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The possibility of combined regulation of heat supply systems as the basis of energy efficiency

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The analysis of existing heating systems, as well as methods for regulating heat supply systems at the place of regulation and its parameters, was carried out. In order to maximise the efficiency of heat consumption, combined regulation should be provided, which should include local regulation and individual regulation in addition to central regulation. But this requires the reconstruction of existing single-pipe heating systems. One of the main conclusions is that modernisation of in-house systems with the existing heat source is more environmentally and energy efficient, fire and explosion safe, technologically easier to implement, and much cheaper than decentralisation of heating by installing independent heating systems with gas boilers in each apartment

Keywords: heating system, heat meter, heat supply system, regulating valves, types of regulation

Можливість комбінованого регулювання систем теплопостачання - основа енергоефективності

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У статті наведено аналіз існуючих систем опалення, а також методів регулювання систем теплопостачання за місцем регулювання та за його параметрами. Будинки масової забудови другої половини XX століття обладнані вертикальними однотрубними системами опалення без замикаючих ділянок. Конструкція цих систем опалення не дозволяє кожному споживачу впливати на своє споживання тепла. У однотрубних, вертикальних системах опалення без замикаючих перемичок і без запірно-регулюючої арматури у кожного нагрівального приладу, споживач отримує не ту кількість тепла, яку йому потрібно, а ту кількість, яку теплопостачальна організація подає йому відповідно до єдиної температури, закладеної у графіку центрального регулювання. Крім того, в основному всі системи опалення будівель другої половини XX століття підключені до теплових мереж за залежними схемами, з вузлами змішування, за допомогою нерегульованих елеваторів. На данні системи не можливо встановити регулятори теплового потоку та передбачити місцеве регулювання. Крім цього одним із суттєвих недоліків однотрубних вертикальних систем опалення – це практично (але не теоретично) відсутність можливості обліку тепла у кожній квартирі. Для можливості максимально ефективного споживання теплової енергії має бути передбачене комбіноване регулювання, яке крім центрального регулювання повинно включати місцеве та індивідуальне регулювання. Для можливості комбінованого регулювання повинна бути реконструкція існуючих однотрубних, нерегульованих систем опалення в двотрубні, горизонтальні, по квартирні та повинна бути проведена модернізація обладнання теплових пунктів, з встановленням змішувальних насосів замість елеваторних вузлів, та встановлення регуляторів теплового потоку систем опалення

Ключові слова: види регулювання, система опалення, система теплопостачання, регулююча арматура, теплолічильник

Introduction

According to [1], a heat consumer is an individual or legal person using heat energy on the basis of a contract.

But, from the technological point of view of heat supply [2], heat consumers of a heat supply system are usually called any building or structure, as well as a group of buildings, a neighbourhood, a district, a settlement, an industrial complex of constructions of one or more enterprises, which need heat energy of certain parameters. Heat consumers are also called separate engineering systems in these buildings, groups of buildings, neighborhoods, settlements, etc., which need heat supplies according to the same principles.

The main task of heat supply systems is to provide consumers with the necessary amount of heat to create comfortable conditions. Comfortable conditions must be provided not only for the building as a whole, but also in each individual premise: living room, office space, hospital ward, etc.

In district heating systems one of the most important tasks is to transport heat through heat networks with minimum losses from the heat supply source to the consumer. To accomplish this task, the heat carrier parameters (temperature, heat carrier flow rate) must correspond to the required amount of heat energy consumption (comfort conditions), which depends on the outside air temperature. In order to provide the required amount of heat energy depending on the outside air temperature, the heat supply and heating systems are regulated.

Review of the research sources and publications

According to [2, 3], the amount of heat provided to the consumer (house, building, etc.) from the heat supply source is determined by the formula:

$$Q = G \cdot (\tau_1 - \tau_2) \cdot c\,, \tag{1}$$

where Q – amount of heat, kJ;
G – heat carrier flow rate, t/hour;
τ_1 – heat carrier temperature in the supply pipeline of the heat supply system, °C; τ_2 – heat carrier temperature in the return pipeline of the heat supply system, °C;
c – heat capacity of the heat carrier, kJ/(kg·°C).

On the other hand, the amount of heat that is transferred from the heat carrier to the air in the heated, ventilated rooms can be determined by the formula:

$$Q = K \cdot F \cdot \Delta t \cdot \tau\,, \tag{2}$$

where K – heat transfer coefficient, W/(m^2·°C) ;
F – heat transfer surface area, m^2;
Δt – temperature drop in the heater of the local system, ºC;
τ – heater runtime, s.

The average heat output is determined by the formula:

$$q = K \cdot F \cdot \Delta t \cdot \beta\,, \tag{3}$$

where q – average heat transfer capacity, kJ;
β – work duration factor:

$$\beta = \tau / \tau_3\,, \tag{4}$$

where τ_3 – total period of exploitation of heating, ventilation including shutdown periods, s.

Based on the formulas (1-4), the amount of heat depends on the heat carrier temperature, heat carrier flow rate, and the operation period of the heating and ventilation systems. Accordingly, by changing the amount of heat carrier (quantitative regulation) or the heat carrier temperature (qualitative regulation), or simultaneously the flow rate and the heat carrier temperature (qualitative-quantitative regulation), or by changing the work duration factor (intermittent regulation), we can change the amount of heat energy provided to the consumer.

Ukraine has adopted qualitative regulation for the main part of heat supply systems. The heat supply from the heat supply source is performed according to the temperature schedule by changing the temperature of the heat carrier at the heat supply source relative to the outside air temperature.

This regulation also depends on:
– vailability of the centralized hot water supply system;
– length and branching of the heat supply system;
– type of consumers and their heat loads;
– thermal characteristics of the building, taking into account its "inertia";
– location of the building in relation to the sides of the world and the wind rose.

Temperature schedules are divided into:
– heating, for thermal loads of heating and ventilation systems;
– heating-domestic, at thermal loads of heating, ventilation and hot water supply systems;
– increasing temperature schedules based on heating and domestic temperature schedules.

The choice of the temperature schedule is determined by the ratio of hot water supply load relative share Q_{hmax} to heating load Q_{omax}:

$$\chi_{max} = Q_{hmax}/Q_{omax}\,, \tag{5}$$

The type of schedule adopted for central regulation at the heat source depends on χ_{max}, but for any values of χ_{max} a purely heating schedule is constructed first, as it is the base for the construction of all other schedules.

In the case of $\chi_{max} = 0$, a purely heated temperature schedule is assumed (Figure 1).

If, in addition to the heating and ventilation systems, hot water systems T1, T2 are also connected to the water heating network, a heating and domestic temperature schedule and a single-stage parallel hot water heater connection scheme is applied for $\chi_{max} < 0{,}2$ and $\chi_{max} > 1{,}0$. An example of a heating and domestic schedule is shown in Figure 2.

The heating and domestic schedule differs from the purely heating schedule in that the minimum temperature in the supply heating mainline is limited from below by the requirements to ensure the minimum design hot water temperature at the consumer's hot water intake valves $t_{hu} \geq 55$°C. Taking into account the temperature loss during transportation and distribution of hot water 5°C, the minimum temperature of the heating carrier in the supply mainline of the heating network for a closed heat supply system is assumed to be $\tau_{1min} = 65$°C. In order to ensure that this heat carrier temperature (τ1t according to the purely heating schedule) is maintained, when the outside temperature rises from the break point of the schedule upwards, the way in which the heat supply is regulated changes from qualitative to quantitative.

In case χ_{max} = 0,2÷1,0 (χ_m = 0,1÷0,5) in closed systems a two-stage mixed scheme and an increased temperature schedule based on the heating and domestic schedule are applied. According to this schedule, the heat supply system maintains a constant flow rate equal to the design flow rate for heating G_o, and the heat consumption for hot water is covered by increasing the supply temperature and decreasing the return temperature. In this case, fluctuations in the heat load for hot water supply cause changes in the amount of heat supplied for heating, which are smoothed by the heat storage capacity of buildings. The balance of heat is provided by the plotting of the elevated schedule according to the "balance" load of hot water supply. An example of the elevated chart is shown in Figure 3.

The choice of a temperature schedule and its construction for a large heat source (CHPP or a district boiler house) is a complex engineering task. It is even more difficult to maintain this temperature schedule because meteorological parameters, especially in recent years, change very quickly and are not always predictable.

The longer the district heat supply system, the greater the number and variety of consumers, the more changeable the weather, the more difficult it is to correctly calculate and set the temperature schedule for its qualitative regulation.

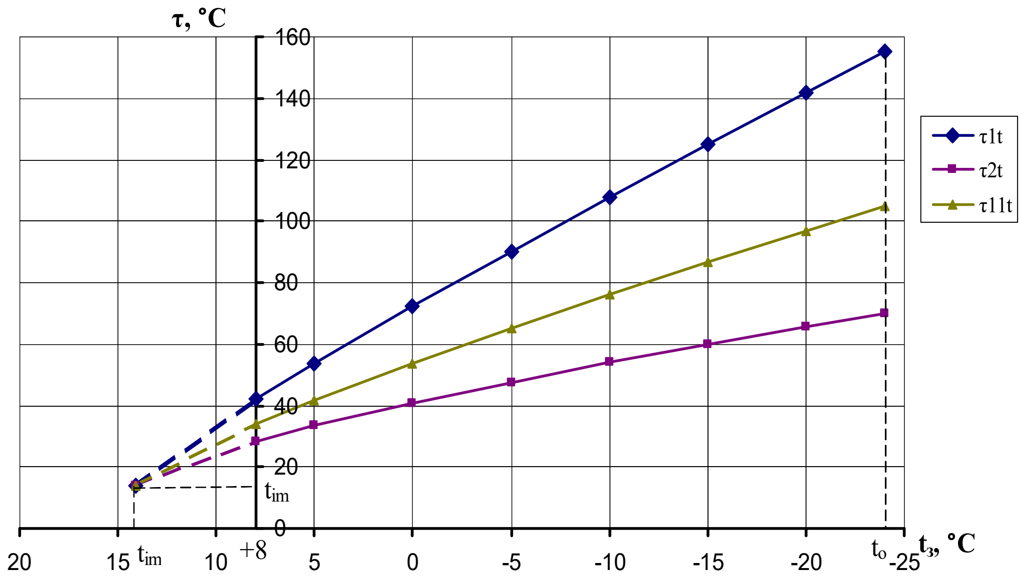

Figure 1 – Heating temperature chart (χmax = 0)

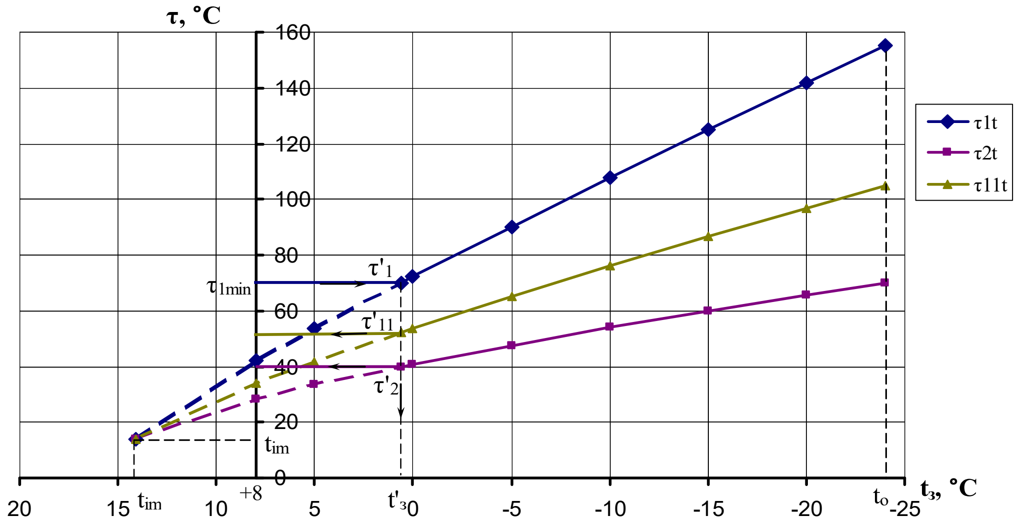

Figure 2 – Heating-domestic temperature chart (χ_{max} < 0,2, χ_{max} > 1,0)

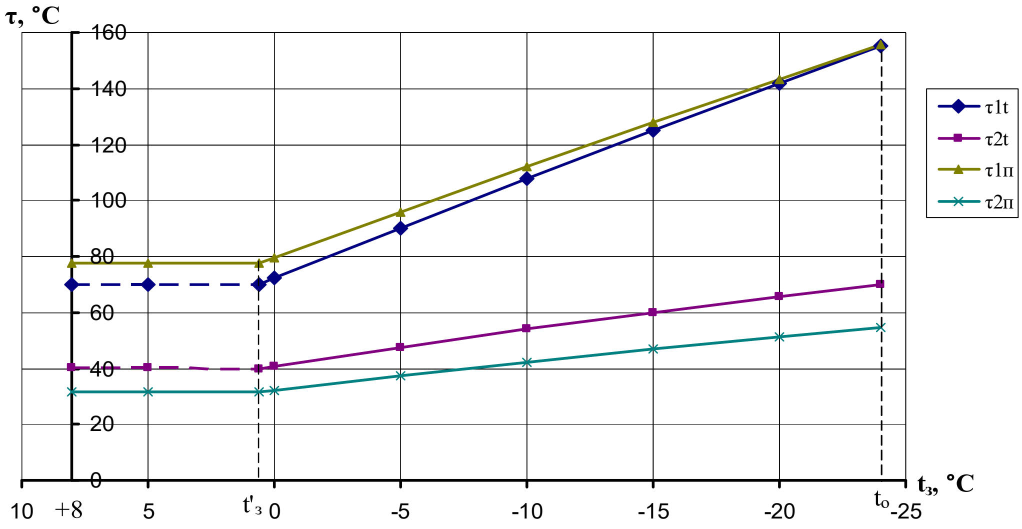

Figure 3 – Elevated temperature chart (0,2 < χ_{max} < 1,0)

When using a domestic-heating or elevated temperature schedule (Fig. 2-3), the temperature of the heat carrier in the supply pipeline is overestimated at the "break" point of the temperature schedule, which leads to further overheating of the heating system.

The constant complaints of consumers about under- and overheating are to some extent the result of inappropriate setting of the heat carrier temperature. Obviously, the more often the weather changes, the more often it is necessary to change the temperature of the heat carrier.

However, even when heat sources try to follow the temperature schedule as closely as possible depending on changing weather conditions and other parameters, they still maintain some kind of notional "average" temperature.

It must be taken into account that each consumer, based on the building's purpose, requires different parameters of heat carrier.

The impossibility of combined (local + instrumental) regulation in existing single-pipe heating systems is given in [4-10].

Definition of unsolved aspects of the problem

Let us consider a city district, where there are residential buildings, schools, kindergartens, medical institutions, shops, administrative buildings and other objects. Obviously, each of the homogeneous objects has its own characteristics and character of heat consumption.

Residential buildings require a fairly stable overall temperature around the clock. At the same time, every room in every apartment in a residential building requires its own temperature.

In kindergartens, schools only require a standard indoor temperature when children are present.

In hospitals, rooms for different purposes must have different temperatures.

In addition to the predominant heat load of residential neighbourhoods, there is also the load of administrative buildings, theatres, cinemas, clubs, educational institutions, research institutes and other facilities in the urban heat supply system. In addition, there is the heat load of industrial enterprises.

Naturally, the temperature schedule is built based on the main consumer - residential buildings. Accordingly, heat supply organizations, when supplying heat centrally, focus on the main consumer – residential buildings built in the second half of the XX century.

Thus, we deliberately set the average temperature of the heat carrier to all other consumers.

Having adopted the method of central qualitative regulation, it is necessary to take into account two principles for the application of this method, which must be observed by all subscribers connected to the heating network.

The first principle of regulating the heat supply from the source to the consumer according to a uniform design temperature schedule is originally based on each consumer having its own heat flow regulator (temperature regulator). These regulators ensure that the averaged heat carrier parameters received from the heat source are brought up to the parameters required by a given subscriber as a whole. For the urban development of the second half of the twentieth century, hydro-elevators with an electric drive, which have the ability to adjust the diameter of the elevator nozzle to the temperature of the outside air, instead of conventional elevators were very rarely designed and installed.

The second principle of heat regulation is by changing the flow rate of the heat carrier in the building heating system. For urban development in the second half of the twentieth century this method was based on the fact that inside the building, primarily in a residential building, the heat consumption is regulated in each room by the consumer himself using shut-off and regulating valves installed on each heater. The shut-off and regulation valves were designed on the principle of double-acting valves or three-way valves. However, these shut-off and regulation valves have hardly ever been installed, and where they have been, they are now out of service.

Buildings built in the second half of the twentieth century have no temperature regulators, as well as shut-off and regulating valves on heating devices. Therefore, with centralised qualitative regulation, we get heat overshoot in the outdoor temperature range from the "cut-off" point of the temperature graph to +8°C, and underheating or overheating of individual rooms at other outdoor temperatures.

To solve the problem of regulation, we must have a real technical ability to change the amount of heat entering each room through the heaters, that is, to increase or decrease the heat transfer of the heater.

Problem statement

In order to reduce the consumption of thermal energy as much as possible, a combined regulation, including local regulation at the individual heating substation and individual (device) regulation, by installing thermostats on each heating device is required.

Basic material and results

However, mass housing developments in the second half of the twentieth century are equipped with vertical single-pipe heating systems without bypass sections. The design of these heating systems does not allow each consumer to influence heat consumption.

Figure 4 shows a typical scheme of a single-pipe heating system without bypass sections. Almost all residential buildings of the second half of the XX century is equipped with such systems.

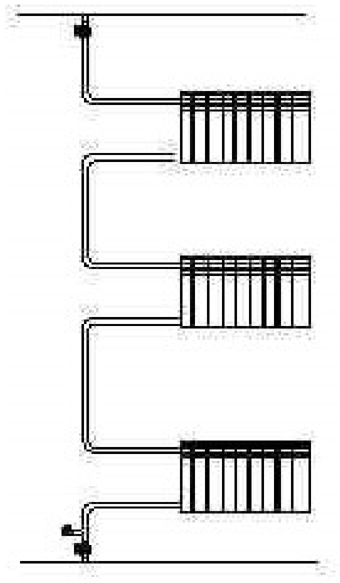

Figure 4 – One-pipe, vertical heating system

The same design flaws are observed in the heating systems of the vast majority of educational, medical, administrative and other buildings built during the same period.

As we can see, in one-pipe vertical heating systems without bypass bridges and without shut-off and regulating valves at each heater, the consumer does not receive the amount of heat he needs, but the amount of heat supplied by the heat supplier in accordance with the only temperature laid down in the schedule of central regulation.

In addition, basically all heating systems of buildings of the second half of the twentieth century are connected to the heating network by dependent schemes, with mixing units, using unregulated elevators (if the temperature of the heat carrier in the supply pipeline is more than 105°C). Heat flow controllers cannot be installed on this system, as the elevator (injection pump) must supply a constant amount of heat carrier to the heating system, changing the flow of heat carrier leads to unbalancing of the heating system. This technical solution was justified by the absence of silent pumps and energy savings. It should be noted that elevators are not as widespread around the world as they are here. Therefore, it is necessary to provide for the reconstruction of the existing control units of the heating system at consumers, which is associated with the replacement of elevator units for mixing pumps (with dependent connection scheme of the heating system to the heating network) and the installation of differential pressure regulators or balancing valves (regardless of the connection scheme of the heating system to the heating network). However, modernization of the individual heating substation without reconstruction of the existing single-pipe heating system is ineffective.

Comparing the domestic and foreign heat supply systems of the last century, it is necessary to emphasize their main difference: *nowhere and never in countries with developed district heating systems have massively implemented in-house heating systems without shut-off and control valves at the heaters*.

In our country, the vast majority of residential and civil buildings of the second half of the twentieth century were first designed and then built in accordance with single-pipe vertical heating systems.

The purpose of such a solution, which makes regulation impossible, was solely to save metal.

Savings have indeed been made, but they have condemned heat consumers and heat suppliers to the impossibility of creating comfortable heat conditions.

Half a century of operating practice has confirmed the correctness of the opponents of single-pipe vertical systems, who argued that the normal operation of shut-off valves in such systems is virtually impossible.

In fact, a single-pipe vertical heating system without bypass sections is a single heating structure in which it is not possible to adjust each heater.

Only the entire heating system can be regulated if a heat flow controller is installed on the heating system control unit (except for heating system control units connected to the heating network by means of elevators). But this is a regulating of the entire in-house heating system as a whole, not each heater in it.

Annual heat losses in heating systems in Ukraine as a whole result in overconsumption of about 25% of the total amount of fuel used for heating.

Based on the above, it should be understood that the widely advertised individual heating substations with heat exchangers in heating systems or with mixing pumps instead of elevator units, with installation of heat flow regulators solve only part of the issue of rational economical heat supply and consumption, due to the fact that the resident himself has no influence on the amount of heat consumed in his apartment. Adjustment takes place in the heating system of the building as a whole, without taking into account the possibility of unbalancing of the heating system. Unbalancing of the in-house heating system can occur due to unauthorised replacement of heating devices in the apartments of tenants, due to the installation of new heating devices with a higher heat transfer, due to replacement of risers with a smaller diameter, etc.

In addition, one of the significant disadvantages of single-pipe vertical heating systems is the practical (but not theoretical, according to [11]) lack of possibility of heat metering in each apartment. This is due to the peculiarities of the heating systems of the buildings of the second half of the twentieth century, many apartments are still equipped with convectors "Accord" or "Comfort", as well as heating panels, etc. *As of May 2022, not a single thermal energy distributor has been installed in Kharkiv*. According to [11], a thermal energy distributor is a device or set of equipment and materials for it, installed on the heating unit of a building heating system, which is used to determine the share of heat consumption of a consumer's individual heating unit in the total consumption in accordance with the readings of the commercial metering unit. *If it is not possible to meter heat consumption in an apartment, many apartment owners will not engage in adjustments of their heating systems, even if it is possible to do so*.

Without the reconstruction of in-house vertical single-pipe heating systems without bypass sections, the problem of adjusting each heating device, and hence the problem of heat consumption of each apartment (premises for any purpose) remains unsolved.

The new residential and civic buildings of the 21st century are fundamentally different from those of the 20th century. These buildings, according to the new Ukrainian regulations, are designed with two-pipe horizontal heating systems (Figure 5). The proportion of modern buildings in Ukraine's cities and towns is growing, but it is still small compared to the amount of twentieth-century urban development.

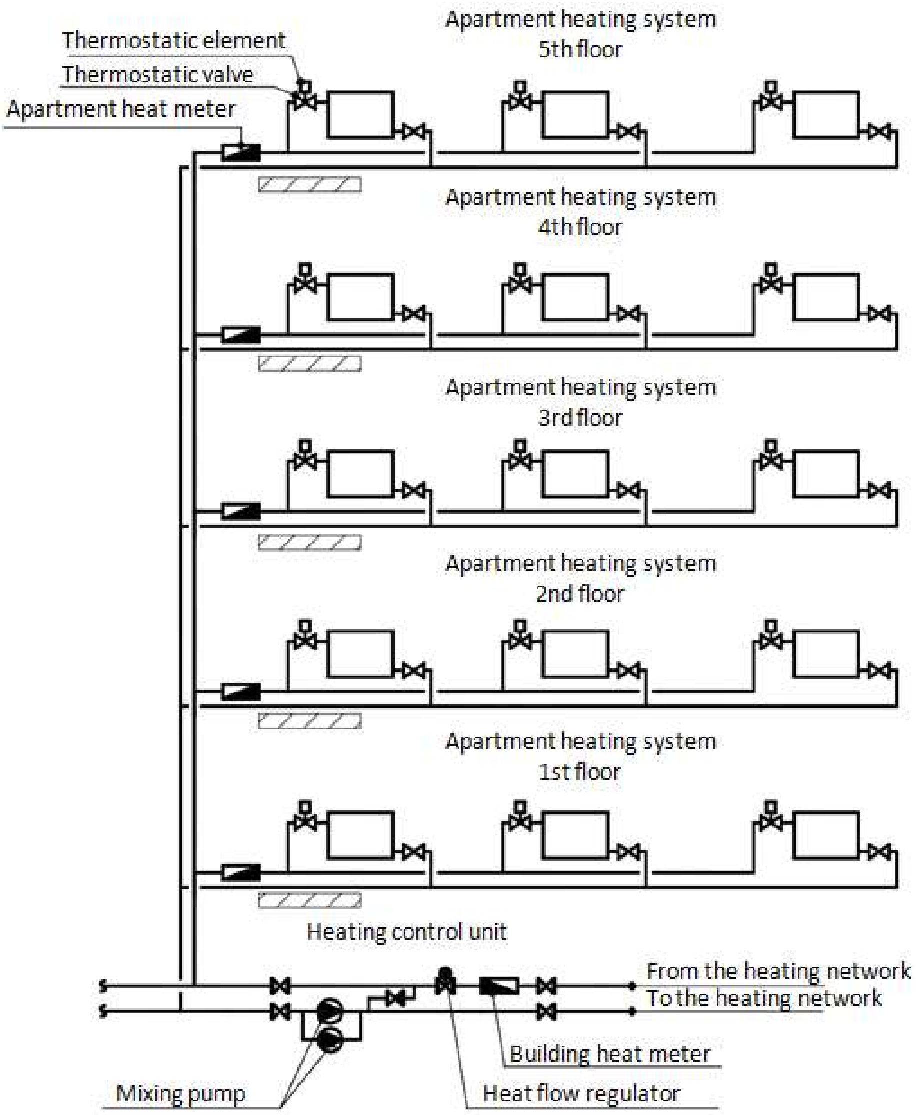

Figure 5 – Two-pipe, horizontal heating system

In this common building heating system, each apartment has a regulated heating system with a commercial heat meter. A thermostatic element (thermostat) in each heating unit allows you to create the desired air parameters in each room. Equipping such systems with a mixing pump with heat flow regulator, instead of an unregulated elevator unit, makes it possible to apply energy-efficient “quantitative-qualitative” regulation instead of the “widely used” “qualitative” one.

These apartment buildings, schools, kindergartens and hospitals are already using two-pipe heating systems. Their main difference from the old single-pipe system is that in addition to the possibility of regulating the quantity and quality of the heat consumed by each tenant or other consumer, we have the possibility of heat metering in each apartment.

This is achieved by installing horizontal apartment-by-apartment heating systems with thermostatic elements on each heater and heat meters in each apartment or office. In these heating systems, each consumer has the opportunity to set the desired comfort temperature in the room, and can save the amount of thermal energy consumed, at his discretion.

The rejection of an one-pipe vertical heating system and its replacement with a two-pipe horizontal system really solves a vital problem – the installation of heat meters in every apartment or office. By having their own meter, the owner of an apartment clearly sees how much their comfort costs and acts accordingly to save their money. At the same time, by their actions, every resident is taking part in the government's energy conservation programme.

Of course, the ability to regulate heat consumption in each apartment and even in each room is a very positive factor in reducing the heating costs of each tenant. By regulating its heat consumption, each resident affects the entire heating system, changing its hydraulics, and therefore affects the distribution of heat between the subscribers as a whole. At the same time, by regulating the heat output of their apartment, each tenant indirectly affects the heat consumption of the other subscribers, who must also make appropriate adjustments to create their own comfort conditions.

Thus, in heat supply systems where all consumers have thermostatic elements (thermostatic controllers), we create the possibility of “quantitative” regulation alongside the common “qualitative” regulation.

Changes in the amount of heat transfer fluid circulating in the district heating system are monitored by control and regulation devices at the heat source. They automatically send commands to the flow regulators and to the network pumps. Thus, we get a district heating system with “quantitative-qualitative” regulation instead of the common system with only “qualitative” regulation.

The “quantitative-qualitative” way of supplying heat is a more progressive and economical solution.

The most important result of the transition from “qualitative” to “quantitative” regulation is also the absence of the need to artificially “overheat” the heating system in the range of outside air temperatures from the “cut-off” point of the temperature graph to +8°C due to hot water supply needs.

A comparison of the specific heat consumption of 20th century residential multi-storey buildings with single-pipe vertical heating systems, and 21st century buildings with two-pipe horizontal heating systems shows a clear advantage of the new buildings. The heat consumption for heating one square meter of new buildings is about half as much as for heating the same space and volume in old buildings. It is clear that the heat consumers' costs and the amount they pay for heat in new buildings are lower.

Fundamental changes of centralized heat supply during reconstruction of in-house heating systems with installation of meters in each apartment provide:

− possibility to regulate heat consumption by the consumer himself;

− heat accounting and payment by the consumer only for the actual amount of heat consumed;

− possibility to create conditions of comfort for each consumer;

− increased reliability due to the possibility of autonomous disconnection of each apartment instead of the n-th number of apartments in the heating standpipe or the entire building for repairs.

Conclusions

1. One of the main reasons for significant losses of thermal energy by consumers and excessive fuel consumption at heat sources is the imperfection of unregulated structures of in-house vertical heating systems without bypass sections in residential buildings built in the second half of the 20th century.

2. Comparison of buildings of the 20th and 21st centuries shows that more than half of the reduction in specific heat consumption by modern multi-storey residential buildings is achieved through the introduction of apartment heating systems with heat meters in each apartment.

3. It is advisable to replace all unregulated vertical single-pipe heating systems of multi-storey buildings with horizontal two-pipe adjustable ones. Without such a replacement, further energy-efficient operation and development of heat supply is impossible.

4. The proposed modernization of in-house systems with the preservation of the existing heat source, more environmentally friendly, fire and explosion safe, technologically easier to implement and significantly cheaper than the decentralization of heating by the device of independent heating systems with a gas boiler in each apartment.

5. Combined (local + individual) regulation of heat supply from source to consumer is a more efficient way than central regulation alone, which is used in Ukraine.

6. To create the possibility of switching to a combined (local + individual) regulation, it is also necessary to replace the elevator units at the individual heating substation of each building with mixing pumps with frequency converter, as well as to provide for the installation of heat flow regulators.

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