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Regulating the temperature of the heating agent in district heating systems with the aim of RES integration and the recovery of residual thermal energy

Reglarea temperaturii agentului termic în sistemele de termoficare cu scopul integrării SER și a recuperării energiei termice reziduale

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Abstract. Given the energy crisis the entire planet is going through, the waste of any form of fuel or energy source is clear evidence of irresponsibility towards both humanity and the planet we manage. The study presents several proposals for making the district heating system more efficient by integrating renewable sources into the heat production process and recovering the residual thermal energy resulting from technological processes.

Key words: renewable energy sources, district heating, waste energy recovery

1. Introduction

District heating systems in Romania are still among the most polluting public services, contributing substantially to the increase in global temperature, through CO_2 emissions per Gcal, which have reached alarming levels [1-3]. Regarding current challenges, the development of urban heating systems is essential to face the energy transition phase.

For this reason, this scientific report presents possible solutions for energy efficiency of district heating systems, using the district heating system in Timișoara as an example. Although the district heating system in Timișoara has the capacity to cover a fairly high percentage of the city's thermal energy consumption, modernization measures by replacing existing pipes with preinsulated pipes have not solved the problem of energy efficiency of the system [4]. Over time, centralized thermal energy supply systems have evolved, moving from generation I and currently reaching, in Timișoara, generation III, and the proposals for the current period are those of moving to generation IV [5,6].

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In the context of the requirements regarding the quality of constructions, regarding energy saving and thermal insulation, respectively the sustainable use of natural resources, the 4th generation of systems represents a natural evolution of the 3rd generation and highlights the efficiency-oriented characteristics. The temperatures of the thermal agent for transporting or distributing thermal energy continue to have a decreasing trend, the equipment used is increasingly modular, and the materials are increasingly flexible and with reduced energy losses, but the most important aspect is the fact that the system allows for easier integration of renewable energy sources (RES).

Currently, district heating systems allow for the long-distance distribution of thermal energy and the use of an increasing percentage of renewable energy, thus increasing the fight against global warming and the energy crisis. For this reason, sustainable district heating systems will have to ensure planning structures, low costs correlated with efficient operation and strategic investments, as illustrated in Fig. 1 [7].

Fig. 1. The concept of 4th Generation District Heating

The main efficiency solutions considered in the study relate to the integration of RES, the reduction of the temperature of the heat carrier in the primary network and the recovery of waste heat [4-6,8,20].

Traditional district heating systems are composed of thermal power plants that pump hot water or steam through pipes to provide heat to metropolitan areas. A district heating system incorporates a heat generating unit, a transport and distribution network, heat points and heat consumers (end users) (Fig. 2) [9].

The scheme of the district heating network is shown in Fig. 2. In the primary circuit, hot water is transported through a transport network to the district heating points and then returns to the heat source, and in the secondary circuit, this heat is transferred to the final consumers via heating elements.

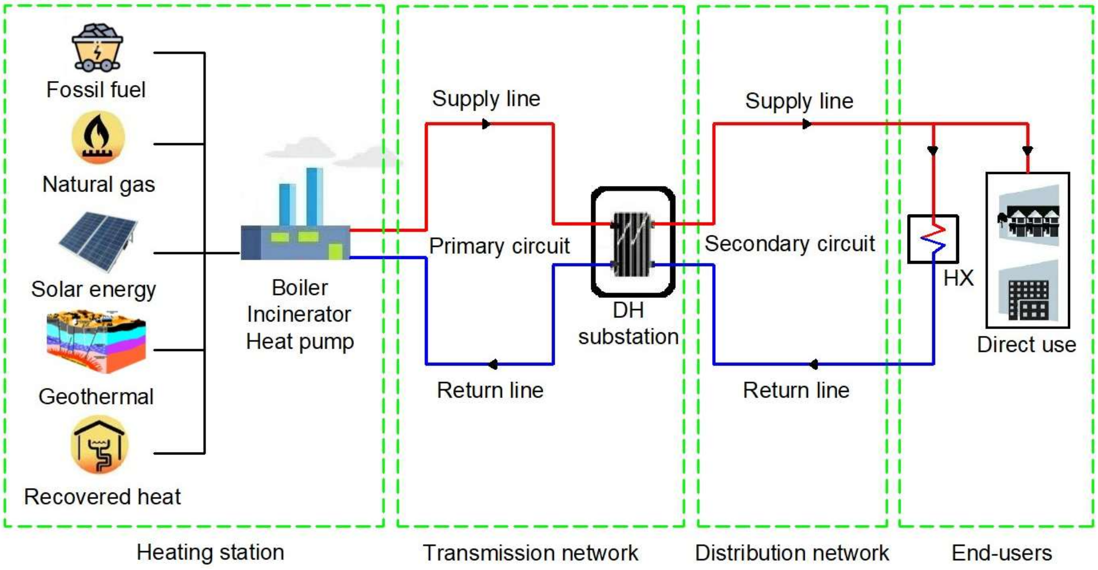

Fig. 2. Essential district heating system components

Surplus industrial heat can be recovered and used in a district heating system [10]. The incorporation of RES into district heating systems results in lower outlet temperatures than those of a conventional supply network. In this context, geothermal systems using heat pumps have attracted increasing interest in several countries in the last few years, as they allow for a sustainable replacement of fossil fuels and create zero CO_2 emissions [9]. In addition, nations such as Sweden, Denmark, Germany and Austria have increased their use of solar energy for the production of thermal energy used in district heating systems [9].

There are four distinct generations of district heating systems [11]. Generation I transported steam at temperatures above 200 °C using concrete pipes. As a result, it was not particularly efficient and was replaced due to the risk of pipe bursting. Generation II used concrete pipes to transport pressurized water at temperatures above 100 °C and is known as high-temperature district heating.

Generation III uses pre-insulated pipes buried directly in the ground and operates with water at supply temperatures between 65 and 95 °C. Generation IV district heating systems are now being developed and referred to as low-temperature district heating systems (50-60 °C). When end-user temperatures are increased with heat pumps, ultra-low supply temperatures (35-45 °C) are also used [12].

The fifth generation of district heating Is an extension of the fourth generation, a new concept based on a decentralized network that allows direct energy flows between and within buildings. Its key features are: low exergy network using low-temperature heat sources; closed thermal energy loops that ensure the exchange of heat and cold between groups of buildings; integration and synergy between thermal and electrical networks; 100% renewable energy target [13]. The evolution of district heating generations over time is presented in Fig. 3.

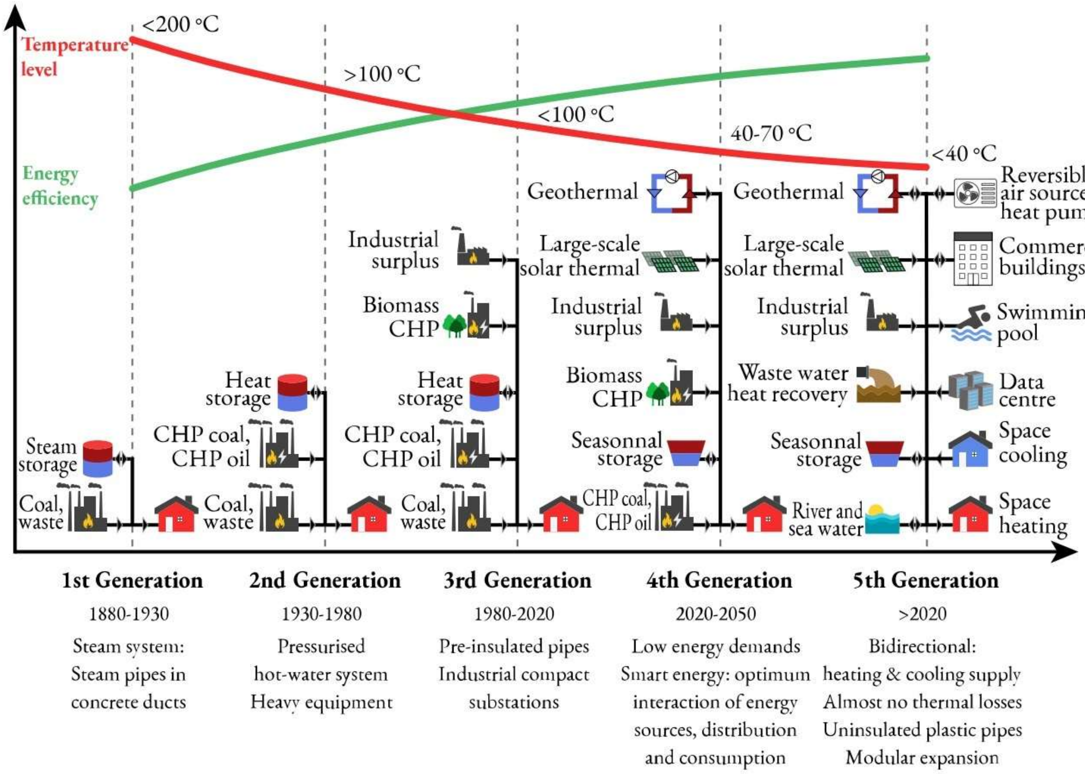

Fig. 3. The evolution of the district heating systems generations [9]

The temperature reduction in district heating networks is constrained by the heat requirements and the technical specifications of residential and commercial buildings (domestic hot water demand or space heating design).

Table 1 defines the different types of district heating systems according to the technical requirements of the buildings, the corresponding heating terminal units and the previous definitions. Recent investigations have suggested that low temperature systems have a significant potential for space heating in existing buildings [14].

Figure 4 illustrates the required supply temperatures for radiators in space heating systems for buildings with different heat requirements.

Table 1

The five types of district heating networks [9]

DH network generation	DH network type	Supply temperature (°C)	Limitation	Suitable terminal unit
1GDH	Very high temperature	160-210	The necessity of using condensate collection and transport equipment	High pressure tubular heater
2GDH	High temperature	100-125	The necessity of using pressurised tanks that may be linked directly to the system	Tubular heating radiator
3GDH	Medium temperature	65-95	Minimum temperature for DHW in the tank (65 °C)	Radiator
4GDH	Low	50-60	Minimum DHW comfort	Radiant system

DH network generation	DH network type	Supply temperature (°C)	Limitation	Suitable terminal unit
	temperature		temperature (50 °C)	(floor, wall, ceiling), radiator, fan coil
4GDH	Ultra-low temperature	35-45	Minimum floor heating temperature (35 °C)	Radiant floor
5GDH	Ambient temperature	0-30	Minimum supply temperature of WSHP (0 °C)	Radiant system

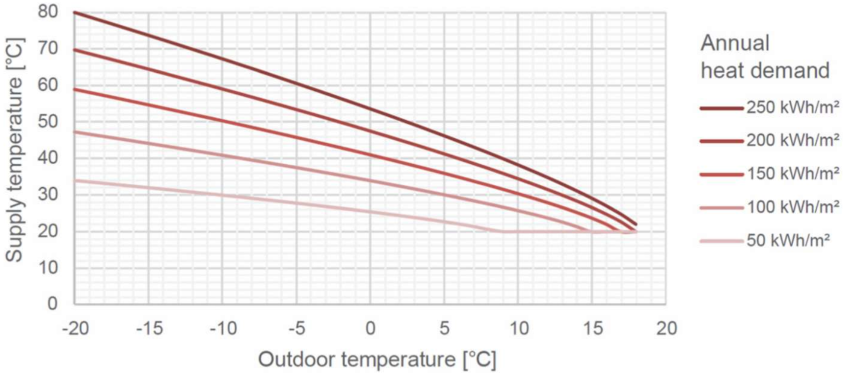

Fig. 4. The necessary supply temperatures in a radiator [15]

2. Proposals to improve the efficiency of the district heating system

As can be seen in Fig. 3, both the reduction of heat losses and the possibility of introducing/using RES and recovering residual heat energy require a decrease in the temperature regime used for transporting energy from the source(s) to the final consumers.

If the entire district heating system is taken into account, both the total heat loss and its saving potential are significant. The typical primary supply network for different areas of the city requires different supply temperatures, depending on the type of existing buildings, so for new residential areas, the required temperature is considerably lower than in residential areas with old buildings or industrial areas. Reducing heat losses on the transport network can be achieved by thermal insulation of the pipes using the most efficient and new solutions and materials or by reducing the temperature of the transported heat carrier [5].

2.1. Delivery temperature zoning in the primary district heating network

Zoning of the primary network is achieved by installing a mixing loop that injects water from the return pipe into the supply pipe (Fig. 5), resulting in a mixture that provides the necessary temperature for end users.

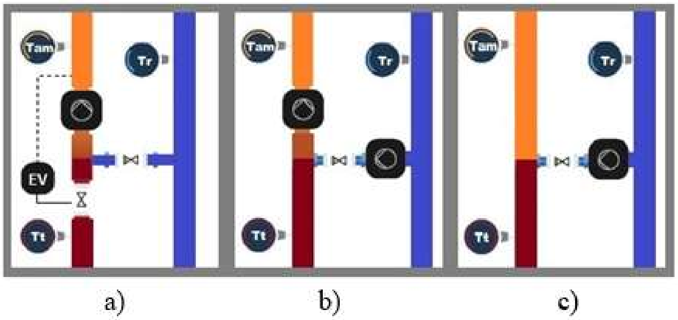

Fig. 5. Mixing loop control systems [5]
a) Classic loop; b) Free flow loop; c) By-pass pump loop
Tt – flow temperature, Tr – return temperature, Tam – mixing temperature, EV – solenoid valve

In Fig. 6a it is observed that each building zone is supplied by a branch of the primary network, and at the branching points a reduction of the flow/return temperature regime can be achieved depending on the specific needs of that zone. In Fig. 6b, the temperature zoning is observed on the branches supplying residential buildings that use a lower temperature heat carrier to ensure the thermal needs for heating and preparation of hot water for consumption.

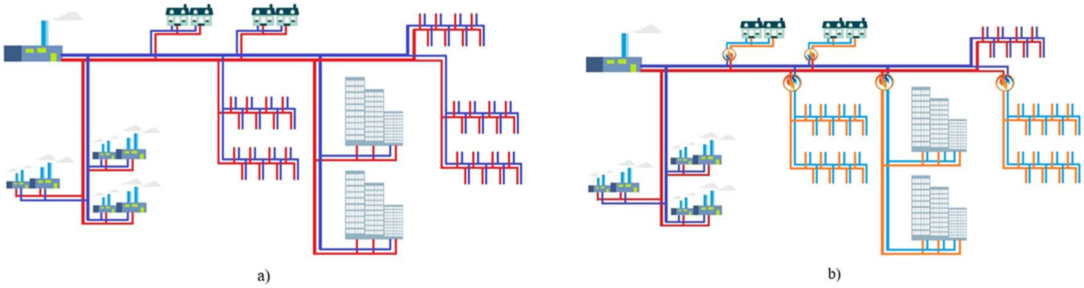

Fig. 6. Schema sistemului centralizat de termoficare [5]
a) înainte de zonare; b) după zonare

2.2. RES integration and expansion of the prosumer concept

The diversification of energy sources, but also the variation in consumption, generates on the one hand the need to store the energy obtained, especially that from renewable sources and to transform some networks from unidirectional to bidirectional. The selection of thermal energy sources that ensure a quality supply for consumers will have an important role in optimizing the operation of thermal networks and transforming classic networks into smart networks. In this context, this study addresses the advantages of smart thermal networks related to the local integration of RES (heat pumps and photovoltaic panels), transforming consumers into prosumers of thermal and electrical energy. The problem of RES variability and fluctuation can only be solved by storage. It is estimated that thermal energy storage in both the civil construction and industrial sectors can ensure annual energy savings of up to 7.8% and a 5.5% reduction in CO_2 emissions [16].

On the other hand, changes are also occurring in terms of the requirements that the sources must provide, emphasizing the ecological aspect at the expense of the economic aspect. For this reason, a mix of conventional and renewable sources is inevitable in the energy sector. The development of energy solutions that integrate renewable energy into thermal and electrical energy production systems has been of major interest to energy producers and distributors in recent years [17]. The proposal for the integration of RES is addressed to the buildings of the educational unit "Henri Coandă Technical College Timișoara" and the thermal point PT34 (Fig. 7).

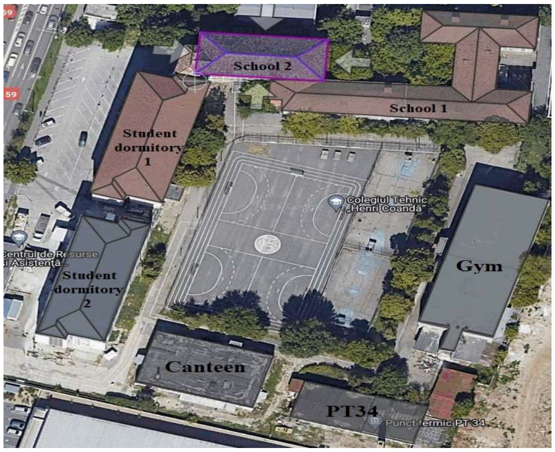

Fig. 7. Situation plan of the studied buildings

The placement of photovoltaic panels on the roofs of the buildings (Fig. 8) was carried out using the Polysun calculation program [18]. The electrical energy produced is used in the first phase to ensure its own electrical energy consumption. Table 2 presents the output data resulting from the simulation performed by installing 1956 EvoloCells 400 MIB 400 W photovoltaic panels, on a total roof area of 13,592 m².

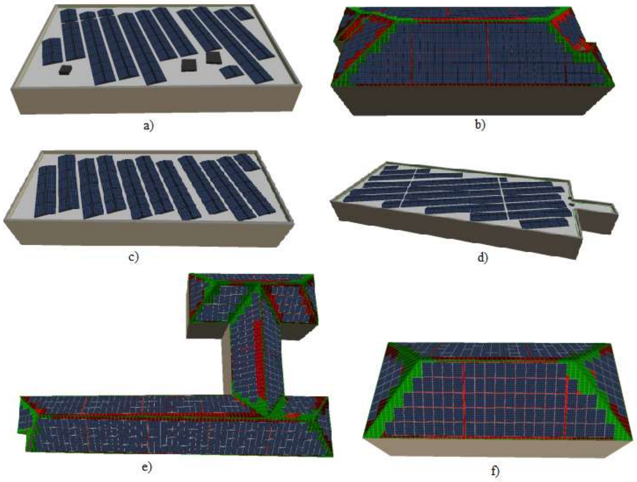

Fig. 8. The placement of photovoltaic panels on the studied buildings [19]
a) Canteen; b) Student dormitory 1 and 2; c) PT34; d) Gym; e) School 1; f) School 2

Table 2

The output data of the studied buildings [19]

Building	Nr. of panels	PV inst. [MW]	PV prod. [MWh/an]
Canteen	154	61.60	67.60
Student dormitory 1	333	133.20	142.60
Student dormitory 2	297	118.80	124.35
PT 34	122	48.80	53.96
Gym	294	117.60	130.04
School 1	552	220.80	218.43
School 2	204	81.60	82.54
Total	1,956	782.40	820.00

Given the considerable surplus of annual electricity produced after ensuring the own electricity consumption necessary for the operation of the educational buildings, 6 air-to-water heat pumps were installed, each with a heating capacity of 200 kW, which use the electricity from the photovoltaic system. The thermal energy produced by the heat pumps using the electricity from the photovoltaic system of the educational institution can be used first for the preparation of hot water consumed in the own buildings as well as for heat supply in their heating installations, resulting on the heating side a hybrid system that uses as primary thermal energy the one from the DH system with input of energy from RES. In table 3 you can see the production of the photovoltaic system (PV prod), the consumption of electricity for lighting (El. Enec), the preparation of hot water for consumption (Hw Enec) and the input of thermal energy for the heating system (Heat. Enec) and surpluses of solar electricity produced (S. Epv).

Table 3

Monthly production and consumption of electricity [19]

Month	Elec. Enec (MWh)	Heat Enec (MWh)	Hw Enec (MWh)	PV prod. (MWh)	S Epv (MWh)
Jan	20.00	90.64	21.74	24.07	-108.31
Feb	18.50	73.11	20.14	36.44	-75.31
March	18.00	57.95	22.25	64.84	-33.36
April	17.00	27.79	20.90	88.45	22.76
May	16.00	9.28	20.49	106.31	60.54
June	9.50	1.62	18.61	111.35	81.61
July	1.00	0.03	18.17	115.98	96.78
Aug.	1.00	0.00	17.58	101.20	82.62
Sept.	10.00	7.88	17.07	70.83	35.88
Oct.	17.00	30.90	18.31	50.99	-15.23
Nov.	18.00	56.08	18.80	30.87	-62.01
Dec.	20.00	81.72	20.68	18.73	-103.67
Sum	166.00	437.00	234.74	820.00	-17.69

Even after using the photovoltaic electricity produced to cover the various types of energy required for the operation of the buildings, there are several months during the summer period that remain with a considerable surplus of electricity produced.

The classic solution is for this surplus electricity to be delivered to the national energy system, but there is a possibility that this surplus cannot be taken over. It is proposed that the electricity not consumed in the summer months be used to produce domestic hot water (DHW), which will be introduced into the DHW distribution network of the district heating system, also considering the fact that the PT34 thermal point is located in the immediate vicinity of the educational buildings.

Also, the surplus photovoltaic energy is used by the 6 heat pumps to prepare DHW and introduce it into the district heating system to supply the neighboring residential district "City of Mara". Table 4 summarizes the solar energy surplus (S Epv) for the summer months, the electrical energy required to produce domestic hot water that is delivered to the "City of Mara" residential district (Hw Enec "City of Mara") and the electrical energy delivered in NES (Elec. In NES).

Table 4

Electrical and thermal energy introduced into the system [19]

Month	S Epv (MWh)	Hw Enec "City of Mara" (MWh)	Elec. in NES (MWh)
April	22.76	52.24	-
May	60.54	51.22	9.32
June	81.61	46.54	35.08
July	96.78	45.43	51.35
Aug.	82.62	43.95	38.67
Sept.	35.88	42.66	-

Fig. 22 shows the functional diagram of the photovoltaic electricity and heating and ACC thermal energy production plant and its integration into the district heating system, so that the beneficiary of the buildings considered becomes a prosumer of thermal and electrical energy [22]. The thermal energy produced is stored in a storage tank (RS).

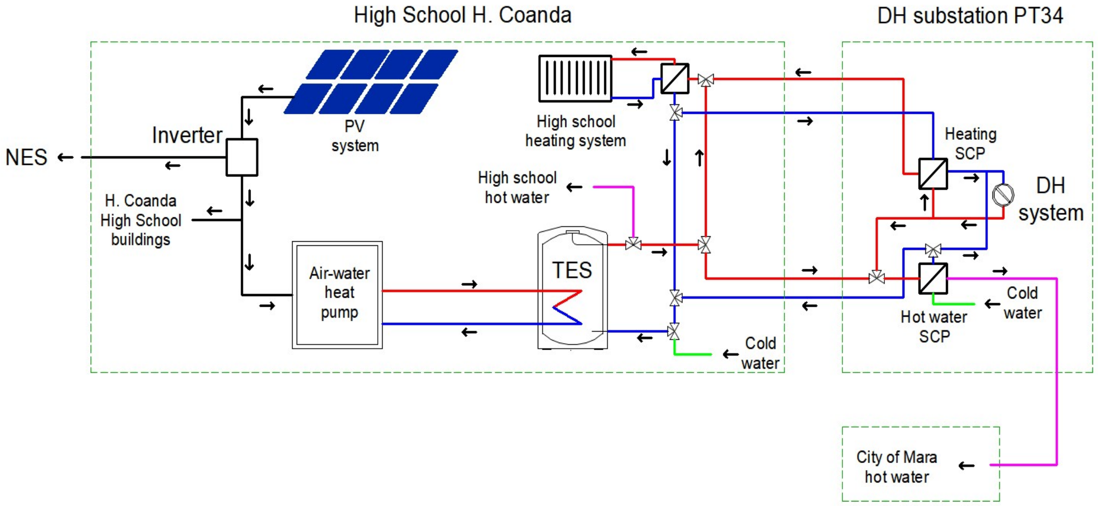

Fig. 22. Functional scheme of the thermal and electrical installation [19]

Beneficiaries of residential or public buildings must view the need to use RES as an opportunity to move from being consumers to being prosumers of thermal and electrical energy.

2.3. The recovery and utilization of residual heat from data centers

The rapid increase in the need for data storage and processing and digital telecommunications have recently generated a massive development of the data center (DC) industry. Although the digitization of various fields of human activity brings major benefits to the quality of his life, the secondary effects that appear because of this trend must also be assumed and solutions found to reduce the negative effects. Considering the exponential increase in human dependence on IT devices and services, an increase in energy consumption for manufacturing and powering these devices is also generated [20].

Considering that the potential of recoverable energy from DC residual heat varies depending on their size, the characteristics of the equipment used and the classification class of the DC, the applications for its subsequent use will be of two types, namely: local use, by integrating the energy under the form of hot water in the own heating installation and hot water supply for consumption and centralized use by providing thermal energy, as a prosumer, to the city's district heating system [20].

2.3.1. Local use of recovered energy

The local use of recovered energy is chosen as a technical solution for situations where the amount of thermal energy recovered is less than or equal to the total thermal energy required to cover the needs of the buildings in which the DC is located, for space heating in the winter and the production of domestic hot water in the summer.

For the recovery of residual heat from DC, an air-water heat exchanger connected to the primary circuit of a water-water heat pump can be used, which will raise the temperature of the heating agent so that it can still be used as needed in the thermal heating installation or for the production and accumulation in a hot water tank (HWT) of domestic hot water. The functional scheme of the waste heat recovery installation and the production of thermal energy in the form of hot water is presented in Fig. 2 [20].

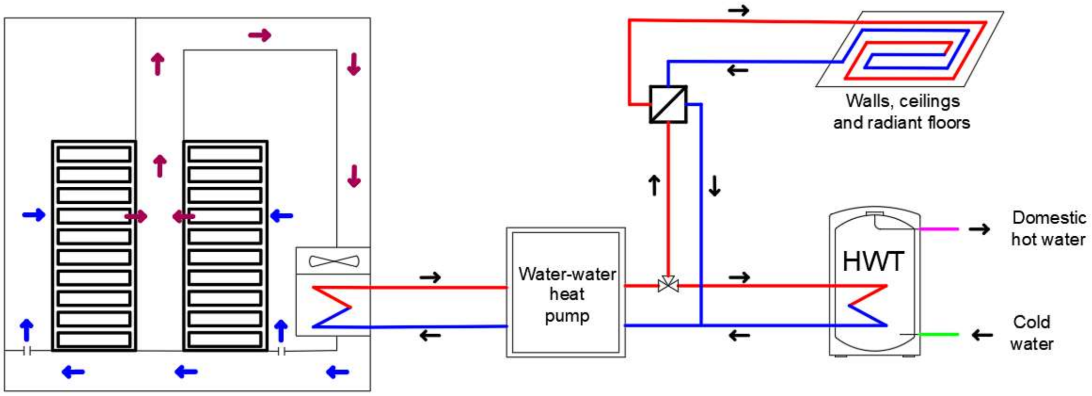

Fig. 2. Functional scheme of the recovery and local use installation

2.3.2. Introducing the recovered energy into the heating system

An important aspect that must be taken into account when we talk about RES integration is the fact that the temperature of the thermal agent produced by these sources is lower than in the case of the classic ones, so that the use of additional equipment is required to raise the temperature of the agent to the necessary value so it could finally be used by the consumers of the heating system, in most cases using water-to-water heat pumps (Fig. 5).

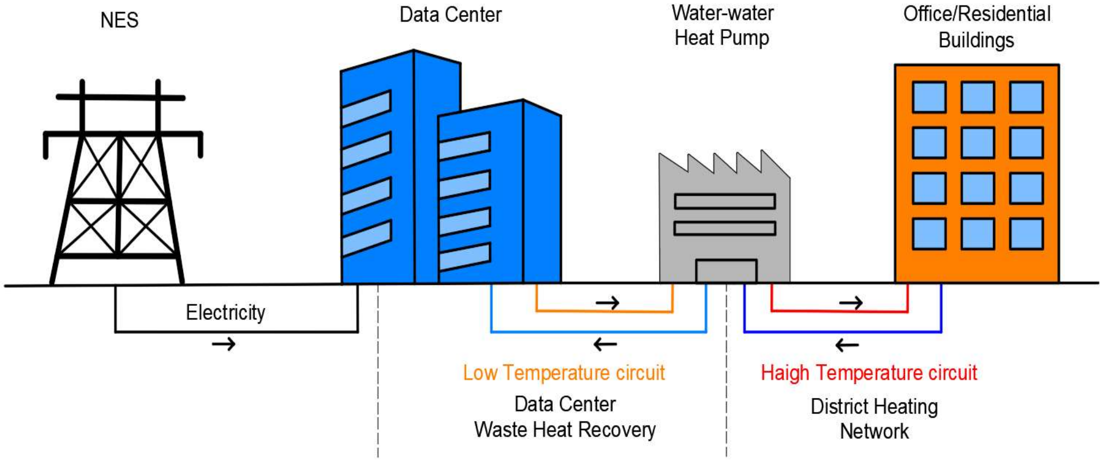

Fig. 5. Integration of thermal energy recovered from data centers in the district heating system

3. Conclusions

The proposed energy efficiency measures aim at the sustainable implementation and use of district heating networks, in accordance with the policy of reducing energy consumption and CO_2 emissions.

The integration of renewable energy sources into the production process of the thermal agent represents a pressing necessity for which the most efficient technical solutions must be found so that thermal energy losses through transport are reduced as much as possible.

The residual energy potential in the EU presented in specialized literature is estimated to be approximately 2860 TWh/year of which approximately 56 TWh/year comes from the DC sector [21,22]. So, the residual energy potential recoverable from DC is a source for the preparation of hot water in various applications like domestic hot water or thermal agent for heating installations.

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