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EVALUATION OF THE INTERRELATION OF HYDRAULIC AND THERMAL RESISTANCE OF WATER HEATING SYSTEMS

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Abstract. The work is aimed at an analytical solution of the problem of establishing the relationship between hydraulic and thermal stability for both traditional multi-storey and modern automated water heating systems for high-rise buildings. From the results of the review of scientific, technical, regulatory literature and patent search, it follows that the data and recommendations obtained are not exhaustive and require further research related to the solution of theoretical and practical tasks of the problem under consideration. Therefore, further improvement of heating systems determines the need to solve new scientific and technical problems, the results of which can create a scientific and methodological basis for improving the hydraulic and thermal stability, energy and overall efficiency of automated heating systems for multi-storey and high-rise buildings.

The result of the work was an analytical solution of the problem with the establishment of the regularity of the relationship between general hydraulic and thermal processes in the heating systems of high-rise buildings in order to analyze the conditions for a possible increase in their energy-technological efficiency. With quantitative and qualitative regulation of the thermal power of the systems, taking into account the change in the gravitational component, the actual pressure losses are compared with the drop for the options under consideration. The thermal power of heating systems was presented as the total heat flow from all heating devices, with the "lower" and "intermediate" location of the heat source. A new dependence is obtained by means of an irrational equation, which establishes an analytical relationship between the processes of thermal and hydraulic stability. It is shown that a new technical solution with an intermediate placement of a heat source along the height of the building minimizes the gravitational pressure during the operation of the heating system, as a result of which its vertical hydraulic stability increases, and, accordingly, the variable part of the excess pressure on the automation means decreases.

Key words: water heating systems, heat source, placement level, devices, hydraulic stability, thermal stability.

Introduction. In most European countries, more than 30-35% of the total consumption of fuel and energy resources is spent on heating buildings. Numerous studies have shown that the current potential for energy savings in Ukraine at the current level of heat supply of buildings reaches 50-60%. Therefore, the current state of the heat industry makes it urgent to find additional ways to significantly improve energy efficiency and quality of heat supply with a decrease in its unit cost.

Analysis of recent research and publications. The theoretical basis for the further advancement of the heat-hydraulic stability of water scorching systems, which is directly related to their energy efficiency and efficiency, was seen in the works of many domestic and foreign authors [1-3], which, in fact, laid the foundation for the theoretical construction of such a structure. However, the results of a long-term view of the scientific and technical, regulatory literature and patent literature are evidently obvious, that the withdrawal of data and recommendations will require further investigation, in relation to the theoretical and practical challenges of the problem. Therefore, further improvement of heating systems determines the need to solve new scientific and technical problems, the results of which can create a scientific and methodological basis for their practical application based on research results. Thus, the relevance and direction of this work are aimed at determining the conditions for improving hydraulic and thermal stability, energy and overall efficiency of automated heating systems of multi-storey and high-rise buildings [3-5].

Known water heating systems usually have a lower location of the intermediate heat exchanger or heat generator on the height of buildings, both central and local heating. The pressure drop in the system is determined by the variable value of the pump and gravitational components in ensuring the required circulation of the coolant. It is characteristic that the gravitational component of pressure in modern automated heating systems of buildings with a height of 5 to 25 floors reaches 25-45% [1, 3, 6]. Both the lower and upper location of the heat source ("roof" boiler room), which has become widespread in recent years, have their drawbacks. They relate primarily to the gravitational pressure, which coincides with or is opposite in action to the pump pressure.

It is characteristic that the increase of thermohydraulic stability of heating systems due to thermoregulatory means, including control valves with heating devices with high hydraulic resistance, as well as automatic pressure relief devices at the base of risers and mains, is largely unjustified, because they themselves bring a very significant additional hydraulic resistance. As a result, the hydraulic resistance of modern automated systems has increased 2-3 times over the past 20 years, and the unit cost of automation has reached 15-20% of the total cost of heating systems, but the payback period has decreased.

It is logical that the placement of the heat generator at a certain level in the height of the building [5, 7], can eliminate the action of the main factor of vertical hydraulic adjustment, which minimizes the resulting gravitational pressure in the circulation circuit of the pump heating system. At the same time, the energy and economic feasibility of using the formed systems with the "middle laying" of distribution and prefabricated mains, which are located at the level of the heat generator, is obvious. In most cases, the device of such systems may be more desirable in comparison with traditional systems with upper and lower location of the supply lines. In recent years, in foreign and domestic practice on energy-economic conditions and functional needs are justified technical solutions, providing for the arrangement of technical floors for the placement of elements of engineering systems, both in high-rise buildings and in buildings of high storeys [4, 8]. Thus increase of thermohydraulic stability of heating systems with decrease in their cost on the above-stated basis is not considered.

It should be noted that for all reasons of hydraulic adjustment, the change in the value of gravitational pressure is the most significant factor with the corresponding negative consequences characteristic of each type of heating system [9]. The main reason for both initial and operational regulation of heating systems is, first of all, the influence of natural pressures on water distribution, so to reduce its consumption should reduce the share of natural pressure difference in the total differential pressure difference.

In [7, 9] the approach to improvement of systems of water heating of high-rise buildings on the basis of rational interrelation and interrelation of structural elements is stated, that allows to increase the general efficiency of work of corresponding systems by excluding negative influence of gravitational pressure reducing vertical thermohydraulic regulation. As a result, the uniformity and efficiency of heat transfer processes of all heating devices both in the design and in the operating modes of the systems increases. In addition, the intermediate device of the heat source determines the technical and economic feasibility of the appropriate placement of common highways of heating systems. At the same time, first, the length of supply and return mains is reduced, and also diameters of distribution and collecting pipelines decrease; second, the hydraulic resistance of the parallel connected sections of the upper and lower zones of the riser decreases, and as a result, the total hydraulic resistance of the whole system in comparison with the systems with the traditional placement of the heat source. At the same time, there is still no mathematically sound and acceptable for practice criterion of general assessment of hydraulic and thermal stability of water heating systems, which would adequately take into account the interrelated regime conditions for highly efficient operation in the process of their operational regulation.

The aim and objectives of the study. The aim of the work is an analytical study of the interconnected processes of hydraulic and thermal stability of automated water heating systems of high-rise buildings, aimed at further improving their thermal efficiency with reducing the corresponding material costs. To achieve this goal it is necessary to develop a mathematical model that summarizes the patterns of interconnected processes in ensuring hydraulic and thermal stability of water heating systems with the expansion of ideas about their further structural and functional improvement in ensuring optimal microclimatic conditions.

Material and methods of research. The paper uses a comprehensive research method, which includes: analysis of known theoretical and experimental works with a scientific generalization of the final results; computational-analytical and mathematical modeling, which is based on the classical equations of hydraulic and heat exchange processes, as well as a method of analytical solution of the problem. In accordance with the recommendations and requirements [1, 4-6] in the practice of engineering development of heating systems to ensure sufficient hydraulic stability it is recommended to take the pressure drop in the riser relative to the pressure drop in the calculated circulation circuit of at least 70%.

It is known [1, 3, 6] that the indicator of hydraulic stability *G* reflects the ratio of the actual consumption of coolant G_x to its calculated value G_c:

$$G = G_x / G_c \,. \tag{1}$$

The main condition for the hydraulic calculation of heating systems, which is associated with the selection of pipe diameters and determine the pressure drop in the relevant areas, is to compare the pressure drop with its actual value. In [7, 9] it is substantiated that in the heating system of a multi-storey building with intermediate placement of the heat exchanger at a rational level the effect of gravitational pressure is minimized in comparison with the similar one at the lower placement of the heat source. On this basis, under the conditions of quantitative and qualitative regulation of the thermal capacity of systems, taking into account the change in the gravitational component, we can compare the actual pressure loss with the difference for the analyzed options in the appropriate form:

$$S_{hs} G_c^2 = \Delta P_{pp}^c + \beta \Delta P_{gp}^c ; \tag{2}$$

$$S_{hs} G_x^2 = \Delta P_{pp}^c + \beta \Delta P_{gp}^x , \tag{2, a}$$

where S_{hs} – is the resistance characteristic of the heating system, Pa · s^2/kg^2;

G_c, G_x – coolant flow at the calculated and variable values, kg/s;

ΔP^c_{pp} – calculated pump pressure drop, Pa;

ΔP^c_{gp}, ΔP^x_{gp} – gravitational pressure of heating systems, respectively, at the lower and intermediate location of the heat exchanger, Pa;

β – is the coefficient of gravitational pressure.

On the basis of dependencies (1) and (2), (2, a), the hydraulic stability of the scorching systems can be presented in an offensive way:

$$G = \frac{G_x}{G_c} = \sqrt{\frac{\Delta P_{pp}^c + \Delta P_{gp}^x}{\Delta P_{pp}^c + \beta \Delta P_{gp}^c}} \,. \tag{1, a}$$

The intermediate distribution of the heat source in a multi-storey building allows minimizing the gravitational pressure in the heating system with piece circulation, at the link with which the fallowness (1, a) is observed:

$$G = \sqrt{\frac{\Delta P^{c}_{pp}}{\Delta P^{c}_{pp} + \beta \Delta P^{c}_{gp}}} = \sqrt{\frac{1}{1+\beta \frac{\Delta P^{c}_{gp}}{\Delta P^{c}_{pp}}}}. \qquad (1, b)$$

The established dependence of the hydraulic resistance index (1,b) is illustrated by the graph, shown in Fig. 1, which shows that the minimization of the gravitational pressure relative to the pump provides a corresponding increase in the hydraulic stability of heating system.

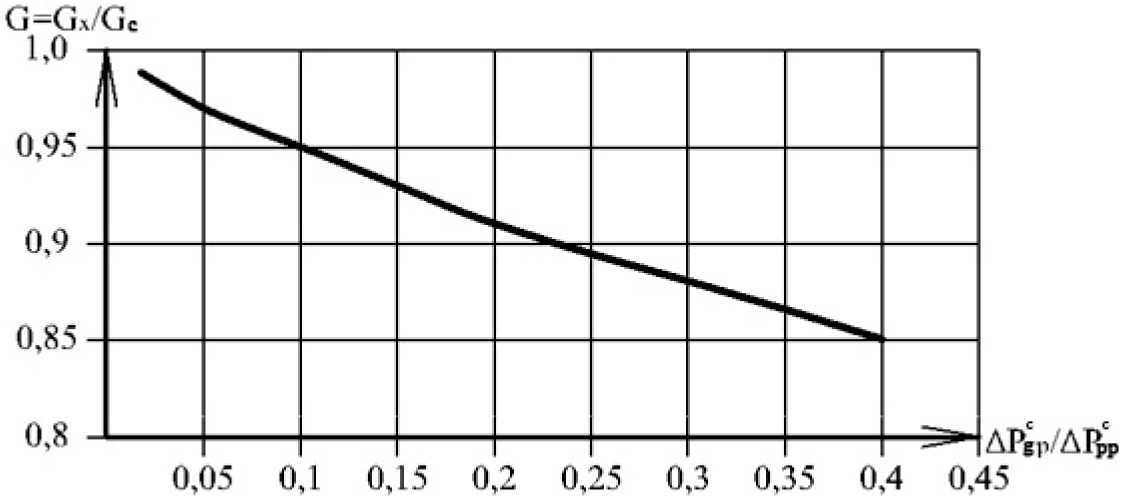

Fig. 1. The dependence of the hydraulic stability of the heating system of a multi-storey building on the ratio of gravitational and pumping components

It is known [1, 3, 6, 10] that an indicator of thermal stability T can be the ratio:

$$T = \frac{Q_X}{Q_c}, \qquad (3)$$

where Qx, Qc – heat capacity in the intermediate and lower location of the heat exchanger, W.

If the heat output of heating systems is presented as the total heat flux from all heating appliances, then for the compared options at the "lower" and "intermediate" location of the heat source can be written:

$$Q_c = \alpha A\,(t^{h}_{e} - \frac{Qc}{2cG_c} - t_r)^{1+m}; \qquad (4)$$

$$Q_X = \alpha A(t^{h}_{e} - \frac{Q_X}{2cG_X} - t_r)^{1+m}, \qquad (5)$$

where A – surface of scorch fittings, m^2;

α – constant heat transfer coefficient of the accessory;

t^{h}_{e} – is the heat transfer temperature at the entrance to the heating system, °C;

t_r – the temperature in the room, °C;

c – the average specific heat of the coolant, J/(kg · K);

m – step indicator at temperature pressure.

Representing the temperature difference of the coolant in the heating device in equations (4) and (5) at the lower location of the heat source in the form:

$$\frac{Q_X}{2cG_X} = \frac{\Delta t_r}{2},$$

and the corresponding value for the intermediate placement of the heat exchanger, taking into account the value $G = G_x / G_p$ and (3) in the form of:

$$\frac{Q_x}{2cG_x} = \frac{TQ_c}{2cG_cG} = \frac{\Delta t_r}{2}\frac{T}{G},$$

the dependence of the thermal stability on the hydraulic is expressed by an irrational equation (at m = 0.1 ... 0.5) of the following form:

$$T = \left[\frac{(t_h^e - t_r) - 0{,}5\Delta,_c \frac{T}{G}}{(t_h^e - t_r) - 0{,}5\Delta,_c}\right]^{1+m} \qquad (6)$$

In case of significant exchanges of water, the solution appears to be close at hand:

$$T = \frac{(t_h^e - t_r) - 0{,}5\Delta,_c}{(t_h^e - t_r) - 0{,}5\Delta,_c} \cdot x, \qquad (6, a)$$

where x – is one of the values of $x_{1,2}$ with modulus $| x_{1,2} | <1$, which is obtained using the corresponding Taylor series expansion, which takes place under the following restrictions:

$$x_{1,2} = \frac{1}{m(1+m)}\left[(k-1-m) \pm \sqrt{(k-1-m)^2 - 2m(1+m)}\right], \qquad (7)$$

in which the generalized parameter k is calculated from the original data:

$$k = -\frac{(t_h^e - t_r)\,\Gamma}{0{,}5\Delta,_c} \cdot \left(\frac{(t_h^e - t_r) - 0{,}5\Delta,_c}{(t_h^e - t_r)}\right)^{1+m}. \qquad (8)$$

Analysis of research results. The solution of the obtained equation (6) when combined with (1, b) is illustrated graphically in Fig. 2.

From the analysis of the presented graphical relationship it follows that the intermediate placement of the heat exchanger, which minimizes the gravitational pressure, provides an increase in hydraulic and thermal stability. The reduction of the gravitational component relative to the pump pressure from 30% to 5% increases, respectively, the hydraulic resistance by 10% (from 0.87 to 0.97) and thermal by 3.2% (from 0.96 to 0.99) in the system with the calculated temperature difference of the coolant (95–70) ° C.

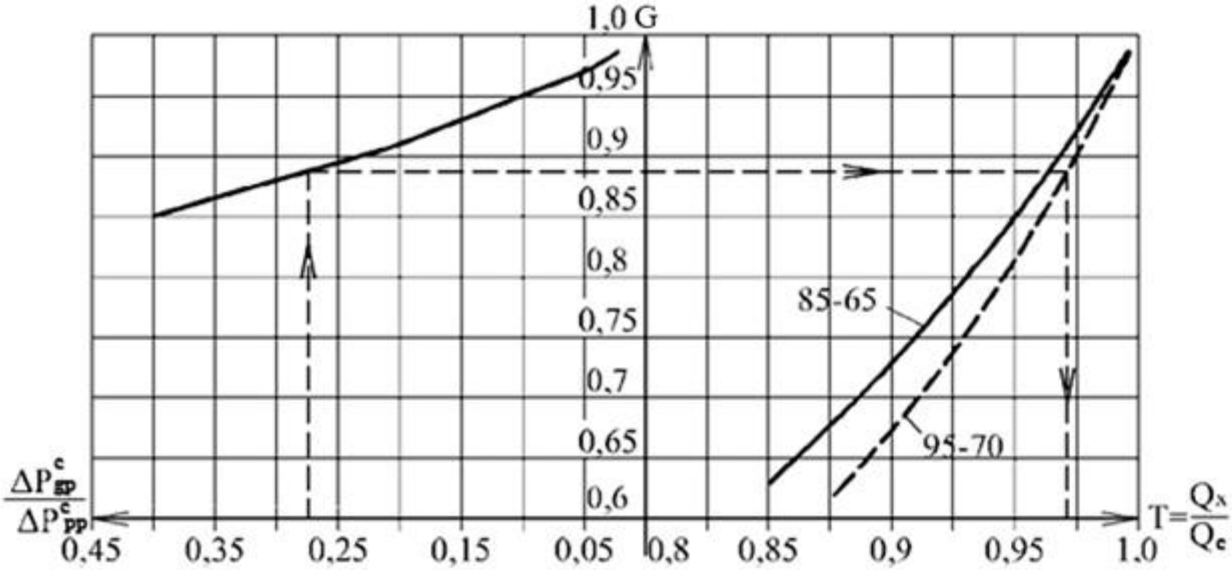

Fig. 2. Interrelation of indicators of thermal and hydraulic stability in heating systems of high-rise buildings

The scientific substantiation of improvement of an estimation of efficiency of high-rise buildings water heating systems on the basis of search of a rational level of intermediate placement of a heat source with the corresponding arrangement of mainlines has been received.

A new approach to the design and evaluation of improvement of water heating systems based on rational mutual arrangement and interconnection of structural elements is proposed, which allows to increase the overall efficiency of the systems by eliminating the negative influence of gravitational pressure, which reduces vertical heat and hydraulic regulation. As a result, the uniformity and efficiency of heat transfer processes of all devices, both in the design and in the operating mode of the systems.

Conclusions. Based on the results of the analytical study, a new dependence is obtained in the form of an irrational equation, which establishes the relationship between thermal and hydraulic stability. The new technical solution with intermediate placement of the heat source minimizes the gravitational pressure, which increases the vertical hydraulic stability of the system, and accordingly reduces the variable part of the excess pressure on the automation. The device of heating systems of high-rise buildings with intermediate placement of a heat source, minimizing gravitational pressure, increases hydraulic and thermal stability, and here reduces functional loading on means of automatic equipment and their cost.

References

[1] L.M. Mahov, *Otoplenie*. M.: ASV, 2014.

[2] G. Kraft. *Sistemy nizkotemperaturnogo otopleniya*:*perevod s nem.* Moskva: Stroiizdat, 1983.

[3] V.P. Turkin, *Vodianye systemy otopienya z avtomatycheskym upravlenyem dlia zhylykh i obshchestvennykh zdanyi*. M.: Strojyzdat, 1987.

[4] DBN V.2.5-67:2013. Opalennya, ventilyaciya ta kondiciyuvannya. Kyiv:Minrehionbud Ukrayiny, 2013.

[5] V.V. Pyrkov. *Osobennosti sovremennyh sistem vodyanogo otopleniya*. Kyiv: Takispravi, 2003.

[6] Adolf Myrovsky, Hzhehosh Lanhe,Ireneush Elen. *Materyaly dlia proektyvania kotelnykh i sovremennykh system otoplenya* .Polsha.: Izdanye 1. Vissmann, 2005.

[7] V.D. Petrash, D.V. Basist, "Sistema vodyanogo opalennya Petrasha V.D. z promizhnim rozmishchennyam teplogeneratora", Patent na vinakhid no. 97991. Byl 7, 2012, Derzhpatent, Ukraïna.

[8] DBN V.2.2-41:2019. Visotni budivli.Osnovni polozhennya. Kyiv: Minrehionbud Ukrayiny, 2019.

[9] V.D. Petrash, D.V. Basist, "Novyjpodhod k ustrojstvu sistem vodyanogo otopleniya s promezhutochnym razmeshcheniem istochnika teploty", *Naukovij visnik budivnictva*, vol. 60, pp.88-95, 2010.

[10] V.D. Petrash, V.P. Baryshev, L.F. Shevchenko, E.A. Geraskina, "Issledovanie energotekhnologicheskih parametrov v processah teplonasosnoj utilizacii teploty otrabotannyh gazov vrashchayushchihsya pechej", *Problemy Regional'no jenergetiki*, vol. 2(50), pp. 76-89, 2021. doi.org/10.52254/1857-0070.2021.2-50.07.

ОЦІНКА ВЗАЄМОЗВ'ЯЗКУ ГІДРАВЛІЧНОЇ ТА ТЕПЛОВОЇ СТІЙКОСТІ В СИСТЕМАХ ОПАЛЕННЯ ВИСОТНИХ БУДІВЕЛЬ

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Анотація. Робота спрямована на аналітичне вирішення завдання встановлення взаємозв'язку гідравлічної та теплової стійкості як для традиційних багатоповерхових, так і сучасних автоматизованих систем водяного опалення висотних будівель. З результатів огляду науково-технічної, нормативної літератури та патентного пошуку випливає, що отримані дані та рекомендації не є вичерпними та потребують подальших досліджень, пов'язаних з вирішенням теоретичних та практичних завдань розглянутої проблеми. Тому подальше вдосконалення систем опалення визначає необхідність вирішення нових науково-технічних завдань, результати яких можуть створити науково-методичну базу для підвищення гідравлічної та теплової стійкості, енергетичної та загальної ефективності автоматизованих систем опалення багатоповерхових та висотних будівель.

Результатом роботи стало аналітичне вирішення задачі із встановленням обліку закономірності взаємозв'язку спільних гідравлічних та теплових процесів в системах опалення висотних будівель для аналізу умов можливого підвищення їхньої енерготехнологічної ефективності. За умов кількісно-якісного регулювання теплової потужності систем, з урахуванням зміни гравітаційної складової, порівняно фактичні втрати тиску з перепадом для аналізованих варіантів. Теплову потужність систем опалення розглянуто як сумарний тепловий потік від всіх нагрівальних приладів, при «нижньому» та «проміжному» розташуванні джерела теплоти.

Отримано нову залежність у вигляді ірраціонального рівняння, якою встановлено аналітичний взаємозв'язок процесів теплової та гідравлічної стійкості. Показано, що нове технічне рішення з проміжним розміщенням джерела теплоти по висоті будівлі мінімізує гравітаційний тиск при роботі системи опалення, внаслідок чого підвищується її вертикальна гідравлічна стійкість, а відповідно зменшується змінна частина надлишкового тиску на засоби автоматики.

Ключові слова: системи водяного опалення, джерело теплоти, рівень розміщення, прилади, гідравлічна стійкість, теплова стійкість.

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