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Heat flow analysis and description of the cooperation of the heat exchange station with heat exchange substations located in apartments

Dawid Taler[a], Tomasz Sobota[a], Jan Taler[b*], Agata Kania[c], Robert Wiśniewski[c]

[a] Department of Thermal Processes, Air Protection and Waste Utilization, Cracow University of Technology, ul. Warszawska 24, Cracow 31-155, Poland
[b] Department of Energy, Cracow University of Technology, al. Jana Pawla I 37, Cracow 31-864, Poland
[c] MPEC S.A. in Cracow, Al. Pokoju 81, 31-564 Cracow, Poland
*Corresponding author email: jan.taler@pk.edu.pl

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Abstract

This paper presents an analysis of the heat flow in a plate heat exchanger located at a building heat exchange station. The plate heat exchanger is the main source of heat for the building system based on microsubstations in the building apartments. The co-operation of the heat exchange station with the substations in the apartments is also described. Such microstations are intended for both domestic hot water preparation and apartment heating. The method of calculating the product of the heat transfer coefficient k and the heat exchange surface area A is presented. In order to verify the correctness of the measured values of the temperatures of hot and cold water at the heat exchange station inlet and outlet, they were compared to the values calculated using the ε-NTU method. Good agreement was found between the results of the calculations and the measurements. Recommendations were made for the temperature of return water to the heating station. The cost of operating the district heating network could be reduced by increasing the surface area of central heating radiators in apartments, so that the temperature of return water to the heating station could be lowered.

Keywords: Monitoring of the heat station; Plate heat exchanger; Heat exchanger efficiency; Building central heating; Residential micro heating station

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1. Introduction

Siegenthaler's comprehensive book [1] presents both individual and central heating systems. Design solutions for building heating systems and issues of heating power control in the entire district heating network as well as in individual buildings are described. Also presented is the principle of the operation of microstations installed in apartments. Such microstations are intended for both domestic hot water (DHW) preparation and apartment heating. With a microstation installed in the apartment, only one heat substation is used instead of the two substations previously required – one to heat the building and the other to supply the apartment with domestic hot water.

A comprehensive analysis of central heating systems, concerning mainly operating and control issues, is presented in [2]. Attention is drawn to the frequent occurrence of excessively high temperatures of return water from apartments and the entire building, which are only 3–5°C lower than the district heating

Nomenclature

A – heat transfer surface area of the exchanger, m^2
$\dot{C}$ – heat capacity rate, W/K
$\bar{c}$ – water mean specific heat, J/(kg K)
k – heat transfer coefficient, $\mathrm{W/(m^2K)}$
$\dot{m}$ – water mass flow rate, kg/s
NTU – number of heat transfer units
$\dot{Q}$ – heat flux, W
$\dot{Q}_m$ – mean heat flux, W
T – temperature, °C
$\dot{V}$ – water volume flow rate, $\mathrm{m^3/s}$

Greek symbols

ΔT_m – logarithmic mean temperature difference, °C
ε – heat exchanger efficiency
ρ – density, $\mathrm{kg/m^3}$

Subscripts and Superscripts

max – maximum
min – minimum
np – medium with low parameters (water in the building system)
pnp – water return from the building system to the station exchanger
pwp – water return from the station exchanger to the heat distribution network
znp – outlet of water supplying the building system from the heat exchange station exchanger
zwp – inlet of water from the heat distribution network to the heat exchange station exchanger
wp – medium with high parameters (network water)

Abbreviations and Acronyms

DHW – domestic hot water
SCADA – supervisory control and data acquisition

system water temperature at the heat exchange station supply. It should be added that if a heat exchange station supplies a residential building equipped with microstations in each unit, which is the case analysed in this paper, the temperature of the building return water is only about 2°C lower than that of the water in the district heating system. In such a situation, it is necessary to select optimal values of both the network water temperature and flow rate to ensure a proper supply of heat and hot water to the building, while maintaining low costs of network water generation and low consumption of energy needed for pumping water in the district heating network.

Issues related to the operation and control of district heating networks are the subject of numerous publications in scientific journals. This is partly due to the increasing use of renewable energy sources in central district heating systems and the application of new solutions in the supply of buildings with heat and hot water.

Ensuring a stable room temperature and adequate operating efficiency by means of predictive control for a district heating station is the subject of [3]. In China, the control of a heating station is mostly realized through weather compensation control. This leads to substantial variations in room temperature and to high consumption of energy needed for water pumping in the heating network.

A literature review of the integration of renewable energy sources with low-temperature district heating systems was conducted by Sarbu et al. [4]. A low-temperature district heating system makes it possible to provide large amounts of heat. This is, however, due to the low temperature in decentralized heat pumps (HPs) that are needed to raise the temperature of the medium before it enters buildings.

Heat exchange substations located in individual apartments, also called micro heat exchange stations or logotherms, provide an individual heat supply for heating and hot water preparation. They are used in multi-family housing where the building has one main source generating heat in a boiler room or in a heat exchanger plant. The heating medium from the main source of the building heat supply is transported by the heating system to individual apartments equipped with heat exchange substations (logotherms). Such a thermal energy management system will just as well find application in commercial premises, as it enables individual regulation of the heating medium, making it possible to set individual preferences for thermal comfort. A heating system in a residential or commercial building based on one main heat source and logotherms in individual units makes it possible to produce domestic hot water efficiently and supply the heating medium. The main source of heat for the building can be a gas boiler room, an oil boiler room or a heat exchange station. In the case of a boiler room, heat is produced directly on site, whereas in the case of a heat exchange station, thermal energy is produced at a combined heat and power plant or at a heating plant, and then distributed to the heat exchange station, where it feeds the building internal heating system through a heat exchanger.

The advantage of boiler plants is their operation with modulated power, which makes it possible to adjust the power of the device to the consumers' current heat demand. When logotherms show less demand for heat from the main source, boiler rooms with modulated power lower the operating parameters.

If the heat exchange station is the main heat source, there is a need to take into account the relevant operating parameters of the district heating network. When logotherms co-operate with a heat exchange station, it is necessary to pay attention to the operating parameters of the heat exchange station on the primary side, i.e. on the side of the working medium with high temperature, and on the secondary side, i.e. on the side of the heating system of the building. Thermal energy has to be supplied to the customer in the amount and with parameters strictly defined, and at the same time care has to be taken to ensure appropriate parameters of the district heating network on the primary side so that they should match the performance characteristic of the sources of energy. The parameters of the district heating network are strictly defined by the heat distribution company. The distribution company is obliged to maintain the parameters of the heat distribution network at both the heat consumer's and the heat producer's end.

This paper presents an analysis of the heat flow in a plate heat exchanger located at a heat exchange station. The heat exchanger is the main source of heat for the building system based on substations in the building apartments. The co-operation of the heat exchange station with the substations in the apartments will also be described.

2. Heat source: the heat exchange station co-operating with the district heating system

Heat exchange stations are sets of devices connecting the heat distribution network to the internal system of a building. They are a part of the heating system affected both by the network and the internal system of the facility.

The station is the place where the heat exchange occurs between the heat distribution network and the consumer. The thermal energy in the heat exchange station is transported through the heating medium. The heat exchange station transforms the high values of temperature and pressure of the heating medium flowing in the network, the so-called high parameter medium, into lower values in the consumers' systems.

The set of devices making up the heat exchange station regulates the heating medium on the side of both high and low parameters.

The main elements of the station are a heat exchanger, a circulation (feed) pump, valves, filters and a heat meter. The composition of the station elements depends on technological aspects, the requirements of the consumer's system and of the distribution network.

Heat exchange stations can be divided based on many criteria. One of them is the number of buildings connected to them. Individual heat exchange stations supply just one facility with thermal energy, whereas group stations supply a few. Heat exchange stations can also be divided depending on the method of the heat distribution network connection to the consumer's system. In this division, direct and indirect heat exchange stations are distinguished. In direct stations, the same medium flows in the network and in the consumer's system. In indirect systems, there are two separate circuits, and the heat exchange is realized through a heat exchanger. Apart from these classification methods, there are also other divisions of heat exchange stations.

Despite their different functions and kinds, the main task of heat exchange stations is to supply thermal energy from the heat distribution network to the consumer.

The parameters of the heat distribution network result from the operating parameters of the receivers. The main parameters are temperature and pressure. Quantitative, qualitative and quantitative-qualitative regulation of the network is used. Qualitative regulation consists in changing the supply and the return temperature. Quantitative regulation consists of changing the heating medium mass flow rate in the pipeline. The supply temperature in the summer period is constant and is about 70°C, whereas in the heating season it is 135°C. It should be remembered that in the heating season the temperature of the heating medium in the network varies depending on the temperature of the ambient air. The heat distribution network must have an appropriate amount of thermal energy to satisfy the current demand of the consumers. The consumers' demand depends mainly on atmospheric conditions, i.e. the ambient temperature. The water circulates in the heat distribution network thanks to the work of circulation pumps. The pumps are located both in the source of heat generation and in special facilities referred to as intermediate pumping stations.

3. Structure and operating principle of a heat exchange microstation

Heat exchange microstations (logotherms), shown in Fig. 1, are made in various configurations. They can be one- and two-function devices. Some deliver heat only for room heating, others can heat domestic water only. Two-function logotherms are able to provide heat for both central heating and domestic hot water preparation. The advantages of microstations are their small size and compact structure [5–10].

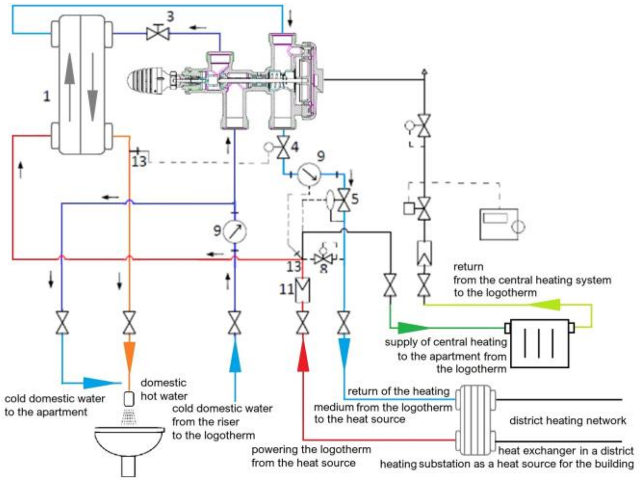

Fig. 1. Diagram of a logotherm fed from a heat exchanger in a district heating substation [11].

The logotherm basic elements are [11] a mounting plate/housing, a console with connections including shut-off valves, piping, a heat exchanger (for domestic hot water systems), a filter, a vent, various types of control valves: a mixing valve, a return limiter, a differential pressure regulator, a thermostatic valve.

The simplest models of microstations do not even need an electronic regulator. The principle of their operation is based, among other things, on specially designed hydraulic regulators, and thermostatic and differential pressure valves.

In their models of microstations, the Herz company used a hydrodynamic regulator, which is the most important element of the heat exchange substation located in an apartment. It is responsible for ensuring the correct temperature of domestic hot water [12]. The basis of the hydrodynamic regulator operation is the pressure difference upstream and downstream of the regulator, caused by the flow of domestic hot water collected by the consumer. Figure 2 shows a simplified diagram of domestic hot water generation in heat exchange substations located in individual apartments based on a self-actuated dynamic regulation unit.

A self-actuated dynamic regulation unit is composed of a primary and a secondary part. One element of the structure of the self-actuated dynamic regulation unit is a movable drive element connected centrally to a stem. The stem moving in the regulator opens and closes the supply of the heating medium on the primary side of the heat exchanger. The cold water flowing through the primary part of the regulation unit has to be heated in the plate heat exchanger. The cold water is heated by the heating medium flowing through the regulator's secondary part. Flowing through the regulator's primary part, the cold water causes a pressure drop due to hydraulic resistance. The resulting difference in pressure causes the opening of the secondary part, which allows the heating medium to flow. A rise in the flow of cold water involves an increase in the flow of the heating medium. The self-actuated dynamic regulation unit is equipped with a DHW priority valve.

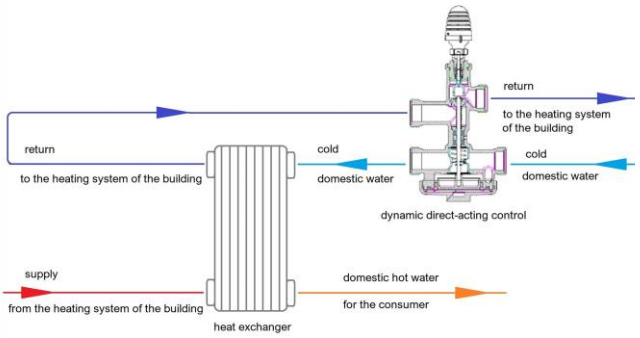

Fig. 2. Simplified diagram of hot water generation in exchanger stations [12].

In their models of microstations, the Flamco company (formerly Meibes) [11] uses three-way PM-Regler valves (Fig. 3). The PM-Regler valve is a hydraulic switching and control valve that controls the process of the switching of the heating medium flow. When domestic hot water is drawn, it directs the heating medium to the heat exchanger to heat cold water. When the domestic hot water intake ends, the PM-Regler valve directs the heating medium to the central heating circuit. Like the Herz self-actuated dynamic regulation unit, the PM-Regler valve has the domestic hot water priority.

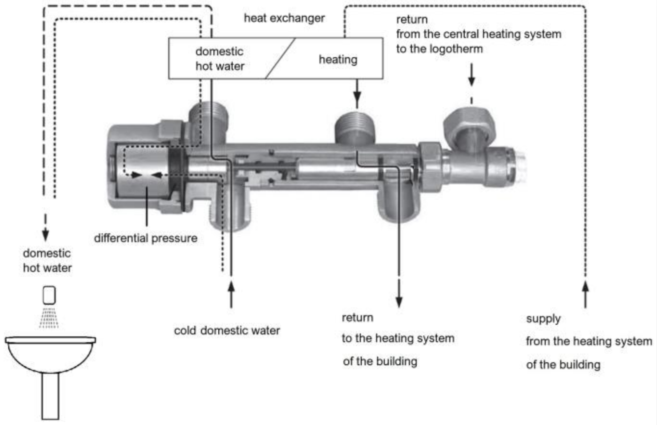

Fig. 3. PM-Regler valve.

Additional equipment of logotherms includes an electric actuator, a water meter, a heat meter, an electronic regulator, a room temperature-setting device, circuit pumps, circulation pumps, etc.

Domestic hot water preparation by the logotherm consists of the rapid heating of cold water in the exchanger, being a part of the logotherm assembly. The heat exchange microstation starts operating only if there is a demand for hot water or central heating. In the standby mode, the heating medium flows through a bypass, referred to as the thermal bridge, the temperature of which is kept at the working temperature level using a return temperature limiter. Owing to that, the heating medium is always available if a need arises to switch on the logotherm. This enables the heating medium minimal circulation which is to ensure an appropriate temperature of the medium at the logotherm inlet.

4. Internal heating system based on heat exchange microstations located in individual apartments

The internal heating systems commonly utilized by thermal energy consumers are pump systems where a circulation pump is used to force the heating medium flow. The circulation pump overcomes hydraulic resistances in the system piping.

Most often, a two-pipe arrangement of the system is used. In the building's internal system feeding logotherms, there are three pipes (Fig. 4). One of them supplies the heat exchange substation with domestic cold water, and another supplies the substation with heat feeding the heating medium. The third pipe carries heating water away from the logotherm.

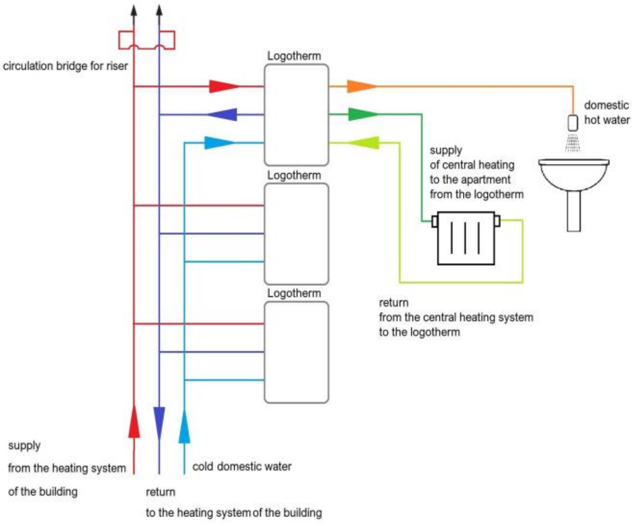

Fig. 4. Diagram of the clip installed at the end of the heating riser.

The pipes in the internal heating system are run both vertically and horizontally. In a system co-operating with logotherms, a circulation bridge, called a clip, should be installed at the end of each riser (Fig. 5). The circulation bridge makes it possible to regulate the temperature of the heating water feeding the microstation and of the water returning from the system to the heat source.

The task of the circulation bridge is to maintain the minimal temperature in the pipe feeding the logotherm. On the market, there are clips with adjustable temperature settings in the range from 45°C to 65°C and clips with a single pre-setting. In the latter case, if a need arises to regulate the operation of the internal system distributing heat in the building, the clip has to be replaced with a clip with adjustable settings or a clip with a different temperature pre-setting that activates the valve located on the circulation bridge. The operating principle of the valve mounted on risers is to observe the feed water temperature: if the temperature in the riser drops to values below the setting, the valve opens, forcing the heating medium flow from the feed riser to the return riser. In the same way the feed riser is filled with hot water with a temperature higher than the value of the circulation bridge setting.

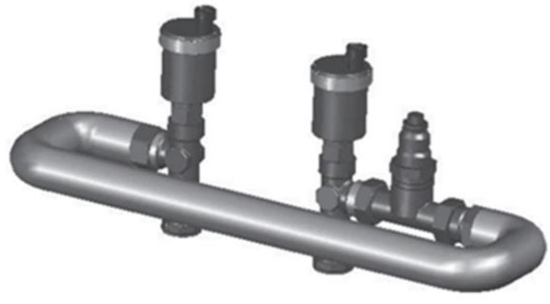

Fig. 5. Circulation bridge installed on the riser [11].

The clips mounted within logotherms operate based on the same principle as the circulation bridges mounted on the internal system risers. This enables the flow of the heating medium close to the logotherm, thus shortening the time of waiting for the heat needed to supply the substation. If the heating medium cools down in the branch feeding the substation, the valve opens, forcing the heating medium flow to the branch returning to the source of supply.

Apart from circulation bridges, the internal network distributing heat in the building can also be regulated using temperature limiters (Fig. 6) intended for the control of the temperature of the return from the apartment's individual central heating system to the heating medium return. This valve regulates the flow by limiting the water flow through the apartment's central heating system, which results in increased cooling of the heating medium and a reduction in the return temperature. Temperature can be regulated in the range from 25°C to 60°C.

Fig. 6. Heating water return temperature limiter of residential central heating system.

The minimum and the maximum temperature of the heating medium in the primary circuit should total 60°C and 80°C, respectively.

5. Description of the heat exchange station and the logotherm system under analysis

The analysis of the operation of the heat exchange station with a system feeding logotherms was performed using the heat exchange system feeding the internal system based on logotherms. Figure 7 presents a schematic diagram of the heat exchange station from which the data for the analysis were obtained.

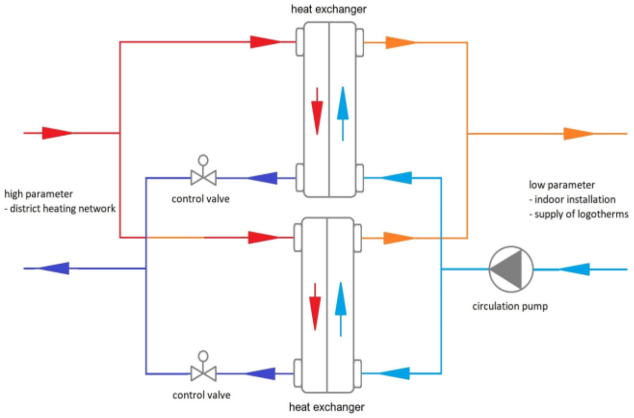

Fig. 7. Schematic diagram of the thermal node from which the data was obtained.

The station is made of two heat exchangers supplied simultaneously and connected in parallel. In both exchangers, the mediums flow in a counter-current configuration. The heat exchange station, both on the exchanger's primary and secondary side, was equipped with heat meters with the ability to transmit data through a communication card and a controller to a supervisory control and data acquisition (SCADA) system, and the data were then recorded. The data transmitted from the station are represented in the on-line mode on the system visualization, in the SCADA system, on purpose-made synoptic schemes showing the heat exchange station operation.

6. Heat flow analysis

The heat flow in a plate heat exchanger was analyzed using the ε-NTU method and the measuring data for which the values of the heat flow rate transferred from the network water to the water heating the building are almost equal.

The exchanger analysis by means of the ε-NTU method makes use of thermal equations transformed into a dimensionless form. The method will be used to assess the impact of changes in the exchanger operating parameters on outlet temperatures of the mediums flowing through the exchanger on the side of the high and the low parameters. The following formula was used to calculate the efficiency of the countercurrent plate heat exchanger:

$$\varepsilon = \frac{1-\exp\left[-NTU\left(1-\frac{\dot{C}_{min}}{\dot{C}_{max}}\right)\right]}{1-\frac{\dot{C}_{min}}{\dot{C}_{max}}\exp\left[-NTU\left(1-\frac{\dot{C}_{min}}{\dot{C}_{max}}\right)\right]}, \quad (1)$$

where the number of heat transfer units (NTU) is expressed as:

$$NTU = \frac{kA}{\dot{C}_{min}}. \tag{2}$$

In order to calculate the number of the heat transfer units, it is necessary to determine the product of the heat transfer coefficient k and the exchanger heat exchange surface area A, using the relation defining the mean heat flux transferred in the exchanger:

$$\dot{Q}_m = kA\Delta T_m. \tag{3}$$

After relevant transformations, product kA can be established using the following equation:

$$kA = \frac{\dot{Q}_m}{\Delta T_m}. \tag{4}$$

In order to determine product kA, it is necessary to establish the mean transferred heat flux $\dot{Q}_m$ and the logarithmic mean temperature difference ΔT_m. Adopting the denotation of the inlet and outlet temperatures of the cold and hot medium presented in Fig. 8, the logarithmic mean temperature difference is calculated using the following formula:

$$\Delta T_m = \frac{(T_{zwp}-T_{znp})-(T_{pwp}-T_{pnp})}{ln\left(\frac{T_{zwp}-T_{znp}}{T_{pwp}-T_{pnp}}\right)}. \tag{5}$$

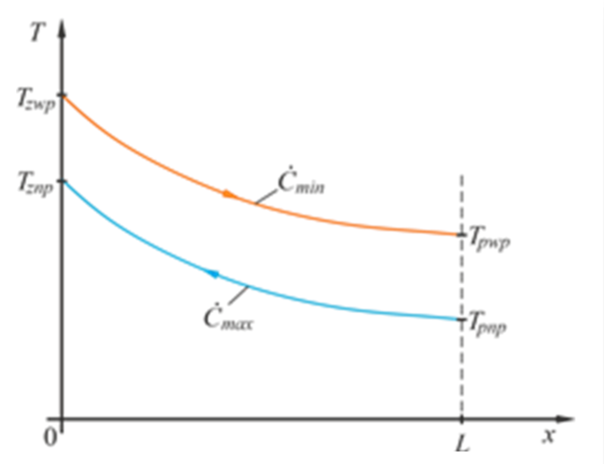

Fig. 8. Changes in the temperature of hot and cold water in a counter-current thermal station.

Heat flow rate $\dot{Q}_m$ in formula (4) was calculated as the arithmetic mean of heat flux $\dot{Q}_{wp}$ given off by hot water and heat flux $\dot{Q}_{np}$ absorbed by cold water. The following formula was used to calculate the heat flow rate transferred from the water with a higher temperature (water from the heat distribution network):

$$\dot{Q}_{wp} = \dot{m}_{wp}\bar{c}_{wp}\left(T_{zwp} - T_{pwp}\right), \tag{6}$$

where the water mean specific heat $\bar{c}_{wp}$ and the water mass flow rate $\dot{m}_{wp}$ are defined by the following relations:

$$\bar{c}_{wp} = \frac{c_{wp}(T_{zwp})+c_{wp}(T_{pwp})}{2}, \tag{7}$$

$$\dot{m}_{wp} = \dot{V}_{wp} \cdot \rho\left(T_{pwp}\right). \tag{8}$$

The heat flow rate absorbed by the building internal system is given by equation given below:

$$\dot{Q}_{np} = \dot{m}_{np}\bar{c}_{np}\left(T_{znp} - T_{pnp}\right), \tag{9}$$

where $\bar{c}_{np}$ and $\dot{m}_{np}$ are calculated as:

$$\bar{c}_{np} = \frac{c_{np}(T_{znp})+c_{np}(T_{pnp})}{2}, \tag{10}$$

$$\dot{m}_{np} = \dot{V}_{np} \cdot \rho\left(T_{pnp}\right). \tag{11}$$

The mean heat flow rate is determined as the arithmetic mean of the given off heat flow rate $\dot{Q}_{wp}$ and the absorbed heat flow rate $\dot{Q}_{np}$:

$$\dot{Q}_m = \frac{\dot{Q}_{wp}+\dot{Q}_{np}}{2}. \tag{12}$$

Knowing the average heat flow rate value from Eq. (4), product kA is calculated, and then the number of heat transfer units (NTU) is established. In order to calculate the exchanger efficiency, it is necessary to know the maximum and the minimum heat capacity rates $\dot{C}_{max}$ and $\dot{C}_{min}$, defined as follows:

$$\dot{C}_{max} = \dot{m}_{np}\bar{c}_{np}, \tag{13}$$

$$\dot{C}_{min} = \dot{m}_{wp}\bar{c}_{wp}. \tag{14}$$

Calculating the heat exchanger efficiency from Eq. (1), it is possible to determine the cold water temperature T_{znp} and the hot water temperature T_{pwp}, taking account of the definition of the exchanger thermal efficiency:

$$\varepsilon = \frac{\dot{C}_{max}(T_{znp}-T_{pnp})}{\dot{C}_{min}(T_{zwp}-T_{pnp})}. \tag{15}$$

Transforming Eq. (15), the following is obtained:

$$T_{znp} = T_{pnp} + \varepsilon\frac{\dot{C}_{min}}{\dot{C}_{max}}\left(T_{zwp} - T_{pnp}\right). \tag{16}$$

After Eq. (16) is used to calculate the temperature of the water feeding the internal system T_{znp}, the exchanger heat balance equation:

$$\dot{C}_{max}\left(T_{znp} - T_{pnp}\right) = \dot{C}_{min}\left(T_{zwp} - T_{pwp}\right), \tag{17}$$

can be used to determine the temperature of the network water leaving the heat exchanger T_{pwp}:

$$T_{pwp} = T_{zwp} - \frac{\dot{C}_{max}}{\dot{C}_{min}}\left(T_{znp} - T_{pnp}\right). \tag{18}$$

The following measuring data of the heat exchange station feeding the logotherm were adopted for the thermal calculations:

- T_{zwp} = 71.1°C – temperature of the heat distribution network water feeding the exchanger of the heat exchange station,
- T_{pwp} = 43.3°C – temperature of the network water leaving the exchanger of the heat exchange station,
- $\dot{V}_{wp}$ = 1.835 m^3/h – network water volume flow rate,

- T_{pwp} = 61.4°C – temperature of the medium heated in the exchanger of the heat exchange station,
- T_{pwp} = 39.8°C – temperature of the medium returning to the exchanger of the heat exchange station,
- $\dot{V}_{np}$ = 2.403 m^3/h – volume flow rate in the building system.

Considering that:

$$\bar{c}_{wp} = c_{wp}\left(\frac{T_{zwp}+T_{pwp}}{2}\right) = c_{wp}(57.2℃) = 4181.82\ \frac{\mathrm{J}}{\mathrm{kg{\cdot}K}},$$

$$\dot{m}_{wp} = \dot{V}_{wp}\cdot\rho\left(T_{pwp}\right) =$$
$$1.835\,\frac{\mathrm{m}^3}{\mathrm{h}}\cdot\frac{1}{3600\ \mathrm{s}}\cdot 990.90\ \frac{\mathrm{kg}}{\mathrm{m}^3} = 0.505\ \frac{\mathrm{kg}}{\mathrm{s}},$$

the heat flow given off by hot water $\dot{Q}_{wp}$ totals:

$$\dot{Q}_{wp} = \dot{m}_{wp}\bar{c}_{wp}\left(T_{zwp}-T_{pwp}\right) = 58.81\ \mathrm{kW}.$$

The heat flow rate absorbed by cold water $\dot{Q}_{np}$ was determined in the similar manner:

$$\bar{c}_{np} = c_{np}\left(\frac{T_{znp}+T_{pnp}}{2}\right) = c_{np}(50.6℃) = 4179.88\ \frac{\mathrm{J}}{\mathrm{kg{\cdot}K}},$$

$$\dot{m}_{np} = \dot{V}_{np}\cdot\rho\left(T_{pnp}\right) =$$
$$2.403\,\frac{\mathrm{m}^3}{\mathrm{h}}\cdot\frac{1}{3600\ \mathrm{s}}\cdot 992.26\ \frac{\mathrm{kg}}{\mathrm{m}^3} = 0.662\ \frac{\mathrm{kg}}{\mathrm{s}},$$

$$\dot{Q}_{np} = \dot{m}_{np}\bar{c}_{np}\left(T_{znp}-T_{pnp}\right) = 59.66\ \mathrm{kW}.$$

The mean heat flow rate transferred in the exchanger is:

$$\dot{Q}_m = \frac{\dot{Q}_{wp}+\dot{Q}_{np}}{2} = \frac{58810\ \mathrm{W}+59660\ \mathrm{W}}{2} = 59235.0\ \mathrm{W}.$$

After the logarithmic mean temperature difference ΔT_m is established:

$$\Delta T_m = \frac{\left(T_{zwp}-T_{znp}\right)-\left(T_{pwp}-T_{pnp}\right)}{ln\left(\frac{T_{zwp}-T_{znp}}{T_{pwp}-T_{pnp}}\right)} =$$

$$\frac{(71.1℃-61.35℃)-(43.25℃-39.8℃)}{ln\left(\frac{71.1℃-61.35℃}{43.25℃-39.8℃}\right)} = 6.1℃,$$

product kA is calculated:

$$kA = \frac{\dot{Q}_m}{\Delta T_m} = \frac{59235.0\ \mathrm{W}}{6.1\ \mathrm{K}} = 9710.7\ \frac{\mathrm{W}}{\mathrm{K}}.$$

Considering that:

$$\dot{C}_{max} = \dot{m}_{np}\bar{c}_{pn} = \dot{m}_{np}\bar{c}_{pn} =$$
$$0.662\ \frac{\mathrm{kg}}{\mathrm{s}}\cdot 4179.88\ \frac{\mathrm{J}}{\mathrm{kg{\cdot}K}} = 2767.08\ \frac{\mathrm{W}}{\mathrm{K}},$$

$$\dot{C}_{min} = \dot{m}_{wp}\bar{c}_{pw} = \dot{m}_{wp}\bar{c}_{pw} =$$
$$0.505\ \frac{\mathrm{kg}}{\mathrm{s}}\cdot 4181.83\ \frac{\mathrm{J}}{\mathrm{kg{\cdot}K}} = 2111.82\ \frac{\mathrm{W}}{\mathrm{K}},$$

$$\frac{\dot{C}_{min}}{\dot{C}_{max}} = \frac{2111.82\,\frac{\mathrm{W}}{\mathrm{K}}}{2767.08\,\frac{\mathrm{W}}{\mathrm{K}}} = 0.763.$$

The value of the number of the heat transfer units NTU is determined:

$$NTU = \frac{kA}{\dot{C}_{min}} = \frac{9768.06\,\frac{\mathrm{W}}{\mathrm{K}}}{2111.61\,\frac{\mathrm{W}}{\mathrm{K}}} = 4.63.$$

The efficiency of the heat exchange station totals:

$$\varepsilon = \frac{1-\exp\left[-NTU\left(1-\frac{\dot{C}_{min}}{\dot{C}_{max}}\right)\right]}{1-\frac{\dot{C}_{min}}{\dot{C}_{max}}\exp\left[-NTU\left(1-\frac{\dot{C}_{min}}{\dot{C}_{max}}\right)\right]} =$$
$$\frac{1-\exp[-4.63(1-0.763)]}{1-0.763\exp[-4.63(1-0.763)]} = \frac{0.666}{0.745} = 0.894.$$

Knowing the exchanger efficiency, temperatures T_{znp} and T_{pwp} are found:

$$T_{znp} = T_{pnp} + \varepsilon\frac{\dot{C}_{min}}{\dot{C}_{max}}\left(T_{zwp}-T_{pnp}\right) =$$
$$39.8℃ + 0.894\cdot 0.763\cdot(71.1℃-39.8℃) = 61.1℃,$$

$$T_{pwp} = T_{zwp} - \frac{\dot{C}_{max}}{\dot{C}_{min}}\left(T_{znp}-T_{pnp}\right) =$$
$$71.1℃ - 1.311(61.4℃-39.8℃) = 42.8℃.$$

The calculated temperature of the medium feeding the logotherm of 61.1°C is very close to the value of measured temperature T_{znp} = 61.4°C. The calculated temperature of the network water in the heat exchange station is 42.8°C, whereas the value of the measured temperature T_{pwp} totals 43.25°C. The difference between the measured and the calculated temperature of the network water leaving the heat exchange station is $\Delta T_{pwp} = (43.3℃ - 42.8℃) = 0.5℃$. This small temperature difference is an effect of the inaccuracy of the measurement of the volume flow rates of the two mediums and their inlet and outlet temperatures.

7. Conclusions

The paper presents an analysis of the heat flow in a heat exchange station being the main heat source for the heating system of a multi-family building using individual microstations (logotherms) located in each residential unit to supply heat and produce domestic hot water for individual apartments. The method of calculating the product of the heat transfer coefficient k and the heat exchange surface area A is presented. In order to verify the correctness of the measured values of the temperatures of hot and cold water at the heat exchange station inlet and outlet, they were compared to the values calculated using the ε-NTU method. Good agreement was found between the results of the calculations and the measurements.

The heating medium temperature in the district heating system in the summer period is a constant value totalling 70°C. The heating medium temperature can be a bit lower in the case of buildings located far away from the heat source. The minimum temperature of the water feeding the logotherm from this source totals about 60°C, which means that the temperature of the heating medium flowing in the district heating network is only a little higher than the required temperature of the water feeding the heating microstations. The value of the minimum temperature of the medium feeding the logotherms depends on the required maximum temperature of domestic hot water of 55°C.

In the summer period, the demand for heat of systems based on logotherms is low due to the low power needed to heat water for the purposes of domestic hot water preparation. Beyond the heating season, the drop in the system water temperature is slight. The temperature of the medium circulating in the consumer's system to feed the logotherms is maintained at the required level by regulating the mass flow rate of the water flowing through the heat exchange station.

In order for the heat exchange station co-operating with the internal system feeding the logotherms in individual apartments to maintain appropriate operating parameters, both on the side of the high-temperature medium and the low-temperature medium, an adequate well-adjusted network distributing the heating medium to the microstations (logotherms) should be ensured. Otherwise, too high temperatures of the heating medium returning to the district heating system may occur. In apartments heated using micro heat exchange stations (logotherms), it is also possible to install central heating radiators with a larger heat exchange surface area. This will make it possible to lower the water temperature at the return from the central heating system to the heat exchange station. Owing to that, the mass flow rate of hot water in the municipal network can be reduced, which will translate into a lower temperature of the water from the heat exchange station and a reduction in the power needed to pump hot water in the network.

References

[1] Siegenthaler, J. (2022). *Modern Hydronic Heating: For Residential and Light Commercial Buildings* (4th ed.). Cengage Learning, Boston. ISBN 9781337904919.

[2] Wiltshire, R. (2015*). Advanced District Heating and Cooling (DHC) Systems,* Woodhead Publishing, Cambridge. ISBN 9781782423744.

[3] Li, Z., Liu, J., Jia, L., & Wang, Y. (2023). Improving room temperature stability and operation efficiency using a model predictive control method for a district heating station. *Energy and Buildings*, 287, 112990. doi: 10.1016/j.enbuild.2023.112990

[4] Sarbu, I.; Mirza, M., & Muntean, D. (2022). Integration of Renewable Energy Sources into Low-Temperature District Heating Systems: A Review. *Energies*, 15(18), 6523. doi: 10.3390/en15186523

[5] Zaborowska, E. (2023). *Design principles for hydronic district heating substations*. Wydawnictwo Politechniki Gdańskiej, Gdańsk. ISBN 978-83-7348-575-4.

[6] Górski, J., Baran, J., Gniewek–Grzybczyk, B., Maludziński, B., Wojciechowski, J., Wojtas, K., Grela, J., & Krupa, J. (2008). *Thermal power generation: A handbook*. TARBONUS, Kraków – Tarnobrzeg. ISBN: 978-83-7394-219-6 (in Polish).

[7] Koczyk, H. (2009). *Practical heating. Design, installation, energy certification, operation* (2nd ed.). SYSTHERM D. Gazińska s.j., Poznań. ISBN 978-83-61265-12-2 (in Polish).

[8] Kołodziejczyk, L. (1984) *Thermal management in heating*. Wydawnictwo Arkady, Warszawa. ISBN: 83-213-3172-6.

[9] Ojczyk, G. (2011). Hot water 'at a glance'. *Instalator,* 2(1) (in Polish).

[10] Ojczyk, G. (2011). Residential heat exchange stations. Dynamic heating, *Instalator*, 8(8) (in Polish).

[11] *LogoThermic G2 – Installation and operating instructions*. https://flamco.aalberts-hfc.com/pl/docfinder/istrukcje/meibes/t+m [accessed 19 Apr. 2024].

[12] *Herz DeLuxe residential station Krakow*. https://katalog.herz.com.pl/pl/stacje-mieszkaniowe/78-stacja-mieszkaniowa.html (in Polish) [accessed 19 Apr. 2024].