UDC 620.9.004.18 DOI 10.31548/energiya1(65).2023.077

TECHNICAL AND ECONOMIC JUSTIFICATION OF THE CHOICE OF THE OPTIMAL DESIGN OF THE HEATING DEVICE WITH THE FUNCTION OF HEAT ACCUMULATION

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Abstract. *In order to increase the cooling time of the heating system of the building, especially in the conditions of its operation in pulse mode, a domestic highly efficient heating device with the function of heat accumulation has been developed. A criterion has been derived that can be used by every consumer when choosing the optimal design of a radiator. A study was conducted and a technical and economic evaluation of heating devices of known and developed new design with the function of accumulating phase transition heat was given. A heating device with the function of accumulating heat based on accumulative materials of organic origin with metal nanoparticles has been developed. Experimentally, it was established that 80 W were spent to "charge" a single "tube" with a total weight of 952.9 g and bring the temperature of the heat-accumulating material to 52.1 ºC. A technical and economic analysis of known designs of heating devices was carried out. It is shown that convectors and copper-aluminum radiators are the most efficient heating devices for modern heating systems, when it is necessary to use energy resources rationally or there is a limited amount of heat. From an economic point of view, the most efficient heating device is a convector, but not from a sanitary and hygienic point of view (the presence of dust between the fins). Comparing the efficiency of the developed heating device with the function of heat accumulation based on accumulative materials of organic origin with metal nanoparticles according to the indicator of the specific cost of the heating device, which is 0.24 €/(kW·year), and the indicator of technical and economic efficiency of the operation of the device - 0.27 €/(kW·year) is the most efficient.*

Key words: *heating device, technical and economic analysis, heat storage, phase transition, optimal design*

Relevance and novelty of the work. During the design of complex systems "heat source - distribution device - heating device", the main attention should also be paid to the "smart" use of thermal energy in the heating system depending on the needs of the user - a person. The latter can be achieved both by using modern shut-off and regulating valves [1] and by changing the thermal inertia of the heating device [2]. Design solutions of the used heating systems are focused on the regulation of heat flows both in a separate room and in the house in general when using heat inputs from external sources. Thus, the modern heating system is transformed from a system with quasi-stationary thermal and hydraulic regimes into a system that is actively thermally and hydraulically regulated. It should respond to changes in environmental parameters and adapt to them - a change in the temperature of the outside air, an increase in the amount of solar radiation during the day, an increase in the number of people or working equipment in the room, a given decrease/increase in the temperature of the indoor air [2]. This means that these requirements must be taken into account when choosing a heating device, since they are the closest part of the building's heating system to the consumer.

At the same time, taking into account the well-founded expediency of introducing a regular mode of operation of the heating system of public buildings, in particular educational buildings of higher education institutions[3], as well as in the conditions of operation of most building heating systems in pulse mode due to frequent power outages, which are caused by the critical state of the energy industry due to constant missile attacks by Russia, the task of developing a new design of a heating device with the function of accumulating heat based on accumulative materials of organic origin with an improved heat-conducting structure arises. This will make it possible to maintain comfortable conditions for the stay of people in the premises during the period of shutdown of the heating systems of a number of buildings of the residential and communal sector. At the same time, the issue of technical and economic comparison of heating devices of known and new design also becomes relevant.

Analysis of recent research and publications. Water heating devices, which are widely offered today, are divided into 5 groups by material and design features: cast iron; steel panel, sectional, tubular; aluminum; bimetallic; design radiators. A separate group includes copper-aluminum radiators [4-6]. Below we will briefly describe the designs of the most common heating devices that are presented on the market of Ukraine.

Cast iron radiators are traditional heating devices in our country. They have a small heat transfer surface and high thermal inertia. The heating process occurs mainly due to radiation. Advantages: cheap, the body material is neutral to almost all coolants, they give off heat well and can withstand relatively high pressure. Disadvantages: labor-intensive installation, material consumption, unattractive design (with the exception of some imported models), high percentage of manufacturing defects and significant thermal inertia, which is a significant disadvantage for regulation processes in modern heating systems. Theoretically, they are durable enough, but poor-quality casting can quickly lead to coolant leaks. The main advantage of domestic cast iron radiators is their low price [4-6].

Panel steel radiators are an attempt to combine the properties of sectional radiators with convective type devices. Such a radiator is two steel plates between which the coolant circulates. Highly efficient devices with low material capacity and, accordingly, thermal inertia. They are designed for a working pressure of 0.6...1.0 MPa with a maximum coolant temperature of no higher than 110 0C. Disadvantage: the thickness of the steel is 1.1...1.4 mm. It is recommended to use them in individual, low-rise buildings, to a limited extent - in centralized heating systems [4, 5].

Aluminum radiators are a more advanced design that uses a material with a very high heat transfer coefficient in the form of an aluminum alloy. They have an aesthetic appearance, low thermal inertia, light weight, and can be designed for high working pressure. Disadvantages: increased requirements for the chemical composition of the coolant, since the increased alkalinity of the coolant and the electrochemical activity of aluminum with some other metals leads to metal corrosion. In systems with aluminum radiators, it is recommended to install additional mudguards and filters and to perform their cleaning and replacement in a timely manner. Aluminum radiators try to be made as thin as possible for better heat transfer, so they are not strong enough, damage often occurs during their installation [6].

Bimetallic radiators are an even more advanced design that allows you to use all the advantages of aluminum radiators, avoiding their disadvantages. The originality of the design of the bimetallic radiator is that it consists of a strong and electrochemical corrosion-resistant steel pipeline frame (skeleton), ribbed from the outside with high-quality aluminum alloy by high-pressure casting. At the same time, a monolithic connection is formed, which excludes the possibility of contact of aluminum with water, and therefore also corrosion. They have good heat transfer, light weight, high working pressure and corrosion resistance, aesthetic. Disadvantage: high price. They are recommended for use in centralized systems [4-6].

Copper-aluminum radiators consist of a copper-aluminum heat exchanger (copper tubes connected to aluminum plates) and a steel (aluminum) casing. Radiators are intended for installation in the floor, indispensable for facades with continuous glazing, while their use as wall devices causes a number of inconveniences [4-6].

However, none of the above-described designs of heating devices have the possibility of autonomous operation in the event of a shutdown of the centralized heat supply system. Some device designs are characterized by high thermal inertia, which has a positive effect on increasing the cooling time of the system, but somewhat complicates the process of quick response to changes in environmental parameters. The appearance and price of the device also play an important role when choosing a heating device, but its technical and operational characteristics remain in the foreground. It follows that the service life of the heating device, taking into account the environmental impact, should be maximal [7]. This indicates the need to find ways to increase the inertia and reliability of the design of heating devices for their operation in building heating systems that operate in pulse mode, while maintaining the speed of response to changes in output parameters.

One of the ways to increase the thermal inertia of the device is to increase the storage capacity of its design. The authors of the works [8, 9] conducted an analysis of various methods of energy storage and the requirements for modern storage devices, compared the characteristics of heat accumulators using different storage materials. It is singled out as one of the most promising systems that accumulate energy due to the heat of phase transitions and can be widely used in electric storage devices for heating systems, especially during periods of reduced electricity tariffs and/or under the conditions of their operation in pulse mode.

Works [10, 11] describe the possibility of operation of a phase-transition heat accumulator with an improved heat-conducting structure in a centralized heating system and electric heat storage (autonomous) systems. It is shown that the efficiency of a heat accumulator based on phase-transition organic compounds, which is proposed for use in a centralized heating system, almost 14 times higher than a heat accumulator with a solid storage material, 5 times higher than a traditional heat accumulator with a liquid material.

Taking into account the received positive research results [12-19] in terms of the possibility of using paraffins as storage materials, it is considered appropriate to develop a domestic highly efficient heating device with the function of heat storage based on phase transition materials with an improved heat-conducting structure.

Setting the problem. In order to increase the cooling time of the heating system of the building, especially in the conditions of its operation in pulse mode, it is necessary to develop a domestic highly efficient heating device with the function of heat accumulation and derive a criterion that can be used by each consumer when choosing the optimal design of the radiator.

Research materials and methods. When choosing a heating device (radiator), the following factors are traditionally taken into account: architectural planning and construction decisions, which determine the height, depth and length of the device; estimated thermal power of the heating device; categories of production in premises according to explosion and fire safety; customer requirements for the appearance of the device; the quality of the coolant and the connection scheme to the heat supply system (from an autonomous source or the heat network of the settlement); the amount of working pressure in the heat network and heating system; the price of the device related to 1 kW of heat flow.

The characteristic of the radiator describes its thermal power as a function of temperature pressure at constant water flow (Fig. 1). The characteristic is a power function with a certain exponent of the power *n*. Indicators of degree *n* for room radiators should be taken from the instructions of the manufacturers or take reference values:

convectors	n = 1,4
radiators	n = 1,3
panel radiators	n = 1,2 ... 1,3

If the consumption of the coolant does not affect the thermal power, the latter is determined by the product of the standard thermal power by the coefficients (Table1).

1. Power factors

	Influence
f_1	Temperature coefficient
f_2	Connection type
f_3	Screens, a niche
f_4	Painting of metal surfaces
f_5	Limited exploitation
f_g	Generalized coefficient

Another important operating parameter of the heating device is the temperature of its working surface. Taking into account the requirements of DBN B.2.5-67-2013, the latter should not exceed 85 ºC and not be lower than 35 ºC, which is the optimal operating temperature range of the developed heating device with the function of accumulating heat based on accumulative materials of organic origin with metal nanoparticles.

The technical task included the possibility of autonomous operation of the device within 4-8 hours without recharging.

The goal was the possibility of using the development both in systems of centralized heat supply and autonomous energy supply, including using portable charging stations or even power banks as a source of primary energy.

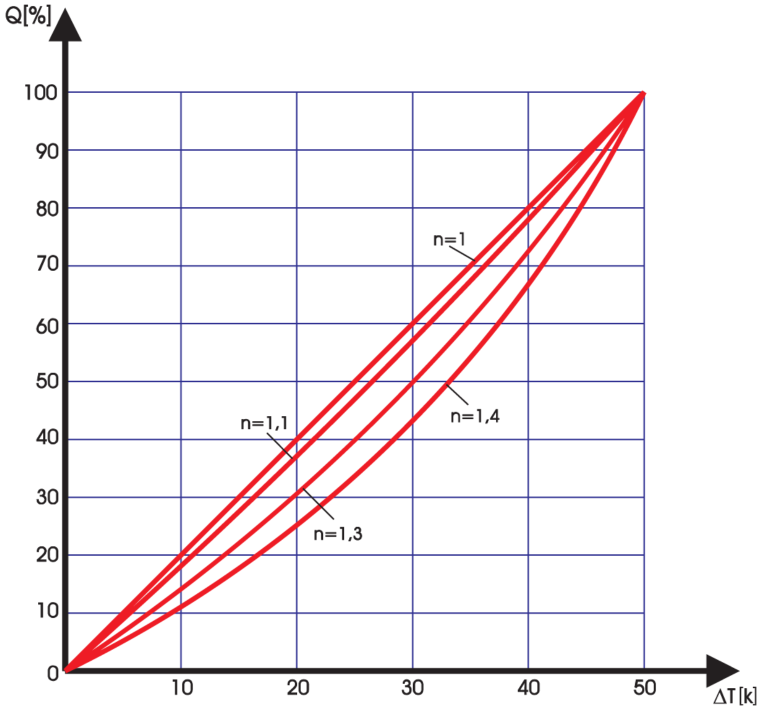

Fig. 1. Characteristics of radiator power at θ_i = 20 °C

Below, in fig. 2 shows the stages of development of the above-mentioned device.

As criteria for choosing the optimal design of the heating device and its comparison with known ones, the following are accepted: inertia of the heating device; specific cost of 1 kW of nominal thermal power of the heating device. The specific volume of the coolant and the mass of the device (section) are also taken into account [2].

Thermal inertia should be understood as the thermal energy content of the heating device (W_{heat}, kJ). It consists of: the heat content of the metal of the heating device (W_M, kJ) and the heat content of the coolant in the heating device (W_T, kJ):

$$W_{heat} = W_M + W_T, kJ. \quad (1)$$

The heat content of the metal of the heating device depends on: the mass of the device/section (M_M, kg), the heat capacity of the material from which the heating device is made (c_M, kJ/(kg·°C)) and the average temperature of the heating device ($\bar{t}_{heat}$ = 70 °C, with the parameters of the heat carrier 80...60 °C):

$$W_M = M_M \cdot c_M \cdot \overline{t_{heat}}, kJ. \quad (2)$$

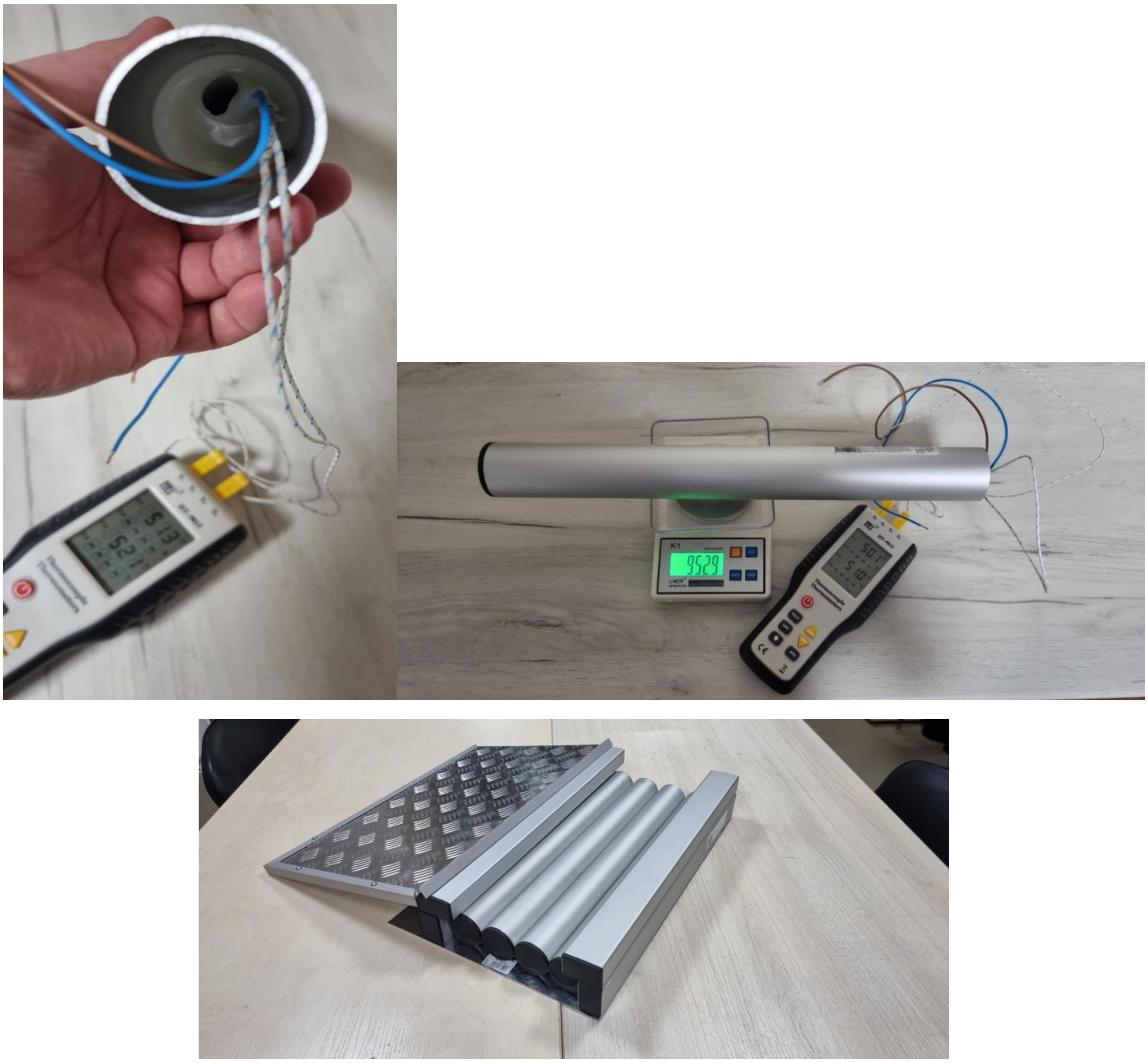

Fig. 2. The process of developing a new design of a heating device with the function of accumulating heat based on accumulative materials of organic origin with metal nanoparticles

The heat content of the heat carrier of the heating device depends on: the volume of the heat carrier, the heat capacity of the heat carrier and the average temperature of the heating device:

$$W_T = M_T \cdot c_M \cdot \overline{t}_{heat}, kJ, \tag{3}$$

$$M_T = 0{,}001 \cdot V_T \cdot \rho_T, kg, \tag{4}$$

where M_T – mass of the coolant in the heating device, kg; V_T – coolant volume, l; ρ_T – density of water at $\bar{t}_{heat}$; 0,001 – conversion factor.

To determine the thermal inertia of different heating devices, it should be reduced to a numerical indicator related to the thermal power of comparatively identical heating devices (Q_n^{relat}, kW), that is, to determine the relative thermal energy content of the heating device. First, we determine the thermal inertia of the heating device (W_{heat}, kJ) at its nominal thermal power (Q_n, kW), and then, by adding the proportion, we arrive at the relative thermal energy content of the heating device (W_{heat}^{relat}, kJ) at the heat power we need (Q_n^{relat}, kW). Most often, Q_n^{relat} = 1 kW. That is, the relative thermal energy content of the heating device (W_{heat}^{relat}, kJ) is defined as the ratio of the thermal energy content of the heating device to its nominal thermal power:

$$Q_n - W_{heat}; \quad Q_n^{relat} - W_{heat}^{relat}. \tag{5}$$

From here:

$$W_{heat}^{relat} = \frac{Q_n^{relat} \cdot W_{heat}}{Q_n}, kJ. \tag{6}$$

Thermal inertia can also be expressed in monetary terms (C_i, UAH):

$$C_i = W_{heat}^{relat} \cdot C_T \cdot 0{,}23865 \cdot 10^{-6}, UAH, \tag{7}$$

where C_T – tariff for thermal energy for heating, UAH/Gcal; $0{,}23865 \cdot 10^{-6}$ – conversion factor.

Time inertia (I, seconds) is defined as the ratio of the thermal energy content of the heating device (W_{heat}, kJ) to the nominal thermal power of the heating device (Q_n, kW):

$$I = \frac{W_{heat}}{Q_n}, \quad seconds. \tag{8}$$

The specific cost of 1 kW of the installed thermal capacity of the heating device (C) is the price of 1 kW of thermal energy, related to the average life of the device. Using this parameter, we will determine how much 1 kW of thermal energy will cost per year, during the entire life of the device:

$$C = \frac{3}{Q_n \cdot a}, \text{€}/(kW \cdot year), \tag{9}$$

where Q_n – nominal thermal power of the heating device (section), kW; 3 – price of the device (section), €; a – the average term of operation of the heating device, year.

To study the indicator of the technical and economic efficiency of the device/group of devices (*E*, €/(kW·year)), the monetary equivalent of the thermal inertia C_i must be converted into the specific monetary equivalent of the thermal inertia of the heating device (C_i^p, €/(kW·year)). Given that:

$$C_i = W_{heat}^{relat} \cdot C_T, \tag{10}$$

$$W_{ann} = W_{heat}^{relat} \cdot A, \tag{11}$$

where C_T – thermal energy tariff, which is a constant for all types of heating devices; *A* – the thermal energy saving coefficient, which depends on the region of construction of the facility and is a constant value for each settlement; W_{ann} – annual heat consumption by the heating device, GJ.

It follows from this that the monetary equivalent of thermal inertia C_i is directly proportional to the relative thermal energy content of the heating device W_{heat}^{relat}, and W_{heat}^{relat} is directly proportional to the annual heat consumption of the heating device W_{ann}:

$$C_i \sim W_{ann} \cdot W_{heat}^{relat}. \tag{12}$$

In consequence:

$$C_i^p \sim C_i \cdot A. \tag{13}$$

Since we are calculating the general case, the factor *A* is not taken into account.

The indicator of the technical and economic efficiency of the device is defined as the weighted average value of the specific monetary equivalent of thermal inertia (C_i^p, €/(kW·year)) and the specific cost of 1 kW of installed thermal power of the heating device (*C*, €/(kW·year)):

$$E = \sqrt{C_i^p \cdot C}, \text{€}/(kW \cdot year). \tag{14}$$

Research results and their discussion. It was established experimentally that 80 W were spent to "charge" a single so-called "tube" with a total weight of 952.9 g and to bring the temperature of the heat-accumulating material to 52.1 ºC. At the same time, the amount of received "discharge" energy was 78 W (taking into account the cyclical operation of the device). Comparing the coefficient of effectiveness of the developed heating device with the simplest heater in which a heater is used as a heating element, their values are approximately the same, 97.5% and 99%, respectively. However, taking into account the thermal inertia of the heating device with the function of accumulating heat based on accumulative materials of organic origin with metal nanoparticles, the advantage of its use for heating the premises of buildings whose heating systems operate in pulse mode, from the economic point of view and the duration of maintaining comfortable conditions for people to stay in such premises, is obvious. The ratio of cooling time ("discharge") of heating devices of known designs (steel panel radiators, ceramic, bimetallic sectional, etc.) and designed (at the temperature of its working surface ≥ 35 ºC) is 1:3.

Using the above methodology, a techno-economic comparison of various types of heating devices was carried out, the results of which are shown in the table 2.

Analyzing the obtained data, it can be concluded that convectors and copper-aluminum radiators are the most efficient heating devices for modern heating systems, when it is necessary to use energy resources rationally or there is a limited amount of heat (for example, from accumulated energy storage). But, since there is a big question of compliance of convectors with sanitary and hygienic standards due to the accumulation of dust between the convector plates, attention should be paid to copper-aluminum radiators. Sometimes the operating conditions do not leave space in terms of choosing a heating device, therefore, in each group of heating devices, after conducting a technical and economic comparison, you can find more energy-efficient radiators. Yes, the most efficient heating device from an economic point of view is a convector, but not from a sanitary and hygienic point of view (the presence of dust between the fins).

And if you look at radiators, copper-aluminum ones turned out to be the most effective. In each group, there is a fairly significant variation in the value of the indicator of technical and economic efficiency of the device, which allows, depending on the operating conditions and technical task, to choose a more efficient heating device in the required group.

2. Technical and economic comparison of heating devices

Name, type of radiator	Power of the heating device (section), kW	The cost of the heating device (section), €	The average period of operation of the heating device (section), year	Weight of the device (section) kg	Thermal stress of metal, M, kg/kW	Volume of heat carrier, V_T, l	Specific volume of heat carrier g_T, l/kW	Specific thermal energy content of the W_{heat}^{relat} heating device, kJ at Q_n^{relat} = 1 kW	The specific monetary equivalent of the thermal inertia of the heating device, C_I^P, €/(kW·year)	Indicator of time inertia of the heating device, I, seconds	Index of time inertia of the opalual device, I, min	The specific cost of the heating device C, €/(kW·year)	Indicator of technical and economic efficiency of the device E, €/(kW·year)
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Aluminum radiators (sectional)													
Sira AMBRA 500 (Italy)	0,161	6,8	30	1,35	8,39	0,25	1,55	982,596	0,00963	982,6	16,38	1,41	0,117
Mirado 500/80 (Spain)	0,163	6,7	30	1,47	9,02	0,38	2,33	1245,277	0,01220	1245,3	20,75	1,36	0,129
Cast iron sectional radiators													
LLMZ RD-100-500-1,2 (Ukraine)	0,12	8,6	80	4,6	38,33	0,8	6,67	3252,612	0,03187	3252,6	54,21	0,90	0,169
MS -140M (Belarus)	0,13	11,1	80	7,1	54,62	1,45	11,15	5106,032	0,05002	5106,0	85,10	1,06	0,231
Kiran 92/500 (Turkey)	0,089	2,9	80	4,2	47,19	0,6	6,74	3586,462	0,03514	3586,5	59,77	0,41	0,120
Bimetallic sectional radiators													
LLC "Press" Bolshevik RBP-1-500 (Ukraine, Kyiv)	0,142	8,6	40	3,2	22,54	0,36	2,54	2173,884	0,02130	2173,9	36,23	1,52	0,180
Global STYLE 500/80 (Italy)	0,1586	13,9	40	1,97	12,42	0,2	1,26	1159,359	0,01136	1159,4	19,32	2,20	0,158
Steel panel radiators													
Kermi Type 22 800x500(h) (Germany)	1,324	89,8	25	23,27	17,58	4,32	3,26	1498,406	0,01468	1498,4	24,97	2,71	0,200
Vonova Type 22 720x500(h) (Austria)	1,1215	86,7	25	26,78	23,88	6,1	5,44	2322,568	0,02275	2322,6	38,71	3,09	0,265
Copper-aluminum radiators													
"Termiya" 40/120 (Ukraine, Vinnytsia)	1,29	68,1	40-50	6,4	4,94	0,80	0,62	494,625	0,00485	494,6	8,24	1,17	0,075
REGULUS R4/100 (Poland)	1,417	126,3	40	5,7	4,02	0,64	0,45	387,791	0,00380	387,8	6,46	1,98	0,087
Convectors													
Termia KSK 40/100K (Ukraine, Vinnytsia)	1,29	30,5	20	13,3	10,34	0,9	0,70	534,062	0,00523	534,1	8,90	1,19	0,079
Comfort KN 20-1,475K(p), l=1040 mm (Belarus)	1,26	29,2	20	16,39	12,96	0,72	0,57	581,574	0,00570	581,6	9,69	1,16	0,081
Aluminum panel with heat storage function													
E NA-1000 (Ukraine)	1,0	147,0	25	7,5	7,5	3,0	3,0	31162,0	0,31	31162,0	519,0	0,24	0,27

Notes:

1. In this calculation: the coolant is water, ρ_w= 971,81 kg/m^3 at $\bar{t}_{heat}$= 70 $^{\circ}$C (coolant parameters 80 $^{\circ}$C – 60 $^{\circ}$C).
2. Heat capacity of case materials: aluminum c_{al}= 0,92, cast iron c_c= 0,504, steel c_s= 0,462 kJ/(kg·$^{\circ}$C); heat capacity of water c_w= 4,19 kJ/(kg·$^{\circ}$C).

Thermal power of heating devices, at which thermal inertia is calculated, Q_n^{relat} = 1 kW.

The technical and economic evaluation of the developed heating device with the function of heat accumulation based on accumulative materials of organic origin with metal nanoparticles showed that the developed design according to the indicator of the specific cost of the heating device, which is 0.24 €/(kW·year), and the indicator of technical the economic efficiency of the device - 0.27 €/(kW·year) is the most effective.

Conclusions and perspectives. A study was conducted and a technical and economic evaluation of heating devices of known and developed new design with the function of accumulating phase transition heat was given. In particular, the following has been established:

1. A heating device with the function of accumulating heat based on accumulative materials of organic origin with metal nanoparticles has been developed. Experimentally, it was established that 80 W were spent to "charge" a single "tube" with a total weight of 952.9 g and bring the temperature of the heat-accumulating material to 52.1 ºC. At the same time, the amount of received "discharge" energy was 78 W (taking into account the cyclical operation of the device). The ratio of cooling time ("discharge") of heating devices of known designs (steel panel radiators, ceramic, bimetallic sectional, etc.) and designed (at the temperature of its working surface ≥ 35 ºC) is 1:3.

2. A technical and economic analysis of known designs of heating devices was carried out. It is shown that convectors and copper-aluminum radiators are the most efficient heating devices for modern heating systems, when it is necessary to rationally use energy resources or there is a limited amount of heat. But, since there is a big question of compliance of convectors with sanitary and hygienic standards due to the accumulation of dust between the convector plates, attention should be paid to copper-aluminum radiators. From an economic point of view, the most efficient heating device is a convector, but not from a sanitary and hygienic point of view (the presence of dust between the fins). And if you look at radiators, copper-aluminum ones turned out to be the most effective.

3. Comparing the efficiency of the developed heating device with the function of heat accumulation based on accumulative materials of organic origin with metal nanoparticles according to the indicator of the specific cost of the heating device, which is 0.24 €/(kW·year), and the indicator of technical and economic efficiency of the device - 0.27 €/(kW·year) is the most efficient.

References

1. Pokotilov, V. V. (2017). Reguliruyushchiye klapany avtomatizirovannykh sistem teplo- i kholodosnabzheniya: uchebnoye posobiye dlya inzhenerov, proêktirovshchikov i studentov [Control valves for automated heating and cooling systems: a textbook for engineers, designers and students].Vienna: "HERZ Armaturen", 232.

2. Lyubarets, O. P., Predun, K. M., Moskvitina, A. S. (2019). Metodyka tekhniko-ekonomichnoho porivnyannya opalyuvalʹnykh pryladiv dlya zastosuvannya v suchasnykh dynamichnykh systemakh vodyanoho opalennya. Upravlinnya rozvytkom skladnykh system [Methodology of technical and economic comparison of heating devices for use in modern dynamic systems of water heating. Management of the development of complex systems: coll. of science works]. Kyiv: KNUBA,37, 210-218.

3. Antypov, I. O., Mishchenko, A. V., Shelimanova, O. V., Tarasenko, S. E. (2021). Analiz vplyvu vnutrishnʹoyi teployemnosti budivli ZVO ta pohodozalezhnoho rehulyuvannya ITP na efektyvnistʹ roboty systemy opalennya v cherhovomu rezhymi [Analysis of the influence of the internal heat capacity of the HEB building and weather-dependent regulation of the ITP on the efficiency of the heating system in the alternate mode]. Energy and automation, 5. http://dx.doi.org/10.31548/energiya2021.05.045.

4. Yulia Zakharenko-Berezyanskaya (2006). [Ukrainian market of radiators. Overview].Magazine "S.O.K., 7.Access mode: http://www.c-o-k.com.ua/content/view/463/.

5. Julia Berezyanskaya. (2007). Radiatory v kazhdyy dom [Radiators for every home. - S.O.K. magazine]. 8. - Access mode: http://www.c-o-k.com.ua/content/view/1123/.

6. Electronic resource. Access mode: https://kte.kmda.gov.ua.

7. Ekolohizatsiya enerhetyky: Navch. pos. [Greening of energy: Education. Village] / Shevchuk V.Ya., Bichivskyi G.O., Satolkin Yu.M., Navrotskyi V.M. (2002). Higher education, 111.

8. Gorobets, V. G. Antypov, I. O. (2016). Akumulyatory teploty na osnovi fazoperekhidnykh akumulyuyuchykh materialiv [Heat accumulators based on phase transition accumulative materials]. CP "Comprint", 165.

9. Antypov, I. O. (2017). Kompleksne vykorystannya ponovlyuvanykh dzherel i akumulyatoriv enerhiyi [Comprehensive use of renewable energy sources and accumulators]. "CP "Comprint", 471.

10. Antypov, I. O. (2019). Kompleksne doslidzhennya protsesiv nakopychennya teplovoyi enerhiyi pry fazovykh peretvorennyakh orhanichnykh akumulyuyuchykh materialiv z nano- ta mikrochastynkamy metaliv [Comprehensive study of thermal energy accumulation processes during phase transformations of organic accumulative materials with nano- and microparticles of metals]. Energy and automation, 5, 131–148.

11. Huo Y., Rao Z., Lattice Boltzmann simulation for solid–liquid phase change phenomenon of phase change material under constant heat flux. Int. J. Heat Mass Tran 2015, 86, 197–206. https://doi.org/10.1016/j.ijheatmasstransfer.2015.03.006.

12. Sharma, A., Tyagi, V., Chen, R., Buddhi, D. (2009). Review on thermal energy storage with phase-change materials and applications. Renew. Sust. Energ. Rev 2009, 13 (2), 318–345. https://doi.org/10.1016/j.rser.2007.10.005.

13. Antypov, I. O. (2015). Chyselʹnedoslidzhennyaprotsesivteploperenosu v nyzʹkotemperaturnykhakumulyatorakhteploty pry fazovykh peretvorennyakh akumulyuyuchoho material [Numerical study of heat transfer processes in low-temperature heat accumulators during phase transformations of the accumulating material]. Scientific Bulletin of the National University of Bioresources and Nature Management of Ukraine. Series "Technology and energy of agricultural industry", 224, 208–213.

14. Zhang, Q., Huo, Y., Rao, Z. Numerical study on solid–liquid phase change in paraffin as phase change material for battery thermal management. Science Bulletin 2016, 61(5), 391–400. https://doi.org/10.1007/s11434-016-1016-z.

15. Trp, A. (2005). An experimental and numerical investigation of heat transfer during technical grade paraffin melting and solidification in a shell-and-tube latent thermal energy storage unit. Sol. Energy 79, 648–660. https://doi.org/10.1016/j.solener.2005.03.006.

16. Kalaiselvam, S., Veerappan, M., Arul, A., Iniyan, S. (2008). Experimental and analytical investigation of solidification and melting characteristics of PCMs inside cylindrical encapsulation. Int. J. Therm. Sci., 47 (7)), 858–874. https://doi.org/10.1016/j.ijthermalsci.2007.07.003.

17. Regin, A., Solanki, S., Saini, J. (2005). Latent heat thermal energy storage using cylindrical capsule: numerical and experimental investigations. Renew. Energ 2006, 31, 2025–2041. https://doi.org/10.1016/j.renene.2005.10.011.

18. Jegadheeswaran, S., Pohekar, D. (2009). Performance enhancement in latent heat thermal storage system: A review. Renew. Sust. Energ., 13 (9), 2225–2244. https://doi.org/10.1016/j.rser.2009.06.024.

19. Kuboth, S., König-Haagen, A., Brüggemann, D. (2017). Numerical Analysis of Shell-and-Tube Type Latent Thermal Energy Storage Performance with Different Arrangements of Circular Fins. Energies, 10, 274. https://doi.org/10.3390/en10030274.

Техніко_економічне обгрунтування вибору оптимальної конструкції опалювального приладу з функцією теплоакумуляції

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Анотація. *З метою збільшення часу охолодження системи опалення будівлі, особливо в умовах її роботи в імпульсному режимі, розроблено вітчизняний високоефективний опалювальний прилад з функцією акумуляції тепла. Виведено критерій, яким може керуватися кожен споживач при виборі оптимальної конструкції радіатора. Проведено дослідження та наведено техніко-економічну оцінку нагрівальних приладів відомої та розробленої нової конструкції з функцією накопичення теплоти фазового переходу. Розроблено нагрівальний пристрій з функцією накопичення тепла на основі накопичувальних матеріалів органічного*

походження з наночастинками металів. Експериментально встановлено, що на «зарядку» однієї «трубки» загальною вагою 952,9 г і доведення температури теплоакумулюючого матеріалу до 52,1 ºС витрачається 80 Вт. Проведено техніко-економічний аналіз відомих конструкцій нагрівальних приладів. Показано, що конвектори та мідно-алюмінієві радіатори є найбільш ефективними опалювальними приладами для сучасних систем опалення, коли необхідно раціонально використовувати енергоресурси або є обмежена кількість тепла. З економічної точки зору найбільш ефективним опалювальним приладом є конвектор, але не з санітарно-гігієнічної (наявність пилу між ребрами). Порівнюючи ефективність розробленого нагрівального приладу з функцією теплоакумуляції на основі накопичувальних матеріалів органічного походження з наночастинками металу за показником питомої вартості нагрівального приладу, який становить 0,24 €/(кВт·рік), та показником техніко-економічної ефективності роботи пристрою - 0,27 €/(кВт·рік) є найбільш ефективним.
Ключові слова: ***нагрівальний пристрій, техніко-економічний аналіз, накопичення тепла, фазовий перехід, оптимальна конструкція***