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H. Balasanian, DSc, Prof.,
V. Liashenko
Odessa Polytechnic National University, Shevchenko Ave. 1, Odesa, Ukraine, 65044, e-mail: balasanyan@op.edu.ua

PRIORITY REGULATION OF HEAT SUPPLY SYSTEMS TAKING INTO ACCOUNT HYDRAULIC BALANCING

Г. Баласанян, В. Ляшенко. **Пріоритетне регулювання систем теплопостачання з урахуванням гідравлічного балансування.** Сучасні системи централізованого теплопостачання в Україні опинилися в умовах, коли дефіцит енергоресурсів перестав бути теоретичною загрозою і набув статусу постійного обмежувального фактора. Запропоновано інтегровану методику регулювання міських систем теплопостачання, що поєднує гідравлічне балансування та алгоритми пріоритетного розподілу теплової енергії. Практичну апробацію проведено на прикладі центрального теплового пункту (ЦТП-27) у місті Чорноморськ, запропонований алгоритм знижує ризики відключень критичних споживачів, оптимізує роботу котелень і теплових пунктів та формує прозорий механізм розподілу тепла. Виконано побудову п’єзометричних графіків, розрахунок сумарних опорів та визначення коефіцієнтів топології, що дозволило ідентифікувати найбільш уразливих з точки зору гідравліки споживачів. Подальший тепловий розрахунок враховував класи споживачів (A–E), сценарії дефіциту (0…30%) та модератор навантаження, який гарантує захист малих об’єктів від витіснення великими. Даний підхід формує так званий «подвійний баланс»: гідравлічний блок забезпечує технічну подачу теплоносія, тоді як тепловий блок створює справедливий і прозорий розподіл ресурсів відповідно до соціальної значущості об’єктів. Очікуваний ефект полягає у зменшенні ризику відключень критичної інфраструктури, підвищенні ефективності роботи котелень і теплових пунктів та зниженні соціальної напруги в умовах дефіциту газу. Наведена модель базується на припущенні постійних параметрів трубопроводів та стабільного складу споживачів, тому в умовах різких змін навантаження або модернізації мережі потрібне коригування розрахунків. Подальші роботи можуть включати прогнозування добового чи сезонного попиту та розробку методів автоматичного настроювання балансувальних клапанів за даними систем, прогнозних моделей і регуляторів.
Ключові слова: теплопостачання, гідравлічний баланс, дефіцит газу, пріоритетний розподіл тепла, п’єзометричний графік, енергетична безпека

H. Balasanian, V. Liashenko. **Priority regulation of heat supply systems taking into account hydraulic balancing**. Modern centralized heat supply systems in Ukraine find themselves in a situation where energy deficits are no longer a theoretical threat but have become a permanent limiting factor. An integrated methodology for regulating urban heat supply systems is proposed, combining hydraulic balancing and algorithms for the priority distribution of thermal energy. Practical testing was carried out using the example of the central heating station (CHS-27) in the city of Chornomorsk. The proposed algorithm reduces the risk of critical consumers being cut off, optimizes the operation of boiler rooms and heating stations, and creates a transparent heat distribution mechanism. Piezometric graphs were constructed, total resistance was calculated, and topology coefficients were determined, which made it possible to identify the most vulnerable consumers in terms of hydraulics. Further thermal calculations took into account consumer classes (A–E), deficit scenarios (0…30%), and a load moderator that guarantees the protection of small objects from being displaced by large ones. This approach creates a so-called “double balance”: the hydraulic block ensures the technical supply of heat carrier, while the thermal block creates a fair and transparent distribution of resources in accordance with the social significance of the facilities. The expected effect is to reduce the risk of critical infrastructure shutdowns, increase the efficiency of boiler rooms and heat distribution points, and reduce social tensions in conditions of gas deficits. The model is based on the assumption of constant pipeline parameters and a stable consumer base, so adjustments to the calculations are needed in the event of sudden changes in load or network modernization. Further work may include forecasting daily or seasonal demand and developing methods for automatically adjusting balancing valves based on system data, forecast models, and regulators.
Keywords: heat supply, hydraulic balance, gas deficit, priority heat distribution, piezometric graph, energy security

Introduction

Modern centralized heat supply systems in Ukraine find themselves in a situation where energy deficits are no longer a theoretical threat but have become a permanent limiting factor [1, 2]. Resolution No. 812 of the Cabinet of Ministers of Ukraine dated July 19, 2022, established a 10% reduction in guaranteed natural gas volumes for heat and power companies compared to previous seasons. This decision was a key signal for the transition from static heat network management to adaptive distribution models focused on the rational use of scarce resources.

Article [3] laid out the conceptual principles of priority regulation of heat supply based on consumer classification, weighting coefficients, and scenario analysis. However, the question of their practical coordination with the actual hydraulic parameters of the networks remained open. It is pre-

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cisely the hydraulic imbalance – pressure losses, differences in height and length of routes – that determines the maximum performance of the system and often makes it impossible to implement even an optimally designed thermal algorithm.

Analysis of literature data and problem statement

The issue of regulating urban heat supply systems is considered in a significant number of works. Researchers emphasize that traditional methods of manual or static network balancing have limited effectiveness in modern conditions: they do not take into account dynamic load fluctuations, daily and seasonal changes in demand, as well as unevenness in supplying different consumer groups [4]. At the same time, regulatory documents, in particular, oblige heat and power companies to reduce guaranteed volumes of natural gas, which requires operators to have more flexible and adaptive resource management schemes.

A separate block of research is devoted to the hydraulic balancing of pipelines. The work of Kulik, Baran, and Kondratyuk proves that hydraulic imbalance is the source of significant energy losses [5, 6]. To eliminate flow unevenness, it is proposed to install automatic balancing valves (for example, Danfoss AFQMP and AME/AMEi actuators) [7, 8]. Properly performed hydraulic balancing not only ensures an even supply of heat carrier to all consumers, but also reduces energy consumption in the system by 15…20% [7]. Some authors introduce topological coefficients that adjust calculations to take into account the length of routes and the height of buildings, but the further integration of these factors into heat distribution procedures remains limited.

Another area of research concerns the priority regulation of thermal loads. A number of studies propose algorithms that take into account the social significance of objects, distributing resources between groups A–E according to their criticality. Such approaches make it possible to protect hospitals, schools, and housing from deficits, but they are most often considered in isolation from the hydraulic properties of the network. Hydraulic constraints (pipes, pressure losses, building height) are not integrated into these algorithms, which complicates their practical application.

Current work on the digitization of heating networks describes the concept of Smart Heat Networks [9]. The authors emphasize the role of SCADA systems, predictive models, and regulators that allow real-time data collection and automatic adjustment of boiler operation. At the same time, in most publications, the digital aspect is reduced to the "thermal" side of the problem – demand forecasting and supply optimization – while hydraulics (network topology, pressure losses) is considered only as a background condition. The lack of synthesis between digital and hydraulic tools limits the effectiveness of such systems.

Thus, there is a "gap" in the literature between the theory of hydraulic balancing and the practice of priority heat distribution. Existing approaches focus either on the physical stabilization of the network or on the social aspect of distribution, but rarely combine these two dimensions. Bridging this gap and forming a "double balance" (hydraulic and thermal) is the basis of this research.

The current state of urban heat supply systems in Ukraine is characterized by a number of critical problems. The most important of these is the high dependence on imported natural gas, which, in conditions of martial law and economic instability, creates real risks of disruption to uninterrupted heat supply [10, 11].

Purpose and objectives of the study

The purpose of the study is to develop and test a methodology for priority regulation of heat supply that takes into account both the hydraulic parameters of the network and the socio-economic significance of different categories of consumers.

To achieve this goal, the following tasks must be solved:

– perform hydraulic calculations and construct a piezometric profile of consumers;

– develop a heat balancing algorithm that takes into account deficit scenarios;

– ensure minimum regulatory levels of heat supply for critical facilities;

– test the effectiveness of the methodology using the example of CHS-27 in the city of Chornomorsk.

Thus, the study aims to create a universal approach that can combine the technical and social aspects of heat network management.

Research materials and methods

Methodology for hydraulic balancing and priority regulation of heat supply. This stage includes the collection of topographical data, pipe characteristics, and consumer heat loads. Using offi-

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cial heat network maps and *Google Earth Pro* tools, the lengths of pipelines, geodetic marks, and the height of buildings were determined. A catalog of consumers was compiled, indicating their heat capacities, which was later used to classify objects according to their criticality.

The parameters below (the longest route from CHS-27 to the building at 8A ZAKHYSNYKIV UKRAINY Street, its height, and elevation marks) are an example of such an inventory and illustrate how the initial data is used in further calculations.

Before performing a hydraulic calculation, it is necessary to collect certain input data, namely to determine the lengths of individual sections of the pipeline. For this purpose, official maps of the heating networks of Chornomorsk (Fig. 1) with the relevant information were used. Based on these maps, the longest route from CHS-27 to the residential building at 8A ZAKHYSNYKIV UKRAINY Street was determined, with a total length of 548.5 m. Although this facility is the most remote, the distance parameter alone does not determine the criticality of the consumer in terms of pressure supply. To clarify the geodetic characteristics of the route, *Google Earth Pro* was additionally used. Relief marks were sequentially recorded, and the heights of buildings were determined based on their number of floors. As a result, at the address 8A ZAKHYSNYKIV UKRAINY, the tallest nine-story residential building with an approximate height of about 27 m was identified, in contrast to other five-story consumers with a height of about 15 m. The maximum relief difference along the route does not exceed 5 m, which confirmed the relative flatness of the terrain.

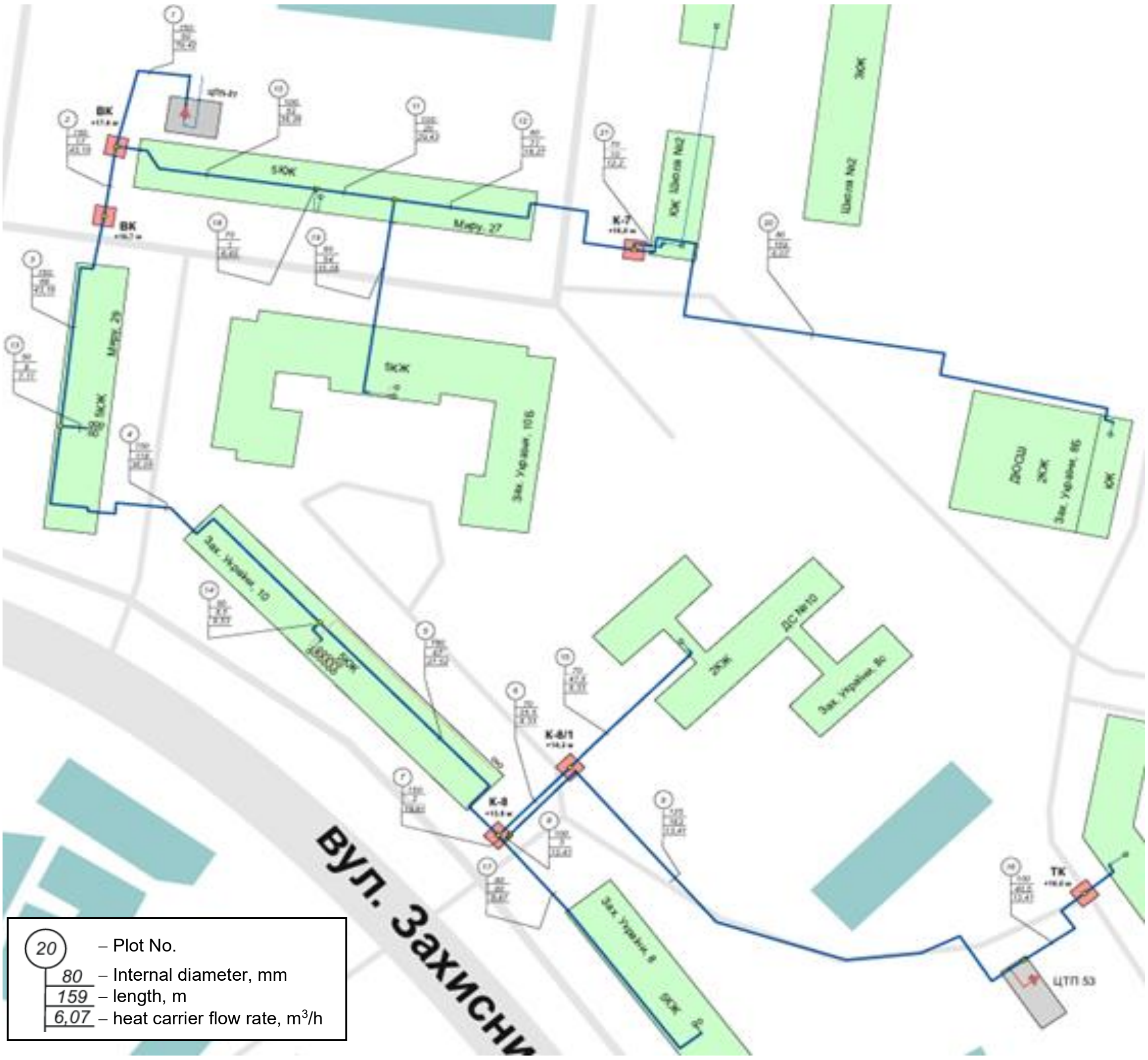

Fig. 1. Map of heating networks from the central heating station 27 m. Chornomorsk

Hydraulic calculation method. The hydraulic calculation was performed in several stages. After determining the lengths of the routes and the heights of the buildings, the volumetric heat carrier flow rate was calculated for each branch. Based on this data, the average flow velocity, Reynolds number, and friction coefficient were calculated, followed by linear and local head losses. The total resistance of each route takes into account the geodetic mark, the height of the building, and the additional pressure reserve for consumers. Based on the values obtained, the most “difficult” objects in terms of hydraulics were identified and piezometric graphs were constructed.

The highest hydraulic losses were obtained for the building at ZAKHYSNYKIV UKRAINY 8B, where the total resistance was 12.4 m water column. The final selection of the “heaviest” consumer, was made on the basis of hydraulic resistance calculated taking into account all pressure losses. The facility at ZAKHISNYKIV UKRAINY 8A was taken as the basis for constructing a piezometric graph, as it combines real geodetic conditions with maximum head losses, determining the maximum performance of the system.

Standard dependencies were used to perform the hydraulic analysis, which allow determining the speed of the coolant, specific and total head losses for each section. The calculated data are shown in Table 1.

Table 1

Hydraulic calculation of pipeline sections for first Quarter 1

Sections	Inner diameter of the pipeline, mm	Section lengt, m	Coolant flow rate, m³/h	Coolant velocity, m/s	Roughness coefficient, mm	Specific linear losses, m w.c./m	Linear losses on the section, m w.c.	Number of local hydraulic resistances on the section and their type										Sum of hydraulic resistance coefficients, Σξ	Local losses, m w.c.	Sum of linear and local losses,	Coolant pressure losses at the end of the section starting from the inlet node, m w.c.
								Valve	Narrowing	Widening	Tee for passage	Tee for branch	Crosspiece for passage	Crosspiece for branching	Turn 30°	Turn 60°	Turn 90°				
1	150	50	79.42	1.249	2	0.020	1.984	1	0	0	0	0	0	0	0	0	2	2.5	0.199	2.182	2.182
2	150	17	43.16	0.679	2	0.006	0.199	1	0	0	1	0	0	0	0	0	0	1.5	0.035	0.234	2.417
3	150	68	43.16	0.679	2	0.006	0.797	0	0	0	0	0	0	0	0	0	2	2.0	0.047	0.844	3.261
4	150	118	36.05	0.567	2	0.004	0.964	0	0	0	1	0	0	0	1	0	7	8.5	0.139	1.104	4.364
5	150	87	27.52	0.433	2	0.002	0.414	0	0	0	1	0	0	0	0	0	2	3.0	0.029	0.443	4.807
6	70	25.5	8.33	0.602	2	0.012	0.609	1	2	0	0	1	0	0	0	0	0	2.2	0.041	0.649	5.457
7	150	2	19.18	0.302	2	0.001	0.005	0	0	0	1	0	0	0	0	0	0	1.0	0.005	0.009	4.816
8	100	3	13.41	0.474	2	0.005	0.028	1	2	0	0	1	0	0	0	0	0	2.2	0.025	0.054	4.870
9	125	163	13.41	0.304	2	0.001	0.480	1	0	1	0	0	0	0	3	0	3	5.5	0.026	0.506	5.376
10	100	52	36.26	1.283	2	0.035	3.614	1	2	0	0	1	0	0	2	0	0	3.2	0.269	3.882	6.065
11	100	20	29.43	1.041	2	0.023	0.916	0	0	0	1	0	0	0	0	0	0	1.0	0.055	0.971	7.036
12	80	71	18.27	1.010	2	0.028	4.040	1	1	0	1	0	0	0	0	0	4	5.6	0.291	4.332	11.367
13	50	8	7.11	1.007	2	0.051	0.814	1	3	0	0	1	0	0	0	0	0	2.3	0.119	0.933	4.194
14	50	8.5	8.53	1.207	2	0.073	1.244	2	3	0	0	1	0	0	0	0	2	4.8	0.357	1.601	5.965
15	70	47.5	8.33	0.602	2	0.012	1.134	1	0	0	0	0	0	0	0	0	1	1.5	0.028	1.162	6.618
16	100	40.5	13.41	0.474	2	0.005	0.385	2	1	0	0	0	0	0	0	0	4	5.1	0.058	0.443	5.819
17	80	80	5.78	0.320	2	0.003	0.456	1	2	0	1	0	0	0	0	0	2	3.7	0.019	0.475	5.291
18	70	1	6.83	0.493	2	0.008	0.016	1	1	0	0	1	0	0	0	0	0	2.1	0.026	0.042	6.107
19	80	54	11.16	0.617	2	0.011	1.148	2	1	0	0	1	0	0	0	0	1	3.6	0.070	1.218	8.253
20	80	159	6.07	0.335	2	0.003	0.998	1	1	0	1	0	0	0	0	0	9	10.6	0.061	1.059	12.426
21	70	10	12.20	0.881	2	0.026	0.512	2	1	0	0	1	0	0	0	0	3	5.6	0.222	0.733	12.101

Coolant flow rate:

$$Q_i = \frac{G_i}{\rho}, \tag{1}$$

where:

G_i is the mass flow rate, kg/s;

ρ is the density of water, kg/m³.

In practical calculations in Excel, the volumetric flow rates Q_i in m³/h, shown in Fig. 1, are used directly.

Average speed of coolant flow in the pipe:

$$v = \frac{4Q}{\pi d^2}, \tag{2}$$

where: d is the inner diameter of the pipeline.

Reynolds number for flow regime assessment:

$$\mathrm{Re} = \frac{vd}{\nu}, \tag{3}$$

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where: ν is the kinematic viscosity of water, m²/s.

Hydraulic friction coefficient (according to Altshul's formula):

$$\lambda = 0.11\left(\frac{k}{d}+\frac{68}{\mathrm{Re}}\right)^{0.25}, \tag{4}$$

where: k is the equivalent roughness of the pipe wall, m.

Linear resistance of the section:

$$r_{\mathrm{lin}} = \lambda\frac{L}{d}\times\frac{v^2}{2g}, \tag{5}$$

where: L is the length of the section.

Losses at local supports:

$$r_{\mathrm{loc}} = \sum \xi_j \times \frac{v^2}{2g}, \tag{6}$$

where: ξ_j – local resistance coefficients (valves, tees, constrictions/expansions).

Total head losses in the section:

$$R_{\mathrm{seg}} = \sum (r_{\mathrm{lin}} + r_{\mathrm{loc}}). \tag{7}$$

Equivalent head:

$$H_{\mathrm{eq},i} = h_{\mathrm{geo},i} + h_{\mathrm{build},i} + R_{\mathrm{loc},i}, \tag{8}$$

where:

$h_{\mathrm{geo},i}$ is the geodetic elevation, m;

$h_{\mathrm{build},i}$ is the height of the building, m;

$R_{\mathrm{loc},i}$ is the consumer resistance, taking into account the additional pressure of 5 m water column.

Total resistance:

$$R_{\mathrm{path},i} = \sum R_{\mathrm{seg}} + H_{\mathrm{eq},i}, \tag{9}$$

where: $\sum R_{\mathrm{seg}}$ – sum of hydraulic resistances of the entire pipeline to consumer i, m water column.

The values obtained allow us to determine the most distant and “heaviest” objects in terms of hydraulics. However, in order to adequately take these differences into account in further balancing, the topology coefficient [5] is introduced:

$$K_{\mathrm{topo},i} = 1 + \beta\times\frac{R_{\mathrm{path},i} - R_{\min}}{R_{\max} - R_{\min}}, \tag{10}$$

where:

$R_{\min}$, $R_{\max}$ – the minimum and maximum values of the total resistance among all consumers;

β – the coefficient of variation of resistance [16]:

$$\beta = \frac{\sigma(R)}{\mu(R)}, \tag{11}$$

where:

$\sigma(R)$ is the root mean square deviation;

$\mu(R)$ is the average value of the total resistance.

This coefficient acts as a corrector that converts hydraulic parameters into a dimensionless form that can be conveniently integrated into further analysis. Its purpose is to emphasize the influence of network topology on the availability of the heat carrier: the greater the resistance of the consumer, the more vulnerable it is to hydraulic deficits. Thus, $K_{\mathrm{topo},i}$ ensures fair consideration of the spatial location of consumers in the system and allows the stages to be divided: first, hydraulic stabilization, and then thermal regulation according to priorities. As a result, calculated data were obtained with the determination of the coefficient $K_{\text{topo},i}$ for each consumer (Table 2).

Table 2

Hydraulic calculation for each consumer

№	Address	Hydraulic resistance, m w.c	Volume flow rate, m^3/h	Absolute elevation, h_{geo}, m	Number of floors	Building height, h_{build},	Consumer pressure, H, m	Total resistance, R_{path}, m w.c	K_{topo}
1	Zakhysnykiv Ukrainy str., 10	7.97	8.53	16	5	15	16	23.97	1.044
2	Zakhysnykiv Ukrainy str., 10-Б	10.25	11.16	17	5	15	17	27.25	1.077
3	Zakhysnykiv Ukrainy str., 8	7.29	5.78	15	5	15	15	22.29	1.027
4	Zakhysnykiv Ukrainy str., 8-A	7.82	13.41	18	9	27	30	37.82	1.183
5	Zakhysnykiv Ukrainy str., 8-6 (Comprehensive children's and youth sports school)	14.43	6.07	18	3	9	12	26.43	1.069
6	Zakhysnykiv Ukrainy str.8-C (preschool educational institution)	8.62	8.33	20	2	6	11	19.62	1.000
7	Mury Av. (Chornomorskoho kozatstva) 17-A	14.10	12.20	20	3	9	14	28.10	1.085
8	Mury Av. 27 (Chornomorskoho kozatstva)	8.11	6.83	18	5	15	18	26.11	1.065
9	Mury Av.29 (Chornomorskoho kozatstva)	6.19	7.11	18	5	15	18	24.19	1.046

Priority heat supply regulation. The priority regulation algorithm combines the social classification of consumers with mathematical methods of heat load correction. First, all heating network objects are classified into groups A–E according to their criticality (hospitals, schools, housing stock, offices, industry, etc.). For each consumer, the calculated thermal load, the minimum guaranteed level of heat supply, and the weight coefficient are determined. In the event of a resource deficit, a load moderator is applied to the distribution, which increases the supply to small facilities and limits large ones. After normalizing this value, "base" supply coefficients are determined, which are adjusted by a scaling factor so that the total heat supplied corresponds to the given deficit scenario. At the final stage, the supply coefficient is calculated for each consumer, which ensures a balance between supplying critical facilities and saving resources.

Publication [3] presented general principles for constructing an algorithm for the priority distribution of thermal energy in conditions of energy resource deficits. In particular, it considered the classification of consumers into groups A–E, the determination of weighting coefficients, and minimum heat supply levels for each category. Basic provisions for a scenario-based approach (0…30% deficit) were also formulated, allowing the behavior of the system to be described under various resource constraints.

In this work, the methodology is further developed. While the main focus was on the conceptual part – justifying the need for priority regulation and describing its basic mechanisms – this paper considers a detailed heat calculation. It includes the introduction of a load moderator, normalization procedures, and the determination of the final heat supply coefficient for each consumer. Particular emphasis is placed on the relationship between the thermal unit and hydraulic constraints, which allows for the creation of a more realistic and applicable model for practical testing using the example of CHS-27 in the city of Chornomorsk.

To take into account the load characteristics of individual consumers, a load moderator is introduced L_i . Its action is activated only in conditions of heat energy deficit:

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$$L_i = \begin{cases} 1; & Def = 0; \\ \left(\dfrac{Q_{\text{ref}}}{Q_i}\right)^{\gamma}, & Def < 1, \end{cases} \quad (12)$$

where: Q_i – is the calculated thermal load of the consumer, Q_{ref} is the reference thermal load (average for a group of consumers), γ is the sensitivity coefficient.

This expression ensures that in the absence of a deficit ($Def = 0$), the heat supply is equal to the calculated value, while in the case of limited resources, small consumers receive a relative "boost" and large consumers receive a restriction:

$$\gamma = \frac{\sigma(Q)}{\mu(Q)}, \quad (13)$$

where:

$\sigma(Q)$ is the standard deviation of heat loads,

$\mu(Q)$ is the arithmetic mean of heat loads.

Thus, γ reflects the degree of heat load dispersion: in systems with almost identical buildings (Q_i close) – γ is small, the correction is minimal; in systems with a wide range of loads (for example, a kindergarten with 200 kW and a factory with 2000 kW) – γ is higher, the correction is stronger.

Further normalization ensures that moderators are brought to a single scale:

$$N_i = \frac{L_i}{\max(L_j)}, \quad (14)$$

where the maximum value determines the highest priority consumer, and the rest are scaled proportionally.

Next, an intermediate "base" heat supply coefficient is determined for the consumer, taking into account the deficit, normalization, and minimum levels:

$$K_{\text{raw},i} = \max(K_{\text{def},i} \times N_i;\ K_{\min,i}). \quad (15)$$

Calculation of the initial amount:

$$Q_{\text{sum}} = \sum K_{\text{raw},i} \times Q_{\text{design},i}. \quad (16)$$

Determination of the target value:

$$Q_{\text{target}} = (1 - Def) \times \sum Q_{\text{design},i}. \quad (17)$$

Scaling factor:

$$K_{\text{scale}} = \frac{Q_{\text{target}}}{Q_{\text{sum}}}. \quad (18)$$

The final heat supply coefficient is determined as:

$$K_{\text{final},i} = \min(1, \max(K_{\min,i}, K_{\text{raw},i} K_{\text{scale}})). \quad (19)$$

Thus, in normal mode, all consumers receive the design loads, and in conditions of deficit, a priority distribution of resources is formed, taking into account the minimum guaranteed levels.

Adding normalization by sum allowed us to eliminate a systemic error: in case of a high deficit, the total heat decreased more than was specified in the scenario. The new scheme ensures that the total heat distributed is always equal to $(1 - Def) \times \Sigma Q_{\text{design},i}$, while maintaining the priority logic.

The final amount of heat supplied to each consumer is determined by the expression:

$$Q_{\text{deliv},i} = K_{\text{final},i} \times Q_{\text{design},i}. \quad (20)$$

During the development of the methodology, the following decisions were made:

– it is advisable to implement the coefficient (K_{time}) not in calculations, but at the SCADA level for controlling electric drives;

– the coefficient (K_{topo}) was moved to the hydraulic block, as it created a conflict with the heat balance.

This emphasizes the importance of achieving hydraulic stabilization before regulating heat distribution.

A key part of the methodology is the analysis of system behavior under various deficit scenarios. Four scenarios were considered to model the operation of the heating network: no deficit (0% deficit), moderate deficit (10%), medium deficit (20%), and significant deficit (30%). In each scenario, the final supply coefficients $K_{\text{final},i}$ and heat release coefficients $Q_{\text{deliv},i}$ were calculated for all consumer groups. It was shown that the algorithm maintains design loads in normal mode, and in case of a deficit, redistributes the resource so that consumers in classes A–C receive the maximum necessary heat, and restrictions fall mainly on categories D–E. This allows us to quantitatively assess the impact of the deficit on each group and identify the limits beyond which the resource no longer guarantees coverage of minimum needs.

In addition to numerical analysis, the technical implementation of the methodology is an important component. To implement priority regulation in practice, the following are required:

– automatic balancing valves with flow regulators suitable for maintaining hydraulic balance in real time;

– electrically driven actuators to change the position of the valves according to the control system commands;

– a SCADA system or similar monitoring platform that collects data on temperatures, pressures, and flows and generates control actions;

– regular updates of reference information on the condition of pipelines, heat loads, and changes in the composition of consumers.

Synchronization of these components ensures not only an automatic response to deficits, but also the ability to proactively predict situations, particularly during seasonal consumption peaks. This implementation also complies with European energy efficiency requirements and contributes to the fulfillment of national standards.

Research results

Hydraulic calculations for nine consumers connected to CHS-27 in the city of Chornomorsk showed significant differences in the values of total resistance and equivalent pressure. The most “difficult” consumers were the buildings at 8B and 8A Zakhysnykiv Ukrainy Street. For the latter, the critical factors were its greatest distance (~550 m) and the presence of nine floors, which determined it as a critical object from a hydraulic point of view.

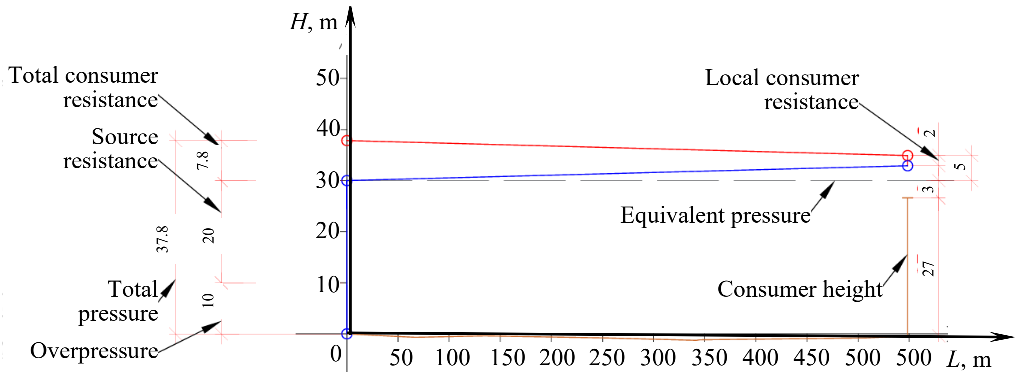

Fig. 2. Piezoelectric graph of the network to the consumer at 8-A Zakhysnykiv Ukrainy Street

Piezometric analysis revealed potential areas of pressure deficiency on the upper floors of this building. This confirms the need to install automatic balancing valves [9] and to take into account the topology coefficient (K_{topo}) in further iterations of regulation (Fig. 2).

With regard to heat regulation, in the base scenario (0%), all consumers receive the design heat loads, which confirms the correctness of the hydraulic and thermal calculations. When the resource is reduced (10…30%), the algorithm forms a priority distribution: critical consumers (classes A–C: hos-

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pitals, schools, housing stock) maintain the necessary level of heat supply, while less significant categories (classes D–E: offices, commercial consumers, industry) receive proportionally smaller volumes.

The load moderator played an important role, preventing the dominance of large consumers with low priority and ensuring fair distribution even for small facilities.

Figure 3 shows the distribution of heat supply between actual and theoretical consumers of CHS-27 in scenarios with a deficit of 0%, 10%, and 30%. It can be seen that classes D and E, "Theoretical consumers", have a significantly greater reduction in heat supply-they are the ones that "absorb" the main reductions, thus emphasizing that the algorithm deliberately "protects" priority categories by redistributing the deficit toward less important ones.

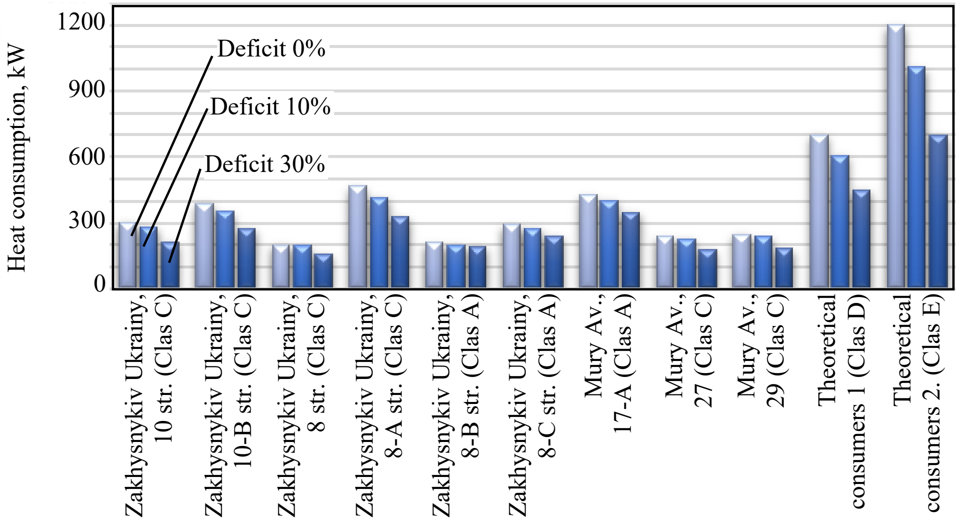

Fig. 3. Diagram of heat supply distribution by priority with theoretical consumers

This model is based on the assumption of constant pipe parameters and a stable consumer composition, so in conditions of sharp changes in load or network modernization, adjustments to the calculations are required. In addition, further work may include forecasting daily or seasonal demand and developing methods for automatically adjusting balancing valves based on SCADA data.

Testing of the methodology on the example of Chornomorsk confirmed its effectiveness. The use of the algorithm allows:

– minimize social risks and shutdowns of critical facilities;

– optimize the operation of boiler rooms and heating stations;

– transparently regulate heat distribution in conditions of deficit.

Wartime conditions and regulatory restrictions necessitate the implementation of such algorithms at the level of heat and power utilities. For practical implementation, it is necessary to use automatic balancing valves and SCADA systems that allow real-time control of the process.

Summarizing the results, it can be noted that hydraulic analysis made it possible to identify the most "heavy" consumers and confirm the need to install balancing valves and use a topological coefficient. The results of heat distribution demonstrate that the integrated algorithm guarantees an adequate level of heat supply for critical groups, which is in line with the principles of energy efficiency and social justice noted in [12, 13]. Comparing the obtained data with previous works, it can be concluded that the combination of hydraulic balance and priority control significantly increases the reliability of the system and allows reducing energy consumption by 15…20% [3, 7]. In addition, the proposed methodology meets regulatory requirements for reducing gas consumption [1] and is consistent with modern Smart Heat Networks concepts [9].

Conclusions

1. An integrated methodology for regulating urban heat supply systems is proposed, which combines hydraulic balancing and priority distribution of thermal energy.

2. The hydraulic unit provides the technical capability to supply heat transfer fluid to all consumers. The construction of piezometric profiles and the calculation of total resistance made it possible to identify the most "difficult" buildings that determine the maximum capacity of the system.

3. The thermal unit implements a priority balancing algorithm that takes into account consumer classes (A–E), deficit scenarios (0…30%), and load moderators. This guarantees that the necessary level of heat supply for critical infrastructure is maintained even in crisis conditions.

4. The proposed "double balance" allows combining the technical stability of the network with social justice in the distribution of heat resources, which is not provided by traditional static methods.

5. Testing of the methodology on the example of CHS-27 in Chornomorsk confirmed its effectiveness: the algorithm reduces the risks of critical consumer disconnections, optimizes the operation of boiler rooms and heat distribution points, and creates a transparent heat distribution mechanism.

6. The implementation of the methodology complies with the regulatory restrictions set out in Resolution No. 812 of the Cabinet of Ministers of Ukraine and can be implemented in practice by heat and power companies through the use of automatic balancing valves and SCADA systems.

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Баласанян Геннадій Альбертович; Hennadii Balasanian, ORCID: https://orcid.org/0000-0002-3689-7409
Ляшенко Владислав Ігоревич; Vladyslav Liashenko, ORCID: https://orcid.org/0009-0006-2546-0419

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