frac{5 \cdot 0{,}5 + 60 \cdot 0{,}34}{0{,}84} = 27{,}3°C$$

The hourly water and accordingly sewage consumption in case of water use during 7 h/day is: $\frac{\mathbf{840\ l/day}}{\mathbf{7\ h/day}}$ **= 120 l/h.**

Table 3 represents results of the gross wastewater energy potential calculation ($Q_{sew}$). The gross (theoretical) potential of the energy source equals to amount of energy that it contains, and that could be fully transformed into useful form with the appropriate level of technology.

According to the formula 7, the energy available for extraction is calculated depending on the temperature difference with an allowance for respective wastewater flow rates (l per time period). During calculations is assumed that the initial sewage flow temperature is equal to an average meaning of +27,3°C. However, considered several temperatures of the sewage to whose the initial temperature is reduced during the heat extraction (from +10°C to +25°C). These temperatures correspond to the evaporating temperature of the refrigerant ($T_2$ in formula 1); the higher it is, the bigger the heat pump's COP in case of its further application.

Wastewater treatment is presumed by means of a septic tank. There an anaerobic decomposition of organic matter happens. To ensure effectiveness of the process, the lower boundary of the allowable effluents temperature is denoted at the level of +10°C.

Example of available for extraction thermal energy (gross potential) calculation in case of heat exchange during an hour of water use with reduction of the sewage temperature from +27,3°C to the +10°C in accordance with the formula 7 is:

$$Q_{sew} = 120 \cdot 4{,}2 \cdot (27{,}3 - 10) = 8\,700 \text{ kJ} = 2{,}42 \text{ kWh},$$

where $m = V \cdot \rho = 0{,}12 \text{ m}^3 \cdot 1000 \text{ kg/m}^3 = 120$ kg – weight of sewage;

$C_p$ – specific heat capacity, assumed = 4,2 kJ/kg·K for the sewage;

$\Delta T = t_{sew,av} - T_1$ – temperature difference [K].

Other results are represented in Table 3.

**TABLE 3. Thermal energy available for extraction from sewage with different lowering of an initial temperature during different time periods**

| Period | Wastewater flow rate, l/period | An average temperature of the sewage, °C | The sewage gross potential ($Q_{sew}$), when the temperature of the mixture is reduced to: | | | |
|---|---|---|---|---|---|---|
| | | | +10°C | +15°C | +20°C | +25°C |
| | | | kWh | | | |
| Hour | 120 | 27,3 | 2,42 | 1,72 | 1,02 | 0,32 |
| Day | 840 | | 16,92 | 12,02 | 7,12 | 2,22 |
| Heating period (213 d/a) | 178 920 | | 3603,25 | 2559,55 | 1515,85 | 472,15 |
| Year | 306 600 | | 6174,58 | 4386,08 | 2597,58 | 809,08 |

## 4.3 Assessment of the technical potential

Under this section, two following cases of a heat pump ap
plying are estimated:

1) Usage of low-grade sewage heat for a contribution to a required heat output of the heating system;
2) Usage of sewage heat for domestic hot water (DHW) heating.

1) The use of low-potential wastewater's heat to produce heat for heating system is considered in the framework of the concept of a hybrid heat pump implementation. Due to inconstancy of flows, wastewater may serve only for reduction the load on the other low-grade heat sources, such as ground probes. This leads to reduction of the wells length, and hence, the system's cost reduction.

With organizing heating supply with the heat pump implementation, the use of low-temperature heating systems is preferable. In this study, the heating is presumed to be realized by a water underfloor heating. The heating of the coolant is up to +35°C.

2) A feature of a DHW preparing mode of sewage heat utilization is a coincidence in time of peak water consumption and maximum effluents potential. When placing the heat exchanger in the storage tank, the process of heat removal turns out to be closed.

The initial data for simulation of the heat pump modes in the CoolPack program are:

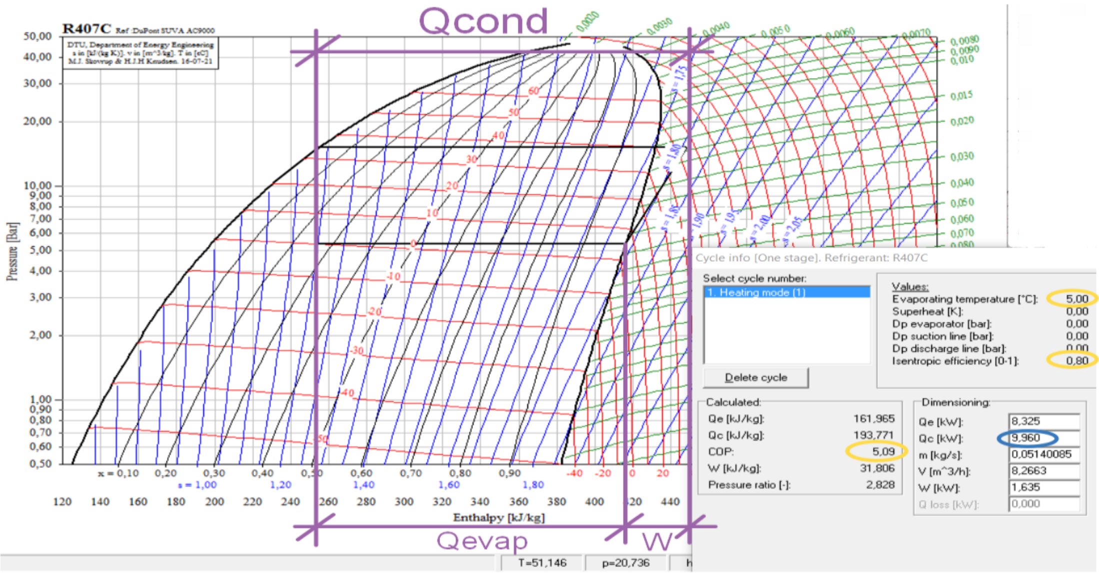
- Refrigerant R 407c, selected as providing a maximum COP among analogues /40, p.75/;
- Minimum temperature of the low-grade heat source (sewage) after heat transfer is $t_{l,2}$ = +10 °C;
- Design temperatures of a high-potential coolant after heat transfer is $t_{h.\,2heat}$ = +35 °C or $t_{h,\,2dhw}$ = +60 °C (DHW);
- Temperature difference at the outlet of the heat exchangers: $\Delta t_{ev}$ = 5 °C, $\Delta t_{cond}$ = 5 °C;
- An isentropic efficiency of the conventional compressor: $\eta_a$ = 0,8.

In accordance with the method described in /40, p.39/ the following values were adopted:

- Refrigerant condensing temperature: $t_{cond} = t_{h,2} + \Delta t_{cond}$ = 35/60 + 5 = +40/65 °C;
- Min evaporating temperature of a refrigerant: $t_{ev} = t_{l,2} - \Delta t_{ev}$ = +10 – 5 = +5 °C.

The simulation is carried out in the CoolPack program, developed at the Technical University of Denmark. It allows to automate the performance calculation of the equipment's, whose operation principle is based on the change of refrigerant's aggregate state. There uploaded thermodynamic properties of over 40 modern refrigerants. At first approximation, the thermodynamic cycle depends on the properties of chosen refrigerant (log(p)-h diagram), assigned condensing and evaporating temperatures and an isentropic efficiency of the compressor. According to the obtained coordinates of the cycle, the program determines the coefficient of performance (COP) of the studied device. Since CoolPack was initially created for the refrigerating systems calculation, to know the COP of a heat pump one should be added (+1) to a demonstrated value.

Figure 19 illustrates the thermodynamic cycle of the studied heat pump working into the heating (1) mode (R 407c, $t_{ev}$ = +5 °C, $t_{cond}$ = +40 °C). Into the Dimensioning section, the user sets the value of a required condensing power (called $Q_c$ in CoolPack, equal to $\Phi_h = 9{,}96$ kW in this study in accordance with formula (2)). Subsequently, the program calculates values listed below in the Dimensioning section. It allows to conclude, that for generating 9,96 kW by the designed heat pump, the power equal to 8,33 kW (called $Q_e$ in CoolPack, but $\Phi_{evap}$ in this study) should be received by the evaporator from the low-potential source.



Cycle info [One stage]. Refrigerant: R407C

Select cycle number:
1. Heating mode (1)

Values:
Evaporating temperature [°C]: 5,00
Superheat [K]: 0,00
Dp evaporator [bar]: 0,00
Dp suction line [bar]: 0,00
Dp discharge line [bar]: 0,00
Isentropic efficiency [0-1]: 0,80

Calculated:
Qe [kJ/kg]: 161,965
Qc [kJ/kg]: 193,771
COP: 5,09
W [kJ/kg]: 31,806
Pressure ratio [-]: 2,828

Dimensioning:
Qe [kW]: 8,325
Qc [kW]: 9,960
m [kg/s]: 0,05140085
V [m^3/h]: 8,2663
W [kW]: 1,635
Q loss [kW]: 0,000

**FIGURE 19. Sample calculation of the thermodynamic cycle of the R407c refrigerant with given parameters in the CoolPack program**

1. The aim of modeling the operation of a heat pump in a heating mode is a comparison of a required thermal energy that should be extracted by the evaporator from the low-potential source ($Q_{evap}$) with the thermal energy that could be extracted from effluents under specified conditions ($Q_{sew}$ from Table 3).

An estimated thermal load of a heating system ($\Phi_h$) is 9,96 kW in accordance with formula (2). Thus, during an hour with the designed load, heat pump should produce 9,96 kWh of thermal energy ($Q_h = Q_{cond}$). Accordingly, during a day (24 hours) with a designed load the heating system should produce 239,04 kWh/day. During a heating period an energy demand is 24647,74 kWh/year (3). It means, that an average value of a thermal load is:

$$\frac{24647{,}74\ \mathrm{kWh/year}}{213\ \mathrm{day/year}\cdot 24\ \mathrm{h/day}} = 4{,}82\ \mathrm{kW}$$

To obtain the values of a required evaporating power (for obtaining 9,96 kW from a heat pump) following initial parameters are used for CoolPack simulation when the effluents are cooled down to +10°C: R 407c, $t_{ev} = +5$°C, $t_{cond} = +40$ °C. Figure 19 illustrates described thermodynamic cycle. Under specified conditions, required evaporating power is 8,33 kW. Thus, during an hour required thermal energy ($Q_{evap}$) is 8,33 kWh. Accordingly, during a day the meaning is 24 times bigger.

As consistent with Table 3, reduction of the effluents temperature from +27,3°C to +10°C (e.g.) during an hour of water use allows to get 2,42 kWh of thermal energy ($Q_{sew}$). As was presumed, the water is used during seven hours a day. Thus, 16,92 kWh of thermal energy could be obtained daily from effluents by reducing their temperature up to +10°C. Different temperature modes are explored to identify the range of this system. Results are represented in Table 4.

**TABLE 4. Shares of replacement a required thermal capacity of low potential source ($Q_{ev}$) by the effluents heat ($Q_{sew}$)**

| | | Temperature mode | | | |
|---|---|---|---|---|---|
| | | 5/40 | 10/40 | 15/40 | 20/40 |
| COP | | 6,09 | 7,18 | 8,72 | 11,02 |
| An hour with the designed load on the heating system, Qcond = 9,96 kWh | Qevap, kWh | 8,33 | 8,57 | 8,82 | 9,06 |
| | Qsew, kWh | 2,42 | 1,72 | 1,02 | 0,32 |
| | % from effluents | **29** | **20** | **12** | **3** |
| | P (mechanical power), kWh | 1,64 | 1,39 | 1,14 | 0,90 |
| A day with the designed load on the heating system, Qcond =239,04 kWh/day | Qevap, kWh/day | 199,80 | 205,76 | 211,62 | 217,35 |
| | Qsew, kWh/day | 16,92 | 12,02 | 7,12 | 2,22 |
| | % from effluents | **8** | **6** | **3** | **1** |
| | W, kWh/day | 39,24 | 33,28 | 27,43 | 21,69 |
| Heating period Qcond =24 647,74 kWh/year | Qevap, kWh/year | 20601,97 | 21216,45 | 21819,92 | 22411,69 |
| | Qsew, kWh/year | 3603,25 | 2559,55 | 1515,85 | 472,15 |
| | % from effluents | **17** | **12** | **7** | **2** |
| | W, kWh/year | 4045,78 | 3431,29 | 2827,82 | 2236,05 |

Simulation demonstrates that in an hour with design load on the heating system, effluents could provide 29 % of the required for the heat pump operation thermal energy. In accordance with made assumptions, there are 7 hours of water consumption per day. Therefore, in a day with the designed load on the heating system effluents heat are able to provide 8 % of the required low-potential thermal energy. During heating period an effluents share amounts 17 % from required.

2. For heating the boiler with volume of 200 l required amount of heat equals to **12,8 kWh**. Similar to the previous simulation case, values of the required low-potential heat for its generation ($Q_{ev}$) are obtained for different temperature modes. By comparing the gross potential of effluents in an hour (Table 3) with a required for a whole boiler

heating amount of heat, an amount of hours of water consumption sufficient for a boiler heating are obtained. Results are demonstrated in Table 5.

**TABLE 5. Required time (h) of the sewage heat extraction for the 200 l of hot water heating with a heat pump application**

| | | Temperature mode | | | |
|---|---|---|---|---|---|
| | | 5/65 | 10/65 | 15/65 | 20/65 |
| COP | | 3,19 | 3,51 | 3,9 | 4,37 |
| $Q_{cond}$ * /for 48,6 l of hot water heating (1h)/ | kWh | 3,12 | | | |
| $Q_{cond}$ /for 200 l heating/ | kWh | 12,8 | | | |
| $Q_{evap}$ | kWh | 8,81 | 9,18 | 9,54 | 9,90 |
| $Q_{sew}$ /in an hour/ | kWh | 2,42 | 1,72 | 1,02 | 0,32 |
| The heating time | h | **3,65** | 5,35 | 9,38 | 31,26 |
| * $Q_{cond} = 48{,}6\ kg \cdot 4{,}2\ kJ/kg{\cdot}K \cdot (60-5)\ K/3600 = 3{,}12\ kWh$ | | | | | |

The boiler's volume is designed for 4 hours of hot water consumption. Thus, obtained heating time less than 4 h demonstrates that sewage's low-potential heat is enough for preparing hot water with application of a heat pump with evaporating and condensing temperatures equal to +5 °C and +65 °C accordingly.

Obtained results indicates that the thermal capacity of wastewaters being converted with a heat pump is sufficient to provide domestic hot water for a private house. The following sections are devoted to study this way of use the effluents heat (domestic hot water heating).

### 4.4 Commercial viability

In the framework of this section provided a comparison of current and capital costs for different autonomous systems of domestic hot water heating. Basing on the obtained results, selected a market model of a heat pump with characteristics closest to the calculated. As traditional solutions considered gas (natural and condensed), diesel and electric boilers. Capital costs for gas and diesel boilers take into account the cost of a storage water heater of indirect heating. Does not taken into account the costs of the connection to the main gas pipeline and the cost of the heating boiler itself. Table 6 lists the models selected as typical for realization of domestic hot water heating by different ways. Their costs are considered as capital investments. Appendix 1 contains the page with technical features of the selected heat pump provided by a manufacturer.

**TABLE 6. Models selected as typical for realization of domestic hot water heating**

| | Brand, model | For HP | | | Power, kW | Capacity, l | Cost, rub |
|---|---|---|---|---|---|---|---|
| | | COP | Operating points | Electric power, kW | | | |
| Storage water heater with integrated HP | SunDue, SDF-300 | 4 | B15 W50 | 1,4 | 5,4 | 300 | 184 800,00 |
| Indirect heating boiler | Nibe-Biawar Mega W-E220.81 | - | | | 24,2 | 220 | 41 107,00 |
| Electric water boiler | Drazice OKCE 300 S/3–6kW | - | | | 6 | 300 | 56 233,0 |

Under current costs for an each case the cost of fuel or energy resources required for preparing 340 l of hot water per day are regarded. Calculated cost depends on the efficiency of the generator, a calorific value of the fuel and the price for it. Utilized fuels are natural and condensed gas, diesel. Electricity is used for heat pump and electric boiler operation. The method of calculation is given below.

The energy required for heating of 1 l of hot water in accordance with formula 7 is:

$$\mathrm{Q} = 1 \cdot 4{,}2 \cdot (60 - 5) = 231\ \mathrm{kJ} = 0{,}064\ \mathrm{kWh}$$

Compared devices uses for the implementation of this heating energy, which depends on their efficiency ($\eta$) or COP for a heat pump:

$$\mathrm{Q}_{dev} = \mathrm{Q}/\eta \qquad (10)$$

Depending on the calorific value of the fuel (q), the necessary amount of fuel/electricity for 1 l of hot water heating is:

$$V = Q_{\mathrm{dev}}/q \qquad (11)$$

Used energy prices are relevant for 2016. Results of the current costs calculation are represented in Table 7.

**TABLE 7. Current costs for different ways of hot water heating**

| | | Storage water heater (indirect) | | | Heat Pump | Electical boiler |
|---|---|---|---|---|---|---|
| | | Natural gas (methane) | Condensed gas (propane-butane) | Diesel | | |
| An amount of heat for 1 l heating (Q) | kWh | 0,064 | | | | |
| | MJ | 0,231 | | | | |
| Efficiency (COP for a HP) (η) | | 0,96 | 0,96 | 0,92 | 4 | 0,98 |
| Required energy (taking into account an efficiency) ($Q_{dev}$) | kWh | 0,07 | 0,07 | 0,07 | 0,02 | 0,07 |
| | MJ | 0,24 | 0,24 | 0,25 | 0,06 | 0,24 |
| Calorific value (q) | | 33,08 | 25,30 | 35,44 | 1 | 1 |
| | | MJ/$m^3$ | MJ/l | MJ/l | kWh | kWh |
| Consumption of fuel/energy carrier per 1 l of hot water heating (V) | | 0,0073 | 0,0095 | 0,0071 | 0,0160 | 0,0655 |
| | | $m^3$ | l | l | kWh | kWh |
| Cost of a unit of fuel/energy carrier, for 2016 | | 5,64 | 14,00 | 33,5 | 2,69 | 2,69 |
| | | rub/$m^3$ | rub/l | rub/l | rub/kWh | rub/kWh |
| Cost for heating of 1 l | rub | 0,04 | 0,13 | 0,24 | 0,04 | 0,18 |
| Fuel/energy carrier cost for a year | rub | 5 087,00 | 16 524,00 | 29 453,00 | 5 355,00 | 21 858,00 |
| Capital costs | rub | 41 107,00 | 41 107,00 | 41 107,00 | 184 800,00 | 56 233,00 |

The payback period for alternative solutions (a heat pump in this case) in comparison with traditional ones (the others) is defined in first approximation by the principle of equality of the discounted costs (Disc.c.). In generalized calculations discounted costs are defined as:

$$\text{Disc.c.} = \text{Cap.c.} + \text{Cur.c.} \cdot t, \qquad (12)$$

where Cap.c. – capital costs [rub],

Cur.c. – current costs [rub/year],

t – the number of years of operation [year].

In case of equality of discounted costs of compared variants, t expresses the payback period of an alternative solution compared to a traditional. In this case, the payback period is calculated as:

$$t = \frac{\text{Cap.c.}_{\text{alt}} - \text{Cap.c.}_{\text{tr}}}{\text{Cur.c.}_{\text{tr}} - \text{Cur.c.}_{\text{alt}}} = \frac{\Delta\text{Cap.c.}}{\Delta\text{Cur.c.}} \tag{13}$$

The same task can be solved graphically. Figure 20 demonstrates the comparative cost-effectiveness of investments, calculated without taking into account the energy resources price rise, as well as the maintenance costs. At the initial moment, expenditures are equal to Capital costs of each solution. In subsequent years, the Current costs for fuel and energy resources are being added. The signed intersection points correspond to the moments of payback for the heat pump application.

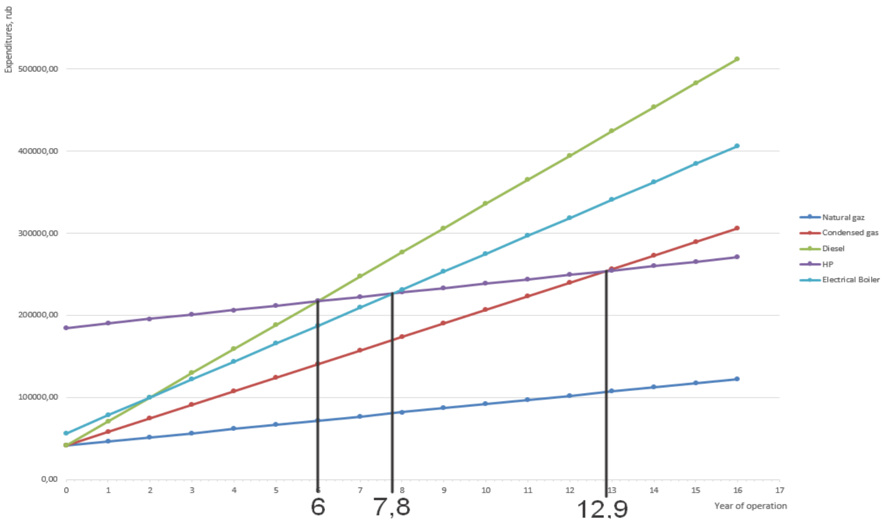


**FIGURE 20. Expenses for DHW heating with the use of different autonomous systems**

Obtained results indicate that the most cost-effective way of domestic hot water heating supposes the usage of natural gas as a fuel. Without an existing connection to a natural gas pipeline, the capital costs are significantly bigger. However, existing tariffs for natural gas provide the lowest current costs. Consequently, the greatest economic attractiveness of this solution subject to the availability of connection to gas supply systems. The use of diesel fuel is the least economically advantageous.

In Table 8 are given results of the payback period calculation in case of replacement by the suggested system the existing traditional ones (excluding the case of natural gas use due to the previously established impracticality of its replacement). Payback period is calculated in a first approximation as the ratio of capital expenditures on the suggested heat pump system to resulted annual savings on operating costs.

**TABLE 8. Payback period calculation in case of replacement by the suggested system the existing traditional ones**

| | | Condensed gas | Diesel | Electrical boiler |
|---|---|---|---|---|
| Capital costs of the HP system | rub | 184 800,00 | | |
| Capital cost of the compared system | rub | 41 107 | 41 107 | 56 233 |
| Savings of current costs | rub/year | 11 169 | 24 098 | 16 503 |
| Payback period | year | 16,55 | 7,67 | 11,20 |

## 4.5 Assessment of the energy efficiency of the proposed solution

Evaluation of the efficiency of different heat generators is performed through the calculation of the utilization rate of primary energy (URPE), which is the main criterion of energy efficiency. According to /40, p.19/, the unit cost of primary energy (PE) used for production of heat is defined as the ratio of used fuel energy ($Q_f$) to the amount of received thermal energy ($Q_{th.en.}$):

$$PE = Q_f / Q_{th.en.} \tag{14}$$

The higher this ratio, the less efficiently the system uses primary energy. URPE is the reciprocal value to the specific cost of primary energy (PE).

For a vapor compression heat pump with an electrical drive, the estimation of the primary energy use should take into account the efficiency of conversion of primary energy at the power plant ($\eta_{p.p.} \approx 0,4$), the efficiency of power supply systems ($\eta_{sup.s.} \approx 0,95$) /40, p.20/ and the COP value. Then, the unit cost of primary energy (PE) is calculated as:

$$PE = \frac{1}{\eta p.p.\cdot \eta sup.s.\cdot COP} \tag{15}$$

The unit costs of primary energy (PE) for gas and diesel boilers are inverse values to their efficiencies (η). In case of electric boiler, similarly to the heat pump, the efficiency of power plants and power supply systems are taken into account.

Based on the energy required to heat 1 liter of hot water ($Q_{th.en.}$ = 0,231 MJ), the amount of primary energy of fuel ($Q_f$) required for each variant is calculated with formula 14. For heat pump and electrical boiler, presumed that electricity is produced by combined heat and power plants (CHP), where the primary fuel is natural gas. The required amount of fuel (V) is calculated using the calorific values of the respective fuel types:

$$V = Q_f \,/\, \text{calorific values} \tag{16}$$

For ease of comparison the obtained values, they are converted into the tons of equivalent fuel on factors outlined in /41/. In Russia the unit of the reference fuel is equivalent to the calorific value of 1 kg of a typical coal (29,33 MJ/kg). An amount of tons of equivalent fuel replaced with using a heat pump could be calculated as the difference of obtained values. Results of described calculation are demonstrated in Table 9.

**TABLE 9. An amount of tons of equivalent fuel replaced by using a heat pump**

| | | Storage water heater (indirect) | | | HP | Electrical boiler |
|---|---|---|---|---|---|---|
| | | Natural gas | Cond. gas | Diesel | | |
| $Q_{th.en}$, for heating of 1 l | MJ | 0,2310 | | | | |
| - efficiency of the device | | 0,96 | 0,96 | 0,92 | 4 | 0,98 |
| - efficiency of the CHP | | - | - | - | 0,4 | 0,4 |
| - efficiency of power supply systems | | - | - | - | 0,95 | 0,95 |
| Unit cost of primary energy (PE) | | 1,04 | 1,04 | 1,09 | 0,66 | 2,69 |
| Utilization rate of primary energy (URPE) | | 0,96 | 0,96 | 0,92 | 1,52 | 0,37 |
| $Q_f$, fuel's energy per 1 year, MJ | | 29861,56 | 29861,56 | 31159,89 | 18859,93 | 76979,32 |
| Calorific value of utilized fuel | | 33,08 | 46,8 | 42,7 | 33,08 | 33,08 |
| | | MJ/$m^3$ | MJ/kg | MJ/kg | MJ/$m^3$ | MJ/$m^3$ |
| Required amount of fuel (V) | | 902,71 | 638,07 | 729,74 | 570,13 | 2327,07 |
| | | $m^3$ | kg | kg | $m^3$ | $m^3$ |
| The conversion factor in tons of reference fuel | | 1,154 | 1,57 | 1,45 | 1,154 | 1,154 |
| | from | 1000 $m^3$ | t | t | 1000 $m^3$ | 1000 $m^3$ |
| Tons of reference fuel / year | | 1,042 | 1,002 | 1,058 | 0,658 | 2,685 |
| Number of the replaced tons of reference fuel per year | | 0,38 | 0,34 | 0,4 | 0,0 | 2,03 |

According to the obtained results, it can be concluded that the use of a heat pump instead of other traditional ways of domestic hot water preparing allows to reduce the reference fuel consumption on 0,38 - 2,03 tons per year. The greatest effect could be achieved by replacing an electric boiler by the suggested wastewater source heat pump system. The calculation does not include energy costs for extraction, transportation and preparation or processing of a fuel.

## 5 RESULTS AND DISCUSSION

Table 10 illustrates obtained results with a further discussion.

**TABLE 10. Compilation of obtained results**

| | | | | Private house |
|---|---|---|---|---|
| Number of inhabitants | | | | 4 |
| Sewage flow | Maximum hours (7/24) | | $q_{max}$, l/h | 120,0 |
| | Per day | | $q_{day}$, l/day | 840,0 |
| $t_{sew}$ | | | °C | + 27,3 |
| Available thermal energy (to +10°C), $Q_{sew}$ | Hourly | | kWh | 2,42 |
| | Per day | | | 16,92 |
| Heating mode | CoolPack | Temperature mode [COP (R407c)] | | 5/40 [6,09] |
| | | Design load per hour, $\Phi_h$ | kW | 9,96 |
| | | Share of substitution of the required low-potential power | % per max hour | 29 |
| | | | % per day | 8 |
| | | | % per heating period | 17 |
| Domestic Hot Water mode | CoolPack | Temperature mode [COP (R407c)] | | 5/65 [3,19] |
| | | Conclusion | | For preparing 200 l of hot water required 3,65 h of a sewage heat utilization |
| | Payback period of the | | | From 6 years to no payback |
| | Number of the replaced tons of reference fuel per year | | | 0,34 - 2,03 |

Discussion of obtained results:

1. The determining factor for assessment of a technical potential of sewage heat recovery in private houses is an absence of stable schedule of water use. In this work made an assumption of 7 hours of water use per day. This presumption allows to consider wastewater only as an additional source of low-grade heat for a heat pump work into a heating mode. Meanwhile, performed calculations show that the heat of sewage is sufficient for preparing hot water for domestic use (with a heat pump application). This fact is predetermined by the coincidence of the peaks of hot water draw-off with moments favorable for the heat extraction from effluents.
2. In a heating mode an utilization of waste water's heat as an additional low-potential source allows to reduce the amount of energy from the primary source by 8% during a day with a design load onto heating system, and by 17% during the heating period.
3. Results of simulation into CoolPack program demonstrate, that for heating of 200 l of hot water (that is enough for 4 hours of water use) required 3,55 hours of sewage heat utilization with medium temperature +27,3°C. Such a buffer of time allows to expect that real models of heat pumps will ensure the effective operation mode.
4. Evaluation of the payback period of the proposed sewage source heat pump system revealed the inexpediency of its application in case of existing connection to the gas pipeline. In this case, with current energy prices the current costs are comparable, while capital expense for the heat pump system is much higher. The most reasonable is to give precedence to proposed system when replacing a boiler on diesel fuel (payback period ≈ 7,5 years).
5. From the standpoint of energy efficiency, the heat pump is the most efficient converter of fuel energy (with using gas as the main fuel on the power station). Due to the COP equal to 4 in considered model of heat pump, it is possible to replace from 0,34 to 2,05 tons of reference fuel compared with conventional heat generators.

# 6 CONCLUSION

There is a technical potential of using waste water as a source of low-grade heat for a heat pump operation. In the world practice, accumulated a significant base of tech-nical solutions. Considered case demonstrates an importance of individual approach in designing the sewage source heat pump systems depending on the initial data. A significant advantage of domestic systems is the minimum number of intermediaries in the heat exchange process. However, unevenness of water consumption in a private house allows to consider wastewaters only as an additional source of low-grade heat.

The most likely is the use of sewage source heat pump systems for domestic hot water heating due to coincidence of time intervals of increased demand for hot water and the presence of sufficient thermal capacity in effluents. The use of this low-potential source of heat is technically possible and recommended for reduction the load on the other sources and the whole system cost in case of application the hybrid heat pumps.

# REFERENCES

1. Elistratov S.L. Комплексное исследование эффективности тепловых насосов (A comprehensive study of the efficiency of heat pumps). The thesis for the degree of Doctor of Science. Novosibirsk. 2010.
2. Газпром Межрегионгаз. Газификация регионов России. WWW document. mrg.gazprom.ru/about/gasification/. Updated 13.09.2016. Referred 13.09.2016.
3. Torío, H., Schmidt, D. Development of system concepts for improving the performance of a waste heat district heating network with exergy analysis. Energy and Buildings, 42(10), 1601–1609. 2010.
4. Schmid F. Sewage water: interesting heat source for heat pumps and chillers. Swiss Energy Agency for Infrastructure Plants. Zürich, Switzerland. 2009.
5. EPA: US Environmental Protection Agency. Global Greenhouse Gas Emissions Data. WWW document. www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data. Updated 13.09.2016. Referred 13.09.2016.
6. Vasilyev G.P., Zakirov D.G., Abuev I.M. О тепловом ресурсе сточных вод и его использовании (On the thermal resource of wastewater and its use). Водоснабжение и канализация (Water supply and Sewerage), № 7-8, 50-53. 2009.
7. Qian J. Heating performance analysis of the direct sewage source heat pump heating system. International Conference on Mechanic Automation and Control Engineering (MACE). Wuhan, China. 1337-1340. 2010.
8. Kalnin I.M., Savickij I.K. Тепловые насосы - вчера сегодня завтра (Heat pumps – yesterday, today, tomorrow). Холодильная техника (Cooling technology), №10, 2-6. 2000.
9. SP 60.13330.2012. Отопление, вентиляция и кондиционирование воздуха (Heating, Ventilation and Air Conditioning). Russian Ministry of Regional Development. 2013.
10. Cipolla S.S., Maglionico M. Heat recovery from urban wastewater analysis of the variability of flow rate and temperature in the sewer of Bologna, Italy. Energy Procedia, 45, 288-297. 2014.
11. Buderus. Рассольно-водяные тепловые насосы Logatherm WPS 6–11 K и WPS 6–17 от 6 кВт до 17 кВт. WWW document. www.buderus.lv/files/201205311348470.Planungsunterlage_Heatpumps_RU.pdf. Updated 13.09.2016. Referred 13.09.2016.

12. Oguzhan Culha, Huseyin Gunerhanb, Emrah Biyikc, Orhan Ekren, Arif Hepbasli. Heat exchanger applications in wastewater source heat pumps for buildings: A key review. Energy and Buildings, 104, 215-232. 2015.
13. Perackova J., Podobekova V. Utilization of heat from sewage. Budownictwo o zoptymalizowanym potencjale energetycznym, 2(12), 79-86. 2013.
14. ThermoDrain. Thermodrain, a unique drain water heat exchange technology. WWW document. ecoinnovation.ca/technicalguide/. Updated 13.09.2016. Referred 13.09.2016.
15. KASAG. Heat exchanger solutions to recover energy from water, sewage and process heat. WWW document. www.kasag.ch/LinkClick.aspx?fileticket=BCxW6w4sF6g%3d&tabid=152&language=en-US. Updated 13.09.2016. Referred 13.09.2016.
16. Rabtherm. Energy Systems. WWW document. www.rabtherm.com/index.php?option=com_content&view=article&id=60&Itemid=35&lan. Updated 13.09.2016. Referred 13.09.2016.
17. Ostapczuk R., Railsback D. Assessment of Sewage Heat Recovery Technology and Applicability to the Milwaukee Metropolitan Sewerage District. ARCADIS. 2013.
18. Huber Technology. Heating and cooling with wastewater. WWW document. www.wwdmag.com/sites/wwdmag.com/files/ThermWin%20Brochure%20trg.pdf. Updated 13.09.2016. Referred 13.09.2016.
19. Vasilyev G.P., Dmitriev A.N., Abuev I.M. Утилизация теплоты сточных вод многоквартирных жилых домов (Wastewater heat recovery of apartment houses). Энергия: экономика, техника, экология (Energy: economy, technology, ecology), 8, 44-48. 2013.
20. Chao S., Yiqiang J., Yang Y. A field study of a wastewater source heat pump for domestic hot water heating. Journal of Building Services Engineering Research & Technology, 34(4), 433-448. 2013.
21. Titar S.S., Klimchuk A.A. Использование сбросного тепла в системе автономного теплоснабжения жилых зданий (The use of waste heat in the autonomous heating systems of residential buildings). Вестник Нац. техн. ун-та "ХПИ" (Collected book of National Technical University "KhPI", 6, 121-125. 2011.
22. Барышенская Ю. Применение тепловых насосов в жилищно-коммунальном хозяйстве. Материалы V Международной студенческой электронной

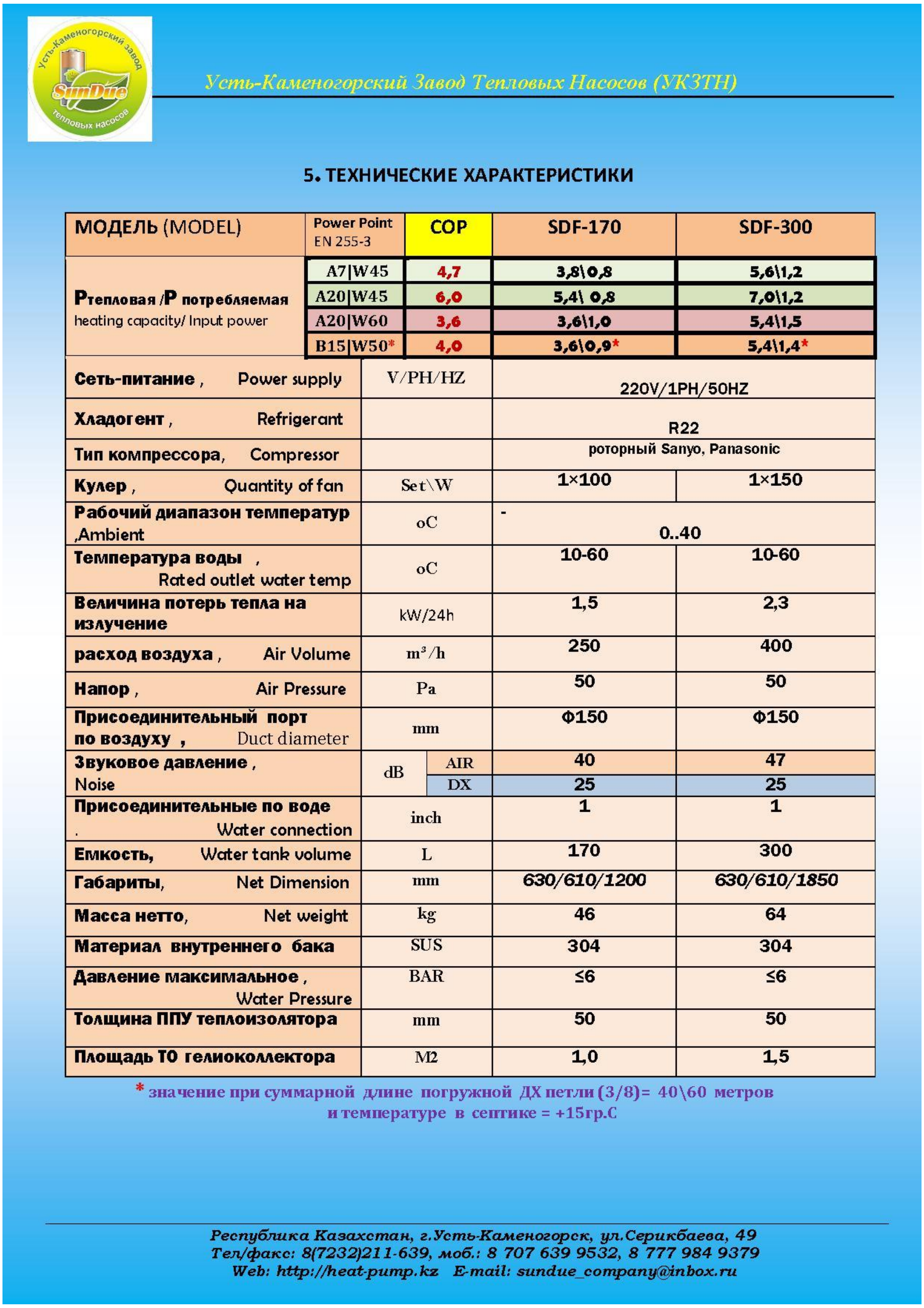
научной конференции «Студенческий научный форум» 15.02 - 31.03.2013 года. WWW document. www.scienceforum.ru/2013/43/5801. Updated 13.09.2016. Referred 13.09.2016.

23. REN21 (Renewable Energy Policy Network for the 21st Centure). Renewables 2015. Global Status Report. WWW document. www.ren21.net/wp-content/uploads/2015/07/REN12-GSR2015_Onlinebook_low1.pdf. Updated 13.09.2016. Referred 13.09.2016.
24. WasteWaterHeat. Heating with wastewater heat. Best practice Catalogue. WWW document. www.grazer-ea.at/cms/upload/wastewaterheat/bp_catalogue_070321.pdf. Updated 13.09.2016. Referred 13.09.2016.
25. Zishu Q., Qing G., Yan L. Status and development of hybrid energy systems from hybrid ground source heat pump in China and other countries. Renewable and Sustainable Energy Reviews, Vol.29, 37-51. 2014.
26. David J. Durrenmatt, Oscar Wanner. A mathematical model to predict the effect of heat recovery on the wastewater temperature in sewers. Water Research, 48, 548-558. 2014.
27. Pamminger F., Scott D., Aye L. Heat energy recovery potential from sewers in Melbourne. Water Journal, November, 68-73. 2013.
28. FRIOTHERM. 5 Unitop 50FY heat pump/chiller units simultaneously generate 90 MW heat energy and 60 MW chilled water. WWW document. www.friotherm.com/webautor-data/41/katri_vala_e012_uk.pdf. Updated 13.09.2016. Referred 13.09.2016.
29. Zakirov D.G., Suhanov V.S., Zakirov D.D. Пути решения проблемы теплоснабжения в коммунальном хозяйстве с использованием тепловых насосов (Solutions of heating supply problems in the municipal economy with the heat pumps application). Новости теплоснабжения (News of heating supply), 4 (20), 53-55. 2002.
30. Васильев Г.П. Автоматизированная теплонасосная установка, утилизирующая низкопотенциальное тепло сточных вод города Зеленограда, Московской области. WWW document. www.insolar.ru/lib_12.php. Updated 13.09.2016. Referred 13.09.2016.
31. SP 131.13330.2012. Строительная климатология (Building Climatology). Russian Ministry of Regional Development. Moscow. 2013.
32. SP 124.13330.2012. Тепловые сети (The heating network). Russian Ministry of Regional Development. Moscow. 2013.

33. SP 30.13330.2012. Внутренний водопровод и канализация зданий (Domestic water supply and sewerage of buildings). Russian Ministry of Regional Development. Moscow. 2013.
34. Pat. 2418251 RF, F 28 C 3/00. Устройство для очистки и утилизации низкопотенциального тепла сточных вод (Device for treatment and disposal of low-grade wastewater heat). Gornov V.F., Ehrchenko I.A., Vasilev G.P. [and others] ; proprtietor «INSOLAR». № 20090133884/06; fil. 10.09.09 ; publ. 10.05.11. 1 p. : dr.
35. Pat. 2349854. RF, IPC1-7: F 28 C 3/04. Фильтровально-теплообменный аппарат (The filter and heat exchanging device). Borinskih I.I., Zakirov D.G., Nekhoroshih I.H. [and others]; proprtietor МНИИЭКОТЭК. № 20000106655/06 ; fil. 05.06.06 ; publ. 20.03.09. 1 p. : dr.
36. Pat. 2440151. Great Britain, E 03 B 1/04, E 03 C 1/12, F 28 D 1/02. Improvements to grey water and energy recycling. Wigley Victor Joseph ; proprietor Wigle V.J., Kingfisher Studio. – № 0614223.6 ; fil. 18.07.06 ; publ. 23.01.08. 5 p. : dr.
37. Pat. 134549. RF, IPC7 E 03 C 1/12. Устройство утилизации теплоты сточных вод жилого дома (The device for utilization the heat of waste water in residential houses). Feoktistov E.V., Yurchenko I.A., Gornov V.F. [and others]; proprtietor «INSOLAR». № 2013104222/13 ; fil. 01.02.13 ; publ. 20.11.13. 1 p. : dr.
38. SP 32.13330.2012 Канализация. Наружные сети и сооружения (Sewerage. External networks and facilities). Russian Ministry of Regional Development. Moscow. 2013.
39. Sadovnikov A.A. Использование тепловых насосов для подогрева воды в бассейнах (The use of heat pumps for heating water in swimming pools). Сантехника (Sanitary equipment), 2, 18-25. 2013.
40. Trubaev P.A., Grishko B.M. Тепловые насосы (Heat Pumps). Belgorod. БГТУ им. В.Г. Шухова (BSTU named after V.G. Shukhov). 2009.
41. Resolution №46 «Об утверждении "Методологических положений по расчету топливно-энергетического баланса Российской Федерации в соответствии с международной практикой» (On the approval of «Methodological guidelines for calculation of the fuel and energy balance of the Russian Federation in accordance with international practice»). State Statistics Committee of the Russian Federation. 1999.

# APPENDIX 1.

## Technical features of the SunDue manufactured heat pumps



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### 5. ТЕХНИЧЕСКИЕ ХАРАКТЕРИСТИКИ

| МОДЕЛЬ (MODEL) | Power Point EN 255-3 | COP | SDF-170 | SDF-300 |
|---|---|---|---|---|
| **Pтепловая /P потребляемая** heating capacity/ Input power | A7\|W45 | 4,7 | 3,8\0,8 | 5,6\1,2 |
| | A20\|W45 | 6,0 | 5,4\ 0,8 | 7,0\1,2 |
| | A20\|W60 | 3,6 | 3,6\1,0 | 5,4\1,5 |
| | B15\|W50* | 4,0 | 3,6\0,9* | 5,4\1,4* |
| **Сеть-питание** , Power supply | V/PH/HZ | | 220V/1PH/50HZ | |
| **Хладогент** , Refrigerant | | | R22 | |
| **Тип компрессора**, Compressor | | | роторный Sanyo, Panasonic | |
| **Кулер** , Quantity of fan | Set\W | | 1×100 | 1×150 |
| **Рабочий диапазон температур** ,Ambient | oC | | - 0..40 | |
| **Температура воды** , Rated outlet water temp | oC | | 10-60 | 10-60 |
| **Величина потерь тепла на излучение** | kW/24h | | 1,5 | 2,3 |
| **расход воздуха** , Air Volume | $m^3/h$ | | 250 | 400 |
| **Напор** , Air Pressure | Pa | | 50 | 50 |
| **Присоединительный порт по воздуху** , Duct diameter | mm | | Ф150 | Ф150 |
| **Звуковое давление** , Noise | dB | AIR | 40 | 47 |
| | | DX | 25 | 25 |
| **Присоединительные по воде** . Water connection | inch | | 1 | 1 |
| **Емкость**, Water tank volume | L | | 170 | 300 |
| **Габариты**, Net Dimension | mm | | 630/610/1200 | 630/610/1850 |
| **Масса нетто**, Net weight | kg | | 46 | 64 |
| **Материал внутреннего бака** | SUS | | 304 | 304 |
| **Давление максимальное** , Water Pressure | BAR | | ≤6 | ≤6 |
| **Толщина ППУ теплоизолятора** | mm | | 50 | 50 |
| **Площадь ТО гелиоколлектора** | M2 | | 1,0 | 1,5 |

* значение при суммарной длине погружной ДХ петли (3/8)= 40\60 метров
и температуре в септике = +15гр.С

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