Recovery of waste heat from the sewer system

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Abstract. In the first part of my article I would like to introduce the possibilities of the recovery of waste heat from the sewer system and react to the answer of minimalism of the demand of energy needed for the preparation of domestic hot water. The recovery of waste heat from the sewer system outside of building is possible using a heat pump in combination of heat exchanger located in sewerage and the recovery of waste heat of sewer system inside of building is possible using a heat from waste water through a heat exchanger to direct preheating of cold water.

The second part is dedicated to design of alternative solutions of the recovery of waste heat from the sewer system in the object of multifunction sports facility which include complete project documentation of the sport complex with application of heat exchanger to direct preheating of cold water in shower. The efficiency of regenerative systems and the saving of hot water was determined thanks to the experimental observation executed under laboratory conditions.

The main point of this article is to introduce the possibilities of the recovery of waste heat from sewer system, apply them in the object of multifunction sport complex and review the energy and economic efficiency.

1. Introduction

Nowadays, more and more energy is consumed in dwelling houses - energy is used for preparing hot water, heating and cooling of the building and energy became very valuable. The energy consumption for heating and cooling decreases due to thermal insulation of the building constructions and replacement of the windows of the building to new plastic windows with triple glazing, while the energy consumption for preparing hot water is constantly increasing. How can we reduce the energy needed to heat the drinking water? One option is recuperation. We are able to recover waste heat from the sewer system to preheat domestic hot water using a heat exchangers. Heat from wastewater can be optimally used for heating, cooling and hot water preparation in low-energy houses.

2. Recovery of waste heat from the sewer system outside of the building

Waste water drained from different types of buildings is full of unused thermal energy. When using heat recovery from the sewer system outside of building, systems consist of two main parts: heat exchanger and heat pump. Heat exchanger extract the thermal energy from the sewage and transfers it to the heat pump, which supplies the building with this energy.

Heat exchanger is installed at the bottom of the drain pipe which is a connecting element between the waste water and heat pump (figure 1). Heat pumps use the energy contained in the wastewater as source of energy. Heat energy is taken through the heat exchanger and is transferred to the circulated heat transfer medium called refrigerant – water or a mixture of water and glycol. Heat pumps exploit the physical properties of the refrigerant - it compresses the refrigerant to make it hotter.

The low-pressure liquid refrigerant (waste water with temperature 6-14 °C) enters the heat exchanger - evaporator, in which the fluid (water or mixture of water and glycol) absorbs heat and boils and transfers to a gaseous state. The working fluid, in its gaseous state, is pressurized and circulated through the system by a compressor. On the discharge side of the compressor, the currently hot and highly pressurized vapor is cooled in a heat exchanger - condenser, until it condenses into a high pressure, moderate temperature liquid. The condensed refrigerant then passes through a pressure-lowering device also called a metering device. The refrigerant then returns to the compressor and the cycle is repeated, see the Figure 1. [1].

Factors for the design and application of heat recovery systems are the distance between the consuming system and the place of heat recovery (should be as short as possible); constant temperature of the wastewater, as possible; diameter of sewage pipe (at least 800 mm); flow of wastewater; flow rate of wastewater) should be as high as possible, at least 15 l/s). These conditions are usually met in municipalities of over 10,000 inhabitants or a group of residential buildings, swimming pools, administrative or industrial building are also suitable [1].

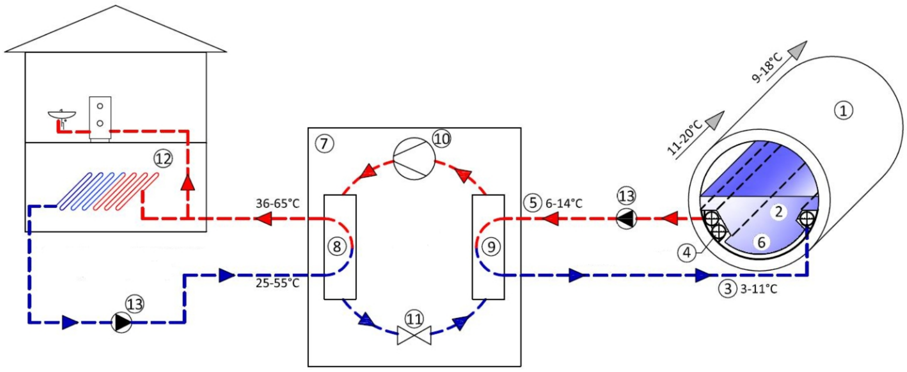

Fig. 1. Circuit layout of heat exchanger embedded in sewage pipe in combination with heat pump [2].

1 - sewage pipeline, 2 – waste water, 3 - cold water supply to the heat exchanger, 4 – pipe for collection of heated water from many heat exchangers if the system Tichelmann is used, 5 - output of the heated water from the heat exchanger, 6 - heat exchanger, 7 - heat pump, 8 - condenser, 9 - evaporator, 10 - compressor, 11 - expansion valve, 12 - heating network in building, 13 - circulating pump

Disposition and design of heat exchangers (Fig. 2) is based on various requirements and the suitability of the sewage network itself.
Heat exchangers (outside the building) are classified according to the structure and location of the:
• heat exchangers embedded in sewage pipe,
• heat exchanger integrated in concrete wall of a sewage pipe,
• sewage pipe with special double jacket

Design of heat exchangers depends on different requirements and on suitability of sewage system itself. Heat exchangers can be installed into existing or new pipelines. It can be used for all kinds of waste water [1].

a)

b)

c)

Fig. 2. Types of heat exchangers for recovery of waste heat from the sewer outside of the building [3,4]

a) stainless steel heat exchanger embedded in the bottom of the sewage pipeline, b) heat exchanger integrated in concrete wall of a sewage pipe, c) sewage pipe with special double jacket

Heat exchangers could be used both in new or in existing pipelines. The advantage of heat exchangers integrated in concrete wall is that the heat exchanger does not detract from the diameter of pipe.

3. Recovery of waste heat from the sewer system inside of the building

Buildings, where is a constant flow rate of waste water and significant amount of it is being drained away, are suitable for heat recovery directly inside them [1]. In this case, it is very convenient to use the heat from the sewage for preheating hot water for immediate consumption. System of the recovery of waste heat from sewage inside of building are based on heat exchangers, which serves to exchange the heat energy between the waste water and the domestic cold water. There is no contact between the water supply and the drain water.

Figure 3 shows the fundamental principle of system of recovery of waste heat from sewage inside of building to direct preheating of domestic hot water. Waste water from the shower with a temperature 38 °C is drained into the sewerage through the heat exchanger. The cold water with the initial temperature 10 °C flows through the heat exchanger, in the opposite direction of the drainage water, and is transported into the thermostatic mixer shower tap via this heat exchanger.

Wastewater transfers the heat through heat exchanger to the cold water to preheat it – cold water can reach a temperature approximately 20 °C. The result is, that we mix a smaller portion of hot water with a larger portion of preheated water for reduce the hot water consumption.

The recovery of waste heat to direct preheat of hot water is recommended for sanitary appliances where the need for hot water exceeds the need for cold water – showers and wash basins. In the case of bath tubs, this principle does not work because the hot water is swallowed at another time as it flows. This type of recuperation is not suitable for kitchen sink because the wastewater contains oils which can settle on the wall of the heat exchanger and thus reduce its effectiveness.

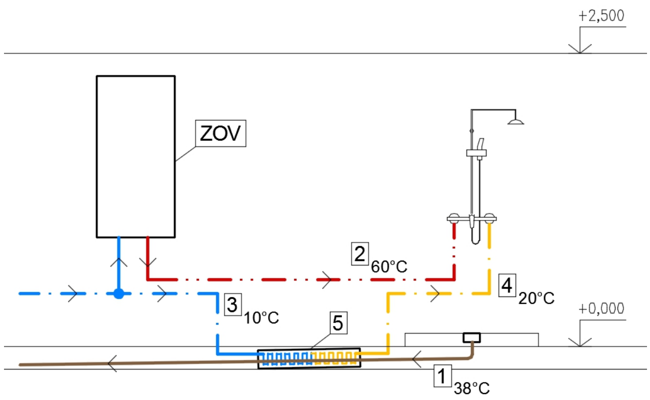

Fig. 3. Cold water preheated for immediate consumption through heat exchanger [5]

1 – waste water drained from the shower (38 °C), 2 – hot water supply from the storage water heater (60 °C), 3 – cold water supply to the heat exchanger (10 °C), 4 – preheated cold water supply to the shower thermostatic mixer tap (20 °C), 5 – heat exchanger, ZOV – storage water heater

Heat exchangers could be installed in a several ways, depending on the type of building, the water requirement in the building or the disposition of the bathroom. The heat exchanger should always be installed as close as possible to the sanitary appliance from which waste heat will be used (shower, washbasin, etc.).

a) direct connection of the heat exchanger to one sanitary appliance (shower):

Figure 4 shows a direct connection of the heat exchanger to one sanitary appliance (shower). Preheated cold water is fed into a thermostatic mixer shower tap, which reduces the hot water consumption. The connection could be comfortably used for showers in flats, family houses, hotels, sanitary equipment of sport facilities, swimming pools, or showers in industrial halls.

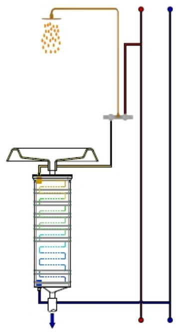

Fig. 4. Direct connection of the heat exchanger to one sanitary appliance (shower) [6]

b) direct connection of the heat exchanger to several sanitary appliances:

Figure 5 shows direct connection of the heat exchanger to several sanitary appliances – one shower and two wash basins. The wastewater drained from the shower and washbasins flows through one common heat exchanger into the sewerage. The preheated water is supplied into the thermostatic mixer tap of the shower and also into the mixer taps of wash basins (Figure 5).

This connection could be used in dwelling houses or apartment flats to direct preheating of the domestic cold water for a sanitary equipment in the bathroom (e.g. a shower and washabsin). Even though this system installation is one of the useful alternatives, for washbasins preheat water to a temperature above 20 °C I do not recommend from the point of view of hygiene of potable water, and the washing times are too low for this system to be effective.

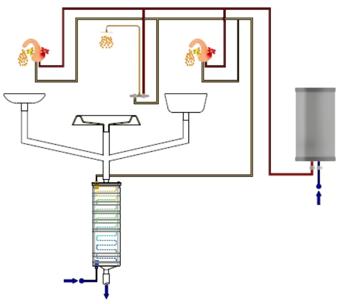

Fig. 5. Direct connection of the heat exchanger to several sanitary appliances (shower and two wash basins) [6]

c) combined connection of the heat exchanger with a storage water heater:

Figure 6 shows a combined connection of the heat exchanger with a storage water heater. The preheated cold water is not only transported into the thermostatic mixture tap but is also transported to the storage water heater which serves to save energy needed for preparation of hot water. This connection could be used in every operation of sanitary equipment where the hot water is prepared locally using a storage water heater.

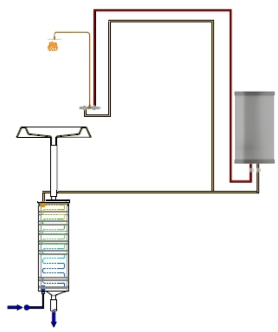

Fig. 6. Combined connection of the heat exchanger with a storage water heater [6]

d) direct parallel connection of the heat exchanger to several sanitary appliances (several showers):

Figure 7 shows a direct parallel connection of the heat exchangers to several sanitary appliances (several showers) which is used in mass showers in objects such as swimming pools, sports facilities, industrial facilities, etc. Sewage from many showers flows into the sewerage through one common sewer pipe into many heat exchangers. With this type of installation, as many heat exchangers are installed as many sanitary appliances there are - heat transfer is more efficient.

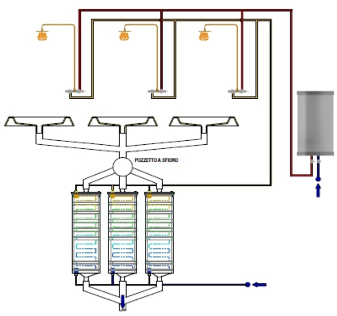

Fig. 7. Direct parallel connection of the heat exchangers to several sanitary appliances – showers [6]

4. Types of heat exchangers for recuperation of waste heat from the internal sewerage system

Several types of heat exchangers for recuperation from the internal sewerage systems are known - special shower trays with integrated heat exchanger [7] (see chapter 4.1), heat exchanger in combination with a shower with floor drain system [9] (see chapter 4.3), wastewater storage tank with integrated heat exchanger, regenerative panels with stainless steel heat exchanger [6] (see chapter 4.4), etc. In the rest of this article I would like to introduce alternative solutions of the recovery of waste heat from the sewer system which I applied in the object of a sport facility.

4.1 Shower tray with integrated heat exchanger

In this case, the recuperation system consists of a special shower tray below which heat exchanger is integrated (Fig. 8). Heat exchanger is placed under a shower tray, normal height of shower tray is maintained. The waste water flows across a spherical copper shell from the centre to the outside, underneath the shell copper pipes are connected to the shell. The fresh water flows through these pipes and is thereby preheated and this preheated cold water is supplied to the water heater or / and the shower mixer tap. There is a trap in the centre of the heat exchanger which prevents smells or vapour entering the bathroom. The heat exchanger has a double wall separation between sewage and potable water. Combining the heat exchanger with copper or multilayer water pipes is recommended. This kind of heat exchangers is recommended to dwelling houses, apartments, hotels, nursing homes, swimming pools, hospitals, industrial applications, gyms, etc.

The energy efficiency depends on the flow of water, and is around 41 %. Efficiency can decrease as a result of dirt accumulating on the inside of the heat exchanger. The surface of the heat exchanger, the dish, can become slightly fouled. It only takes a couple of minutes, once or twice a year to clean the surface using a brush [7].

Fig. 8. Shower tray with integrated heat exchanger [7]

4.2 Heat exchanger in the form of regenerative panel placed under the shower tray

Recuperative panels are designed to recover energy from waste water from the shower. This panel has a plastic casing and the heat exchanger is made of a copper in the form of a spiral (Fig. 9). The efficiency of these heat exchangers is approximately 30%. The wastewater flows around the heat exchanger. Cold water is supplied to the thermostatic shower mixer through this heat exchanger. The heat extracted from the waste water through the heat exchanger is supplied to the cold water in order to preheat it [8].

Fig. 9. Heat exchanger in the form of regenerative panel placed under the shower tray [8]

The efficiency of this type of heat exchanger depends on the shower flow rate of water – at the flow of 5,8 l/min the efficiency is 36,6 % and at the flow of 12,5 l/min the efficiency is 27,9%.

The design of this water heater allows to minimize Legionella-related risks, as follows:

- The unit has no dead spaces and is subject to high flow rates which prevents water from stagnation.
- Drain water never stays a long time inside of the unit since its construction guarantees that it is fully drained out at the end of the shower.
- After a shower, fresh water cools down below 25°C,
- Copper coil itself contributes to reducing Legionella-related risks.

The maintenance of a heat exchanger is very – this device must be installed with a shower drain filter and trap to prevent the passage of debris. Like any other drain pipe, is strongly recommended a periodically cleaning [8].

4.3 Heat exchanger in combination with a shower with floor drain system

This recuperative panel in combination with the shower with floor drain system (Fig. 10) offers a compact and efficient solution for heat recovery from wastewater inside of building. Waste water passes through a heat exchanger which is a double walled stainless steel heat exchanger in the form of a spiral. The energy efficiency depends on the flow of water The reported efficiency of these heat exchangers depend on the shower flow rate - at the flow of 9 liters/min the efficiency is 38,9 % and at the flow of 11 liters/min the efficiency is 38,6% [9].

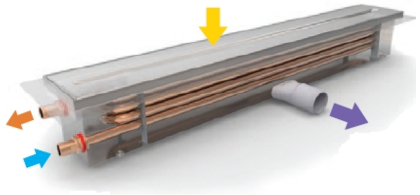

Fig. 10. Waste water heat recovery system for showers with floor drain system [9]

The maintenance required for the heat exchanger is very minimal, however, it is recommended to clean the unit periodically to avoid any reduction in efficiency. This cleaning will remove any build - up of soap and dirt residue on the inside of the copper pipe where the waste water passes [9].

4.4 Regenerative panels with stainless steel heat exchanger

Regenerative panel consists of a plastic waterproof case and a stainless steel heat exchanger (Fig. 11). The heat exchanger is placed as close to sanitary equipment as possible. Through the heat exchanger to sanitary equipment cold water (10 °C) is transported to the thermostatic shower mixer tap. Heat from wastewater is transferred to cold water to preheat it. The regenerative panel is available in two versions –630 mm long version and 1320 mm long version. [6].

Fig. 11. Regenerative panel with stainless steel heat exchanger [6]

The energy efficiency greatly depends on the the temperature of hot water at the output of water heater and the type of installation. If the preheated water out of the heat exchanger is sent both to the mixer and to the water heater, the energy savings are at the maximum. In this case, if the heat exchanger is placed at some distance from the drain point, a certain loss of heat from the pipes must be taken into consideration. If we use direct connection of the heat exchanger to one sanitary appliance, there is the advantage of a very short connection and therefore minimizes any heat losses.

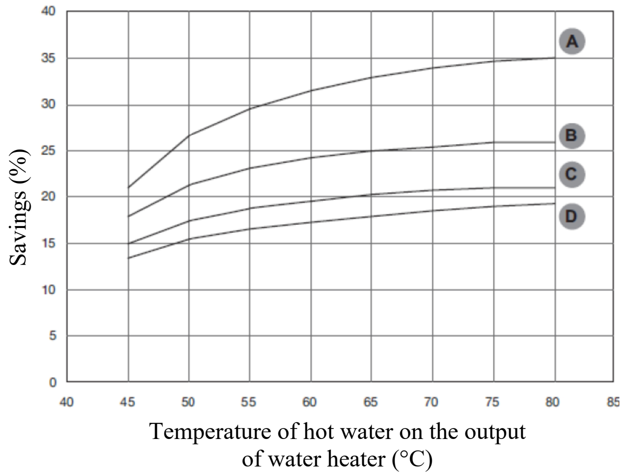

Fig. 12. Saving of energy according to the temperature of hot water at the output of water heater for different flow rates [6]
A – flow rate of hot water in the shower 4 l/min
B – flow rate of hot water in the shower 8 l/min
C – flow rate of hot water in the shower 12 l/min
D – flow rate of hot water in the shower 16 l/min

5. Alternative solutions of recovery of waste heat from sewer system inside of building

In the project documentation of multifunction sports facility I consider the sanitary equipment using recovery of waste heat from sewage from showers. I propose alternative solutions for the use of waste heat from internal sewerage as follows:

<u>a) recuperation using a shower trays with an integrated circular heat exchanger</u> through which the waste water flows. The cold water (10 °C) supply into the shower tray from the bottom of the heat exchanger. At the bottom of the heat exchanger there is a drainage of cooled wastewater. Preheated cold water (20 °C) is transported from the shower tray to the wall-mounted thermostatic shower mixer through the heat exchanger. The temperature 20°C of preheated cold water was experimentally observed.

In the Figure 13 we can see a floor plan of the sports facility, where the heat recovery is solved using a shower trays with an integrated circular heat exchanger through which the wastewater flows.

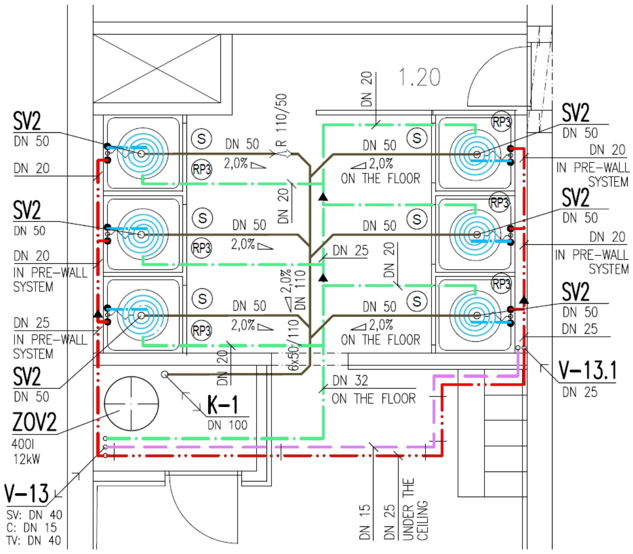

Fig. 13. Floor plan with alternative solution of recovery of waste heat using a shower tray with integrated heat exchanger

V – rising pipe of cold water, hot water and circulation of hot water, K – foul water stack, ZOV – water heater, SV2 – squared shower tray with drain in the middle, RP3 – shower tray with integrated heat exchanger, S – wall-mounted thermostatic shower mixer

b) recuperation using a heat exchanger in the form of regenerative panel placed under the shower trays.

Figure 14 shows a floor plan of the sports facility, where the heat recovery is solved using a heat exchanger in the form of regenerative panel placed under the shower trays, in the floor. The wastewater will be drained from the shower tray through the regenerative panel and the cold water flows through the heat exchanger.

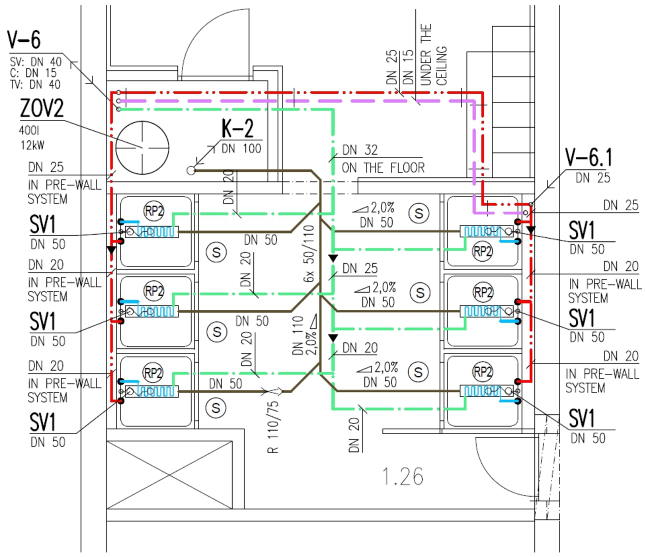

Fig. 14. Floor plan with alternative solution of recovery of waste heat using a heat exchanger placed under the shower tray

V – rising pipe of cold water, hot water and circulation of hot water, K – foul water stack, ZOV – water heater, SV1 – squared shower tray with drain up, in the middle, RP2 – heat exchanger-regenerative panel placed under the shower tray, S – thermostatic shower mixture tap

c) recuperation using the with regenerative panel with stainless steel heat exchanger placed in the floor, close by the shower. I propose to drain the sewage water from the shower tray through the branch pipe situated in the floor via the regenerative panel. The cold water with the initial temperature 10 °C flows through the heat exchanger in the opposite direction of the drainage water and is transported into the thermostatic mixer shower tap as a preheated water with temperature approximately 20 °C. It is recommended that preheated cold water pipe and the regenerative panel are thermally insulated. The temperature 20°C of preheated cold water was experimentally observed.

In the Figure 15 is shown a floor plan of the sports facility, where the heat recovery is solved using the regenerative panel with stainless steel heat exchanger placed in the floor, close by the shower. I propose a direct connection of the heat exchanger with length of 613 mm to one sanitary appliance, shower, and a direct connection of the heat exchanger with a length of 1319 mm to two sanitary appliances – two showers.

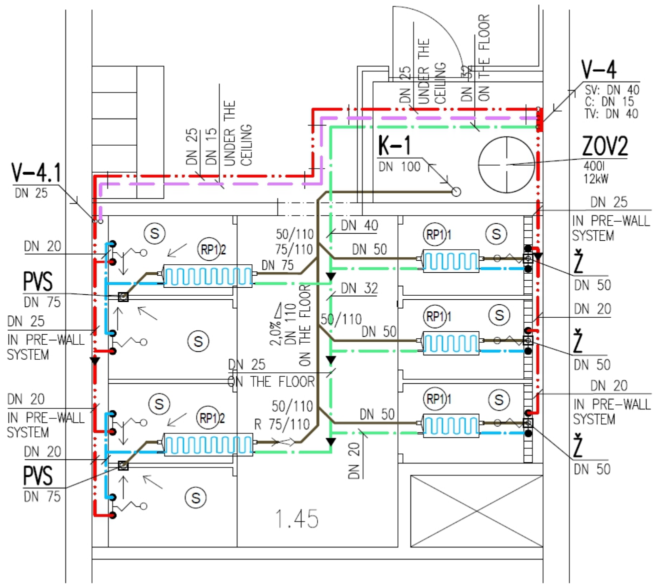

Fig. 15. Floor plan with alternative solution of recovery of waste heat using a panel with stainless steel heat exchanger

V – rising pipe of cold water, hot water and circulation of hot water, K – foul water stack, ZOV – water heater, PVS – shower floor drain, RP1 –regenerative panel with stainless steel heat exchanger: RP1.1 – length of the panel 613 mm, RP1.2 – length of the panel 1319 mm

cold water (10 °C)
preheated cold water (20 °C)*
hot water (50 °C)
foul water (38 °C)
circulation of hot water (55 °C)

*The temperature 20°C of preheated cold water was experimentally observed.

Figure 16 shows the recuperation using regenerative panels with stainless steel heat exchanger with a direct parallel connection of the regenerative panels. Parallel connection I propose for three showers - I propose installing three heat exchangers through which cold water will be supplied for three thermostatic shower mixers and to a water heater.

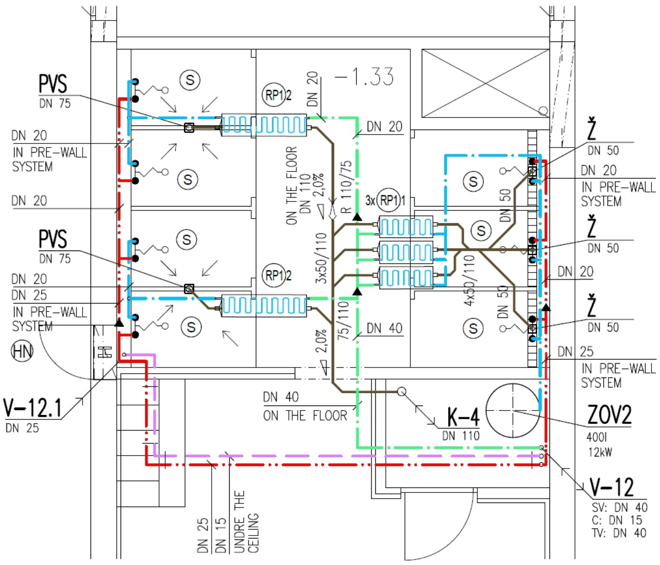

Fig. 16. Floor plan with alternative solution of recovery of waste heat using direct parallel connection of panels

V – rising pipe of cold water, hot water and circulation of hot water, K – foul water stack, ZOV – water heater, PVS – shower floor drain, RP1 –regenerative panel with stainless steel heat exchanger placed in the floor: RP1.1 – length of panel 613 mm, RP1.2 – length of panel 1319 mm

cold water (10 °C)
preheated cold water (20 °C)
hot water (50 °C)
foul water (38 °C)
circulation of hot water (55 °C)

6. Evaluation of the system of recovery of waste heat from the energetic and economic point of view

The last part of my article is dedicated to experimental observation of the system of recovery of waste heat from the sewer system inside of the building.

The energy evaluation of this system is based on the results of the experimental observation carried out in the laboratory of the Department of Building Services in The Faculty of Civil Engineering. The purpose of the experimental observation was to calculate the energy savings and payback period of heat exchanger. In this observation regenerative panel with stainless steel heat exchanger was used [6].

Technical equipment installed in the laboratory:

In the laboratory there was only potable cold water supply installed. For the experimental observation was necessary to provide water heater as a source of heat needed for hot water preparation. Electrical water heater with a capacity of 100 liters was installed in the laboratory.

As the pressure conditions in the system of water supply were insufficient, it was necessary to increase the pressure using water pressurization system – compact electronically controlled home waterworks was installed in order to provide the required pressure.

The measured values were:

- Temperature of hot water
- Temperature of cold water
- Temperature of mixed water
- Temperature of waste water
- Temperature of preheated cold water
- Flow of hot water
- Flow of mixed water

The experimental model was based on a direct connection of the regenerative panel to one shower. Experimental model was installed in order to shower could be started with recovery of waste heat and without recovery, because we wanted to compare measured values of both cases. On the cold water route there are bypasses installed with shut-off valves which allowed measurements to be made for both recovery and non-recovery system (Figure 17).

The hot water consumption was measured during a shower with recovery of waste heat and without a heat recovery, values were compared and the evaluation of system of recovery of waste heat was made.

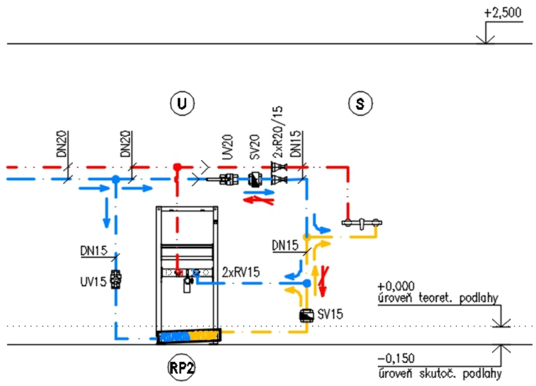

Fig. 17. Detail of connection of heat exchanger with bypass of cold water

S – wall-mounted thermostatic shower mixer, U – wall-mounted thermostatic washbasin mixer, RP2 – heat exchanger in the form of regenerative panel placed in the floor of laboratory, UV – shut-off valve, SV – backflow prevent

cold water (10 °C)
preheated cold water (20 °C)*
hot water (50 °C)

*The temperature 20°C of preheated cold water was experimentally observed.

For the purpose of the evaluation of system of recovery of waste heat I chose the object of a sports facility. The input data for evaluation were as follows:

- operating hours of the object of sports facility: 12 hours per day, 350 days a year
- is considered one shower per hour
- duration of one shower: 5 minutes
- totally 4,200 showers per year on one shower with one heat exchanger

Shower without recovery of waste water:
- hot water flow: 5.71 l/min
- hot water consumed per 5-minute shower: 28.55 liters

Shower with recovery of waste water:
- hot water flow: 4,407 l/min
- hot water consumed per 5-minute shower: 23.70 liters

The total hot water savings were approximately 5 liters per one shower.

With these data obtained in experimental measurement was possible to calculate the cost of shower with and without recuperation - it was considered preparation hot water using electrical water heater and gas water heater. First I calculate the power consumption – energy needed for heating a cold water and I multiply the energy needed for heat by the price of every type of energy (electricity and gas) – I obtained the price of one shower. I consider totally 4,200 showers per year on one shower with one heat exchanger – prices for one year showering with recuperation and without recuperation was determined.

When comparing prices for showering with and without recuperation, we can calculate the annual savings for each type of energy (Fig. 18):

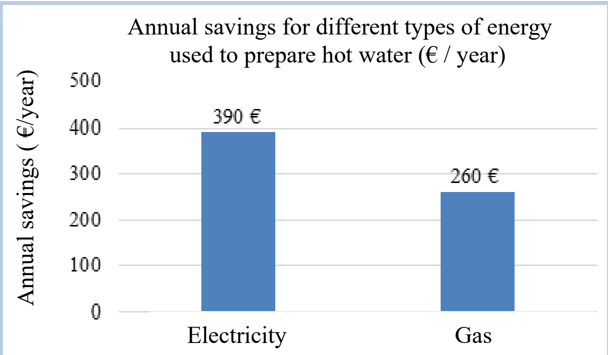

Fig. 18. Annual savings for each type of energy used to prepare hot water

The payback period of installed regenerative panel with stainless steel heat exchanger to one shower is 1.5 years when electricity is used for preparation of hot water and for using gas, the payback period is 2 years and 4 months.

7. Conclusion

The aim of this article was to introduce different possibilities of using heat from external and internal sewerage systems and answer to the question about reducing the need of energy for preparation hot water. Recovery of waste heat from sewer systems outside of building is applied in municipalities over 10,000 inhabitants, in order to ensure sufficient flow. Suitable consumers are building complexes of several buildings near the source of heat.

Heat recovery from sewerage systems inside of the buildings could be applied in dwelling houses and apartment flats, in sports facilities, swimming pools or factories and the advantage of these systems is that, in addition to their simplicity and price, there is no need for electricity to operate them.

In the paper I presented various ways and alternative solutions by using recuperation, the options of recovery of waste heat from sewerage systems are many and these systems can also be applied in our conditions. Sewage water discharged from dwelling houses, residential, administrative, sports or other buildings is full of unused energy and presents a low-potential renewable source of energy that can be used to prepare hot water or heating and cooling the building.

Acknowledgement

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