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An Improved Method of Serial Balancing of Hybrid Boiler Station Systems

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Abstract: This paper presents a prototype of a thermo-hydraulic distributor for a hybrid boiler station supplying a small hotel in Koszalin. The task of the device was to balance the hybrid system with four circuits with different operating parameters, also changing in an extremely irregular manner. A prototype of a thermo-hydraulic distributor with improved internal structure was developed, ensuring the operation of the device in accordance with the temperature logic. Dimensions of the device have been calculated in accordance with the existing design principles of hydraulic distributors.

Keywords: thermo-hydraulic distributor, hybrid boiler station, system balancing, temperature logic

1. Introduction

Hybrid boiler stations with heating and supply circuits with different operating parameters are very effective and at the same time complex heating systems that need innovative technological solutions for their correct balancing both hydraulically and thermodynamically in order to achieve high operating efficiency (Szkarowski et al. 2007). In line with the policy of the European Union countries, it is of key importance, inter alia, for increasing the improvement of energy efficiency in the residential sector (Żelazna 2012). One of such devices influencing the correctness and efficiency of operation may be an innovative

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thermo-hydraulic distributor, the feature of which is a serial connection of boiler and heating circuits (Szkarowski et al. 2007).

In recent years, many heating systems have been developed based on the economization of the process of preparing and supplying heat to consumers, minimizing both losses and energy consumption costs. The essences of the planned energy – efficient economy in modern heating systems are the appropriate, precise design criteria and quality assumptions (Orłowska 2020). The design criteria include: type and number of heat sources, method of heat distribution, type of heating devices and regulation system. The qualitative assumptions take into account: the specificity of systems that require a lowered or increased temperature of the heating medium, periodic overheating in the hot water system, associating heat from primary and alternative sources, and using the heat of the flow returning from the system in the absence of consumption. In such a defined thermal energy management system, newer solutions can be noticed in technological systems such as: layered heat buffers, vertical hydraulic distributors (PRH), ZORT – System hydraulic distributors and mini – hot water nodes. Despite numerous examples of their effective application, especially in housing construction, paradoxically new problems may arise related to their comprehensive operation (Szkarowski & Naskręt 2008). The most common problems during the operation of new systems include:

- overheating or underheating of buildings, while overheating increases energy costs,
- too long heating time of rooms after the morning start – up of the system,
- failure to ensure the required thermal comfort, despite the use of devices with the required thermal power,
- too large fluctuations in air temperature in rooms caused by improper operation of control valves or improper difference between the supply and return water temperatures,
- too low temperature of hot water during its distribution,
- reduction of the efficiency of the heat source or sources by insufficient use of thermal energy in receiving circuits (Szkarowski & Naskręt 2008, Dopieralska et al. 2015).

The technology of heat supply in multi – family buildings, offices, public buildings, etc., is more and more often characterized by diversified operating parameters of heating, hot water, ventilation and air conditioning circuits. Moreover, they can be powered from several sources and cooperate with renewable energy sources (RES). The main condition for the proper functioning of these systems in terms of hydraulics is the elimination of the mutual influence of water flows, e.g. caused during pump switching on, and from the thermodynamic point of view – the supply of a heating medium with an appropriate supply and return temperature for each circuit, consistent with the adopted calculation parameters. Economical selection of the number and parameters of devices, mainly such as boilers, pumps, control valves, etc., is possible when the technological system is separated into a boiler circuit (primary) and a heating circuit (secondary) (Szkarowski 2019).

The commonly used PRH or ZORT – System distributors use the principle of parallel coupling of hydraulic circuits. In the case of PRH, the circuits remain thermodynamically independent, while the ZORT – System devices are the zero point in terms of hydraulics and thermodynamics. Where heat loads differ and change unevenly over time, the common principle of parallel coupling of hydraulic circuits into one system may not be entirely effective.

Vertical hydraulic distributors (PRH and others) only provide hydraulic balancing at the same flow temperature of the circuits equal to the temperature of the heat source. ZORT distributors equalize the temperature of all flows returning to the coupling and this temperature is the same for supplying these circuits. The multi – section ZORT – Multi devices allow you to combine thermally diverse circuits. However, when the heat demand of these circuits varies, additional devices are needed.

Serial coupling of heat consumption circuits with a gradually decreasing supply temperature of the circuits (according to the so – called temperature logic) is particularly advantageous when efficient condensing heat sources are used (Janta-Lipińska 2020). Compared to parallel systems, the series circuit enables the guaranteed return water parameters from the heat source to be obtained for a longer time during sudden and unpredictable fluctuations in the heat load. Serial connection of circuits allows to avoid mutual hydraulic and thermodynamic contradictions or at least to alleviate these contradictions (Shkarovskiy & Zelenov 2012).

2. Object, goals and methodology of research

The object of the research is the hotel "Services & Bistro" in Koszalin. The facility has a multi – circuit heating system, which is characterized by the demand for a heating medium with very varied parameters, which also change in an extremely irregular manner. It was the unpredictable nature of these changes that initiated the idea of balancing them with an improved serial hydraulic – distributor and the need for this solution.

The facility has 4 heating circuits:

1. Hot water with the parameters of the heating medium 70/50°C and the power of demand $\boldsymbol{Q}$ = 25 kW,
2. Mechanical ventilation with the parameters of the heating medium 50/40°C and the power of demand $\boldsymbol{Q}$ = 35 kW,

3. Radiator heating with the parameters of the heating medium 45/35°C and the power of demand $\boldsymbol{Q}$ = 17 kW,
4. Floor heating with the parameters of the heating medium 42/30°C and the power of demand $\boldsymbol{Q}$ = 4 kW.

The diagram of the existing hybrid boiler station is shown in Figure 1. The system includes: heat generation circuit, internal systems circuits consuming heat, and indirect systems of heat exchangers, heat storage and distribution systems. An additional element is the cooling system of the mechanical ventilation circuit.

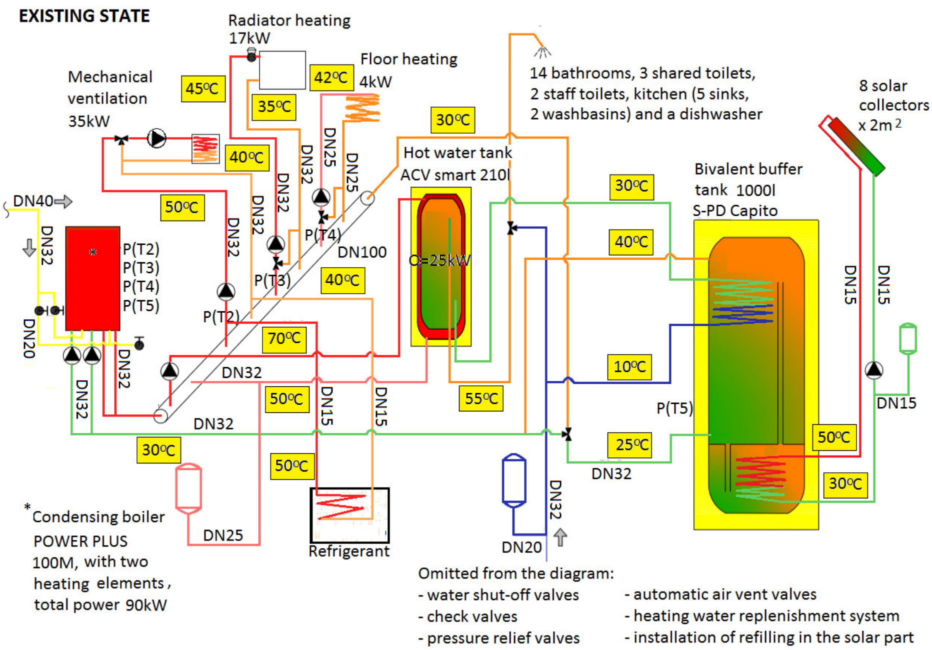

Fig. 1. Technological scheme of a hybrid boiler station in Hotel Services & Bistro

The diagram omits a number of typical devices that are not significant in terms of system operation.

In terms of technology, the scheme of the boiler station can be divided into four units:

1. Main heat source – gas condensing boiler PLUS 100M from POWER with two heating elements with a total power of 90 kW.
2. Auxiliary heat source – 8 solar collectors with an area of 2 m^2 each as the main heat source in the summer period.

3. Heat storage system – bivalent buffer tank with a capacity of 1000 dm^3 S – PD Capito.
4. Domestic hot water heating system – ACV smart 210 shell heat exchanger with a capacity of ***Q*** = 25 kW, supplying batteries in 14 bathrooms, 3 shared toilets, 2 toilets for staff. The kitchen has 5 sinks, 2 washbasins and a dish-washer.

Currently, the role of a serial distributor is a stainless steel pipe with a diameter of DN100 with pipe stubs of DN32 and DN25. The distributor was tilted assuming that the change in density would act by gravity in the direction of the fluid's movement. During the tests, it was found that it is of little importance in the case of the pump cycle. However, the tilt of the device has proven useful in bleeding and desludging. The pipe stubs in the distributor are immersed to the half of the pipe diameter, and besides, the device has no additional internal elements. The heating circuits are connected in serial to each other, from the highest parameters to the smallest, as shown in the diagram (Fig. 1).

Fig. 2. Photo of the device prototype during operation

The research problem of this boiler station is the temperature fluctuation of the supply heating medium, especially in subsequent circuits, at the moment of peak power demand. The authors concluded that the existing distributor, despite its simplicity, performs its task well, but requires improvement.

The aim of this research was to develop a concept of a thermo-hydraulic distributor, the task of which is the optimal hydraulic and thermodynamic balancing of hybrid boiler station systems with heating and supply circuits with different operating parameters. The research method was mainly theoretical calculations based on the initially obtained technological information and partially on the performed measurements.

3. Working on a conception

3.1. Principles of operation of the device

As mentioned above, the basic idea behind serial connection of circuits needed to be improved. The concept of an improved serial thermo-hydraulic distributor was developed. The method of its operation is based on appropriate separation of the flow in each segment of the distributor supplying the receiving circuit. The part that feeds this circuit is separated from the common flow with a predetermined flow rate and temperature. The remainder of the flow moves freely, mixing with the recycle flow.

After the temperature has stabilized, the combined flow feeds the next distributor segment. The establishing mixture temperature is the design temperature for supplying another recipient circuit. This means that the device works by the so – called temperature logic.

3.2. Design of a thermo-hydraulic distributor

The shape of the device is in the form of a cuboid with a total length $\boldsymbol{L}$ = 1170 mm, height $\boldsymbol{H}$ = 200 mm and width $\boldsymbol{W}$ = 200 mm (Fig. 3).

The device consists of 5 segments of various lengths resulting from technological or design requirements. The division into segments was made with the use of $\mathbf{PP_{1\text{-}4}}$ perforated plates. Their function is to even out and calm the flows after they have been combined and mixed.

Moreover, each segment is equipped with a dividing plate $\mathbf{DP_{1\text{-}4}}$. Structurally, the partition divides the segment into a division zone $\mathbf{DZ_{1\text{-}4}}$ and a mixing zone $\mathbf{M_{1\text{-}4}}$. The hydraulic operation of the partition is complex. First, it promotes the separation of part of the inlet flow for the next cycle from the part of the flow moving on. Second, the partition disturbs the flow and ensures effective mixing with the return flow. This helps to obtain a homogeneous mixing temperature in the entire volume of the zone.

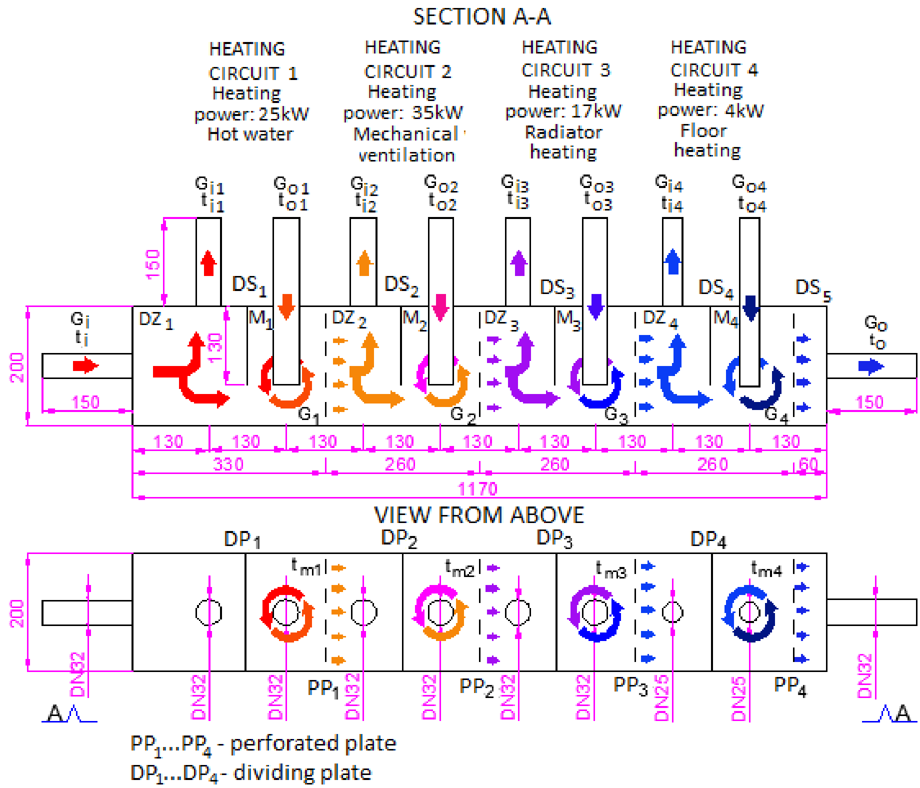

Fig. 3. Construction of an improved thermo-hydraulic distributor

DN32 pipe stubs are used for the 1st, 2nd and 3rd circuit and boiler connections. Circuit 4 pipe stub are DN25 (according to the existing technological state). For an efficient mixing process, the length of the return pipes stubs are the same as that of the dividing plates.

3.3. Theoretical basics

Along with the changes in the design of the device, the previously developed theoretical foundations of its operation (Szkarowski et al. 2007) have been clarified.

First divider segment **DS**$_I$ is supplied from the boiler with the heating medium flow $\boldsymbol{G_i}$ about the inlet temperature $\boldsymbol{t_i}$ (Fig. 3). Then the inlet flow is divided. Thanks to the design of the distributor, a heating flow is generated in the division zone **DZ**$_I$ with the temperature $\boldsymbol{t_{iI}} = \boldsymbol{t_i}$ and the flow rate $\boldsymbol{G_{i1}}$, proportional to the design power of the heating circuit "1". This flow feeds the first circuit.

The remainder of the flow, with a flow rate G_i - G_{i1} and a temperature t_{Il}, flows around the dividing plate **DP₁** and is mixed with the recycle flow of circuit "1" with a flow rate G_{o1} = G_{i1} and a temperature outlet t_{ol}. A mix flow G_1 at temperature t_{m1} is formed.

This flow leaves the first distibutor segment and feeds the second segment through the perforated plate **PP₁**. The principle of operation in subsequent segments is the same as for the first.

Summarizing for the operation of the entire device can be saved:

$$G_i = G_1 = G_2 = G_3 = G_4 = G_O \tag{1}$$

$$t_i = t_{i1}\ ;\ t_{m1} = t_{i2}\ ;\ t_{m2} = t_{i3}\ ;\ t_{m3} = t_{i4}\ ;\ t_{m4} = t_o \tag{2}$$

$$G_{i1} = G_{o1}\ ;\ G_{i2} = G_{o2}\ ;\ G_{i3} = G_{o3}\ ;\ G_{i4} = G_{o4} \tag{3}$$

where:

$$t_{m1} = t_i - \frac{G_{i1}}{G_1\left(t_i - t_{o1}\right)} \tag{4}$$

$$t_{m2} = t_{m1} - \frac{G_{i2}}{G_2\left(t_{m1} - t_{o2}\right)} \tag{5}$$

$$t_{m3} = t_{m2} - \frac{G_{i3}}{G_3\left(t_{m2} - t_{o3}\right)} \tag{6}$$

$$t_{m4} = t_{m3} - \frac{G_{i4}}{G_4\left(t_{m3} - t_{o4}\right)} = t_o \tag{7}$$

3.4. Design calculations

The common principle of dimensioning vertical hydraulic distributors is used in the distributor design. It consists in determining the size of the distributor diameter ***D*** as a function of the diameter of the inlet conduit ***d***.

It is assumed that the water velocity in the inlet stub pipe is 0.7-0.9 m/s, while the average water velocity in the device itself should not exceed 0.10-0.15(0.20) m/s (Mizielińska & Olszak 2005). With this assumption, the condition for optimal dimensioning is $D \geq 3d$ (Szkarowski et al. 2007).

However, the case under consideration differs significantly from vertical distributors. First, the distributor works in series. The device is not vertical but slightly inclined. In addition, the device has the shape of a cuboid. These differences caused the ***D/d*** ratio to be quadrupled. Size ***D*** was assumed to be the lateral side of the cross – section.

The distance between the connection pipe stub in vertical distributors is ***(3-4)d***. This ensures proper mixing of the flows and stratification of the temperature field (Mizielińska & Olszak 2005). In the case at hand, the stratifying principle is not applied. However, due to the good mixing, this ratio is correct. The same distance of 130 mm has been assumed for the DN32 and DN25 pipe stubs.

The next step in the design was the dimensioning of the perforations of the perforated plates. The general rule is that the cross – section of the perforation in the light should be approximately three times larger than the inlet stub (Szkarowski et al. 2007). As the cross – sectional area of the DN32 pipe stub is approx. 1000 mm^2, the required area of perforation is approx. 3000 mm^2. In order to reduce the hydraulic resistance, this ratio was increased by 1/3, i.e. to approx. 4000 mm^2.

The final symmetry design decided to use 81 perforation holes with a diameter of 10 mm (Fig. 4. a). The dimensions of the dividing plate (Fig. 4. b) were determined by the issues of effective division of flows in front of it and effective mixing of flows in the mixing chamber.

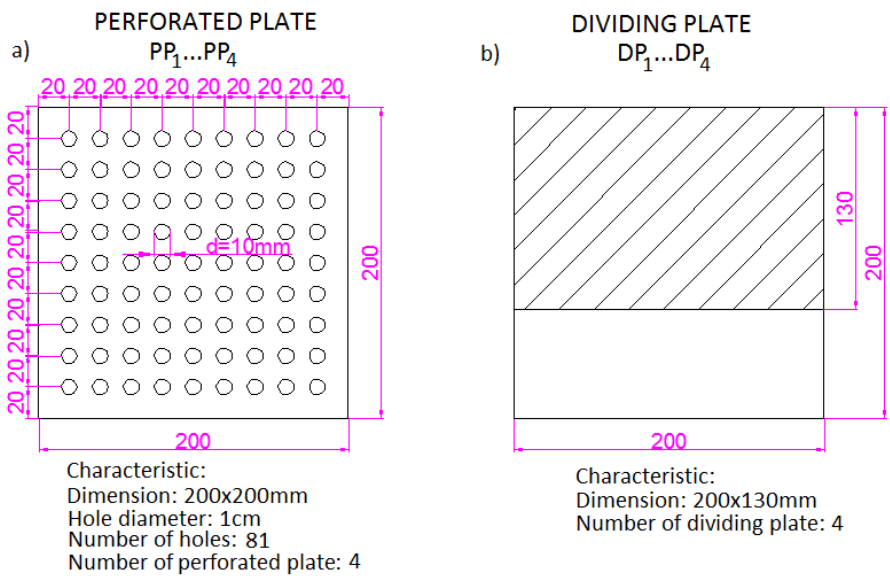

Fig. 4. Perforated plate a) and dividing plate b)

4. Summary

An improved design and operating principles of the thermo-hydraulic distributor were developed, the purpose of which is to balance the hybrid boiler station system with heating and supply circuits with different operating parameters in a hotel located in Koszalin.

A characteristic feature of the device is its internal structure, which allows the flows to be divided and mixed in order to adapt to the calculated temperature of the heating medium for the given circuits according to the temperature logic.

There is no such type of distributors on the market. However, the length of the device may be a problem, as the more heating circuits, the longer the manifold becomes. This would require more space in the boiler station or in the district heating substation. For a given object, this length was not a problem for the placement and assembly of the device.

References

Dopieralska, K., Siuta-Olcha, A., Cholewa, T., Tatara, G. (2015). Technical and Economic Analysis of Hydronic Balancing for Central Heating System. *Rocznik Ochrona Środowiska*, *17*, 1609-1621 (in Polish).

Janta-Lipińska, S. (2020). The Method of Nitrogen Oxide Emission Reduction During the Combustion of Gaseous Fuel in Municipal Thermal Power Boilers. *Rocznik Ochrona Środowiska*, *22*(1), 376-390.

Mizielińska, K., Olszak, J. (2005). *Low – power gas and oil heat sources*, Warszawa: Publishing House of the Warsaw University of Technology (in Polish).

Orłowska, M. (2020). Experimental Research of Temperature Distribution on the Surface of the Front Plate, of a Flat Plate Heat Exchanger. *Rocznik Ochrona Środowiska*, *22*(1), 256-264.

Shkarovskiy, A., Zelenov, G. (2012). Solution of hydraulic and thermodynamic problems of heat supply of various loads by the method of serial connection. *Bulletin of Civil Engineers*, *4*(33), 208-213 (in Russian).

Szkarowski, A. (2019) *Heat supply*. 3rd edition, updated. Warszawa: PWN (in Polish).

Szkarowski, A., Nakręt, L., Szokalski, W. (2007). Differential thermal system based on a series hydraulic clutch. Savings pooled. *Magazyn Instalatora*, *10*, 52-53 (in Polish).

Szkarowski, A., Naskręt, L. (2008). Theoretical Issues of Use of Hydraulic Dividers and Buffer Tanks in Heating Systems. *Rocznik Ochrona Środowiska*, *10*, 319-334 (in Polish).

Żelazna, A. (2012). Assessment of Environmental Effects of Thermomodernization on the Example of a Detached House. *Rocznik Ochrona Środowiska*, *14*, 729-740 (in Polish).