

**MINISTRY OF NATIONAL EDUCATION
TECHNICAL UNIVERSITY OF CIVIL ENGINEERING BUCHAREST
DOCTORAL SCHOOL**

RESEARCH REPORT No. 3
**Structural and operational energy-efficient solutions for district
heating systems. Economic and energy aspects**

PhD Supervisor
Prof. IORDACHE FLORIN, PhD

PhD candidate
SECARĂ (STĂNIȘTEANU) CRISTINA ALICE

September 2017

Contents

1. Foreword	3
2. Energy savings achieved by the thermal rehabilitation of the building envelope as a function of the degree of renovation	5
3. Energy savings due to using low temperature heat carriers in distribution networks	14
4. Connection schemes that allow the renovated buildings to be supplied with low-temperature heat carrier	19
a. The thermal substation supplies only high energy efficient buildings	20
b. A branch of the distribution system supplies only high energy efficient buildings	41
c. The thermal substation or heat-only boiler station supplies both high-energy and low-energy buildings	48
5. Conclusions	52
6. Symbols and abbreviations	53
7. References	55

1. Foreword

Following the recast of the Energy Performance of Buildings Directive (2010), the Romanian Government amended the provisions of the Regional Operational Program so that part of the funds allocated through this program were directed to the energy rehabilitation of buildings. Local authorities in Romania have reacted, so thousands of apartment buildings in dozens of cities have been rehabilitated so far, and the rehabilitation programs continue at the same pace, being further financed through the Regional Operational Program, Priority Axis 4 (Supporting urban development). Thermal rehabilitation of buildings aims to reduce heat loss through building elements, resulting in a significant reduction in heat demand for heating the building.

Feeding these consumers with a heat carrier at the same temperature as they had been previously fed leads to a decrease in the efficiency of the district heating systems by increasing energy losses. Consequently, investments made to improve the energy performance of buildings are not justified, as the energy efficiency of heat generation and distribution systems decreases. The demand for thermal energy in areas with low energy buildings will be low and the operation of district heating systems at current parameters could lead to a situation where they are no longer economically viable and will be closed down. Obviously, there is an objective need to reduce heat loss in the system and this can be achieved by supplying consumers with a lower temperature heat carrier.

The efficiency of the district heating systems in our country is low. According to Romania's Energy Strategy for the period 2016-2030, it is estimated that total energy losses between sources and consumers are about 30% of the thermal energy produced. At the same time, the financial resources allocated to the rehabilitation of these systems were quite low. According to the same source, only 20% of the transportation networks and 30% of the distribution networks have been upgraded. [1] The lack of investment, coupled with low maintenance costs, has led to advanced physical wear of the pipelines, whose lifespan is often exceeded, and to low efficiency systems with high operating costs.

Low temperature district heating ensures an increase in the efficiency of these systems at no cost for local authorities.

Although the measures for energy conservation in buildings was aimed at reducing the heat demand of the buildings, it did not cover the surfaces of the radiators. High energy efficiency buildings are supplied with heat carrier using common distribution networks with low energy buildings, at a temperature level corresponding to the adjustment curve of the latter. If the radiators in low energy buildings have not been fitted with thermostatic valves, this leads to an increase in the indoor temperature in the rooms of these buildings.

The following measures are required to achieve maximum energy efficiency at the level of the district heating system

- the implementation of energy conservation measures in buildings
- feeding low energy buildings with a heat carrier having a temperature in accordance with the adjustment curve determined for these buildings
- fitting the radiators with thermostatic valves
- fitting the systems with meters for heat consumption and domestic hot water consumption
- insulation of distribution pipes in the technical basement of buildings
- fitting the systems with separation valves and drain valves.

2. Energy savings achieved by the thermal rehabilitation of the building envelope as a function of the degree of renovation

This paper presents the assessment of energy savings as a result of applying the first two measures of increasing the efficiency of district heating systems (thermal rehabilitation of buildings and using low temperature heat carrier for low energy buildings). The two types of measures are not independent, as the delivery temperature of the heat carrier depends on the level of thermal rehabilitation. Fitting the radiators with thermostatic valves and cost allocators is a measure of reducing the heat consumption which can be applied independently of the other two measures, but the efficiency of this measure is impossible to determine by calculation because of its subjective character (it is impossible to predict the behavior of people living in the building). Using thermostatic valves in conjunction with cost allocators has been proven as a very efficient method of energy saving by numerous experimental studies, including in Romania. An extensive study conducted in Poland over a period of 17 years (1997-2014) has established that the installation of cost allocators in buildings has led to a reduction in heat demand by an average of 26.6%. Thermal rehabilitation of buildings has led to a 20.3% reduction of heat consumption in buildings where no cost allocators are installed and a 27.2% reduction of heat consumption in buildings where the heating system is equipped with cost allocators. [2] In Romania, a study carried out in 2003-2004 on 65 apartment buildings, out of which 32 had the heating system fitted with thermostatic valves and cost allocators, showed that the heat consumption in these buildings was 25% lower, compared to other buildings.

In order to assess the energy consumption, the formulas associated with the heat supply curves for constant flow rates have been used: [4]

$$t_t = \left[1 + \frac{t_{i0} - t_{i0}}{t_{i0} - t_{e0}} \cdot \frac{1 - E_0}{1 - E} \cdot \frac{H}{H_0} \right] \cdot t_{i0} - \frac{t_{i0} - t_{i0}}{t_{i0} - t_{e0}} \cdot \frac{1 - E_0}{1 - E} \cdot \frac{H}{H_0} \cdot t_e \quad (1)$$

$$t_r = \left[1 + \frac{t_{r0} - t_{i0}}{(t_{i0} - t_{e0})} \cdot \frac{E}{E_0} \cdot \frac{1 - E_0}{1 - E} \cdot \frac{H}{H_0} \right] \cdot t_{i0} - \frac{t_{r0} - t_{i0}}{t_{i0} - t_{e0}} \cdot \frac{E}{E_0} \cdot \frac{1 - E_0}{1 - E} \cdot \frac{H}{H_0} \cdot t_e \quad (2)$$

where:

$$E_0 = \exp(-NTU_0) = \exp\left(-\frac{k_0 \cdot S}{G_0 \cdot \rho \cdot c}\right) = \frac{t_{r0} - t_{i0}}{t_{i0} - t_{i0}} \quad (3)$$

$$E = E_0^{\frac{k}{k_0}} \quad (4)$$

$$\frac{k}{k_0} = \left(\frac{\Delta t_{ml}}{\Delta t_{ml0}} \right)^{0.3} \quad (5)$$

$$\Delta t_{m/0} = \frac{t_t - t_r}{\ln \frac{t_t - t_{i0}}{t_r - t_{i0}}} \quad (6)$$

Using the formulas above, the heat flows transmitted by the heating system to the heated space were calculated, assuming that they are equal to the heat losses from the heated space to the outdoor environment. The temperatures of the heat carrier and the indoor temperature have been determined.

The reduction of the annual heating energy consumption was analyzed as a result of the two types of measures presented above, namely:

- the implementation of energy efficiency measures in the building (by reducing the thermal coupling coefficient of the building envelope, H)
- the adjustment of the temperature of the heat carrier to the new heat demand of the building, according to the degree of renovation.

Calculation assumptions:

1. For the assessment of the annual heating energy consumption, the case of a building with a rated heat load of 1 MW located in the climatic zone 2 was considered. [5]
2. The design indoor temperature, determined as the predominant temperature of the design indoor temperatures of the building, was considered +20°C according to SR 1907/2-2014.
3. The daily average values of the outdoors temperature during the period 1997-2007, provided by the National Weather Administration, were considered for the assessment of annual heating energy consumption.

The first case analysed was that of the building before renovation; the temperature of the heat carrier is in accordance with the heat supply diagram established at the design stage. The typical design temperatures for the primary (transport) the secondary (distribution) networks were considered: $t_{T0}/t_{R0} = 150/80^\circ\text{C}$, $t_{T0}/t_{R0} = 90/70^\circ\text{C}$.

Table 1 shows the hourly and annual heating energy consumption for the unrenovated building ($H/H_0=1$ case):

Table 1 Hourly and annual heating energy consumption for the unrenovated building

Heat load P0 = 1 MW		Secondary (distribution) network					
		H/H0 = 1 (unrenovated envelope)					
No. of days	te (°C)	t _{tB} (°C)	t _{rB} (°C)	t _{iB} (°C)	RPTS	P (MW)	Q (MWh)
2	-15	90,0	70,0	20	1,00	1,00	48
11	-10	81,8	64,7	20	0,857	0,857	226
32	-5	73,4	59,1	20	0,714	0,714	549
60	0	64,6	53,2	20	0,571	0,571	823
53	5	55,5	46,9	20	0,429	0,429	545
24	10	45,7	39,9	20	0,286	0,286	165
	15	34,8	31,9	20	0,143	0,143	0
	20	20	20	20	0,00	0,00	0
							2356

The second case was that of the renovated building supplied with a heat carrier having a temperature corresponding to the unrenovated building (according to the heat supply curves determined at the design stage) - heat carrier used for the heating of the other unrenovated buildings supplied by the same DHS (the current situation of all renovated buildings supplied by DHS in Romania). Several degrees of building renovation have been studied ($H/H_0=0,8$; $H/H_0=0,6$; $H/H_0=0,4$).

Table 2 shows the indoor temperature in the renovated building as a result of using the same temperature on the supply pipe of the heat carrier as for the unrenovated buildings, and the resulting temperature on the return pipe of the heat carrier. The table also shows the hourly and annual heating energy consumption for the renovated building ($H/H_0=0,8$ case) when the temperature of the heat carrier supplied to the building is the same as the one for the unrenovated buildings.

Table 2 Hourly and annual heating energy consumption for the renovated building (H/H0=0,8 case); uncorrected heat supply curve)

Heat load P0 = 1 MW		Secondary (distribution) network					
		H/H0 = 0,8 (renovated envelope + uncorrected heat supply curve)					
No. of days	te (°C)	t _t (°C)	t _r (°C)	t _i (°C)	RPTS	P (MW)	Q (MWh)
2	-15	90,0	71,7	24,9	0,913	0,91	44
11	-10	81,8	66,2	24,3	0,784	0,78	207
32	-5	73,4	60,3	23,6	0,654	0,65	503
60	0	64,6	54,2	23,0	0,525	0,52	755
53	5	55,5	47,6	22,3	0,395	0,39	502
24	10	45,7	40,4	21,6	0,264	0,26	152
	15	34,8	32,1	20,8	0,133	0,13	0
	20	20	20	20,0	0,00	0,00	0
							2163

Table 3 shows the indoor temperature in the renovated building as a result of using the same temperature on the supply pipe of the heat carrier as for the unrenovated buildings, and the resulting

temperature on the return pipe of the heat carrier. The table also shows the hourly and annual heating energy consumption for the renovated building ($H/H_0=0,6$ case) when the temperature of the heat carrier supplied to the building is the same as the one for the unrenovated buildings.

Table 3 Hourly and annual heating energy consumption for the renovated building ($H/H_0=0,6$ case); uncorrected heat supply curve)

		Secondary (distribution) network					
Heat load $P_0 = 1$ MW		$H/H_0 = 0,6$ (renovated envelope + uncorrected heat supply curve)					
No. of days	t_e (°C)	t_t (°C)	t_r (°C)	t_i (°C)	RPTS	P (MW)	Q (MWh)
2	-15	90,0	74,0	31,6	0,799	0,80	38
11	-10	81,8	68,1	30,1	0,687	0,69	181
32	-5	73,4	61,9	28,5	0,575	0,57	442
60	0	64,6	55,4	27,0	0,462	0,46	666
53	5	55,5	48,5	25,4	0,349	0,35	444
24	10	45,7	41,0	23,7	0,235	0,23	135
	15	34,8	32,4	22,0	0,119	0,12	0
	20	20	20	20,0	0,00	0,00	0
							1906

Table 4 shows the indoor temperature in the renovated building as a result of using the same temperature on the supply pipe of the heat carrier as for the unrenovated buildings, and the resulting temperature on the return pipe of the heat carrier. The table also shows the hourly and annual heating energy consumption for the renovated building ($H/H_0=0,4$ case) when the temperature of the heat carrier supplied to the building is the same as the one for the unrenovated buildings.

Table 4 Hourly and annual heating energy consumption for the renovated building ($H/H_0=0,4$ case); uncorrected heat supply curve)

		Secondary (distribution) network					
Heat load $P_0 = 1$ MW		$H/H_0 = 0,4$ (renovated envelope + uncorrected heat supply curve)					
No. of days	t_e (°C)	t_t (°C)	t_r (°C)	t_i (°C)	RPTS	P (MW)	Q (MWh)
2	-15	90,0	77,2	41,1	0,641	0,64	31
11	-10	81,8	70,8	38,4	0,553	0,55	146
32	-5	73,4	64,1	35,6	0,464	0,46	356
60	0	64,6	57,1	32,8	0,375	0,37	540
53	5	55,5	49,8	29,9	0,284	0,28	362
24	10	45,7	41,8	26,9	0,193	0,19	111
	15	34,8	32,8	23,7	0,099	0,10	0
	20	20	20	20,0	0,00	0,00	0
							1546

The third analysed case was that of the low-energy building supplied with a heat carrier having the temperature adjusted to the new heat demand. In order to maintain a standard indoor temperature of 20°C in the building. A new heat supply graph was developed based on the newly determined supply and return temperatures of the heat carrier. To this end, the flow and return temperatures of the heat

carrier that ensure this indoor temperature were determined and a new heat supply curve was established for the renovated building (the corrected heat supply graph), depending on the degree of thermal rehabilitation:

Table 5 shows the supply and return temperatures of the heat carrier for the renovated building ($H/H_0=0,8$ case) corresponding to the corrected heat supply curve. The table also shows the hourly and annual heating energy consumption for the renovated building when the temperature of the heat carrier supplied to the building is adjusted to the degree of renovation.

Table 5 Hourly and annual heating energy consumption for the renovated building ($H/H_0=0,8$ case); corrected heat supply curve

Heat load $P_0 = 1$ MW		Secondary (distribution) network					
		$H/H_0 = 0,8$ (renovated envelope + corrected heat supply curve)					
Nr. zile	t_e (°C)	t_{iB} (°C)	t_{rB} (°C)	t_{iB} (°C)	RPTS	P (MW)	Q (MWh)
2	-15	78,5	62,5	20	0,80	0,80	38
11	-10	71,7	58,0	20	0,686	0,686	181
32	-5	64,6	53,2	20	0,571	0,571	439
60	0	57,3	48,2	20	0,457	0,457	658
53	5	49,7	42,8	20	0,343	0,343	436
24	10	41,5	36,9	20	0,229	0,229	132
	15	32,4	30,1	20	0,114	0,114	0
	20	20	20	20	0,00	0,00	0
							1884

Table 6 shows the supply and return temperatures of the heat carrier for the renovated building ($H/H_0=0,6$ case) corresponding to the corrected heat supply curve. The table also shows the hourly and annual heating energy consumption for the renovated building when the temperature of the heat carrier supplied to the building is adjusted to the degree of renovation.

Table 6 Hourly and annual heating energy consumption for the renovated building ($H/H_0=0,6$ case); corrected heat supply curve

Heat load $P_0 = 1$ MW		Secondary (distribution) network					
		$H/H_0 = 0,6$ (renovated envelope + corrected heat supply curve)					
Nr. zile	t_e (°C)	t_{iB} (°C)	t_{rB} (°C)	t_{iB} (°C)	RPTS	P (MW)	Q (MWh)
2	-15	66,4	54,4	20	0,60	0,60	29
11	-10	61,0	50,7	20	0,514	0,514	136
32	-5	55,5	46,9	20	0,429	0,429	329
60	0	49,7	42,8	20	0,343	0,343	494
53	5	43,6	38,4	20	0,257	0,257	327
24	10	37,1	33,7	20	0,171	0,171	99
	15	29,9	28,2	20	0,086	0,086	0
	20	20	20	20	0,00	0,00	0
							1413

Table 7 shows the supply and return temperatures of the heat carrier for the renovated building ($H/H_0=0,4$ case) corresponding to the corrected heat supply curve. The table also shows the hourly and annual heating energy consumption for the renovated building when the temperature of the heat carrier supplied to the building is adjusted to the degree of renovation.

Table 7 Hourly and annual heating energy consumption for the renovated building ($H/H_0=0,4$ case); corrected heat supply curve

Heat load $P_0 = 1$ MW		Secondary (distribution) network					
		$H/H_0 = 0,4$ (renovated envelope + corrected heat supply curve)					
Nr. zile	t_e (°C)	t_{tB} (°C)	t_{rB} (°C)	t_{iB} (°C)	RPTS	P (MW)	Q (MWh)
2	-15	53,6	45,6	20	0,40	0,40	19
11	-10	49,7	42,8	20	0,343	0,343	91
32	-5	45,7	39,9	20	0,286	0,286	219
60	0	41,5	36,9	20	0,229	0,229	329
53	5	37,1	33,7	20	0,171	0,171	218
24	10	32,4	30,1	20	0,114	0,114	66
	15	27,2	26,0	20	0,057	0,057	0
	20	20	20	20	0,00	0,00	0
							942

Figure 1 is a graphical representation of the energy savings of the building characterized by a rated heat load of 1 MW in the climatic zone 2. The energy consumption reductions due to the thermal rehabilitation of the building, the energy consumption reductions due to the use of a low temperature heat carrier, as well as the cumulative effect of both measures, were represented in the chart. In the figure below, the **R1 curve represents the percentage reduction in energy consumption due to building renovation**, R2 represents the percentage reduction in energy consumption due to adjusting the temperature of the heat carrier to the new heat demand of the rehabilitated building, and R12 represents the percentage reduction in energy consumption due to the cumulative effect of both the thermal rehabilitation and the use of a low temperature heat carrier. The energy consumption reductions were plotted according to the degrees of building renovation.

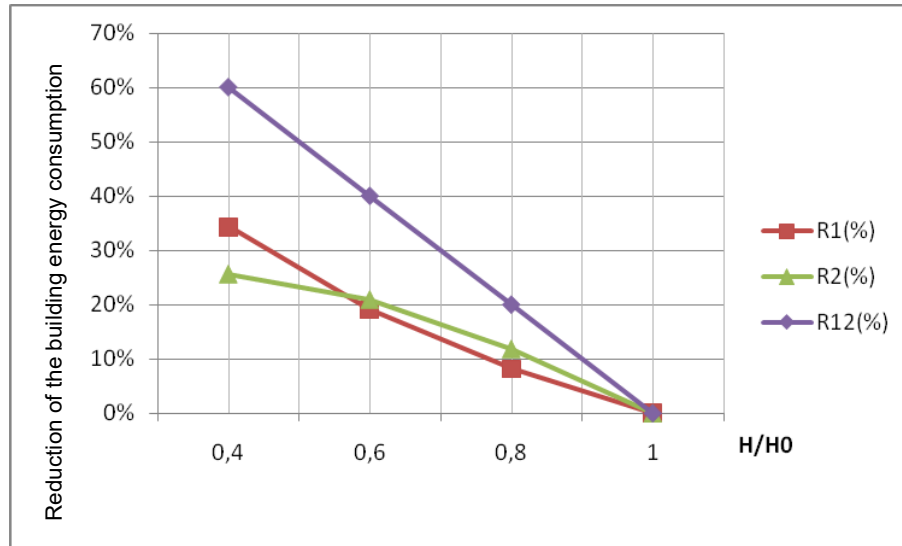


Figure 1 Reduction of the building energy consumption as a result of the thermal rehabilitation of the building and as a result of adjusting the temperature of the heat carrier to the new heat demand of the rehabilitated building, corresponding to the degree of building renovation

The chart illustrates that the reduction of energy consumption as a result of the thermal rehabilitation and the supply of a lower temperature heat carrier, corresponding to the degree of thermal renovation, lead to significant energy consumption reductions of about 20% for $H/H_0 = 0.8$, about 40% for $H/H_0 = 0.6$ and about 60% for $H/H_0 = 0.4$.

The above figure shows that for a degree of building renovation $H/H_0 > 0.55$, $R_2 > R_1$, hence the adjustment of the heat supply curve has a more significant weight in the percentage reduction of the energy consumption than the thermal rehabilitation of the building, and for a degree of thermal renovation $H/H_0 < 0.55$, $R_1 > R_2$, hence the weight of the two components is reversed and the thermal rehabilitation of the building prevails.

Example

We analysed the case of a typical building in Romania subject to thermal rehabilitation: an 11 floor apartment building with 3 entrances, having commercial spaces at the first floor. We calculated the thermal coupling coefficient of the building envelope for the initial situation (unrenovated building) and for the typical case of building renovation in Romania (10 cm of polystyrene applied on the opaque parts of the building envelope and fully replacement of the windows with thermally insulated windows).

$$H = G \cdot V = \frac{S}{R_m} + 0,34 \cdot n_a \cdot V \quad (7)$$

where:

H = thermal coupling coefficient of the building envelope (W/K)

G = global thermal insulation coefficient of the building ($W/m^3 \cdot K$)

V = building volume (m^3)

S = area of the building envelope (m^2)

R_m = average thermal resistance of the building envelope ($\text{m}^2 \cdot \text{K/W}$)

n_a = average number of air changes per hour (h^{-1})

Building length 75 m

Building width 15 m

Building height 32 m

S = 5760 m^2

V = 36000 m^3

The building envelope consists of an opaque part and a glazed part. We consider that the opaque part (S_1) represents 85% of the area, and the glazed part (S_2) is 15%.

S_1 (opaque) 85% 4896 m^2

S_2 (glazed) 15% 864 m^2

We consider the unrenovated building first.

The thermal resistance of the opaque part of the building envelope is:

R_1 = 0,65 $\text{m}^2 \cdot \text{K/W}$

The thermal resistance of the glazed part of the building envelope is:

R_2 = 0,35 $\text{m}^2 \cdot \text{K/W}$

The average thermal resistance of the building envelope is:

$$R_m = \frac{S_1 + S_2}{\frac{S_1}{R_1} + \frac{S_2}{R_2}} \quad (8)$$

R_m = 0,58 $\text{m}^2 \cdot \text{K/W}$

We consider the average number of air changes per hour:

n_a = 1,20 h^{-1}

The global thermal insulation coefficient of the building for the unrenovated building, calculated with formula (7), is:

H_0 = 24.689 W/K

We consider the case of the renovated building, by applying 10 cm of polystyrene applied on the opaque parts of the building envelope ($\lambda_{iz}=0,044 \text{ W/m} \cdot \text{K}$) and fully replacing the existing windows with thermally insulated windows.

The thermal resistance of the opaque part of the building envelope is:

$$R_1 = 2,92 \text{ m}^2 \cdot \text{K/W}$$

The thermal resistance of the glazed part of the building envelope is:

$$R_2 = 0,55 \text{ m}^2 \cdot \text{K/W}$$

The average thermal resistance of the building envelope (formula (8)) is:

$$R_m = 1,77 \text{ m}^2 \cdot \text{K/W}$$

We consider the average number of air changes per hour:

$$n_a = 0,50 \text{ h}^{-1}$$

The global thermal insulation coefficient of the building for the unrenovated building, calculated with formula (7), is:

$$H = 9.368 \text{ W/K}$$

We found that, for the typical case of renovation of residential collective building in Romania, the ratio $H/H_0 = 0,4$. As a result of the analysis, the thermal rehabilitation of the building results in a reduction of the energy consumption of 35%. If this measure were complemented by the adjustment of the temperature of the heat rier to the new heat demand of the renovated building, it could reduce the energy consumption by another 25% compared to the initial energy consumption (before thermal rehabilitation), resulting in a total reduction of 60%, so the energy consumption for the heating of the renovated building is reduced to only 40% compared to the initial one.

3. Energy savings due to using low temperature heat carriers in distribution networks

In this chapter, an analysis has been carried out on the effect of the reduction of temperatures of heat carriers on the heat losses in distribution networks.

To this end, the modelling of a branch (part of a distribution system of a thermal substation) was carried out. The thermal substation and the associated distribution network are part of the district heating system in Bucharest. In 2000-2003, the beneficiary of the START P7L2 program, funded by the European Investment Bank, was RADET, the operator of the district heating system in Bucharest. This pilot project aimed at the real-time monitoring of the distribution network for 24 thermal substations by implementing control and monitoring systems at both the thermal substations and the customers. The system offers the possibility of real-time monitoring of parameters at the thermal substations and at the consumers connected to the thermal substations. The data is processed and archived into a computer database in the thermal substation.

One of the 24 thermal substations was selected for the analysis carried out in this project

The branch of the distribution system feeds 3 apartment buildings: building A having 7 entrances, block B having 6 entrances, and block C having 5 entrances. The heat distribution system that supplies the three buildings consists of pre-insulated pipes buried directly in the ground. The connection to each building is fitted with a heat meter, but the distribution pipes in the buildings are installed in the basement of each building. Only the distribution network outside the building was included in the analysis.

Figure 2 represents the branch of the distribution system that is analyzed theoretically and experimentally. The diagram shows the length of the pipe sections, as well as the diameters of the pipes on each section.

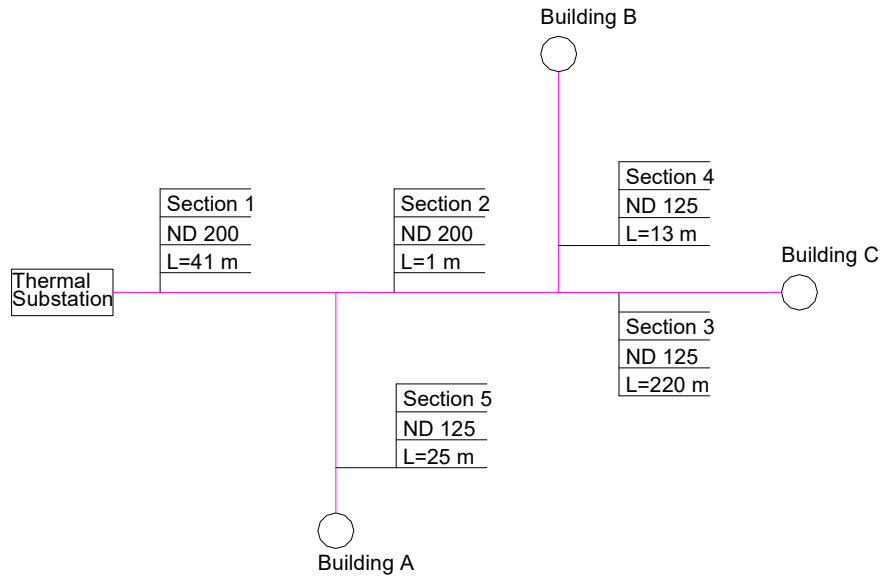


Figure 2 The branch of the distribution network for which the theoretical heat losses were calculated

The physical and thermal characteristics of the pipe sections of the studied branch of the distribution system are presented in Table 8.

Table 8 Physical and thermal characteristics of the pipe sections

				Building C	Building B	Building A
Section	UM	1	2	3	4	5
D_i	m	0,2101	0,2101	0,1325	0,1325	0,1325
δ_t	m	0,0045	0,0045	0,0036	0,0036	0,0036
D_e	m	0,2191	0,2191	0,1397	0,1397	0,1397
δ_{iz}	m	0,048	0,048	0,043	0,043	0,043
D_{iz}	m	0,315	0,315	0,225	0,225	0,225
α_i	W/m ² K	1000	1000	1000	1000	1000
λ_t	W/mK	45	45	45	45	45
λ_{iz}	W/mK	0,03	0,03	0,03	0,03	0,03
L	m	41	1	220	13	25
λ_s	W/m ² K	0,8	0,8	0,8	0,8	0,8
R	mK/W	1,93	1,93	2,53	2,53	2,53
G	m ³ /s	0,03113889	0,01900000	0,0115	0,0075	0,01213889

The measured flow rates on the supply line to each of the three consumers were used in the calculation. The thermal resistances of the sections, calculated with formula (10), are also presented in the table.

The following formulas were used to assess the heat losses of the distribution network:

$$Q_p = \frac{1}{R} \cdot l \cdot \Delta t_{ml, sol} \quad (9)$$

$$R = \frac{1}{\pi \cdot D_i \cdot \alpha_i} + \frac{1}{2 \cdot \pi \cdot \alpha_t} \cdot \ln \frac{D_e}{D_i} + \frac{1}{2 \cdot \pi \cdot \lambda_{iz}} \cdot \ln \frac{D_{iz}}{D_e} \quad (10)$$

The theoretical heat losses of the sections of the distribution network were determined for two situations:

- feeding the consumers with a heat carrier having a temperature corresponding to the uncorrected heat supply curve (unrenovated buildings)
- feeding the consumers with a heat carrier having a temperature corresponding to the corrected heat supply curve (renovated buildings).

The results were then compared.

Table 9 Heat losses of the distribution network when consumers are supplied with a heat carrier having a temperature corresponding to the uncorrected heat supply curve (unrenovated buildings)

				Supply						Return								
No. of days	te (°C)	t _B (°C)	tr _B (°C)	Qp1 (kW)	Qp2 (kW)	Qp3 (kW)	Qp4 (kW)	Qp5 (kW)	Qt (kW)	Qp1 (kW)	Qp2 (kW)	Qp3 (kW)	Qp4 (kW)	Qp5 (kW)	Qr (kW)	Qtot (kW)	Qp (MWh)	
2	-15	90,0	70,0	1,49	0,04	6,07	0,36	0,69	8,65	1,06	0,03	4,35	0,26	0,49	6,19	14,84	0,7	
11	-10	81,8	64,7	1,31	0,03	5,37	0,32	0,61	7,64	0,95	0,02	3,89	0,23	0,44	5,53	13,17	3,5	
32	-5	73,4	59,1	1,14	0,03	4,63	0,27	0,53	6,60	0,83	0,02	3,41	0,20	0,39	4,84	11,44	8,8	
60	0	64,6	53,2	0,95	0,02	3,87	0,23	0,44	5,52	0,71	0,02	2,89	0,17	0,33	4,11	9,63	13,9	
53	5	55,5	46,9	0,75	0,02	3,08	0,18	0,35	4,38	0,57	0,01	2,34	0,14	0,27	3,33	7,71	9,8	
24	10	45,7	39,9	0,55	0,01	2,23	0,13	0,25	3,17	0,42	0,01	1,74	0,10	0,20	2,47	5,64	3,2	
									35,95							26,49	62,44	39,9

Tabelul 10 Heat losses of the distribution network when consumers are supplied with a heat carrier having a temperature corresponding to the corrected heat supply curve (renovated buildings)

				Supply						Return								
No. of days	te (°C)	t _{IB} (°C)	tr _B (°C)	Qp1 (kW)	Qp2 (kW)	Qp3 (kW)	Qp4 (kW)	Qp5 (kW)	Qt (kW)	Qp1 (kW)	Qp2 (kW)	Qp3 (kW)	Qp4 (kW)	Qp5 (kW)	Qr (kW)	Qtot (kW)	Qp (MWh)	
2	-15	66,4	54,4	0,99	0,02	4,03	0,24	0,46	5,74	0,73	0,02	3,00	0,18	0,34	4,26	10,00	0,5	
11	-10	61,0	50,7	0,87	0,02	3,56	0,21	0,40	5,07	0,65	0,02	2,68	0,16	0,30	3,81	8,88	2,3	
32	-5	55,5	46,9	0,75	0,02	3,08	0,18	0,35	4,38	0,57	0,01	2,34	0,14	0,27	3,33	7,71	5,9	
60	0	49,7	42,8	0,63	0,02	2,57	0,15	0,29	3,67	0,49	0,01	1,99	0,12	0,23	2,83	6,49	9,4	
53	5	43,6	38,4	0,50	0,01	2,05	0,12	0,23	2,91	0,39	0,01	1,61	0,09	0,18	2,29	5,20	6,6	
24	10	37,1	33,7	0,43	0,01	2,05	0,10	0,20	2,79	0,29	0,01	1,19	0,07	0,13	1,69	4,48	2,6	
									24,56							18,21	42,77	27,3

It can be noticed that, during a heating season, the heat losses of the distribution network are reduced by 31.6% if the renovated buildings are fed with a heat carrier having a temperature corresponding to the corrected heat supply curve, compared to the situation when they are fed with a heat carrier having a temperature corresponding to the uncorrected heat supply curve.

4. Connection schemes that allow the renovated buildings to be supplied with low-temperature heat carrier

It should be borne in mind that, when apartment buildings were included in local authorities renovation programs, the criteria that were considered did not include an essential factor, namely supplying low energy buildings from the same thermal substation, or at least from the same branch of the distribution network. This has led to the current situation, where the same thermal substation, or the same branch of the distribution network, supplies both high and low energy buildings. Because of this, supplying low-energy buildings with a low-temperature heat carrier raises some additional problems.

Since district heating systems in Romania supply both renovated and unrenovated buildings, these systems must continue to operate by the current heat supply adjustment curves (corresponding to the unrenovated buildings). In order to supply low energy buildings with a low-temperature heat carrier, we propose a connection scheme whereby the heat supply of energy-efficient buildings is carried out mainly from the return pipe of the system, and only if the temperature of the heat carrier on the return pipe is insufficient, the required flow will be taken over from the supply pipe. The adjustment will be made by means of a three-way, electrically driven mixing control valve, adjusting the temperature of the heat carrier supplied to the renovated building according to the heat supply curve corrected for the energy-efficient buildings.

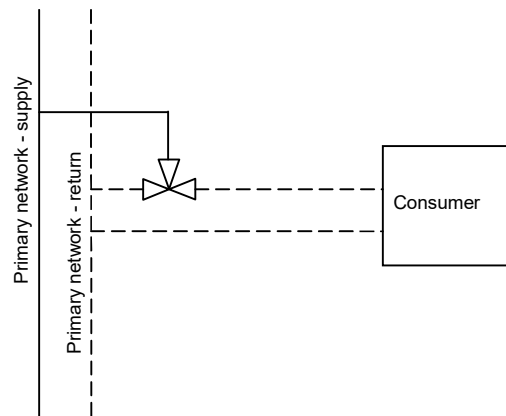


Figure 3 Connection scheme for energy-efficient buildings

This paper explores the possibility of connecting low-energy buildings to existing district heating systems in several scenarios, covering all the possibilities that may arise in practice today and in the future. Three possible scenarios have been identified:

- a. The thermal substation supplies only high energy efficient buildings**
- b. A branch of the distribution system supplies only high energy efficient buildings**
- c. The thermal substation or heat-only boiler station supplies both high-energy and low-energy buildings**

The solutions corresponding to each of the scenarios are analyzed below.

a. The thermal substation supplies only high energy efficient buildings

This scenario analyses the way thermal substations feeding only low-energy buildings can supply low-temperature heat carrier to consumers. Low-energy buildings include both renovated buildings and new buildings, built in accordance with the new regulations for energy-efficiency in buildings.

In order to supply consumers with a low temperature heat carrier, according to the corrected heat supply adjustment curve, the most convenient solution would be to use the scheme shown in Figure 3 at the point of connection of the thermal substation to the heat transportation system (primary network), in order to supply the thermal substation with a primary heat carrier in compliance with the corrected heat adjustment curve for renovated buildings. This would make it possible to additionally increase the efficiency of the district heating system by reducing the heat losses in the transportation network representing the connection to that thermal substation. However, this solution has not been proposed in this paper for several reasons:

- the connection point is a point on the route where there is at most one connection chamber; the installation of the control valve requires space, as well as power supply. Transmitting information from the controller in the thermal substation or from another controller to the control valve can be done by wire, internet or GSM, all requiring equipment and materials, which are additional costs. On the other hand, in the thermal substation there is space, power supply, and it is necessary only to reprogram the controller by entering the data corresponding to the new heat supply adjustment curve
- feeding the thermal substation with a heat carrier of a temperature different from the one for which it was designed requires a thorough analysis of the capacity of heat exchangers to produce domestic hot water at the temperature provided by the norms (60°C). This analysis should be performed at the level of the whole district heating system, so that, when all the buildings supplied by the thermal substation will be energy-efficient, it can operate with low temperature heat carrier.

In the first scenario (a), several connection schemes of thermal substations to district heating systems were analyzed, and the most common were selected for analysis below.

- Indirect connection of the heating systems and the preparation of domestic hot water in two stages, in series with the heating system. Both situations occurring in the operation of the district heating systems were analyzed: constant flow operation (temperature control) (Figure 4) and variable flow operation (mixed control) (Figure 5).

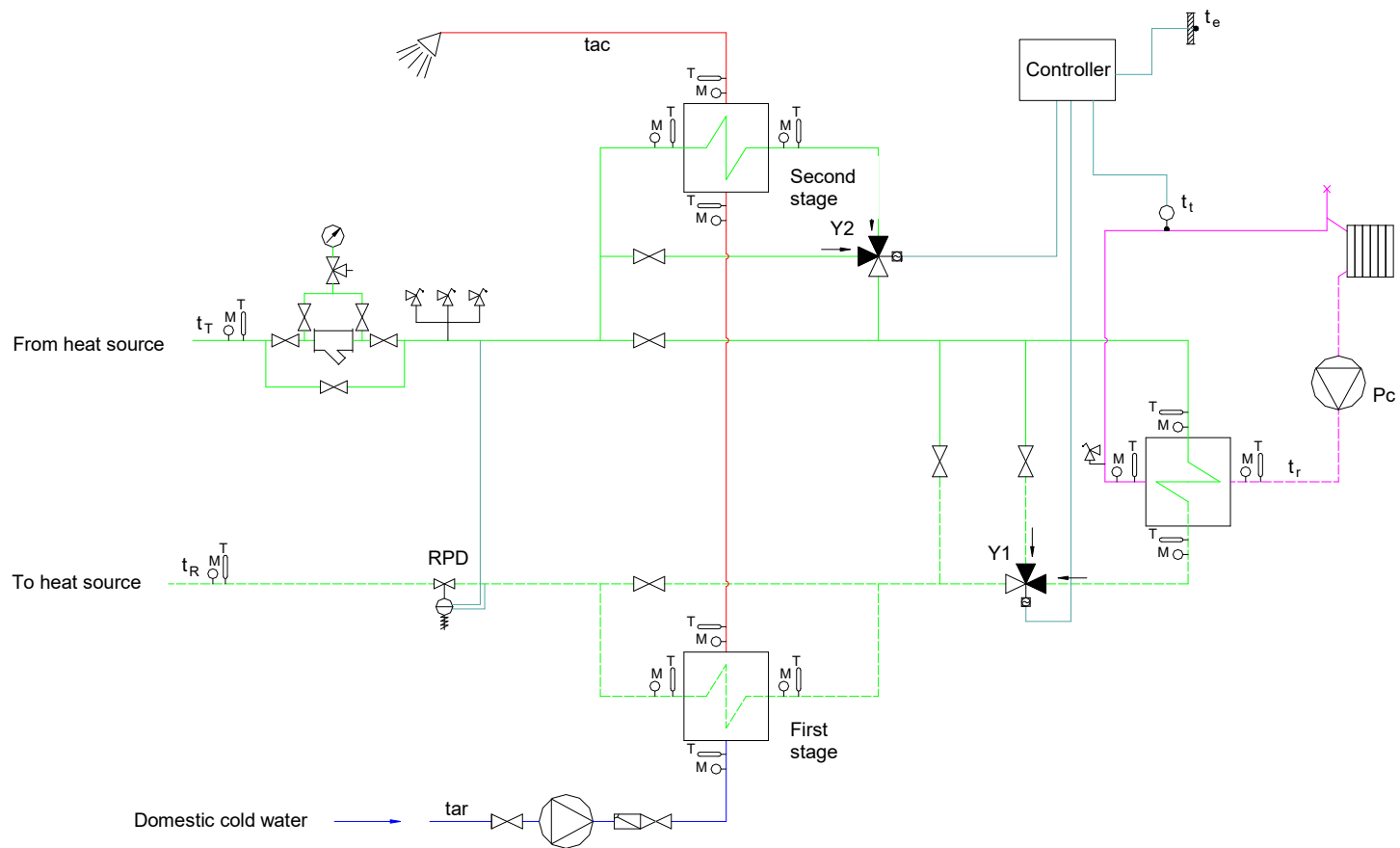


Figure 4 Indirect connection of the heating systems and the preparation of domestic hot water in two stages, in series with the heating system - constant flow operation (temperature control)

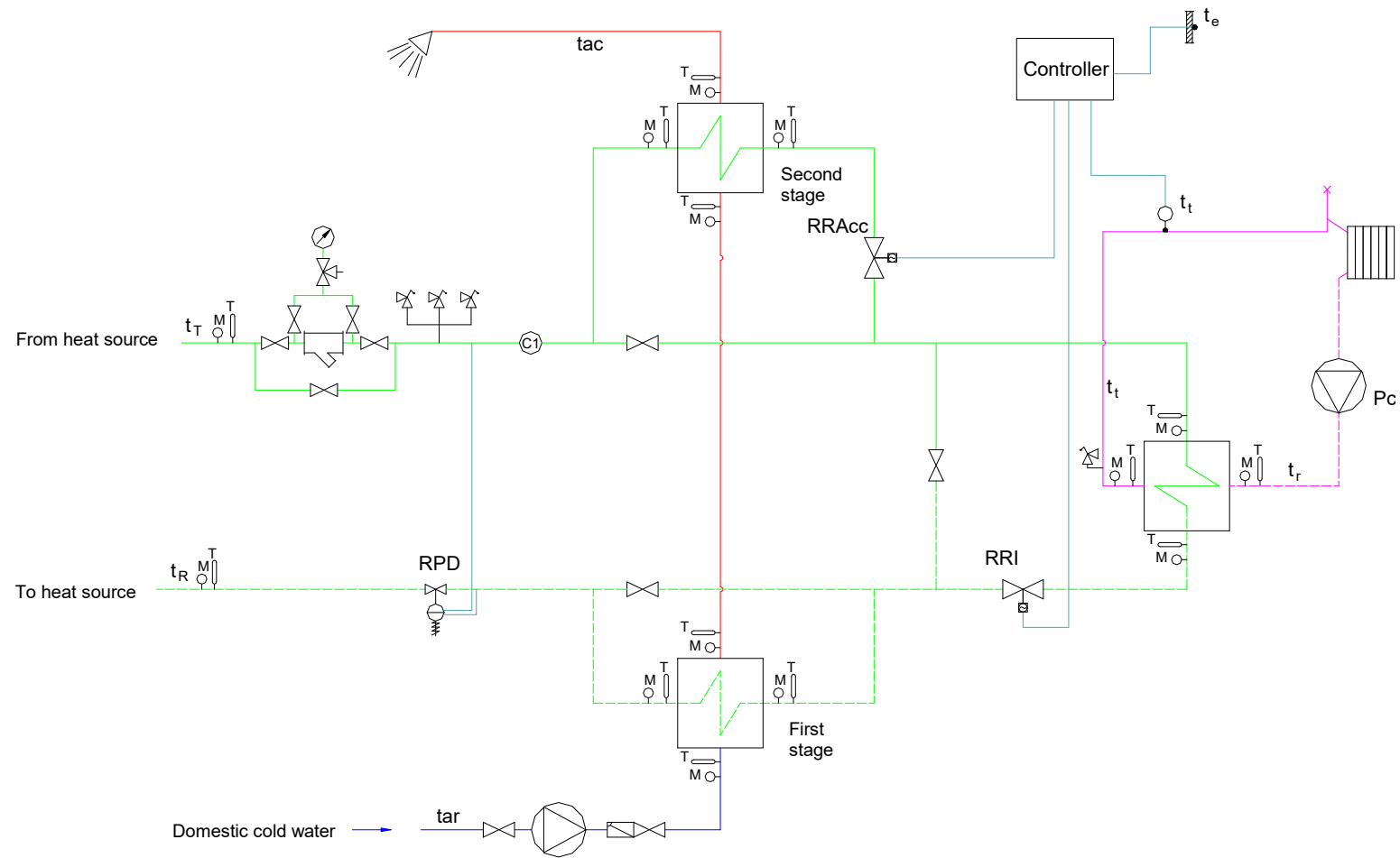


Figure 5 Indirect connection of the heating systems and the preparation of domestic hot water in two stages, in series with the heating system - variable flow operation (mixed control)

In the case of constant flow operation (Figure 4), no additional equipment is required. The solution consists in reprogramming the existing electronic controller to enter the temperatures of the corrected heat supply adjustment curve. The existing three-way control valve will continue to operate in the same way: only the flow required to prepare the heat carrier at the set temperature for the energy efficient buildings will be circulated through the heat exchanger from the high-temperature primary network, depending on the outdoor temperature. The electronic controller compares the temperature in the corrected heat supply curve corresponding to the outdoor temperature to the temperature on the flow (supply) pipe of the distribution system. If the temperature of the heat carrier is higher than the one provided in the corrected heat supply curve, the controller commands the reduction of the flow through the heat exchanger and the increase of the flow on the bypass pipe to the return pipe of the primary network. If the temperature of the heat carrier is lower than that provided in the corrected heat supply curve, the controller commands the increase of the flow through the heat exchanger and the reduction of the flow on the bypass pipe to the return pipe of the transportation network (Figure 6).

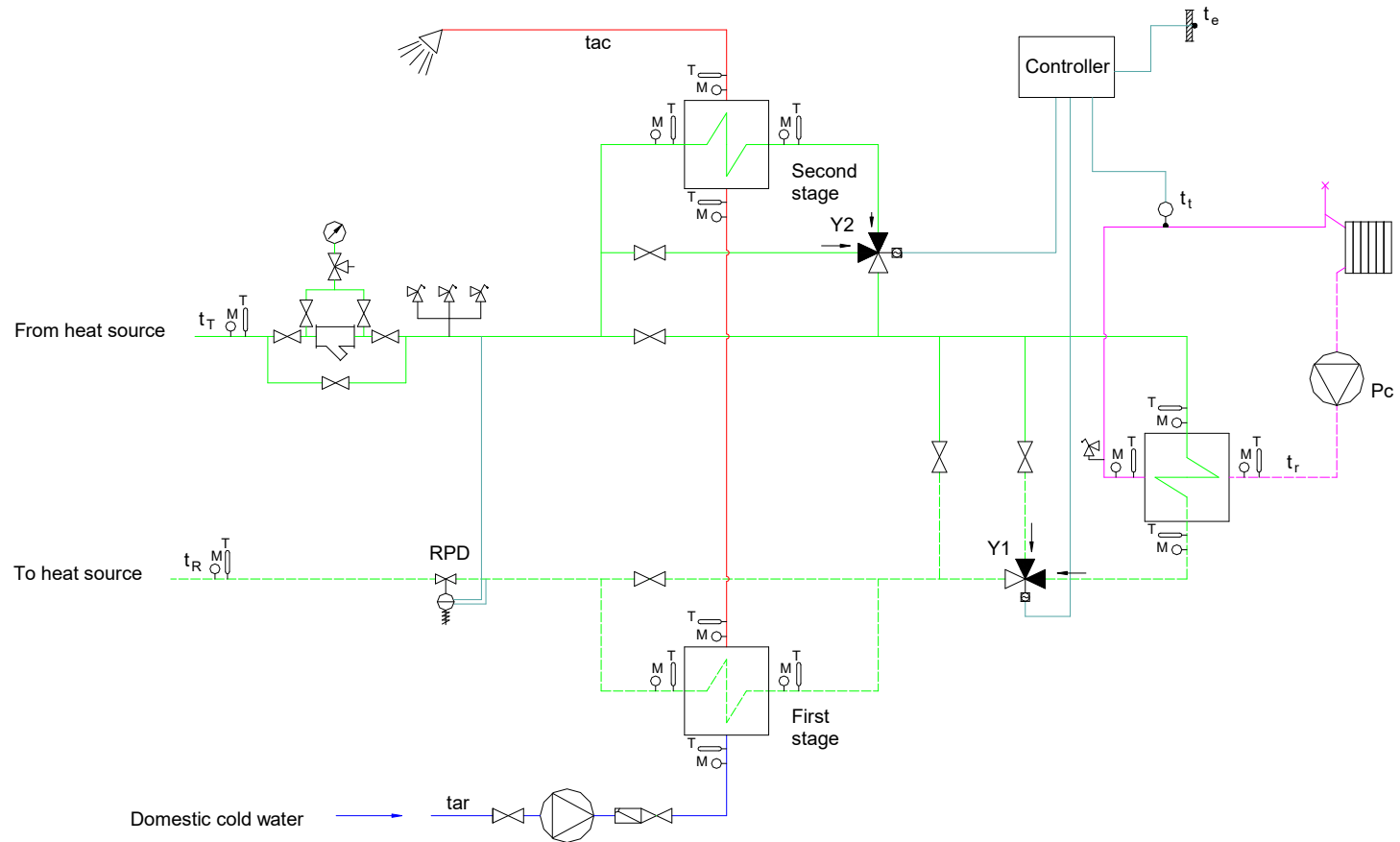


Figure 6 Indirect connection of the heating systems and the preparation of domestic hot water in two stages, in series with the heating system - constant flow low temperature operation (temperature control)

The introduction of new equipment is also not required for variable flow operation (Figure 5). The solution is the same: reprogramming the existing electronic controller by introducing the corrected heat supply adjustment curve. The two-way control valve will have the same function, allowing the circulation through the heat exchanger of the exact flow required to prepare the heat carrier at the set temperature for the energy efficient buildings, depending on the outdoor temperature. The electronic controller compares the temperature in the corrected heat supply curve corresponding to the outdoor temperature to the temperature on the flow (supply) pipe of the distribution system. If the temperature of the heat carrier is higher than the one provided in the corrected heat supply curve, the controller commands the reduction of the flow through the heat exchanger. If the temperature of the heat carrier is lower than that provided in the corrected heat supply curve, the controller commands the increase of the flow through the heat exchanger (Figure 7).

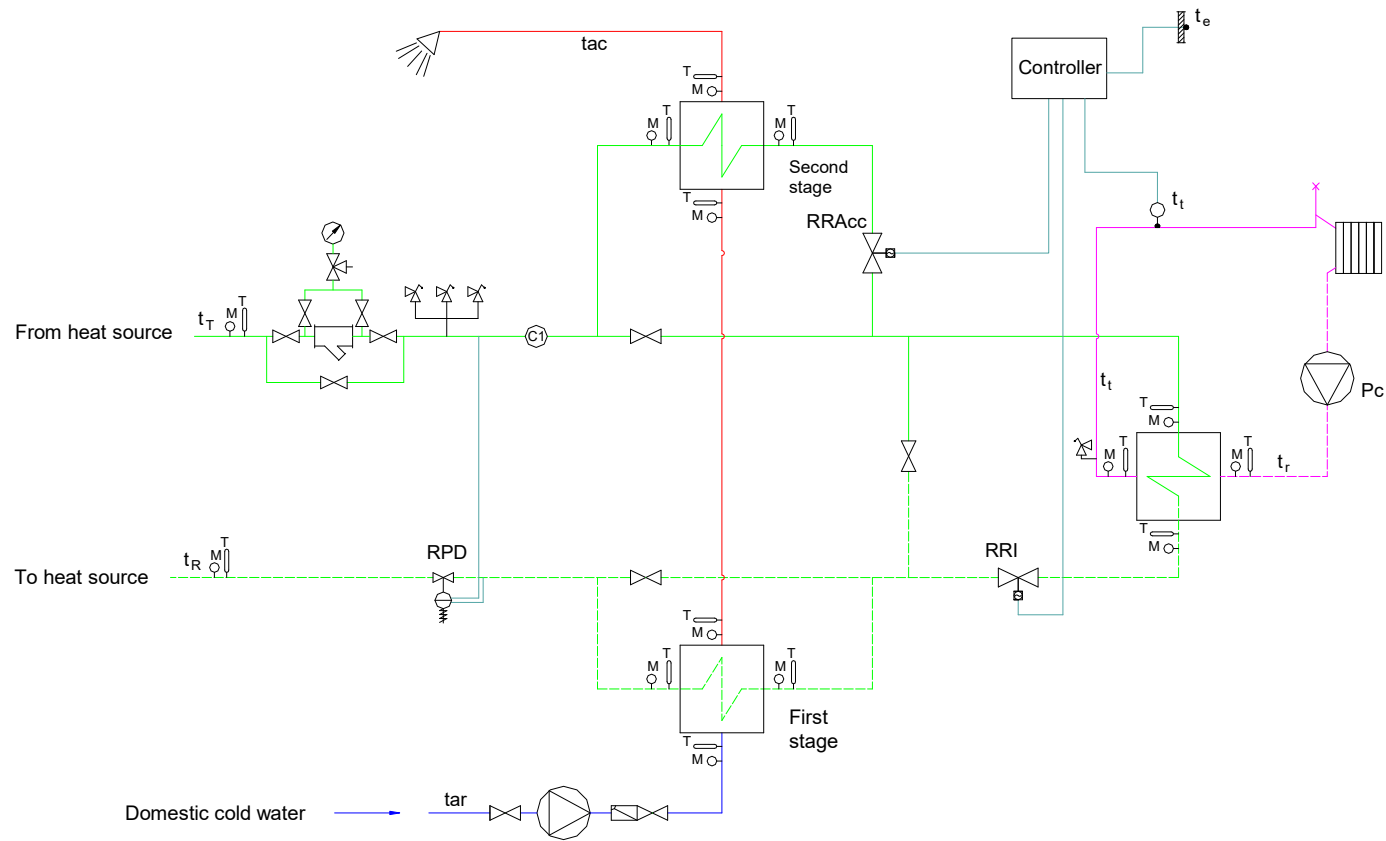


Figure 7 Indirect connection of the heating systems and the preparation of domestic hot water in two stages, in series with the heating system - variable flow low temperature operation (mixed control)

- Indirect connection of the heating system and domestic hot water preparation in one stage in parallel with the heating system. Both situations occurring in the operation of the district heating systems were analyzed: constant flow operation (temperature control) (Figure 8) and variable flow operation (mixed control) (Figure 9).

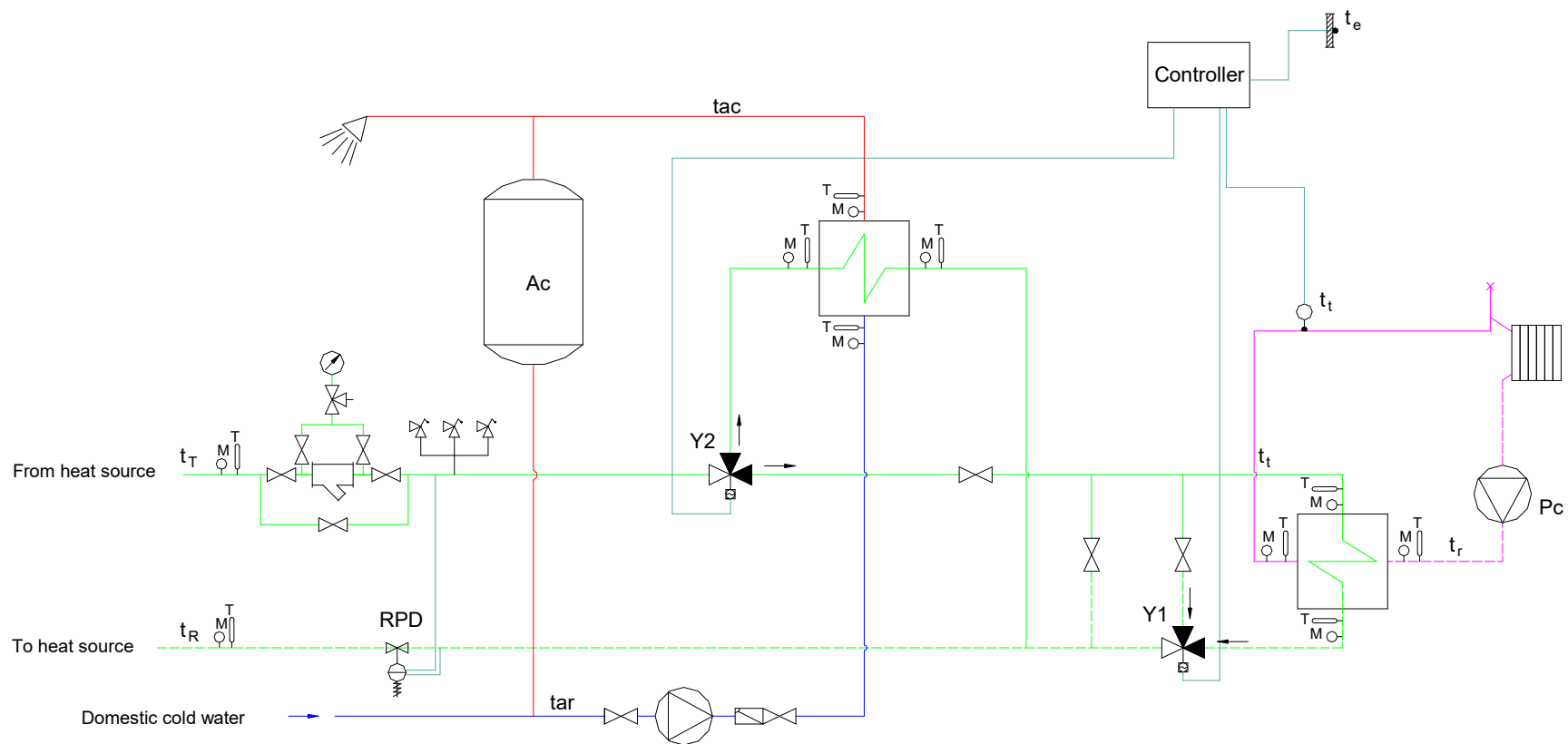


Figure 8 Indirect connection of the heating system and domestic hot water preparation in one stage in parallel with the heating system - constant flow operation (temperature control)

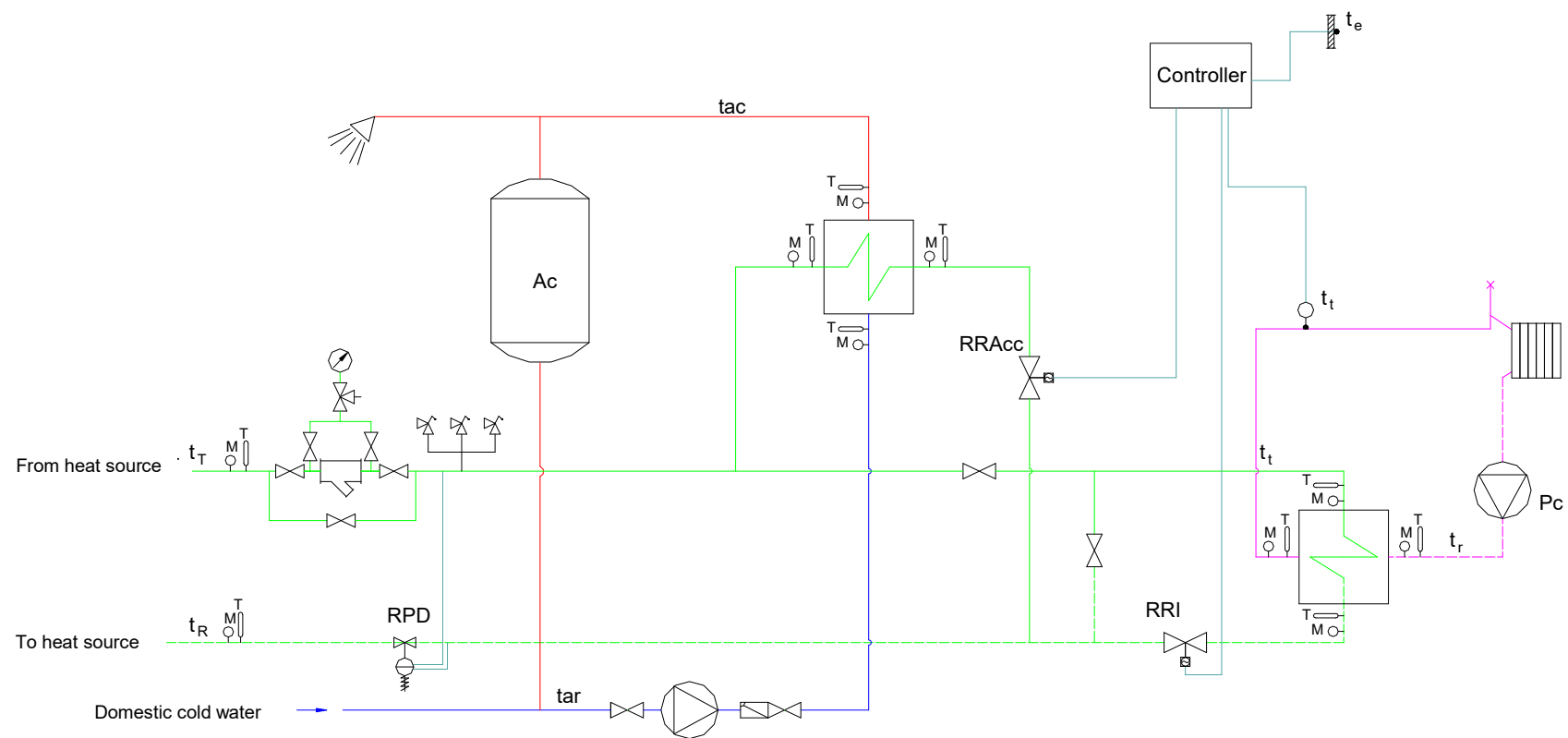


Figure 9 Indirect connection of the heating system and domestic hot water preparation in one stage in parallel with the heating system - variable flow operation (mixed control)

In the case of constant flow operation (Figure 8), the same solution is proposed as in the previous scheme: entering the temperatures of the corrected heat supply adjustment curve into the existing electronic controller. The existing three-way control valve will continue to operate in the same way: only the flow required to prepare the heat carrier at the set temperature for the energy efficient buildings will be circulated through the heat exchanger from the high-temperature primary network, depending on the outdoor temperature. The electronic controller compares the temperature in the corrected heat supply curve corresponding to the outdoor temperature to the temperature on the flow (supply) pipe of the distribution system. Dacă temperatura agentului termic care pleacă spre consumatori este mai mare decât cea prevăzută în graficul de reglare, controllerul comandă reducerea debitului de agent termic primar prin schimbătorul de căldură și mărirea debitului pe conducta de by-pass spre conducta de retur a rețelei primare. If the temperature of the heat carrier is higher than the one provided in the corrected heat supply curve, the controller commands the reduction of the flow through the heat exchanger and the increase of the flow on the bypass pipe to the return pipe of the primary network. If the temperature of the heat carrier is lower than that provided in the corrected heat supply curve, the controller commands the increase of the flow through the heat exchanger and the reduction of the flow on the bypass pipe to the return pipe of the transportation network (Figure 10).

The introduction of new equipment is also not required for variable flow operation (Figure 9). The solution is the same: reprogramming the existing electronic controller by introducing the corrected heat supply adjustment curve. The two-way control valve will have the same function, allowing the circulation through the heat exchanger of the exact flow required to prepare the heat carrier at the set temperature for the energy efficient buildings, depending on the outdoor temperature. The electronic controller compares the temperature in the corrected heat supply curve corresponding to the outdoor temperature to the temperature on the flow (supply) pipe of the distribution system. If the temperature of the heat carrier is higher than the one provided in the corrected heat supply curve, the controller commands the reduction of the flow through the heat exchanger. If the temperature of the heat carrier is lower than that provided in the corrected heat supply curve, the controller commands the increase of the flow through the heat exchanger (Figure 11).

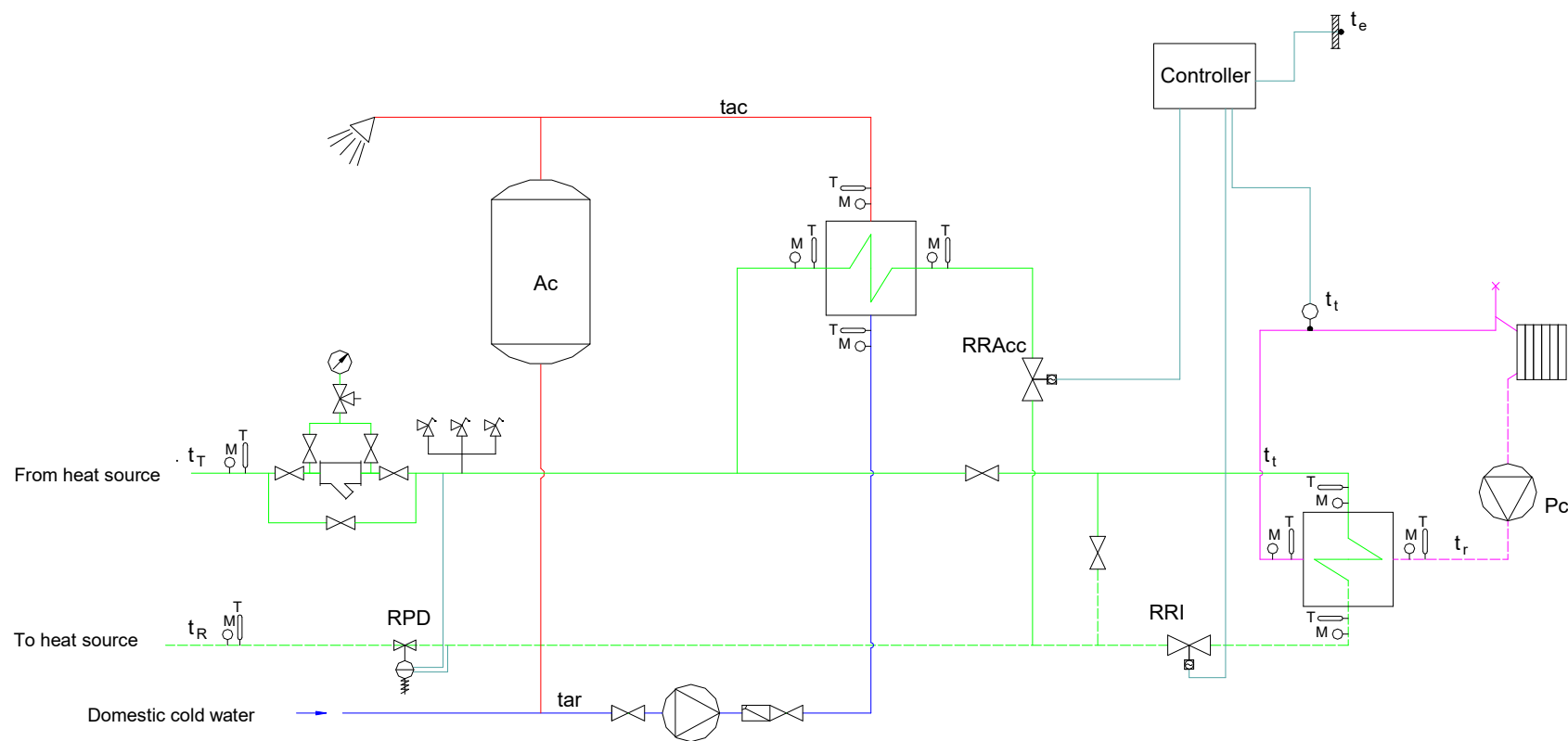


Figure 11 Indirect connection of the heating system and domestic hot water preparation in one stage in parallel with the heating system - variable flow low temperature operation (mixed control)

- Indirect connection of the heating system and domestic hot water preparation in one stage in series with the heating system, with flow injection and storage system. Both situations occurring in the operation of the district heating systems were analyzed: constant flow operation (temperature control) (Figure 12) and variable flow operation (mixed control) (Figure 13).

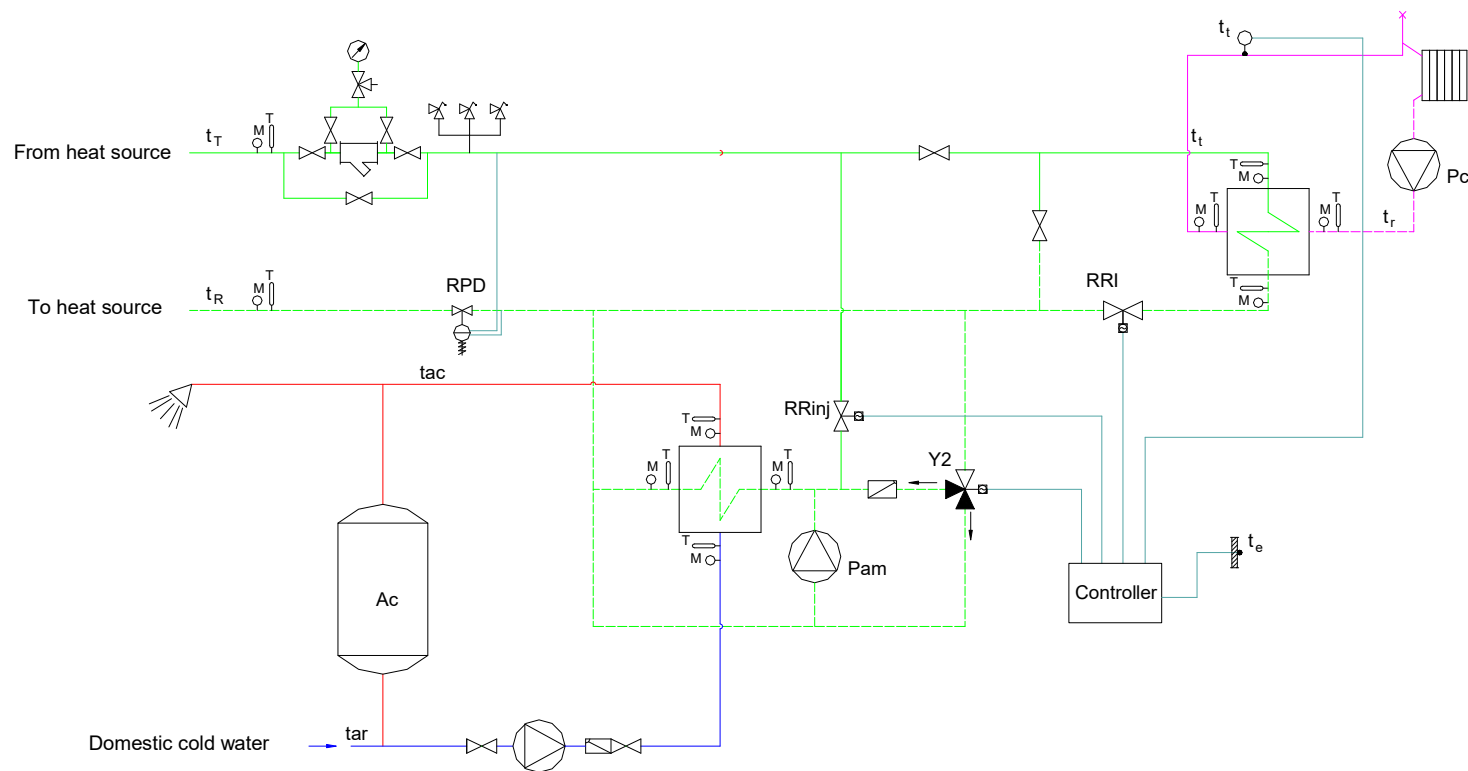


Figure 13 Indirect connection of the heating system and domestic hot water preparation in one stage in series with the heating system, with flow injection and storage system - variable flow operation (mixed control)

In the case of constant flow operation (Figure 12), the same solution is proposed as in the previous scheme: entering the temperatures of the corrected heat supply adjustment curve into the existing electronic controller. The existing three-way control valve will continue to operate in the same way: only the flow required to prepare the heat carrier at the set temperature for the energy efficient buildings will be circulated through the heat exchanger from the high-temperature primary network, depending on the outdoor temperature. The electronic controller compares the temperature in the corrected heat supply curve corresponding to the outdoor temperature to the temperature on the flow (supply) pipe of the distribution system. Dacă temperatura agentului termic care pleacă spre consumatori este mai mare decât cea prevăzută în graficul de reglare, controllerul comandă reducerea debitului de agent termic primar prin schimbătorul de căldură și mărirea debitului pe conducta de by-pass spre conducta de retur a rețelei primare. If the temperature of the heat carrier is higher than the one provided in the corrected heat supply curve, the controller commands the reduction of the flow through the heat exchanger and the increase of the flow on the bypass pipe to the return pipe of the primary network. If the temperature of the heat carrier is lower than that provided in the corrected heat supply curve, the controller commands the increase of the flow through the heat exchanger and the reduction of the flow on the bypass pipe to the return pipe of the transportation network (Figure 14).

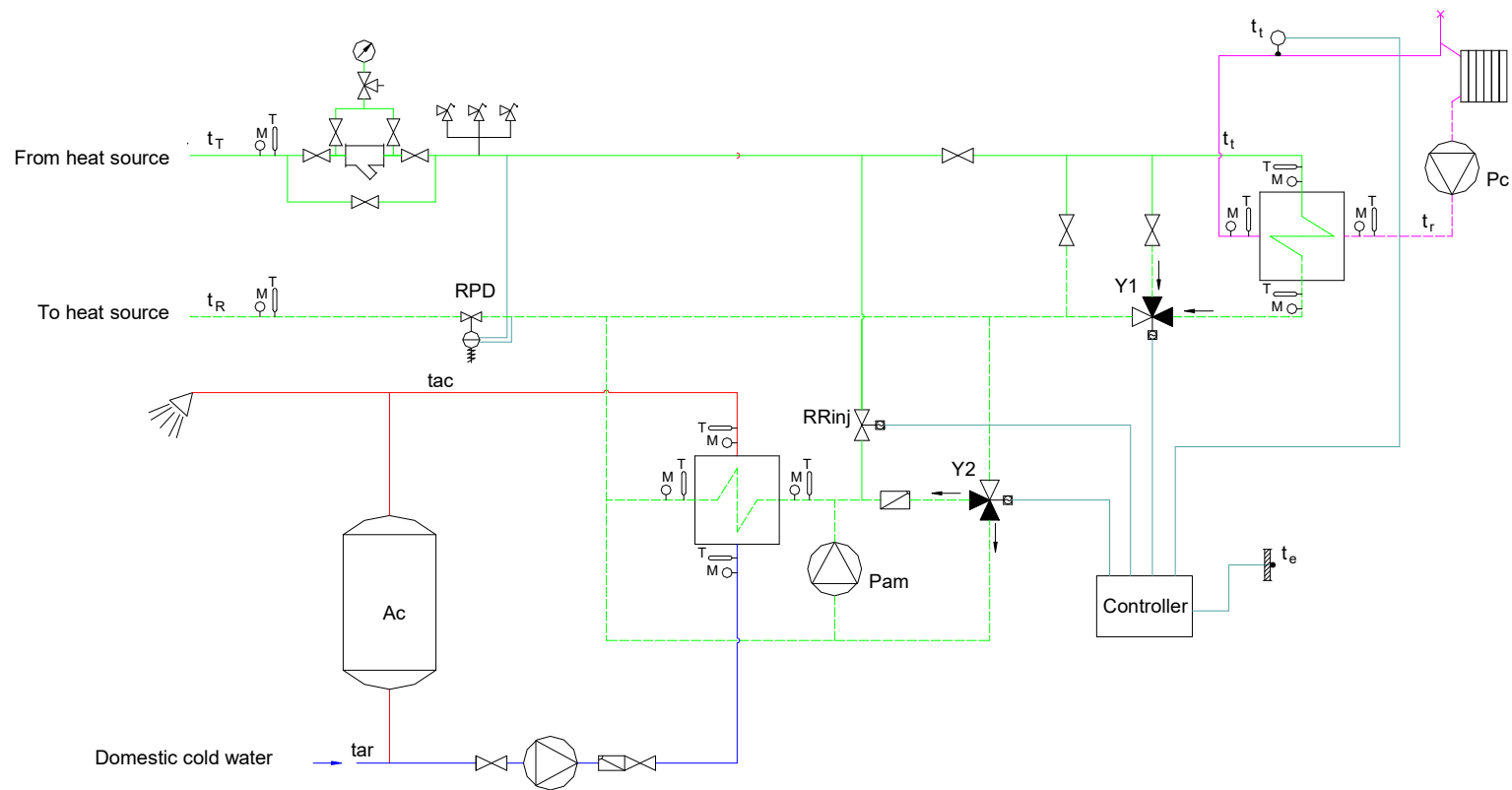


Figure 14 Indirect connection of the heating system and domestic hot water preparation in one stage in series with the heating system, with flow injection and storage system - constant flow low temperature operation (temperature control)

The introduction of new equipment is also not required for variable flow operation (Figure 13). The solution is the same: reprogramming the existing electronic controller by introducing the corrected heat supply adjustment curve. The two-way control valve will have the same function, allowing the circulation through the heat exchanger of the exact flow required to prepare the heat carrier at the set temperature for the energy efficient buildings, depending on the outdoor temperature. The electronic controller compares the temperature in the corrected heat supply curve corresponding to the outdoor temperature to the temperature on the flow (supply) pipe of the distribution system. If the temperature of the heat carrier is higher than the one provided in the corrected heat supply curve, the controller commands the reduction of the flow through the heat exchanger. If the temperature of the heat carrier is lower than that provided in the corrected heat supply curve, the controller commands the increase of the flow through the heat exchanger (Figure 15).

We mention that the method presented in this paper of supplying low-temperature heat carriers for heating to energy-efficient buildings can be applied in an analogous way to the other, less common, connection schemes that have not been addressed in this report.

It can be concluded that the proposed solutions do not require new investments in equipment and materials, the only necessary costs being related to the development of studies to establish the new heat supply adjustment charts, depending on the degree of thermal rehabilitation of the buildings, and the reprogramming of the electronic controller for entering the appropriate data.

It is obvious that the degree of rehabilitation of the buildings is different and it is possible that the heat demand of the buildings supplied from the same thermal substation could not be ensured with heat carriers of the same temperature. In this situation, it is necessary for the operator of the district heating system to carry out certain studies to determine in each case the temperature of the heat carrier that can meet the heat demand of the consumers. For maximum efficiency of the system operation, but also to ensure the optimum indoor temperature in each room, fitting the radiators with thermostatic valves is essential.

b. A branch of the distribution system supplies only high energy efficient buildings

- For this scenario, the acquisition of a three-way valve that works as a mixing valve is necessary. It will be installed on the branch that supplies energy efficient buildings, at the output of the heating manifold. It is also necessary to purchase a temperature transducer to be installed on the branch supplying low-energy buildings. The three-way valve will mix part of the flow from the return pipe with the exact flow from the supply pipe in order to ensure the required thermal comfort (Figure 16).

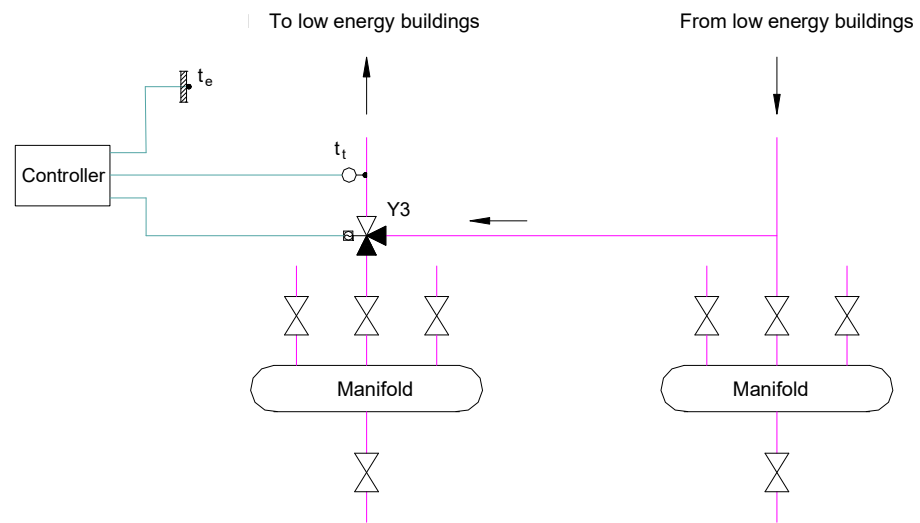


Figure 16 Supplying low-temperature heat carrier to energy-efficient buildings in the case when they are supplied from the same branch of the distribution system - case 1

It is not mandatory for the flow taken over from the return pipe to come from the energy efficient buildings. It can also come from another branch of the manifold (Figure 17) or even from the general return pipe that takes the heat carrier from the manifold to the heat exchanger (Figure 18), if the three-way valve can be installed easier. However, it is recommended to take the flow from the return pipe of the low energy buildings (Figure 16), as the temperature on the return pipe of the other branches may be higher than that required to supply these consumers. The heat supply adjustment curves for the high energy buildings needs to be determined and entered into the electronic controller. The controller compares the temperature in the adjustment chart corresponding to the outdoor temperature to the temperature of the heat carrier supplying the low energy buildings. If the temperature of the heat carrier is higher than the one provided in the adjustment chart, the flow from the supply pipe is reduced and the flow from the return pipe is increased. If the temperature of the heat carrier is lower than the one provided in the adjustment chart, the flow from the return pipe is reduced and the flow from the supply pipe is increased.

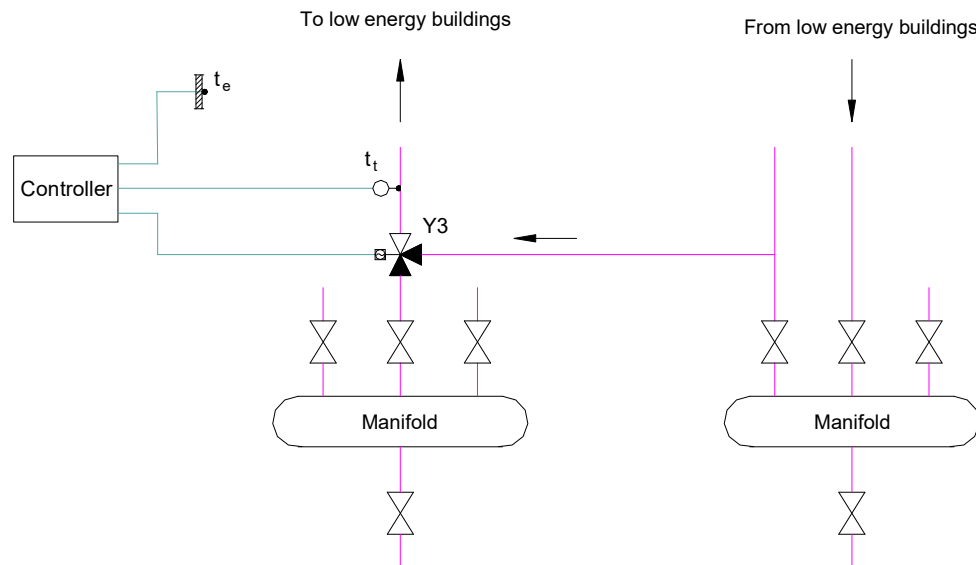


Figure 17 Supplying low-temperature heat carrier to energy-efficient buildings in the case when they are supplied from the same branch of the distribution system - case 2

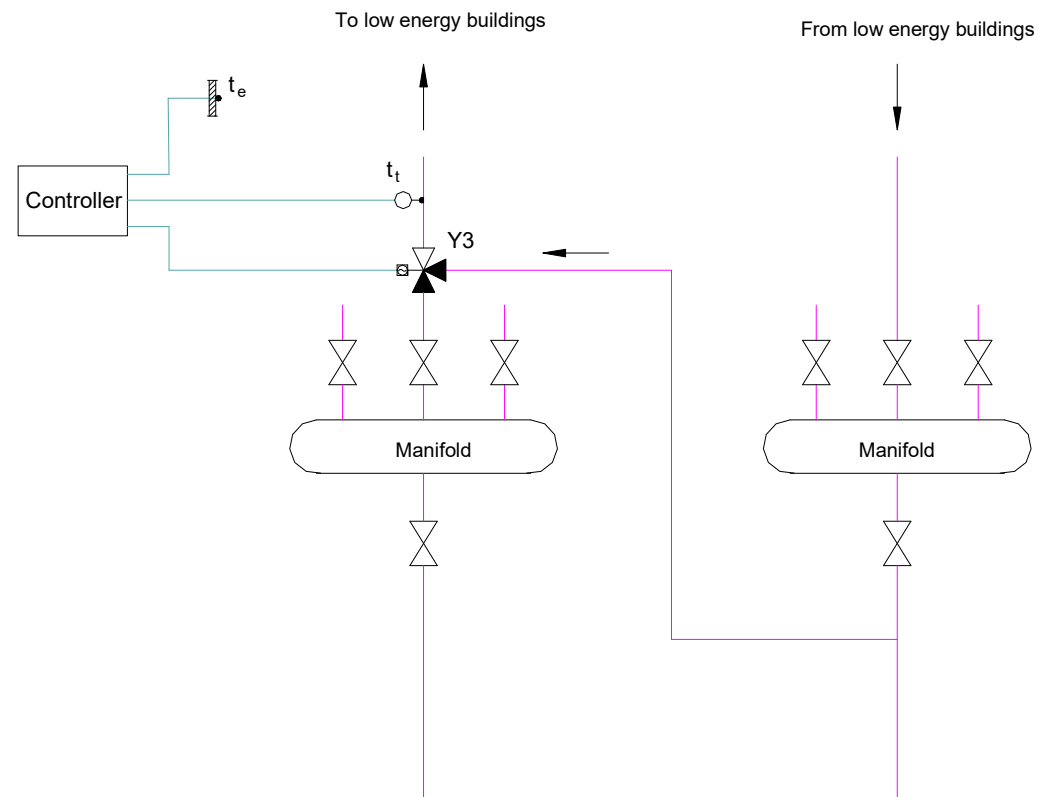


Figure 18 Supplying low-temperature heat carrier to energy-efficient buildings in the case when they are supplied from the same branch of the distribution system - case 3

Another solution is the use of a two-way control valve (Figure 19), the operation of which is also based on the temperature transmitter installed on the branch supplying the energy efficient buildings. The heat supply adjustment curve for the low energy buildings must be entered into the electronic controller, which compares the temperature in the adjustment chart corresponding to the outdoor temperature to the temperature of the heat carrier. If the temperature of the heat carrier is higher than the one provided in the adjustment chart, the heat flow from the supply pipe is reduced; if the temperature of heat carrier is lower than the temperature set in the control chart, the flow from the supply pipe is increased.

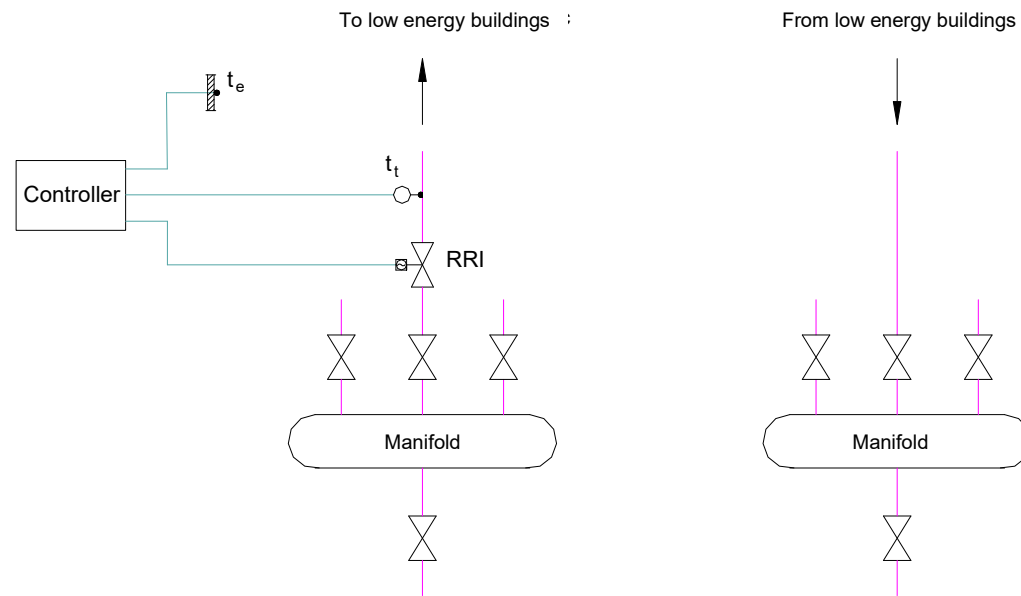


Figure 19 Supplying low-temperature heat carrier to energy-efficient buildings in the case when they are supplied from the same branch of the distribution system - case 4

Both diagrams (using the three-way control valve and the two-way control valve) can only be applied in systems equipped with pumps with variable speed drives, as both lead to variable-flow operation of the system.

Choosing the solution for using the three-way valve or the two-way valve is done following a rigorous analysis for each case. The option must be based on the following aspects:

- the minimum flow rates that may occur when using the two-way control valve shall not affect the operation of the system;
- the flow rate of the heat carrier that may occur in the operation of the heating system when using the two-way control valve shall not be less than the minimum flow rate at which the pump can operate.

These aspects depend on the number and size of the energy efficient buildings, as well as the degree of renovation, i.e. their share in the total capacity of the heating system.

c. The thermal substation or heat-only boiler station supplies both high-energy and low-energy buildings

This situation is also the most difficult to solve in practice since the flow control should be performed at the point of connection of the consumer or even at the consumer, which is difficult to achieve because the flow control involves the existence or the installation of a controller. If the connection to an electronic controller in the neighborhood can be achieved, the scheme in Figure 20 is recommended.

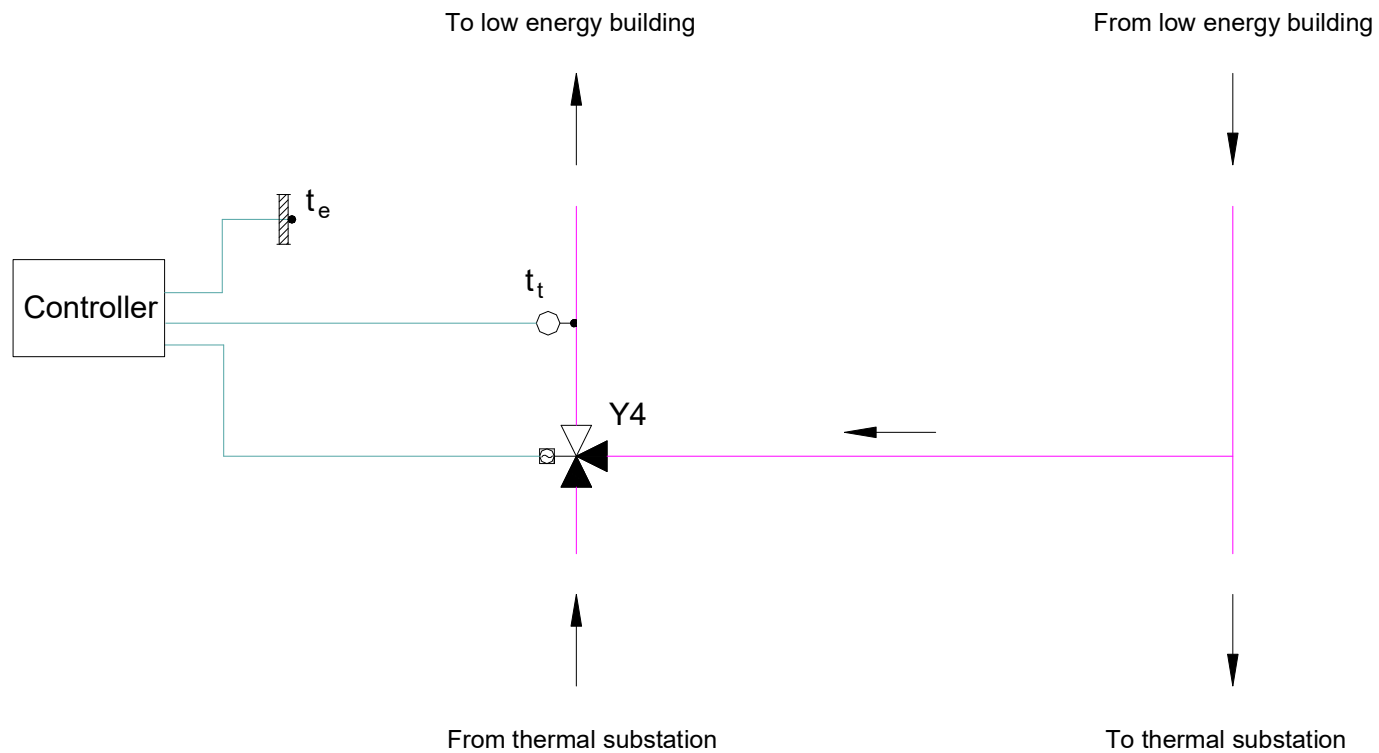


Figure 20 Supplying low-temperature heat carrier to one or more low-energy buildings in the case they are supplied from the same branch as high-energy buildings

Another solution, which requires a higher investment cost, is to fit the energy efficient building with its own thermal substation. The equipment will be sized for low-temperature system operation. The solution requires a new connection to the heat transportation (primary) system and a thermal substation to prepare both the heat carrier and the domestic hot water, or a connection to the heat distribution (secondary) system and a thermal substation to prepare only the heat carrier at the temperature required by the energy efficient buildings. This solution can also be adopted for a group of two or more renovated buildings located at a short distance from each other. On a case-by-case basis, a technical-economic analysis will be carried out, which will analyze several possible solutions and choose the most efficient one.

If the low-energy building is already connected to the district heating system by its own thermal substation, one of the solutions described in Scenario (a) will be applied, depending on the connection scheme and the type of operation (constant flow, variable flow).

Although the installation of a thermal substation is the best technical solution for connecting a low-energy building to a district heating system, the solution has a number of disadvantages which require a thorough analysis and application on a case-by-case basis of this solution, taking account of all the technical and economic considerations.

Advantages:

- the possibility of preparing the heat carrier according to the heat supply adjustment curve corresponding to each building, depending on the degree of renovation

Disadvantages:

- the need for a special space for the installation, operation, maintenance and repair of the thermal substation, a space that most often does not exist in the apartment buildings or is inappropriate for this purpose. It is preferable that the space in question be located at the ground floor, so that there is no need to significantly change the existing distribution system (which would increase costs even further). The decision must be made by the owners' association (which is difficult). The destination of an existing space can be changed, if it is large enough (e.g. drying room, laundry), which deprives the tenants of a service that was assured during the initial construction of the building. The noise associated with equipment operation must be considered as well. If there is no suitable space or if the building occupants can not agree on a space for the installation and operation of the thermal substation, a new building can be built on the public domain, in the immediate vicinity of the building (disadvantages: tree cutting, alteration of the urban landscape, obturation of some windows on the ground floor, the requirement of obtaining the building permit and other associated permits,

the need to connect a the new building to utilities (electricity, water, district heating, internet, GSM) etc.);

- since the installation of the thermal substation at the building level also involves the preparation of domestic hot water at this level, it is necessary to ensure the required flow of cold water for the preparation of domestic hot water. The cold water supply to the apartment building is designed exclusively to cover the cold water demand of the tenants and can not provide the additional flow. A rigorous case-by-case analysis is required and a solution should be found, including, if necessary, resizing the cold water distribution system in the area and the connection pipe to the building;
- if the system operator does not allow the filling of the internal heating system and the use of make up water from the primary network, it is necessary to install a softening system within the make up and expansion module, which involves additional investment and maintenance costs, qualified personnel etc;
- the connection of the thermal substations to the existing district heating system involves the designing of new routes of the heat transportation system, the installation of new pipelines on new routes, which, besides related costs, also requires the obtaining of permits, solving the situations of clashing/overlapping or intersection with other underground utilities (water, sewerage, electricity, gas, telecommunications etc.), which is particularly difficult in large cities;
- it is the solution associated with the highest costs, both for investment and operation;
- it is expected that, in the end, all residential buildings will be renovated, which leads to the possibility of using one of the other solutions presented, solutions that have much lower associated costs; for this reason, the thermal substations will be installed only after studying the renovation plans for the buildings developed by the municipalities. If it is only temporary, this solution will not be chosen, as the related costs and the disadvantages mentioned above are not justified.

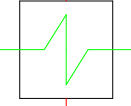
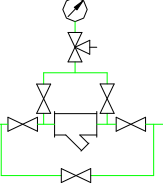
5. Conclusions

1. The measures for energy conservation in buildings associated with low-temperature district heating, corresponding to the degree of renovation, lead to significant energy consumption reductions, of about 20% for $H/H_0 = 0.8$, about 40% for $H/H_0 = 0.6$ and about 60% for $H/H_0 = 0.4$. For a degree of building renovation $H/H_0 > 0.55$, the adjustment of the heat supply curve has a more significant weight in the percentage reduction of the energy consumption than the thermal rehabilitation of the of the building, and for a degree of thermal renovation $H/H_0 < 0.55$, the weight of the two components is reversed and the thermal rehabilitation of the building prevails.
2. During the heating season, the heat losses of the distribution network are reduced by 31.6% if the renovated buildings are fed with a heat carrier having a temperature corresponding to the corrected heat supply curve, compared to the situation when they are fed with a heat carrier having a temperature corresponding to the uncorrected heat supply curve.
3. To supply low-temperature heat carrier to low-energy buildings, the solution will be chosen based on a case-by-case analysis. Simple solutions can be proposed, that do not require new investments in equipment and materials.

6. Symbols and abbreviations

$\dot{Q}_0$	= energy needs for heating (design conditions) [W]
H	= global thermal insulation coefficient of the building [W/K]
H ₀	= global thermal insulation coefficient of the building for the unrenovated building [W/K]
t _{i0}	= conventional design indoor temperature, determined according to SR 1907/2-2014 [K]
t _e	= outdoor temperature [K]
t _{e0}	= conventional design outdoor temperature, determined for each climatic zone, according to SR 1907/1-2014 [K]
t _t	= flow (supply) temperature of the heat distribution system (secondary network) [K]
t _{t0}	= flow (supply) temperature of the heat distribution system (secondary network) corresponding to the conventional design outdoor temperature (design conditions) [K]
t _r	= return temperature of the heat distribution system (secondary network) [K]
t _{r0}	= return temperature of the heat distribution system (secondary network) corresponding to the conventional design outdoor temperature (design conditions) [K]
t _{ml}	= logarithmic average temperature of the heat carrier [K]
Δt _{ml}	= logarithmic average temperature difference between the fluids involved in the heat transfer [K]
Δt _{ml0}	= logarithmic average temperature difference between the fluids involved in the heat transfer (design conditions) [K]
k	= global heat transfer coefficient [W/m ² K]
k ₀	= global heat transfer coefficient (design conditions) [W/m ² K]
G	= flow of the heat carrier [m ³ /s]
G ₀	= flow of the heat carrier (design conditions) [m ³ /s]
ρ	= density of the heat carrier [kg/m ³]
c	= specific heat capacity of the water [W·s/kg·K]
S	= heat transfer area [m ²]
NTU	= number of thermal units [-] (dimensionless)
E	= thermal module of the heating system [-] (dimensionless)
E ₀	= thermal module of the heating system (design conditions) [-] (dimensionless)
E _C	= thermal module of the consumer heating system [-] (dimensionless)
E' _C	= thermal module of the heat exchanger preparing the heat carrier [-] (dimensionless)
E _R	= thermal module of the distribution system (secondary network) [-] (dimensionless)
E' _R	= thermal module of the transportation system (primary network) [-] (dimensionless)

Q_C	= amount of heat used by the consumer [W]
Q_{sursa}	= amount of heat delivered by the heat source [W]
η_{SD}	= efficiency of the heat distribution system [-] (dimensionless)
η_{ST}	= efficiency of the heat transportation system [-] (dimensionless)
R	= average thermal resistance of the heat distribution network [m·K/W]
Q_p	= heat losses of the heat distribution network [W]
l	= length of pipeline sections of the heat distribution network [m]
$\Delta t_{\text{ml, sol}}$	= logarithmic average temperature difference between the heat carrier and the ground where the pipe is buried [K]

RPD 	Differential pressure regulator
	Safety valves
Y1, Y2 	Electrically driven, mixing or separating three-way control valve
RRinj 	Electrically driven, two-way control valve
M 	Manometer
T 	Thermometer
	Pump
	Heat exchanger
	Strainer
t_t 	Temperature transducer

7. References

- [1] Ministerul Energiei - Strategia Energetică a României 2016-2030, cu perspectiva anului 2050, 19 decembrie 2016, p. 32
http://www.mmediu.ro/app/webroot/uploads/files/2017-03-02_Strategia-Energetica-a-Romaniei-2016-2030.pdf
- [2] Tomasz Cholewa, Alicja Siuta-Oлча, Long term experimental evaluation of the influence of heat cost allocators on energy consumption in a multifamily building, Energy and Buildings, Volume 104, 1 October 2015, Pages 122-130, ISSN 0378-7788,
<http://dx.doi.org/10.1016/j.enbuild.2015.06.083>
<http://www.sciencedirect.com/science/article/pii/S0378778815300967>
- [3] Florin Iordache, Bogdan Caracaleanu, Vlad Iordache: Modernizarea instalațiilor de încălzire centrală. Aspecte energetice - iarna 2003/2004, în: Expertizarea și reabilitarea sistemelor de alimentare cu căldură și instalațiilor interioare de încălzire centrală, Editura CONSPRESS, București, 2006, pp. 64-71
- [4] Florin Iordache – Instalații de încălzire centrală. Reglajul termic calitativ centralizat – Revista Română de Inginerie Civilă, volumul 8 (2017) nr.1 – ISSN 2068-3987 – ed. Matrixrom 2017, București, pp. 19-30
- [5] Florin Iordache, Cristina Stănișteanu, Clădiri reabilite termic – consecințe energetice, în - Florin Iordache Coordonator – Echipamente și sisteme termice. Metode de evaluare energetică și funcțională (culegere de articole) - ISBN:978-606-25-0325-3 – ed. MATRIXROM, București, 2017, pp. 29-37
- [6] Adrian Marin, Cristina Stănișteanu, Florin Iordache, Rețele termice de distribuție. Aspecte energetice – Revista Română de Inginerie Civilă – Ed. MATRIXROM, București, Nr.2/2018