# Heat supply control as a method of increasing energy efficiency in reconstruction of the district heating system in Brovary

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*One objective of SUDH[1] is to demonstrate modern and energy-efficient district heating, where a significant share of production is based on renewable energy sources and waste heat, to ultimately meet EU requirements for efficient district heating. The SUDH programme implements technology and design principles that have been proved to be sound, after having been applied for decades in the Nordic countries. This state-of-the-art technology has led to improved energy efficiency, lower operating costs, and high-quality district heating services.*

*Unfortunately, immediate full implementation of the Nordic experience of district heating systems in Ukrainian realities is difficult. This is due to the current state of district heating systems and the historical aspect of their development.*

*So, the initial approach should be a combination of the Nordic experience and the status and technical solutions typical for Ukraine that allow for gradual further modernisation.*

*This fully applies to the control of heat supply and the choice of temperature in district heating networks. Energy losses caused by the low efficiency of production, transmission and supply control systems are the main weak link in district heating systems compared to autonomous systems, i.e. the main factor influencing the choice of heat consumers in favour of autonomous systems. The issue of the temperature regime at production plants also deserves special attention.*

*In this article, we want to inform readers about the main decisions on the issues forming the basis for the development of a feasibility study for the reconstruction of the district heating system in Brovary.*

## Control methods of Ukrainian district heating systems

The most common control method in Ukrainian district heating systems is qualitative[2] and central control, i.e. changing the supply water temperature at the production plants. But this method has a significant disadvantage - inefficient control during the period when the temperature for space heating could be reduced but has to be maintained for hot water supply. This means significant heat losses during this period.

During this rather long period, which could cover most of the heating season, adequate temperature control from heating plants is not possible because of the need to maintain a constant temperature of about 60-65°C for generation of domestic hot water, which requires a temperature of about 50-55°C. The period has become even longer as supply temperatures have been lowered because of non-functional control equipment in the connected buildings and other deteriorated equipment in district heating systems.

This problem and its consequences can be illustrated by the annual heat generated by the boilers of a district heating company (Figure 1).

As seen in Figure 1, operation during “break” (B-F) of the temperature graph leads to significant "overheating" in buildings and unproductive heat losses (green area). The situation in Figure 1 is caused by the lowering of the temperature graph, which makes the "break" in the temperature graph occur at a

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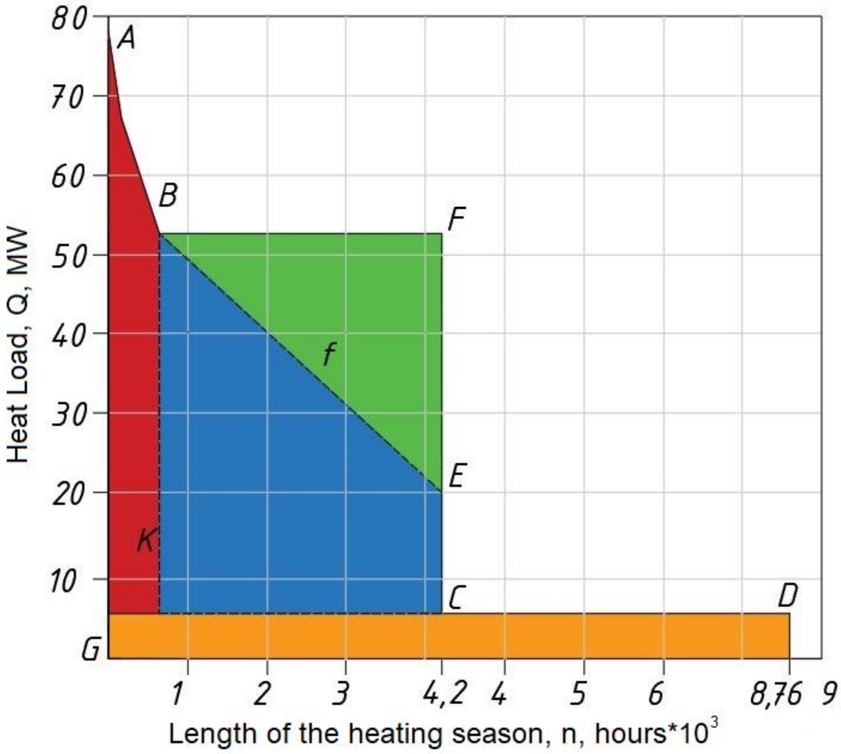
[1] The Sweden-Ukraine District Heating (SUDH) programme was established by Nefco and Sweden with the vision of supporting energy-efficient district heating in Ukraine that delivers qualitative services with low environmental impact to its customers. SUDH offers funding for long-term sustainable projects, creating a significant positive impact on Ukrainian district heating systems. More information at https://dh-ukraine.nefco.int/sweden-ukraine-dh/

[2] Ukrainian DH systems, as well as DH system in other former Soviet countries, generally employ a control strategy using constant flow (and hence constant pressure throughout the network) all year and vary the supply temperature depending on the outdoor temperature (production-driven systems). The fixed control equipment in the buildings is based on such constant flow and constant pressure to work properly. The flow in Nordic DH systems is controlled by control valves in the individual heat substations in each building (demand-driven systems) with the supply temperature varying depending on the outdoor temperature. Heating plant pumps are equipped with variable speed drives allowing them to adapt to the actual flow.

significantly lower outdoor temperature resulting in an increased duration of the operation period in the mode of "overheating".

**Figure 1: Annual heat generated by boilers in a district heating system for different methods of heat supply control**




Line A-B-F-E-C-D - heat flow under the current system of qualitative and central control; at point B ("break" point) qualitative control becomes impossible due to the need to generate domestic hot water

Line A-B-f-E-C-D – heat flow under the condition of transition to quantitative central control

Area B-F-E-f-B - annual heat losses that occur under the current qualitative control of heat supply. Such heat losses account for as much as 18% of the annual heat potential of the fuel used; they can be avoided in the transition to quantitative and qualitative control, which is proposed for the project in Brovary

As seen in Figure 2, the transition from heat carrier with a maximum temperature of 150°C to 95°C at an outdoor temperature of -23ºC causes an increase in duration of the operation period in the mode of "overheating" to more than double - from 1,159 to 3,600 hours. The possibility of central control is excluded already at an outdoor temperature of -7.5°C instead of +3.8°C. Therefore, unproductive heat losses increase from 1.8% of annual heat production to a significant 18% due to inadequate control with a lowering of the temperature graph (Figure 3).

**Figure 2: Temperature dependence at the "break" point and duration of the "overheating" period on the estimated temperature in the supply pipeline (type of temperature graph) for meteorological conditions in Poltava**

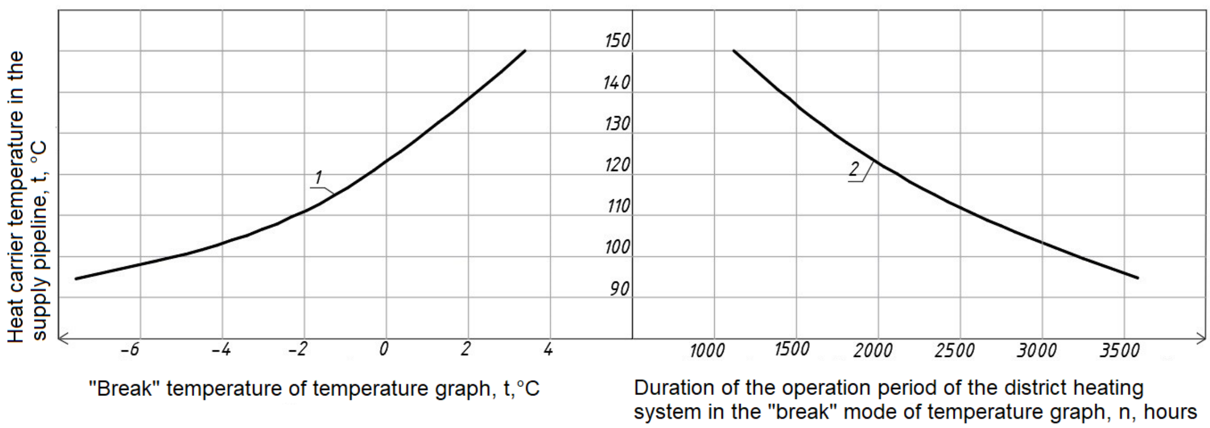
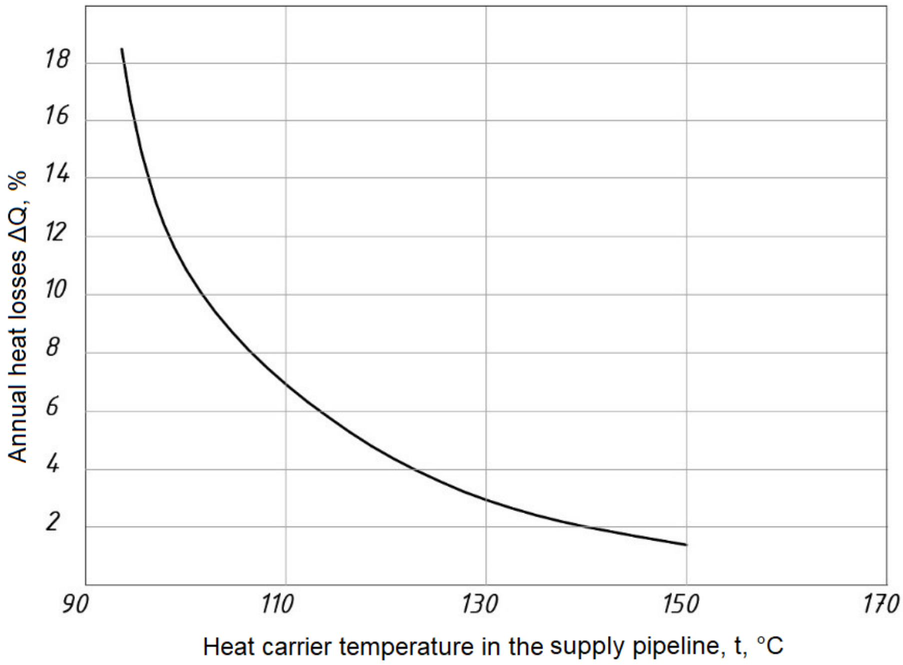


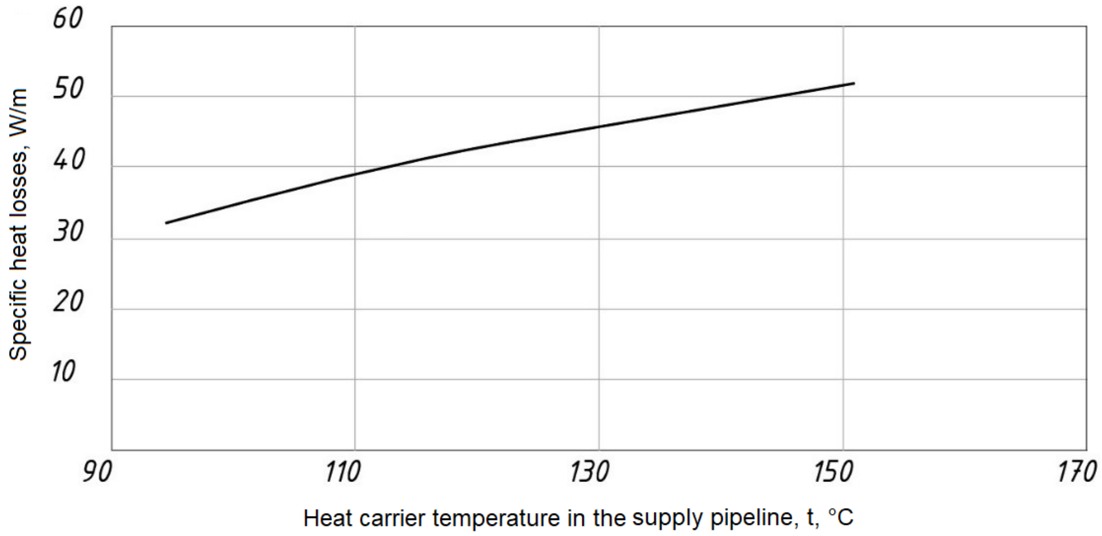
**Figure 3: Dependence on annual heat losses ΔQ in the “break” mode of the supply temperature for weather conditions of an estimated temperature curve with design outdoor temperature -23°C**




At first glance, the graph shows the benefit of heat generation according to a high supply temperature as is the case with current Ukrainian qualitative central control. However, the problem of optimal temperature graph should also consider another important factor - heat losses from the surface of district heating pipelines, which will increase with a higher supply temperature.

The graph in Figure 4 shows that for heating networks of about 5 km in length, heat losses during the transition to a temperature graph of 150/70°C increase from 762 MWh to 1,211 MWh per year.

**Figure 4: Dependence of specific heat losses on the supply temperature for meteorological conditions in Poltava**




Quite another factor having the opposite influence on the efficiency of district heating systems is the influence of the return pipe temperature on the performance and thermodynamic efficiency of heat generators. The use of elevated heat carrier temperatures accordingly means a higher exhaust gas temperature and an increase in the corresponding heat losses in the boilers. The average value of the exhaust gas temperature for traditional (non-condensing) hot water boilers in district heating systems is 160-180°C, usually even higher. At this temperature, heat losses with the exhaust gases of the boiler are up to 9-12% of the thermal potential of the fuel. Such losses in the system generally reduce the overall efficiency of the district heating system. On average in Ukraine, the integrated efficiency of heat generation, transportation and supply processes is 60-75%. Thus, unproductive heat losses are 40-25%.

A significant reduction in such losses can be achieved by reducing the temperature of the exhaust gases leaving the boilers. In the absence of special condensing boilers, this problem can be solved by installing condensing heat exchangers (flue gas condensers) after the boilers. But the condensation of water vapour and the latent heat of condensation in the combustion products will begin only if their temperature is less than the water dew point, i.e. 56°C.

At a temperature of about 180°C of combustion products at the inlet to the heat exchanger of the flue gas condenser, up to 9-10% more of the heat potential of the fuel can be utilised, provided that the temperature of the heat carrier in the return pipe is about 45-56°C. But when this temperature increases to 58-60°C (as for the high-temperature graph of heat release), the efficiency of heat utilisation decreases to 6.0-6.5%.

Ukraine, has historically had a requirement to maintain, if possible, a higher supply temperature in order to reach a higher temperature difference Δt between the supply and return temperatures, and at the same time maintain the lowest possible temperature in the return pipe. Increasing the temperature difference, of course, reduces the heat carrier flow and the heat network's hydraulic resistance or the diameter of the pipelines. A smaller diameter means a lower heat network volume, which, particularly in DH systems with substantial leakages, contributes to decreased leakage volume and reduced water treatment costs. Increased Δt is a priority also for Nordic DH systems, but the focus has been more on a lower return temperature, which has allowed also for decreased supply temperature.

Currently, the transition from high temperature (115/70°C and 130/70°C) to a lower temperature (90/70°C) is typical for district heating systems in Ukraine. This is primarily due to the absence or technical malfunction of the mixing devices in the heating substations in the buildings. In most cases, previously used elevators in heating substations have been lost or decommissioned. Generally, the substation equipment is obsolete and worn out, and it has become impossible for district heating companies and maintenance personnel of buildings to properly operate and maintain.

After the loss of mixing devices in connected buildings, the transition to operation at lower temperatures has become a logical consequence for most district heating companies. This was also facilitated by the current state of heating networks, compensators, and energy sources. But in the transition to lower heat carrier temperatures (95°C and below) of district heating systems, the joint load on hot water supply and heating results in significant unproductive heat losses, i.e., losses during the "break" in the temperature graph, with the inevitable "overheating" in buildings.

Foreign district heating systems of the fourth generation are also focused on reducing the temperature graph of heat supply, but the situation for them is radically different from the Ukrainian realities.

Modern automated individual heating substations with control depending on the outdoor temperature and the function of limiting the maximum flow of the heat carrier, contribute, within their capabilities, to reducing the return temperature. But today, the number of buildings equipped with such individual heating substations is insignificant in most DH systems in Ukraine, and their ability to lower the temperature is insufficient.

Obtaining lower temperatures in the return pipe of district heating networks and achieving high rates of heat utilisation in flue gas condensers and other advantages (further described later in this article) is possible by switching to lower temperature graphs, changing the method of heat supply control. And also by introducing qualitative control in modern automated individual heating substations to limit the maximum flow of the heat carrier entering the heat supply systems.

Thus, the transition to lower supply temperatures without the simultaneous implementation of flue gas condensers in district heating boilers, and without changing the method of control in heating plants does not make sense because it only significantly impairs the overall efficiency of district heating systems. The reason for this is a significant increase (up to 18% of the fuel potential) in unproductive heat losses during the "break" in the temperature graph during the transition to lower temperature graphs.

There are also significant energy losses in the local control of heat flow in buildings, due among other things to the imperfection of hydroelevators, as well as devices for controlling the operation of heating systems.

As a rule, centralised and local control of heat supply systems contradict each other. Thermal modernisation of buildings reduces the heat flow for heating and hot water supply of buildings. Thus, this increases the unfavourable gap between the installed heat production capacity and the heat load actually connected. Equipping some consumers connected to the district heating network with automated individual heating substations leads to the appearance in the system of consumers with different required pressure of the heat carrier on the entrance to buildings. In addition, the presence of pressure drop controllers at modern individual heating substations leads to a violation of the hydraulic and thermal stability of the heating system in buildings which remain without automated individual heating substations.

On the other hand, automatic local control by automated individual heating substations of the flow that enters the building makes it impossible to carry out adequate central qualitative control of the heat supply. During the transition periods of the year, the mass closing of thermostats in the inlet substations leads to a significant reduction in the heat carrier flow in the heating networks. Thus, there are natural prerequisites for the transition to other methods of control in district heating systems.

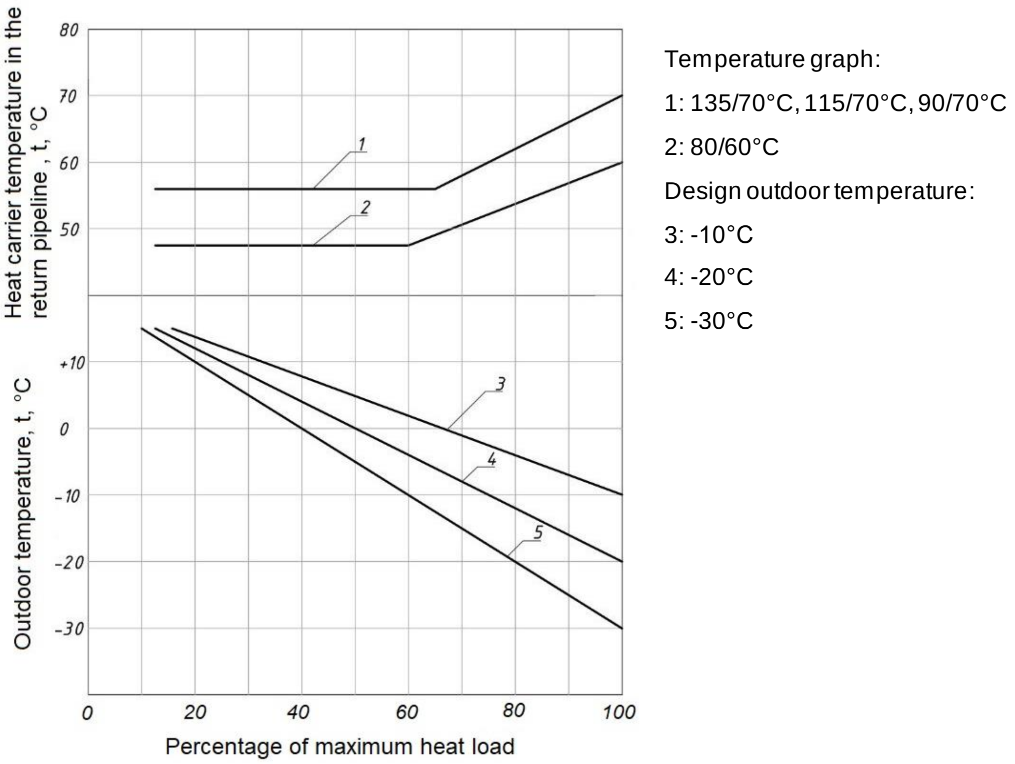
The feasibility study for the reconstruction of the heat supply system in Brovary presents recommendations on how to arrange optimal control of heat supply in district heating systems taking the above factors into account.

It was proposed to introduce a combined, qualitative-quantitative control (qualitative control before reaching the "break" in the temperature graph and the transition to quantitative - after the "break" point of the temperature graph).

## Analysis of the heat carrier temperature in the return pipe of district heating networks for current qualitative control

Figure 5 shows the heat carrier temperature in the return pipe of heating networks for current qualitative district control and different design outdoor temperatures.

**Figure 5: Dependence of the return temperature on different supply temperatures with current qualitative central control**



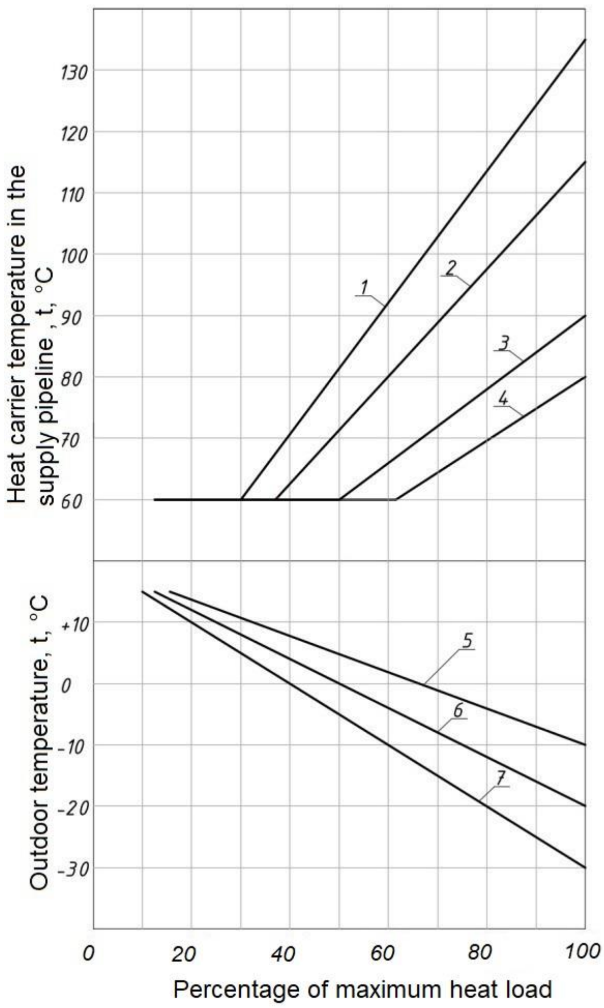

As shown in Figure 5, the temperature of the heat carrier in the return pipe for all accepted temperature graphs in the current district heating system, and the entire range of control, is quite high. It only approaches the dew point of water vapour in the combustion products and does not reach it, which significantly reduces the efficiency of flue gas condensers and the district heating system. In addition, after reaching the "break" point, effective control of heat dissipation becomes impossible, and the operation of the district heating system is accompanied by significant losses.

The situation changes significantly with the transition to a lower temperature graph of 80/60°C. The temperature of the heat carrier in the return pipe is already at a heat load of 84% of the calculated value of the heat load and comes below the dew point. And the minimum value reaches about 48°C. This guarantees the high efficiency of flue gas condensers and a significant increase in the efficiency of boilers during almost the entire heating period. But problems with adjustment at the "break" point remain.

## Analysis of the heat carrier temperature when introducing central quantitative control

The transition to the central quantitative control of heat supply at the production plant significantly improves the operating conditions of flue gas condensers and convective heating surfaces of boilers and increases the efficiency of heat generators and district heating systems in general. This is because of lower return pipe temperatures, compared with qualitative control (Figure 6).

**Figure 6: Return temperature for different supply temperatures and different design outdoor temperatures**




Temperature graph:

1: 135/70°C

2: 115/70°C

3: 90/70°C

4: 80/60°C

Design outdoor temperatures:

5: -10°C

6: -20°C

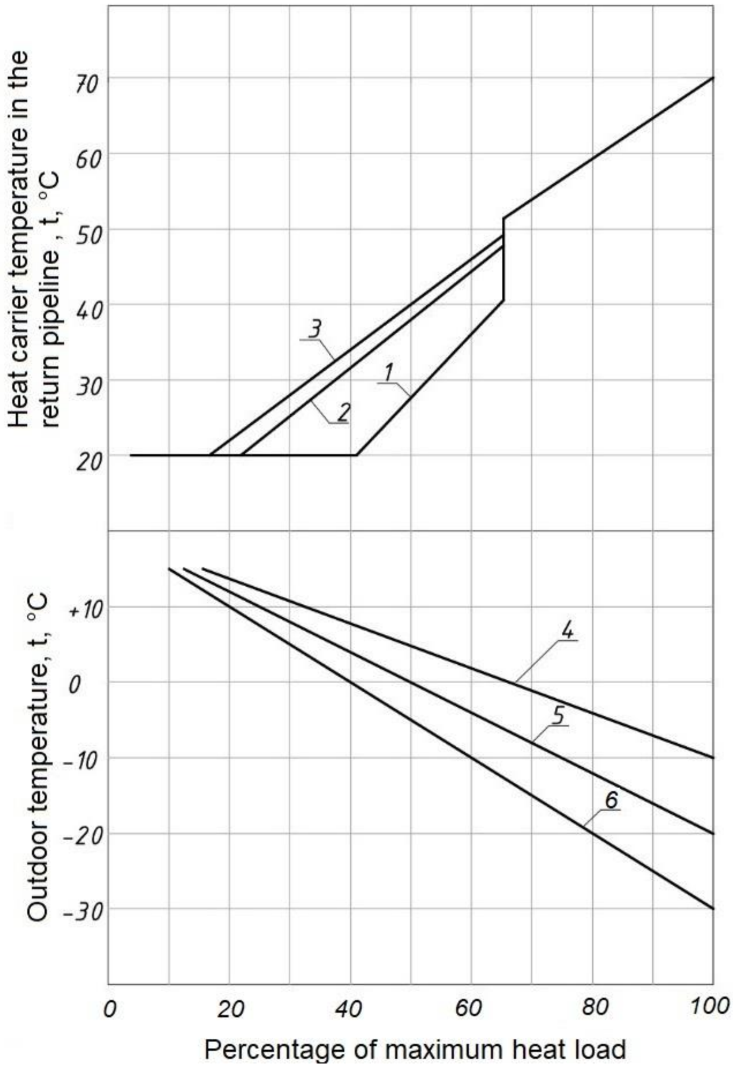
7: -30°C

According to Figure 6, a return temperature below the dew point is reached for almost all possible temperature heat supply graphs when adjusting the heat load to 80% of the calculated heat load. The minimum possible temperature in the return pipeline reaches values down to 30°C. This ensures the high efficiency of flue gas condensers and district heating systems. There are no problems with "overheating" after reaching the "break" point.

## Analysis of the heat carrier temperature when introducing combined qualitative-quantitative control

Combined qualitative-quantitative control includes qualitative control by changing the temperature under conditions of constant heat carrier flow before reaching the "break" of the temperature graph and the transition to quantitative - after the point of "break". Figure 7 below shows the graph of temperature change in the return pipeline of heat networks for such a case.

**Figure 7: Return temperature for different supply temperatures and different design outdoor temperatures with qualitative-quantitative central control**




Temperature graph:

1: 90/70°C

2: 115/70°C

3: 135/70°C

Design outdoor temperatures:

4: -10°C

5: -20°C

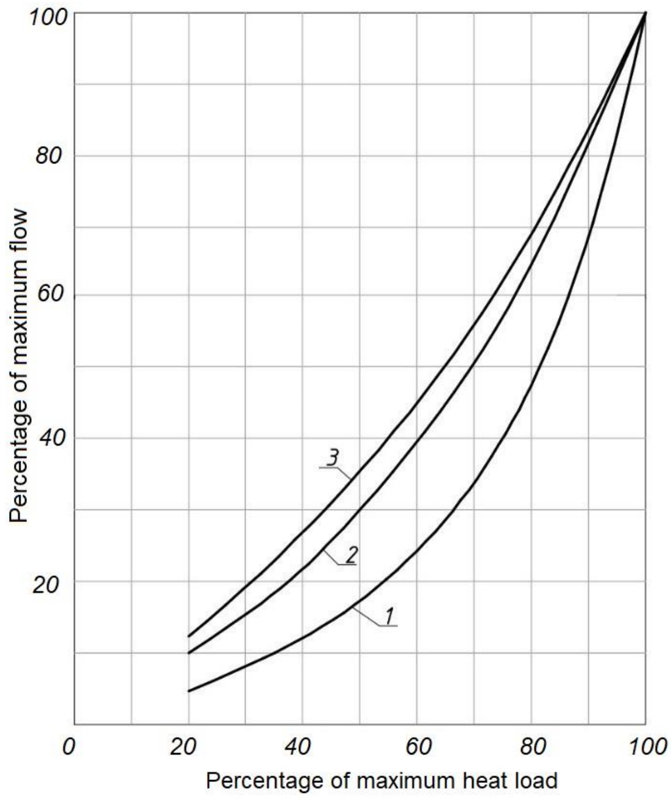
6: -30°C

Return temperatures below the dew point, required for the efficient operation of flue gas condensers and district heating systems in general, are achieved in the entire range of heat load control, starting from 65-70% of the calculated heat load.

Thus, the transition to combined qualitative-quantitative central control avoids "overheating" of buildings during the "break" in the temperature graph, preserves the possibility of hot water production of the required quality, avoids unproductive heat loss and ensures the high energy efficiency of district heating systems. A lower supply temperature graph can be used.

Heat carrier flow control depending on heat load can be carried out according to Figure 8.

**Figure 8: Quantitative central control and determination of relative heat carrier flow for different temperature graphs**



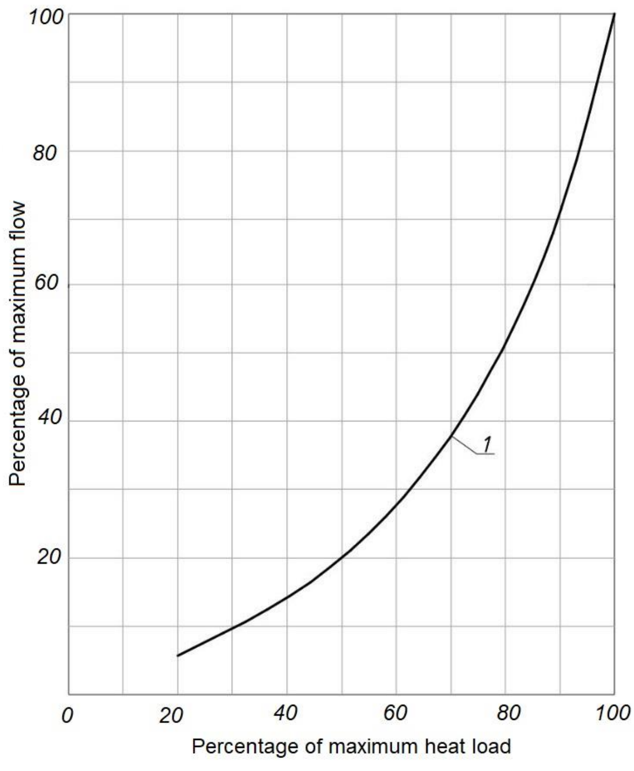

Temperature graph

1: 90/70°C

2: 115/70°C

3: 135/70°C

**Figure 9: Quantitative central control and determination of relative heat carrier flow for temperature graph 80/60°C**




The graphs above illustrate the required change in the value of the relative heat carrier flow rate in the heating network with quantitative control in the entire range of relative heat load for heating q. For example, to ensure optimal heat load control, typical for the average temperature of the heating period (about 50% of the calculated heat load) for a heating network with a temperature heat supply graph of 115/70°C, the relative heat carrier flow should be reduced to about 30% of the calculated heat load.

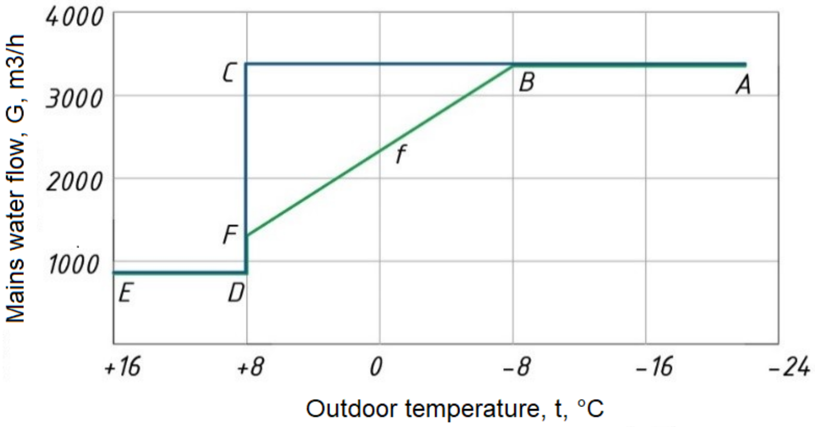
In addition to the above advantages, there are other advantages of lower temperature heat supply graphs:

- reduction in heat losses in district heating networks and reduction in thermal expansion of pipes and, as a consequence, simplification of heating network construction and elimination of compensators,
- increase in electricity production at combined heat and power plants (CHPs), by reducing the pressure during steam extraction from steam turbines,
- lowering the temperature in the return pipe of heating networks and increasing the efficiency of heat generators,
- ability to reduce the temperature of combustion products after heat generators, reduce heat losses with exhaust gases, and increase the efficiency of flue gas condensers as “boiler tail heating surfaces”,
- possibility of integrating district heating systems with alternative and renewable energy sources including industrial waste heat, geothermal heat, solar heat and similar.

## Less energy used for pumping

In addition to reducing heat losses, quantitative or qualitative-quantitative control allows additional savings in the form of reducing electricity costs for pumping. Figure 10 shows, as an example, the results of calculating main water flow using different methods of district heating system control at a heat load of about 100 MW and the design outdoor temperature of about -23°C.

**Figure 10 Heat carrier flow change in district heating system depending on the outdoor temperature**



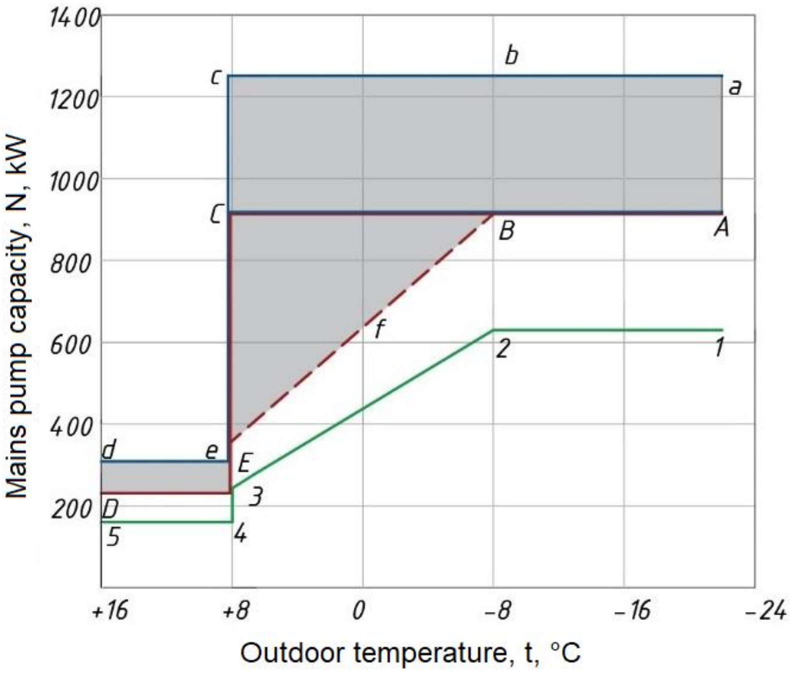

Line A-B-C-D-E - current qualitative control temperature graph

Line A-B-F-D-E on the path f – qualitative-quantitative control

Qualitative control is carried out on the segment from point A to point B. At an outdoor temperature of -8°C, there is a "break" of the temperature graph at which the transition from qualitative to quantitative control is proposed. This makes it possible to reduce the heat carrier flow along the line f.

Reducing the heat carrier flow creates the conditions for a significant reduction in electricity for pumping. This can be seen in Figure 11.

**Figure 11: Capacity change of main pumps of the heating system depending on the outdoor temperature:**




Line a-b-c-e-d: Required capacity of main pumps for the current state of district qualitative control (dependent connection scheme of multi-family buildings, pumps without quantitative control of heat carrier flow)

Line A-B-C-E-D: Required pump capacity after replacement (without changing the connection scheme of buildings and the method of control). Savings as existing pumps are generally oversized.

Line A-B-f-E-D: Required capacity of main pumps after the transition to qualitative-quantitative control

Line 1-2-3-4-5: Pump capacity after full change to modern individual heating substations

Equipping buildings connected to the district heating system with modern automated individual heating substations and the accompanying process of transition to combined qualitative-quantitative central control of the energy source requires mandatory installation of main pumps with variable speed drives in heating plants and optimisation of the thermal capacity of boilers to the appropriate heat load. The reconstruction of heating plants should include separation of the boiler circuits and the district heating network circuit. Additional investments required for such reconstruction of heating plants must be considered in the implementation of projects for the installation of automated individual heating substations with control depending on the outdoor temperature.

## Central heating substations

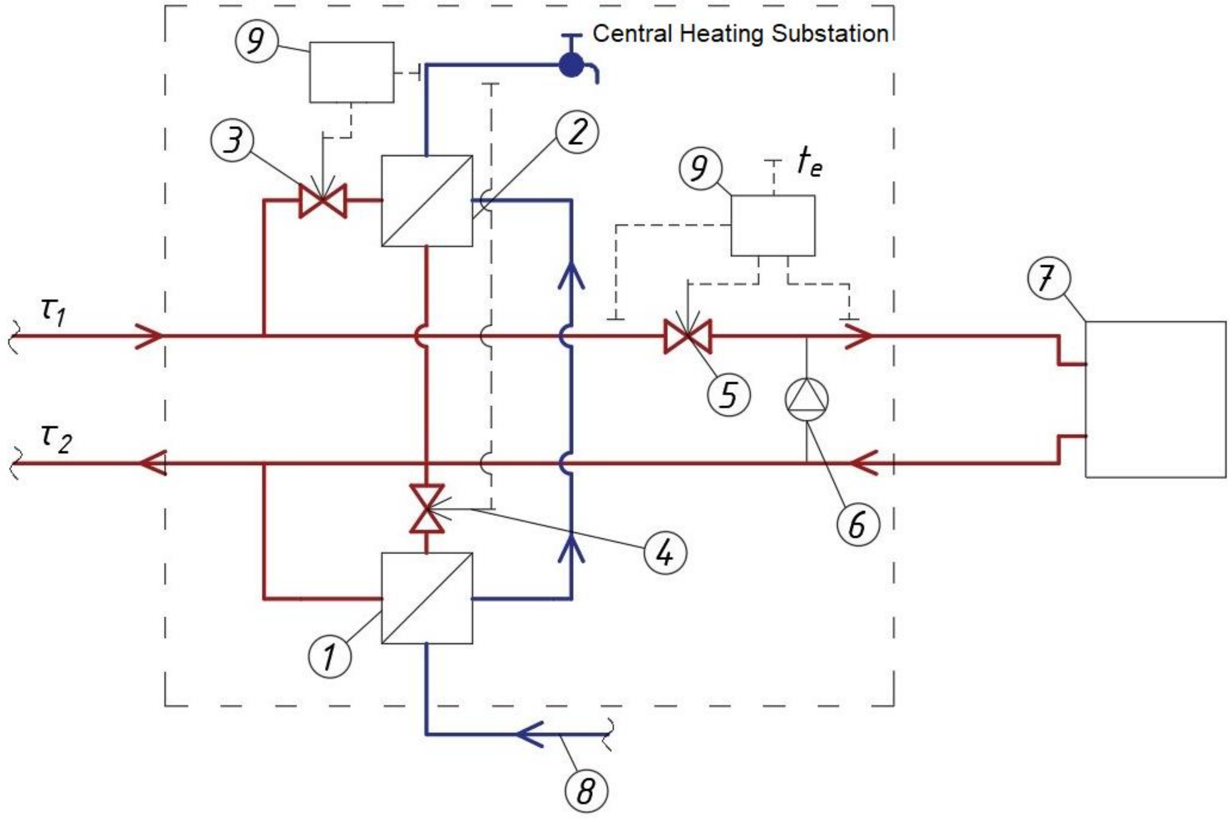
The main obstacle to the implementation of automated individual heating substations and qualitative-quantitative control of the heating system is not only the unpreparedness of heating plants. Equally important is the violation of hydraulic and thermal stability of district heating systems for those buildings that will not have (temporarily or for a long time) automated individual heating substations. This will happen because of the unavoidable change in the pressure drop and heat carrier flow from the heating networks to such buildings. Especially in the case of significant changes in the flow rate, as well as in the case of dependent connection of building systems and, as mentioned above, in the absence of mixing devices and circulating pumps.

The transition to such control can be fully implemented only after the introduction in all, without exception, buildings connected to the district heating system of an independent connection scheme or the introduction of automated individual heating substations with mixing devices. But this requires significant investment and time.

A transitional option in this regard proposes local group control at central heating substations in a district heating system with buildings without automated individual heating substations. To do this, it is necessary to reconstruct the central heating substations. This will allow all buildings directly connected to the heat network to be fully equipped with automated individual heating substations to make the transition to more efficient qualitative-quantitative control of heat supply, which in turn prevents unproductive heat loss with "overheating".

Figure 12 shows a schematic diagram of the reconstruction of a central heating substation for the potential transition to qualitative-quantitative group control of heat supply in the absence of automated individual heating substations in buildings.

**Figure 12: Schematic diagram of the reconstruction of a central heating substation for the implementation of qualitative-quantitative control of heat supply for heating and hot water supply**




τ1- supply pipeline in the heating network

τ2- return pipeline in the heating network

1 - heat exchanger (first stage) for hot water supply; 2 - heat exchanger (second stage) for hot water supply; 3 - temperature controller for hot water (second stage); 4 - temperature controller for hot water (first stage); 5 - flow controller; 6 - mixing pump with frequency control; 7 - heat consumer; 8 - cold water supply for hot water supply; 9 - controller

The purpose of the reconstruction is to equip the central heating substation with mixing units (5, 6), which will be able to maintain constant water flow in the distribution networks after the central heating substation, and thus avoid hydraulic and thermal maladjustment of internal heating systems in all buildings connected to the central heating substation.

The heat flow that will be supplied for heating under such a scheme may vary depending on the ratio between the heat extraction for heating and hot water supply. During the time of maximum heat extraction for hot water supply, the heat flow for heating will decrease. However, after a short period, short enough to prevent any changes of indoor temperatures to be observed, the lack of heat flow for heating will be compensated.

## Combined qualitative-quantitative control of district heating systems in Brovary

Table 1 presents the main indicators of the effectiveness of the introduction of combined qualitative-quantitative control of district heating systems in Brovary.

**Table 1: The main technical and economic indicators of the transition to qualitative-quantitative control for the city of Brovary**

| № | Indicator | Annual Savings | | |
|---|---|---|---|---|
| | | Heat energy MWh | Natural gas equivalent million $m^3$ | Electricity MWh |
| 1 | Reduction of unproductive heat and electricity losses as a result of the transition to qualitative-quantitative control of heat supply | 27,560 (14% of annual heat production) | 2,995 | 2,451 (41% of electricity consumption during the period of " break" the temperature graph) |

## Conclusions

During the preparation of the SUDH feasibility study for the reconstruction of the heating system of Brovary the current qualitative central control of heat supply, the transition to a lower temperature heat supply graph and the lack of flue gas condensers are shown to cause low efficiency of the system as a whole. The main shortcomings are significant heat losses in the transition periods following the "breaks" in the heat supply temperature graph. Such heat losses can be as high as 18% of the heat potential of the fuel used.

The introduction of qualitative-quantitative control is proposed, where heat output from heating plants in the period from the design outdoor air temperature before reaching the "break" temperature graph is controlled by changing the temperature of the heat carrier, and after "break", the transition to quantitative central control by changing the heat carrier flow.

During the transition period, the temperature controllers of modern automated individual heating will automatically reduce the flow, and the transition to central quantitative control will be the only acceptable solution for the district heating system. Qualitative-quantitative central control in combination with group control in central heating substations for buildings connected to district heating systems according to dependent schemes (without mixing devices and without automatic control depending on outdoor temperature) allows the avoidance of significant unproductive heat losses with "overheating". It also provides improved conditions for the operation of heat generators, including flue gas condensers and other low-temperature heat sources. This system provides the possibility of providing domestic hot water supply services throughout the heating period and reduces electricity costs, which significantly increases the overall efficiency of the district heating system.

The control method described in this article, including the use of a lower temperature heat supply graph, is recommended at the stage when automated individual heating substations are not installed in all buildings in a district heating system. In addition to the above, other advantages of lower temperature heat supply graphs include:

- reduction in heat losses in the district heating network and a reduction in thermal expansion of the pipes, and, as a consequence, simplification of heating network construction, and elimination of compensators
- increase in electricity production at combined heat and power plants (CHPs), by reducing the pressure during steam extraction from district heating turbines
- possibility of integrating district heating systems with alternative and renewable energy sources

Transition to the proposed control strategy requires installation of variable speed drives on the main pumps, as well as changes in the thermomechanical scheme of heating plants. Such reconstruction of heating plants should secure the heat carrier flow circulating through the boilers and ensure boiler and heat network circuit separation.