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INCREASING THE EFFICIENCY OF USING CENTRALIZED HEAT SUPPLY SYSTEMS IN THE RECONSTRUCTION OF HEAT NETWORKS

О.. Климчук, О. Вудвуд, Є. Бабаєв, М. Сергеєв, І. Аксьонова. **Підвищення ефективності використання централізованих систем теплопостачання при реконструкції теплових мереж.** В роботі проведено аналіз існуючого стану систем теплопостачання житлових масивів. Показано необхідність урахування сучасних вимог до термомодернізації будівель різного типу призначення, а також режимів експлуатації внутрішніх систем теплопостачання при різних видах теплового навантаження (опалення, гаряче водопостачання, вентиляція). Показано основні типи будівель, що можуть розташовуватись в житлових масивах (багатоповерхові житлові будинки, гуртожитки, котеджі, адміністративні будівлі та офіси, навчальні заклади, торгівельні центри, підприємства харчування тощо) та охарактеризовано особливості роботи їх систем теплопостачання. На основі представленої методики проведено розрахунок добового та тижневого графіку споживання теплоти для двох узагальнених типів будівель: житлової (багатоповерхівки, котеджі, гуртожитки, тощо) та громадського призначення (адміністративні будівлі, навчальні заклади, офіси тощо). На основі розрахунків складено узагальнений графік теплового навантаження для двох типів будівель з урахуванням взаємного впливу на максимальну потужність джерела теплоти. На основі отриманих результатів проведено розрахунки та складено добові графіки узагальненого споживання теплоти будівлями різного типу із урахуванням сучасних вимог енергоефективності (двоперіодний режим опалення та термомодернізації). Показано доцільність застосування акумуляторів теплоти у теплових пунктах для згладжування піків сумарного навантаження та зменшення максимальної потужності джерела теплоти. Показано вірогідне зниження максимальної потужності систем теплопостачання та надано рекомендації щодо розрахунків систем теплопостачання при їх реконструкціях та модернізації.
Ключові слова: системи теплопостачання, акумулятори теплоти, графіки споживання теплоти, енергоефективність

O. Klymchuk, O. Vudvud, Ye. Babaiev, M. Serheiev, I. Aksyonova. **Increasing the efficiency of using centralized heat supply systems in the reconstruction of heat networks.** The paper analyzes the existing state of heat supply systems of residential areas. The need to take into account modern requirements for thermal modernization of buildings of various types of purpose, as well as operating modes of internal heat supply systems with different types of heat load (heating, hot water supply, ventilation) is shown. The main types of buildings that can be located in residential areas are shown (high-rise residential buildings, dormitories, cottages, administrative buildings and offices, educational institutions, shopping centers, catering enterprises, etc.) and the peculiarities of their heat supply systems are characterized. Based on the presented methodology, the calculation of the daily and weekly schedule of heat consumption for two generalized types of buildings: residential (high-rise buildings, cottages, dormitories, etc.) and public (administrative buildings, educational institutions, offices, etc.) was carried out. Based on the calculations, a generalized heat load schedule for two types of buildings was drawn up, taking into account the mutual influence on the maximum power of the heat source. Based on the obtained results, calculations were made and daily schedules of generalized heat consumption by buildings of various types were made, taking into account modern energy efficiency requirements (two-period mode of heating and thermal modernization). The expediency of using heat accumulators in thermal points for smoothing the peaks of the total load and reducing the maximum power of the heat source is shown. A probable decrease in the maximum power of heat supply systems is shown, and recommendations are given regarding the calculations of heat supply systems during their reconstruction and modernization.
Keywords: heat supply systems, heat accumulators, heat consumption graphs, energy efficiency

1. Introduction

Centralized heat supply systems of cities were designed and installed for the most part during the times of Soviet power. The total power of the heat source was usually calculated from the condition of covering the maximum load at the calculated temperatures of the external environment [1], as well as taking into account the perspective of the development of residential areas [2].

Heating networks and central heating points were also calculated from the condition of passing the coolant to cover the total needs at peak loads with quality regulation. These factors led to an exaggeration of the capacities of heat sources and oversizing of heat networks, which in turn affected the efficiency of heat supply systems and increased their capital investment and the cost of operating costs. Nowadays, the issue of modernization of heat networks and reconstruction of heat supply

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sources is becoming acute. At the same time, the existing housing estates, as a rule, are no longer expanded, that is, there is a concept of their condition, as well as the modes of operation of existing buildings. In addition to the above, the requirements for the energy efficiency of the use of heat by buildings have also changed, which in turn has led to a decrease in heat supply needs. The operation of a number of heating networks also showed the inability to adhere to the schedule of quality regulation (150/70 at the calculated temperatures of the external environment). In turn, heat sources (water heating boilers) are technically and morally obsolete. It is necessary to replace them with the reconstruction of thermal circuits according to modern technologies. Another factor that significantly affects the technical characteristics of heat supply systems is the mutual influence on the heat supply capacity - heat supply modes of buildings of different types of purpose. At the same time, it is worth noting the unevenness of heat consumption both daily and weekly, which in turn affects the total heat capacity. All the specified factors must be taken into account during reconstruction and modernization of existing heat supply systems, which will lead to a significant reduction of capital investments in reconstruction and will significantly increase the efficiency of heat energy consumption.

2. Analysis of literary data and formulation of the problem

Conventionally, for residential areas, the types of buildings according to their purpose can be divided into multi-story residential buildings; administrative buildings (office centers) and educational institutions; trade enterprises; food establishments. Each of the specified categories differs in the ratio of the shares of heat consumption by types of heat load and organizational and operational modes of buildings [2].

Heat consumption by multi-apartment buildings, as a rule, has pronounced heat load peaks in the morning and evening. This is explained by a sharp increase in hot water consumption during this period [3]. However, these peaks can be prevented by installing hot water storage tanks in the heating stations. It should be noted that in recent years, additional factors have appeared that also affect the mode of operation of the heat supply system in the apartments of these buildings, namely individual electric boilers and heat meters with automatic temperature control in the room.

These factors significantly affect the thermal regime of buildings and lead to an increase in the amplitude of fluctuations in daily heat consumption.

Administrative buildings (office centers) and educational institutions usually have an even schedule of heat consumption for hot water supply needs during the working day, while the percentage of the indicated load is relatively small [3]. Ventilation systems work only during the working day and, usually, in recent years, they are equipped with recuperators, which allows to significantly reducing the share of heat for heating the outside air. The heating system works throughout the day and its thermal power depends on the outside air temperature. Shopping complexes work throughout the week and day, in many cases, therefore, irregularity in the specified period is usually not observed [4]. It is not always possible to equip ventilation systems with recuperators, so the share of heat for heating the outside air increases. Hot water supply systems have a peak consumption in the morning and an increased mode of consumption in the evening. The heating system works 24 hours a day. In shopping complexes, it is possible to use the heat of condensation of refrigerating machines for heating the premises and preparing hot water.

In catering facilities, depending on the direction of operation (cafes, canteens, restaurants, etc.), unevenness is observed throughout the day and week [4]. The peak load on ventilation and hot water supply occurs during the period of greatest occupancy of the hall (for cafes and canteens it is the lunch break, and for restaurants and some cafes it is the evening). When the dining hall is fully occupied, the heating load is significantly reduced. In the technological premises during the day, the load on ventilation increases sharply, while the load on heating decreases significantly.

In works [3, 5, 6], the authors analyze the operation of heat supply systems for individual buildings, and indicate ways to improve the efficiency of local systems, without taking into account the influence of the operating modes of buildings of different purposes on the heat supply system.

On the other hand, the authors [1, 2, 7, 8] consider the problems of centralized heat supply systems without taking into account the possibility of deep thermal modernization of buildings and internal heat supply systems.

The analysis of the current state of the existing centralized heat supply systems of the existing residential areas determined the setting of the main task of this study – the study of the operating modes of

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buildings of different types of purpose, their mutual influence on the heat supply systems in order to increase the efficiency of their use and reduce capital costs for the main equipment and materials.

3. The purpose and objectives of the research

The main goal of this study is to obtain modeling data that characterizes the operation of the heat supply system of existing residential areas, taking into account the operating modes of buildings of different types of purpose.

To solve the set goal, the following tasks must be solved:

– generalize heat consumption regimes by type for buildings of different types of purpose;

– conduct modeling of the mutual influence on the heat supply system of operating modes of buildings of different types of purpose;

– provide proposals for the reconstruction of existing heat supply systems of residential areas.

4. Methods of conducting research and processing experimental data

Determination of the maximum thermal load of the building is calculated according to the formula [1]:

$$Q_{\Sigma} = Q'_h + Q'_v + Q'_{hw}, \tag{1}$$

where Q'_h – heat consumption for heating, W;

Q'_v – heat consumption for ventilation, W;

Q'_{hw} – heat consumption for hot water supply, W.

Generalized heat consumption for heating [1]:

$$Q'_h = (1+\mu) q_h V (t_i - t_o), \tag{2}$$

where μ – infiltration rate;

q_h – specific heat loss, W/(m^{3}K) (26 W/m^3 [1]);

V – volume of the building in terms of external dimensions, m^3 (3608 m^3);

t_i – estimated internal air temperature, °C (+12 °C);

t_o – calculated outside air temperature, °C.

Generalized calculation of heat consumption for ventilation [1]:

$$Q'_v = m V_v C_v (t_{i.} - t_{ov}), \tag{3}$$

where Q'_v – heat consumption for ventilation;

m – air exchange rate, 1/s;

V_v – ventilated volume of the building, m^3;

C_v – volumetric heat capacity of air is equal to 1260 W/(m^3 K) or 0.3 kcal/(m^3 °C);

t_i – the temperature of the heated air supplied to the room, °C;

t_{ov} – outside air temperature, °C.

For ease of calculation, formula (3) is reduced to the form [1]:

$$Q'_v = q_v V (t_i - t_{ov}), \tag{4}$$

where q_v – specific heat consumption for ventilation, i.e. heat consumption per 1 m^3 of a ventilated house according to external measurements and per 1°C difference between the average calculated air temperature inside the ventilated room and the temperature of the outside air;

V – external volume of the ventilated house, m^3;

t_i – average internal temperature, °C.

Heat consumption for hot water supply (HWS) [1]:

$$Q_{hw} = vnc(t_{hw} - t_{cw}) \frac{1}{\tau} \chi_w \chi_d Q'_{hw}, \tag{5}$$

where v – specific water consumption, l/person;

n – number of residents, pers;

c – heat capacity of water J/(kg·K);

t_{hw} – temperature of hot water, °C;

t_{cw} – cold water temperature, °C;

τ – estimated duration of heat supply for hot water supply, s/day;

χ_w – coefficient of weekly unevenness of heat consumption;
χ_d – coefficient of daily unevenness of heat consumption.

Expressions [7] were used to determine the power value of heating and ventilation systems:

$$Q_h = Q_h' \frac{t_i - t_o}{t_i - t_{oc}}, \tag{6}$$

$$Q_b = Q_b' \frac{t_i - t_o}{t_i - t_{ov}}. \tag{7}$$

The equation of the temperature graph for direct connection [7]:

$$t_1 = t_i + 0.5(t_1' - t_2')\frac{t_i - t_o}{t_i - t_o'} + 0.5(t_1' + t_2' - 2t_i)\left(\frac{t_i - t_o}{t_i - t_o'}\right)^{0.758}, \tag{8}$$

$$t_2 = t_1 - (t_1' - t_2')\frac{t_i - t_o}{t_i - t_o'}, \tag{9}$$

where t_1, t_1' – water temperature in the supply main of the heat network at any outside air temperature and at the calculated outside air temperature, (150 °C is accepted) °C;

t_2, t_2' – water temperature in the return main of the heating network at any outside air temperature and at the calculated outside air temperature, °C (70 °C is assumed);

t_o, t_o' – current and calculated value (corresponding to the city specified by the option) of outside air temperature, °C.

5. Results of studies of the processes of heat supply by a centralized heat supply system, taking into account the modes of operation of buildings of different types of purpose

The mode of heat consumption during the week is mainly influenced by the purpose of the building [9, 10]. Two main types of buildings were chosen for the analysis of heat supply modes: residential and public buildings.

Calculations of heat consumption during the week (Figs. 1, 2) and during the day (Figs. 3, 4) were carried out for the indicated types of buildings.

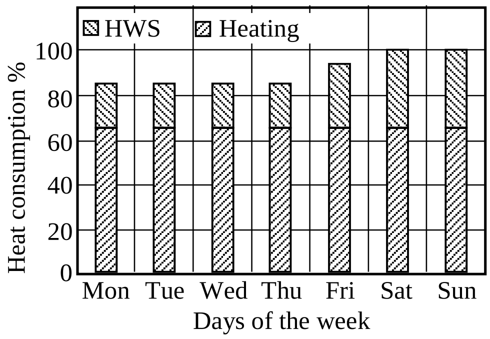

Fig. 1. Diagram of heat consumption during the week by a residential building

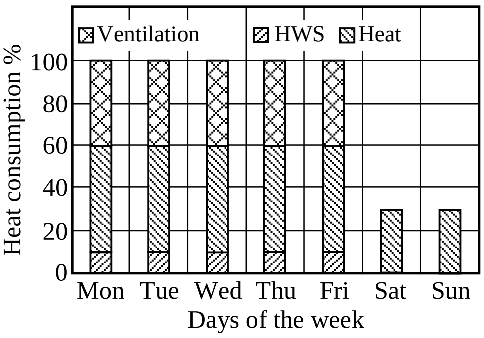

Fig. 2. Diagram of heat consumption during the week by a public building

Analysis of graphs (Fig. 1, 2) shows that the weekly maximum for residential buildings occurs on weekends. During this period, there is a significant decrease in heat load needs for public buildings.

The mode of heat consumption during the day is also mainly influenced by the purpose of the building. The same buildings were chosen for the analysis of heat supply modes (Figs. 3, 4).

As can be seen from the diagrams (Figs. 3, 4), in all types of buildings, there is a drop in thermal load during the night period of the day. The graphs also show the zone of the working period, which is characterized by a load drop in residential buildings and a peak in public buildings. In turn, in the evening, the picture changes on the contrary. This makes it possible to ask the question of load redistribution for buildings with different types of purpose during the day.

It should be noted that for centralized heat supply systems, a real energy saving factor is the possibility of realizing a useful phenomenon – “self-compensation” of the heat load. Self-compensation of

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heat needs is possible if there are buildings of various purposes (public, residential, commercial and entertainment, etc.) in the neighborhood, capable of mutually compensating redistribution of heat consumption. This is possible due to the fact that heat consumption peaks for buildings of different types occur on the heat load graphs at different time intervals, so there is a possibility of mutual compensation of heat needs. For example, the increase in heat needs of residential buildings on weekends can be compensated for by reducing the heat consumption of public buildings when they implement an intermittent heat supply regime. In addition, "self-compensation" of heat load due to the rational redistribution of heat needs between houses of different types leads not only to energy saving, rational use of heat generators, but also to a reduction of the load on heat networks without additional monetary costs. To assess the possibility of compensating load peaks of one type of building with load dips of other types of building, we will calculate the relative need for heat under the condition of the total ratio of heat supply capacity for two types of buildings in a residential area of 50/50 (Fig. 5).

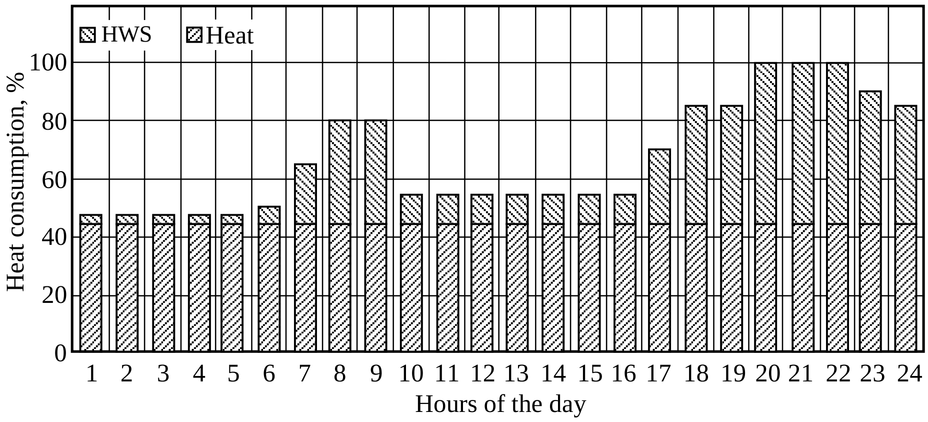

Fig. 3. Diagram of heat consumption during the day by a residential building

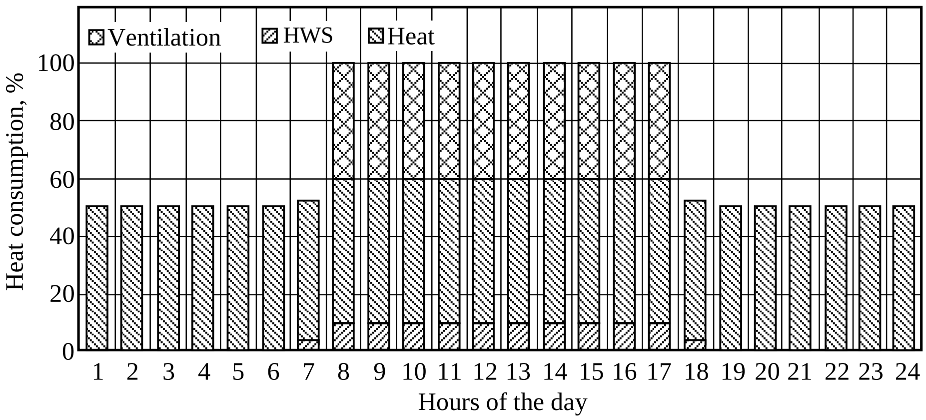

Fig. 4. Diagram of heat consumption during the day by a public building

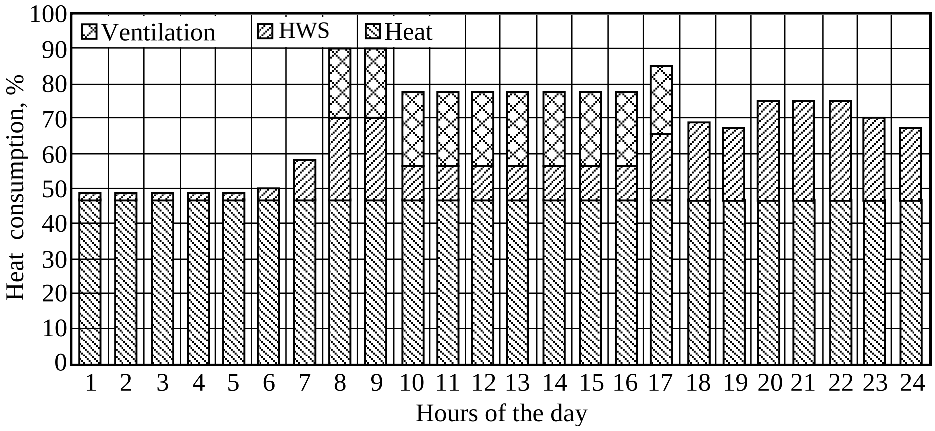

Fig. 5. Diagram of heat consumption during the day by houses of different types of purpose

As can be seen from the graph, the total power of the heat supply source, taking into account the operating modes of buildings of different types of purpose and their mutual influence on the total load of the heat supply system, allows reducing the maximum power by 10 %.

These calculations do not take into account modern requirements for thermal modernization of buildings and do not use the variable mode of the building heating system. Taking into account the possibility of alternative heating mode in public buildings during non-working hours, and in residential buildings during working hours, an additional reduction of the total load percentage is possible (Fig. 6).

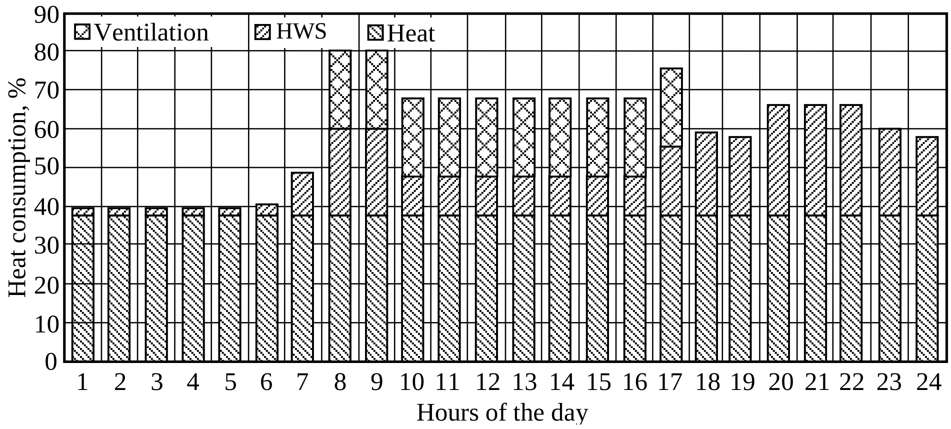

Fig. 6. Diagram of heat consumption during the day by houses of different types of purpose when using the regular heating mode

As can be seen from the graph, the use of alternate heating allows reducing the maximum load by 10 %. However, over the past 30 years, the requirements for the level of thermal modernization have become much stricter, which leads to the need for thermal modernization of existing buildings. In a relative comparison of the old requirements with the new ones, it is known that only compliance with the new requirements for thermal modernization can at least halve the costs of heating and ventilation (Fig. 7).

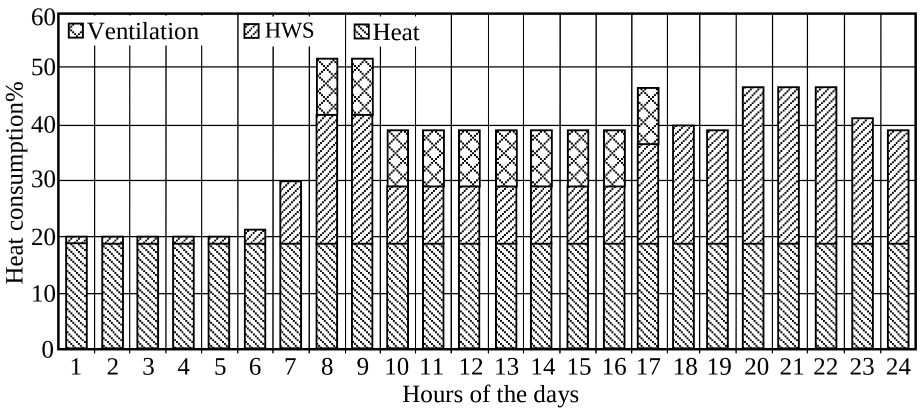

Fig. 7. Diagram of heat consumption during the day by houses of different types of purpose when using the regular heating mode and complying with the requirements for thermal modernization of buildings

The analysis of the results allows us to determine that the maximum heat load, relative to the primary one, is slightly more than 50 %. At the same time, a reduction of up to 40 % is possible if heat accumulators are used in central heating points (or in individual heating points), which will accumulate heat at night and compensate for peaks during working and evening hours.

Such a reduction of the maximum heat load on heat supply systems allows to reduce the power of the heat source and reduce capital costs for equipment and materials of heat networks. The specified approach must be adapted to specific tasks, taking into account local conditions (number of different types of buildings and modes of their operation).

Conclusions

Based on the results of the work, the following conclusions can be drawn:

– The study of heat consumption regimes and their generalization made it possible to identify opportunities for reducing heat consumption by buildings of various types of purpose, including when applying a two-period heating regime and thermal modernization of the building in accordance with existing norms;

– The results of simulation of heat supply regimes by buildings of different types of purpose and the study of their mutual influence on the system of centralized heat supply of residential areas show the possibility of significantly reducing the maximum power of the heat source (up to 50 %) and significantly saving costs for the main equipment and materials of heat networks;

– When modernizing the heat supply system, it is necessary to take into account the modes of operation of buildings of different types of purpose, their influence on the operation of the centralized heat supply system, to apply a two-period mode of operation of the heating system in buildings, to conduct calculations for the heat supply system in accordance with the current norms of thermal modernization, and to use heat accumulators in heat points to smooth out peaks thermal load.

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