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PECULIARITIES OF THERMOMODERNIZATION OF THE HEATING SYSTEM OF MILITARY INFRASTRUCTURE COMPLEXES

Purpose. To develop a solution for modernization of heat supply systems (HSS) of infrastructure complexes including, in particular, in military towns (MT), the problem of both efficient and effective heating of which is especially important at present. To develop a mathematical model for finding an effective solution to the problem of modernizing heating and detecting leaks of the heat-conductor.

Methodology. Special and general methods are used: mathematical formalization – to build mathematical model of the problem of heat supply of MT and detection of heat-conductor leaks; induction and deduction – for choosing and substantiating the expediency of using equipment for HSS of MT; analysis and synthesis – for the development of a schematic solution HSS of MT.

Findings. Decision options regarding the choice of heat-generating equipment for the modernization of HSS of MT are substantiated. A combined system using boilers and solar collectors is proposed. For the combined system, a schematic solution for integrating equipment into a single autonomous HSS of MT and an economical option for automatic system control are developed. For boilers of the combined system, it is suggested to use cheap and affordable fuel – pellets. A mathematical model has been developed for finding an effective system solution for HSS of MT and detecting heat-conductor leaks.

Originality. Special requirements for HSS of MT were formulated: autonomy; high level of reliability, survivability; flexibility in ensuring the volume of heat supply during the day, week, season; minimizing the cost of equipment and fuel for it; the possibility of inexpensive repair and renewal. Variants of modernization of HSS in MT have been analyzed and a schematic solution of an integrated HSS of MT with combined use of generating equipment has been developed.

Practical value. The developed mathematical model and schematic solution of HSS in MT as well as proposed options for using equipment and fuel for it allow ensuring the proper level of fulfillment of special requirements for HSS in MT.

Keywords: *thermal modernization, military towns, military infrastructure complexes, heat networks, energy efficiency*

Introduction. The proper provision of working and living conditions for the military and their families is one of the components of the implementation of tasks and motivation of the military. This, first of all, requires the establishment of an effective and reliable heat supply to military towns, including that during wartime. Military towns were designed, built and equipped over a long enough period, primarily during peacetime. Their functioning, to a large extent, nowadays does not meet modern requirements for efficiency, reliability and challenges caused by large-scale military operations on the territory of Ukraine. These military actions, for example, now complicate and sometimes make impossible the reliable supply of all types of energy carriers for the heat-generating equipment of military towns: liquid fuel, solid fuel, even natural gas, and carry the threat of damage and destruction of the specified equipment.

The useful life of a significant number of units of this equipment has long passed. It functions due to permanent repairs, which significantly reduces its reliability. Of course, the concept of energy efficiency cannot even be applied to outdated equipment.

The functioning of heat supply systems (HSS) of military towns (MT), whose heat networks are tied to large cities, also becomes unreliable due to the possibility of an aggressor attacking the energy systems of the specified cities and damaging the power supply lines from them to military towns.

This leads, firstly, to the unreliability of providing heat to military personnel and their families and determines the need for the autonomy of the heat supply systems of military towns. Secondly, the equipment, the energy efficiency of which is not at the proper level, requires significantly more funds for the purchase of energy carriers. Thirdly, the above said greatly complicates the reporting of military units, in particular, in accordance with the orders of the Ministry of Defense of Ukraine No. 448 "On the approval of the Regulation on the organization of housing and operational support of the Armed Forces of Ukraine" and No. 524 "On the approval of the Procedure for determining the objectively necessary amount of fuel for economic and household needs in the Armed Forces of Ukraine", "Instructions for housing and operating institutions and divisions of engineering and infrastructural support", etc. A significant limiting factor for the urgent modernization of the heating supply of military towns is the lack of funds, which is especially severe in wartime conditions. Therefore, it becomes urgent to offer such systemic solutions to the problem, which, under the conditions of the mentioned restrictions, will be able to lead to increasing the reliability of heat supply to military towns; increasing the energy efficiency of the use of heat networks; reducing fuel costs and simplifying the logistical task of supplying the necessary fuel for heat-generating equipment; providing an opportunity to speed up repair work at emergency sections of the heating network, especially at remote sections of the specified network, and simplify its operation.

Literature review. Many scientific works are devoted to the problems of designing and modernizing heat supply systems of small towns, in particular, military towns. For example, in the article by Touš, et al. [1], the issue of energy efficiency and resource saving for heating systems of military towns is researched. Touš, et al., add that implementing cost-saving measures for a military camp is not only a cost issue, but also a security issue. This is used in the presented article. Makropoulos, et al. [2] proposed a SmartBlue Camp tool to assess the status of military camps in terms of resource management and infrastructure sustainability, which is also useful in the design and modernization of heating systems. Teng, et al. [3] indicate the advantages and disadvantages of digital methods for providing heat supply to infrastructure facilities. Farid [4] studied the energy management systems of an army base and pointed out the importance of its integrated construction. Such a systematic approach was also used by the authors of the presented article. Dyrelund, et al. [5] considered the "campus approach" to centralized heat supply, which enabled the transition from centralized to local energy production and the implementation of the Program "Integration of technologies to achieve sustainable military installations with low energy consumption". Engel [6] analyzes the strategy of the Department of Defense (DOD) as the largest energy consumer in the US and, accordingly, one of the largest energy consumers in the world, and indicates the feasibility of using alternative and combined thermal energy systems. This approach is also considered by the authors of this article. Winfield, et al. [7] analyze heating, ventilation and air conditioning systems and heat energy systems that function in special conditions and indicate the need to increase their reliability, durability and functionality. Samaras, et al. [8] indicate the need to increase the share of renewable energy for the minigrid of military towns and alternative fuels for them. Basok, et al. [9] focused on "reducing the use of energy resources, increasing energy efficiency in construction and implementing automated individual heat points for effective regulation of heat consumption". Máša, et al. [10] analyze in detail the key approaches and ensuring the efficiency of heat supply systems in small towns, in particular, pointing out the need to achieve their autonomy, which reduces resource losses on the leads to these towns. This is also considered in the presented article.

Guzek, et al. [11] used advanced algorithms for optimization of operation and predictive maintenance of heat supply systems based on heat balance. Moustakidis, et al. [12] proposed an innovative control system that uses the method of thermal and material balances. Johansson, et al. [13] proposed real-time network optimization based on balance equations. The method of thermal and material balances is also applied in the presented article. Ntakolia, et al. [14] indicate the need to use intelligent systems for effective regulation of heat consumption. Benalcazar, et al. [15] propose the use of artificial neural networks for short-term forecasting of heat load in heat supply systems. Kim, et al. [16] conducted a detailed study on efficiency improvement for thermal energy consumer locations based on training intelligent control systems with reinforcement. Gong, et al. [17] proposed a model using neural networks for forecasting the load of heat supply systems. Yuan, et al. [18] proposed a model based on support vectors for the control and forecasting of the heat supply system. Winkler, et al. [19] used the decision tree method to model the failure of heat network pipes. Reynolds, et al. [20] and Bilan, et al. [21] used artificial neural networks and a genetic algorithm for the same purpose.

The analysis of these works indicates the use of modern information systems to ensure the energy efficiency of the heating supply of military towns for Western countries. Unfortunately, the methods proposed, in particular, in the cited scientific works and schematic solutions proposed, for example, in the article by Engel [6] require significant financial resources, which, in the conditions of war, are beyond the capabilities of the Ukrainian budget. This indicates the urgency of solving the problem of developing such models and finding such schematic solutions that are able to ensure the proper characteristics of heat supply systems with a strict economy of budgetary resources.

Purpose of the article. To propose solutions for the modernization of heating systems of military towns. To develop a mathematical model of the formalization of the search for an effective system solution for the task of modernizing the heating of the military town and detecting the facts of heat-conductor leaks.

Methods. Special and general methods of scientific knowledge were used in the presented research. In particular, the method of mathematical formalization was used to build a mathematical model of the formalization of the task of finding the best solution for the heating supply of a military town and identifying heat-conductor leaks from heating pipe networks.

A mathematical model for increasing the efficiency of the heating system of a military town can be formed under the condition of realizing the balance of produced and consumed heat

$$Q_{produced} \xrightarrow{opt} Q_{consume} + \Delta Q,$$

where $Q_{produced}$ is the total amount of heat produced; $Q_{consume}$ is the total amount of heat consumed; ΔQ is heat losses during the transfer of produced heat to consumers under the condition $\Delta Q \to \min$.

The total amount of heat produced by the combined system using, for example, boiler houses and solar collectors can be represented as follows

$$Q_{produced} = \cup\left(\sum_1^n m_i r_i + \sum_1^m Q_j\right),$$

where $i = 1, \ldots, n$ is the index of boiler houses; $j = 1, \ldots, m$ is the index of solar collectors; m_i is mass of fuel burned in the i^{th} boiler house; r_i is calorific value of fuel; Q_j is the amount of heat produced by the j^{th} solar collector.

The total amount of heat consumed can be represented as

$$Q_{consume} = \sum_1^h Q_z,$$

where $z = 1, \ldots, h$ is the consuming building heat index; Q_z is the amount of heat consumed by the h^{th} consuming building.

Then the formulation of the task of increasing the efficiency of the heating system of the military town will look as follows. At the first stage, we will determine the required amount of heat for the supply and heating of water for the MT while minimizing the amount of fuel for the boiler houses and achieving the specified level of heating the heat conductor

$$\sum_1^n m_i r_i + \sum_1^m Q_j = f\left\{\cup\left[c_{pz} G_z (t_{input} - t_{output})_z\right]\right\} \to$$
$$\to \begin{cases} m_i \to \min \\ (t_{input} - t_{output}) \to opt \end{cases},$$

where c_{pz} is heat capacity of water in the individual heat supply system of the z^{th} consumer; G_z is mass consumption of heat carrier in the heat supply system of the z^{th} consumer; $(t_{input} - t_{output})_z$ is the difference between the input and output temperatures of the heat conductor in the heat supply system of the z^{th} consumer.

The need to minimize fuel consumption determines the need to increase the efficiency of the joint use of the heat resource in the circumstances of a significant daily disproportion of its consumption by the contingent at individual locations. The conditions for this are the need, firstly, for the formation of a sufficient resource to cover the daily maximum consumption (it is proposed to decide on the use of a system of water tanks); secondly, the formation of a sufficient resource to cover the total daily consumption (provided by the total capacity of the heat generation subsystem). This allows one to supplement the mathematical model by formulating the first condition mentioned above

$$\bigcup_{n=1}^{m}\left(\int_{\tau_p}^{\tau_k} Q_{produced}\,d\tau \cap \int_{\tau_p}^{\tau_k} Q_{storage}\,d\tau \cap \int_{\tau_p}^{\tau_k} Q_{consume}\,d\tau\right) \to opt,$$

where τ_k is the time of the beginning and end of the generation-accumulation-distribution period of the resource; $Q_{storage}$ is the amount of accumulated heat in the entire system of storage tanks.

The requirement for the survivability of the HSS of MT is ensured, in particular, by the distribution of heat generation and storage equipment in different locations with the condition, if possible, of minimizing the total length of the pipelines.

The amount of heat produced per year by solar absorbers has two components. The first is for the purpose of compensating the heat of the boiler houses for heating Q_{komp} premises, the second is for providing the contingent with hot water. A significant difference between the HSS of civilian cities and the MT is that providing the contingent with hot water is necessary not only for hygienic purposes, but also in emergency situations, after contact with dangerous and poisonous substances, etc.

A feature that conditions the operation of the HSS in MT, in contrast to other small cities, is that the number of their residents (N) can be a value with a large amplitude of change in short periods of time, the conditions of the activities of military personnel make the number of buildings whose solar collectors work equally variable on the general system (p), because a certain part of the buildings in certain periods of the year may not function due to the temporary absence due to duty of the contingent, which causes a significant difference in the daily consumption of hot water at individual locations.

The total amount of heat for water heating by absorbers (Q_{sa}) can be calculated as

$$\sum_{1}^{m} Q_j = \sum_{1}^{m}(Q_{sa} + Q_{komp}) =$$
$$= \sum_{1}^{m}\left\{V\,\mathrm{var}(N)\rho c_p\,\mathrm{var}(\Delta t)\,\mathrm{var}(p)\right\} + \sum_{1}^{m} Q_{komp},$$

where V is a daily volume of hot water consumption by a serviceman; ρ is density of water; c_p is heat capacity of water.

The minimum necessary heat-absorbing area of solar collectors is formed by the conditions for ensuring the minimum amount of heat $\left(Q_{sa}^{\min}\right)$ for the production of hot water

$$Q_{sa}^{\min} = \begin{cases} N = N^{\min} \\ p = p^{\min} \\ t_{output} \ge 40\,^{\circ}C \end{cases}.$$

The maximum heat-absorbing area of solar collectors is

$$Q_{sa}^{\max} = \begin{cases} N = N^{\max} \\ p = p^{\max} \\ t_{output} \ge 90\,^{\circ}C \end{cases}.$$

We suggest considering Q_{komp} as $Q_{komp} = (Q_{sa}^{\max} - Q_{sa}^{\min}) \sim \sim 19 Q_{sa}^{\min}$.

The minimum capacity of tanks should be calculated according to two conditions. The first condition – the capacity of each location (V_j, *liters*) must meet the requirements: $V_j \ge k \cdot h \cdot \tau \cdot 80 \cdot N_j^{\max}$, where 80 is the daily rate of hot water use (liters per person); $N_j^{\max}$ is the maximum possible number of people in the j^{th} location; h is the lowest rate of restoration of the specified amount of water by the solar collector of the location to the required temperature for the specified period (hours^{-1}; τ is the recovery time (hours); k is the coefficient of coverage of the general needs of the HSS of MT ($k \ge 1.2$). The second requirement is the ability to provide volley use of hot water by the MT contingent in a specified number of shifts (at least three per day).

Winkler, et al. [16] used the method of decision trees to model heat-conductor leaks from heating pipe networks. Since the use of expensive computer equipment in the heat supply systems of Ukrainian military towns requires excessive monetary resources in the conditions of strict economy, we proposed the use of an analysis of the imbalance of the energy carrier in the heat network as a whole and in its isolated parts using analog sensors and compliance of the network operation with the balance equation

$$(G_{input} - G_{output}) \to 0.$$

The method of induction and deduction was used to select and substantiate the feasibility of using cogeneration plants and the option of combining technological equipment for the heat supply system of the military town.

The method of analysis and synthesis was used to develop a schematic solution for the heating system of the military town.

Results. The problem of supplying heat to military towns should not be limited only to the winter period. In other seasons, servicemen, civilian personnel, families of servicemen living in military towns need hot water. This sets additional conditions for the organization of the use of heat-generating equipment in warm periods of the year. This, in particular, naturally raises the demand for modular implementation of the mentioned equipment.

Military towns are not only barracks and residential buildings, but also military buildings and structures. Therefore, the heat supply of military towns should meet not only the target function of energy efficiency, but also the target function of reliability and survivability, which is especially important during a large-scale military aggression. The above said conditions the fact that all proposals for thermal modernization of the heating system of military towns must be considered from the point of view of ensuring all target functions. For example, how important is the high efficiency of expensive equipment when it can be destroyed by a single strike drone?

Equipping military towns with cogeneration plants, which are designed for the production of electric and, at the same time, thermal energy, and the total (by types of energy produced) whose efficiency reaches 90 %, could be the solution to the problem. The task of wide production of cogeneration units is simplified by the fact that the main high-tech node for them can be, in particular, aviation turbo engines of Motor Sich JSC, which have already served their term. JSC "Motor Sich" has experience in creating cogeneration plants based on aviation turbo engines. In Ukraine, there are other producers of cogeneration plants, for example, Scientific and Production Enterprise "Interenergo". There are other options for engines for cogeneration plants, in particular, gas piston engines. But one more factor regarding the use of aircraft engines in cogeneration systems is the fact that a certain part of them, after repair, can be taken from the downed aircraft of the enemy, of course, if this aircraft is not completely destroyed. Electric power of cogeneration plants is 400–1000 kW at 1500 min^{-1} (50 Hz); thermal power is 404–1123 kW; fuel consumption power is 948–1891 kW; gas consumption is 100–199 n. cube. m/h; electrical efficiency makes 41.5–43.6 %; thermal efficiency is 43.6–46.6 %. The cost of energy for the use of cogeneration plants is lower than tariffs by 40–60 %.

But there are also problems with their use for electricity and the heat supply of military towns.

The first, as it is noted above, is that the number of people in such towns is a variable. This variability is characterized by high amplitudes during the rotation of military units (from the minimum to the maximum number of people) in sufficiently short time intervals.

The second is that these installations are expensive.

Third, they are too vulnerable to air attacks and do not meet the survivability requirements of the systems required by the military. The concentration of all electricity and heat supply of military towns in one unit, even if it is of a modular type, significantly increases the risk of leaving a military town without both electricity and heat. In this case, the modular implementation of the cogeneration plant does not exclude the need to locate it on a small plot of land.

Fourth, the need to maneuver the amount of heat supplied to the network depending on the season poses the problem of using the produced excess heat in the summer, which can significantly reduce the seasonal energy efficiency of cogeneration plants.

The indicated problems of the use of cogeneration plants for electricity and heat supply of military towns allow us to formulate special requirements for the HSS in MT. Such special requirements are as follows: autonomy; high level of reliability, survivability; flexibility in ensuring the volume of heat supply during the day, week, season; minimizing the cost of equipment and fuel for it, the possibility of inexpensive repair and renewal.

Most of the military towns nowadays have their own heat generation facilities and their own heat pipe networks. Even if the heat carrier is supplied to some of these towns from the heat generation systems of neighboring civilian towns, the transition of their heat pipe networks to the use of autonomous sources of generation will require lower costs, because there is an internal system of piping throughout the territory of the town, which can be used in the modernization of the heat supply system.

Suggestions for choosing boiler house parameters are as follows. MT with ~5000 sq. m. meters of the heated area were equipped with a boiler house capacity of ~650 kW. The thermal power of the boiler house must meet the total needs of heat and hot water according to the mathematical model presented above. If this power exceeds 1000 kW, we recommend applying the modular principle and dispersing the location of the modules territorially, which will increase the survivability of the system. In terms of fuel consumption, we recommend a universal boiler house with the possibility of using pellets, which is substantiated in the text of the article. All of the above indicates the possibility of using a cogeneration plant as the main or, to ensure the reliability of energy and heat supply, as an alternative source in military towns, provided that the Ministry of Defense of Ukraine allocates the money necessary for the purchase of this equipment, the possibility of protecting it from the threat of a missile attack and other solutions to the problems mentioned above.

Due to the mentioned problems in the use of cogeneration plants, in our opinion, it becomes more expedient to consider an alternative option of step-by-step modernization of the existing heat supply systems of military towns using boiler houses according to a single long-term plan.

This is facilitated by the fact that, according to the analysis of the regulatory documents of the Ministry of Defense of Ukraine, groups of boiler rooms are mainly used to supply heat to military towns, which in most cases use solid fuel. The analysis also shows that pellets are not mentioned among the recommended types of solid fuel for boiler houses of military towns in the regulatory documentation of the Ministry of Defense of Ukraine. This is especially surprising because this documentation, in particular, regulates in detail the care of trees and bushes on the territory of military towns. The requirements for pruning trees and bushes are accompanied by an instruction on regulated costs for the removal of pruned branches and dead trees from the territory of military towns. In our opinion, low-cost equipment for chopping wood and making pellets could reduce to zero the cost of removing wood waste from the territory of military towns and significantly reduce the cost of purchasing additional solid fuel.

Consider the fact that at present the market price of wood pellets ranges from UAH 10890 per ton. Since there may be a shortage of wood for the production of pellets in military towns, it is advisable to consider the use of mix pellets. Mix pellets are made from various types of raw materials: agricultural waste (corn cobs, husks, seeds, etc.), plants (reeds, straw, etc.), other natural combustible substances (coal dust, peat, lignin).

Pellets, unlike coal, are characterized by a low ash content – from 0.5 to 1 %. The low ash content prevents excessive slag deposition in the combustion chamber of the boiler house and slagging of air ducts, which leads to a reduction in costs for current maintenance and repair of heating equipment. One ton of pellets gives as much energy as burning 1.6 tons of firewood. Although pellets are inferior to liquid fuel in terms of calorific value, they are environmentally friendly – the smoke emitted during combustion is odorless and does not pollute the atmosphere with sulfur dioxide. The required volume of pellets for continuous heating of 150 m² for the north of Ukraine is 72 kg per day, that is, it is not excessive.

Our research indicates that in the conditions of lack of funding, the threat of damage and, at the same time, the need to ensure the energy efficiency of the heat supply systems of military towns (provided that current fuel costs are reduced), the modernization of the specified systems should be based on the principles of equipment modularity, phasing (with achieving improvements in system characteristics at each stage) and a single, systematic approach in their redesign.

The principle of phasing in the modernization of the specified systems is determined by the need to use existing equipment (in particular, boiler houses), if the costs of its maintenance and repair, its fuel costs do not exceed reasonable limits.

The principle of equipment modularity requires the provision, if necessary, of increasing its capacity by putting additional modules into operation, facilitating the possibility of changing its location, meeting the requirement of distributed placement of modules (which reduces the vulnerability of the equipment).

The need for a unified, systematic approach in the redesign of heat supply systems excludes eclecticism, which leads to a certain level of inefficiency of the system as a whole.

In our opinion, given the above peculiarities of thermal modernization of the heating system of military towns, it is advisable to also use combined options of equipment with elements that use alternative energy sources (Figure), which fully

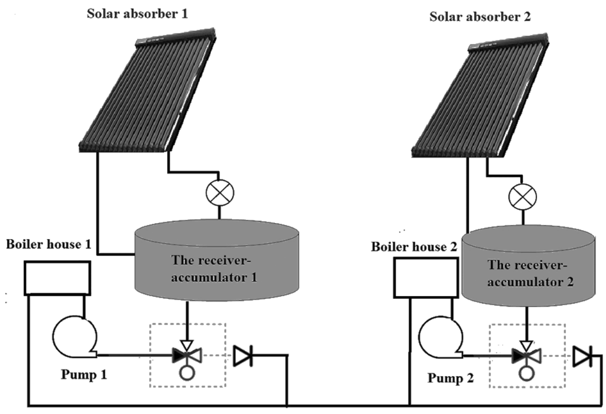

Fig. Combined version of the heat supply system for military towns using boiler houses and solar collectors corresponds to the mentioned conditions: the survivability of heat generation systems due to their dispersion on the territory of the military towns and not the localization of their placement; reliability, due to their attachment to heat-consuming objects; modularity of such boiler houses, which allows efficient and real saving of fuel resources; the possibility of phased implementation (which makes it possible to finance the modernization of the existing system in stages, distributed over time), etc.

Unfortunately, the geothermal systems proposed in the majority of scientific works by scientists from Europe and North America, in particular [6, 8], are too costly, so they are not used in the given analysis.

From this point of view, the geographical location of Ukraine favors the use of solar-absorbers. The simplicity of solar absorbers allows them to be produced in the workshops of military units, which greatly simplifies their implementation. In summer, solar-absorber can cover the need for hot water. At other times of the year, fuel consumption is reduced. The efficiency of solar absorbers depends on the geographical location of the military town. Ukraine is characterized by the presence of 4 zones. The most effective are, in particular, the Autonomous Republic of Crimea and Kherson district, where 1 sq. meter accounts for up to 1350 kWh of solar energy, which is equivalent to burning 140 cubic meters of natural gas. The least effective zone includes, in particular, Dnipro, Chernihiv, Sumy, Vyshhorod, Bucha, Brovary districts, where 1 sq. meter accounts for up to 1000 kWh of solar energy, which is equivalent to burning 120 cubic meters of natural gas. The advantages of solar absorbers are also that they: form a certain level of thermal autonomy of military towns due to the fact that they allow reducing the use of solid, liquid types of fuel and natural gas; do not require installation permits; have a long service life – more than 15 years.

Installation of solar absorbers requires the use of heat-insulated (perhaps, dug in the ground for this purpose) reservoirs – heat accumulators. Such tanks should be combined into a single system. Unification into a single system allows avoiding uneven distribution of heat load in the buildings of the military town and conducting heat accumulation in an efficient manner. According to the specifics of the activity, service premises are mostly characterized by uneven heat consumption during the day, and personal facilities are characterized by uneven heat consumption, in particular, due to the variable number of residents, because the composition of units in military towns is mostly variable, especially in war conditions.

Figure shows a conventional system that includes two solar absorbers and two boiler houses. Of course, there will be much more solar absorbers and boiler houses in the heat supply system of the military town.

We consider the fact that the number of boiler houses will not be equal to the number of solar absorbers, but will usually be much smaller – one boiler house per a certain number of consumers. The distribution of heat-generating equipment on the territory of the military town, its modular implementation reduces the vulnerability of the heat supply system, i.e. increases its survivability and reliability. The possibility of accumulating heat when using accumulator tanks increases the flexibility of the system during the day and even longer time intervals. The increase in the efficiency of heat accumulation and, accordingly, the increase in the flexibility of the system is facilitated by proper thermal insulation of the tanks, their number and size.

The data shown in Table 1 indicate that, with the condition of adequate funding provided for the modernization of the thermal generation system of the military town and the possibility of reliable shelter of the cogeneration plant from enemy aircraft and missile-bomb attacks and the solution of other problems indicated above, it is worth choosing these plants for energy and heat supply of military towns. At the same time, the analysis of the data presented in Table 1 indicates that the use of pellets allows reducing the fuel costs for the boiler houses of military camps, and that even in the winter period, the combined system of boiler houses and solar absorbers provides an additional opportunity to reduce costs for fuel This also shows that the cogeneration plant and the combined heat supply system based on boiler houses and solar absorbers are not competitive, because the conditions for their implementation are different. The difference in the specified conditions requires situational solutions regarding the modernization of heat supply systems of specific military towns.

The analysis of the tools for increasing the efficiency of the HSS in MT using a combined system is as follows.

The formation of a single system of accumulation and distribution of resources to consumers from storage tanks distributed in separate locations allows significantly increasing the efficiency of HSS in MT, firstly, due to the possibility of increasing the parameter p^{min} to p^{max} because this makes it possible to use not only the absorbers of temporarily uninhabited premises, but also their storage tanks. We draw attention to the fact that the lack of current consumption of the resource in these premises allows the accumulation of hot water of the highest temperature – that is, to create greater reserves of heat in them. Decreasing the t_{output} parameter for the entire system makes it possible to redistribute the resource between consumers in a more rational way, to reduce the likely wasteful use of high-temperature resources by some consumers and to avoid lack of the required quality resource for others, which, as a result, allows reducing specific heat losses for heating the required amount of water for each consumer. This allows one not only to offer the option of replacing or adding different sources of heat generation that work on a common heat supply system, to ensure the formation of a single HSS in MT, which creates and uses an intermediary subsystem from elements that differ in location, amount of resource, potential of this resource – for accumulation and effective distribution resource. This gives the reservoir system a new status rather than a secondary function. Modernization of the HSS on MT in the conditions of strict economy of budgetary resources involves the maximum use of the previously delivered heat generating equipment, boiler houses, and heating pipe networks. Therefore, the main task was to form a new network architecture, which ensured the formation of an intermediary subsystem. If it is possible to use an intelligent control system instead of a distributed analog system, this would allow creating a new quality of HSS in MT. We will give an example of choosing the power of heat supply sources, their parameters and characteristics, the method for choosing the parameters of these systems for thermal modernization of HSS for MT, the total heat consumption of which is close to 1000 kW (Table 2).

The location of the MT in the north of the country was chosen for the analysis. On the basis of the mentioned pecu-

Table 1

Comparison of average fuel costs for heating during the winter period of the military town building with a heating area of 200 m² by geographical zones, hryvnias

Type of fuel	Cogeneration plant	Boiler house	Combined option: boiler house and solar absorber
Mains gas	13,700	–	–
pellets	–	35,000	27,490
Briquettes	–	35,200	27,600
Coal	–	35,900	28,200
Birch firewood (moisture 40 %)	–	45,150	35,217
Diesel fuel	–	66,900	52,182
Electricity	77,750	–	–

Table 2

Characteristics of the combined HSS for MT, the total heat consumption of which is close to 1000 kW

Month	Total consumption, kW	Heat production capacity HS of MT, kW	Fuel economy, %
January	9500	800	8.4
February	9000	800	8.9
March	8000	800	10.0
April	5000	800	16.0
May	6000	6500	100.0
June	6500	7000	100.0
July	7000	7000	100.0
August	7000	7000	100.0
September	6000	6000	100.0
October	4800	800	16.7
November	7000	800	11.4
December	9500	800	8.4

liarities of HSS in MT, a water heating and steam boiler plant consisting of two modules and using solid fuel was chosen to replace the old boiler house. In addition to the need to meet the above conditions, these boiler houses are convenient to transport. If boilers, the production of which takes place in Ukraine, are selected, they can be replaced in a short period of time in case of their damage or destruction, which meets the requirements of HSS in MT. Flat water solar panels with a specific heat output of 0.7 kW per square meter with a total area of 10 acres are proposed for solar generators. They are inferior to tubular vacuum collectors in terms of efficiency and adsorption and emission coefficients, but are cheaper than them, which simplifies their replacement in case of damage or destruction, and are easier to maintain. It is assumed in the calculations that in the May-September period they should provide water heating by 15 °C on average in peak modes, and by 30 °C in the autumn-winter period. As it can be seen from Table 2, combined storage tank subsystem with the effective implementation allows providing consumers 5 months a year without the use of boiler houses.

Conclusion. The conducted research made it possible to propose a decision regarding the choice of heat-generating equipment for the modernization of the heat supply systems of military towns with the existing peculiarities of the thermal modernization of their heating system. The specified peculiarities are due to the need to provide the contingent with hot water in emergency situations, to meet the requirements of reliability and survivability of life support systems as well as of a significant number of normative documents of the Ministry of Defense of Ukraine, and the presence of certain problems of the operation of the heating system of military towns. These problems consist of considerable variability of the thermal load of military towns according to the seasons, due to changes in the number of contingents, etc.; their considerable cost; the fact that they are too vulnerable to air attacks. An analysis of a number of options was carried out and a combined option using boiler houses and solar absorbers was chosen. This makes it possible to make maximum use of the existing MT boiler equipment and heat networks during modernization. A combined option for the use of boiler houses and solar absorbers is proposed. For this option, a schematic solution for integrating the specified equipment into a single autonomous heat supply system of the military town has been developed. This made it possible to form a single HSS of MT, which not only creates an efficient subsystem of thermal energy generation, but, most importantly, creates an intermediary subsystem – from the accumulation and effective distribution of the resource for the system as a whole, from elements that differ in location, amount of resource, potential of this resource, previously intended to perform the local function of stable heat supply of a certain building, which significantly increases the efficiency of the HSS in MT. The specified decision allows one to increase the efficiency of the system, its reliability, survivability, to reduce costs, and provides the possibility of phased modernization according to the funding of the modernization of the specified system spread over time by the Ministry of Defense. It is suggested to use pellets for boiler houses of the combined system. This will not require changes to relevant regulatory documents of the Ministry of Defense. A mathematical model has been developed for the task of finding an effective system solution for supplying heat to a military town and identifying the facts of heat conductor leaks. It is noted that the use of computer equipment for the implementation of permanent control of the heat supply system of the military town is beyond the budget of the Ministry of Defense of Ukraine in wartime conditions. Therefore, automatic control of the solenoid valves based on the readings of the temperature sensors and heat conductor consumption is proposed. The developed mathematical model and schematic solution will allow one, even in the conditions of war and lack of budgetary funds, to carry out the modernization of the heat supply systems of military towns, to ensure the proper level of their efficiency, reliability, survivability, saving money and fuel resources.

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Особливості термомодернізації системи опалення військових інфраструктурних комплексів

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Мета. Запропонувати рішення модернізації систем теплопостачання (СТ) інфраструктурних комплексів, у тому числі військових містечок (ВМ), проблема надійного та ефективного опалення яких особливо важлива сьогодні. Розробити математичну модель пошуку ефективного рішення для задачі модернізації опалення й виявлення витоків теплоносія.

Методика. Використані спеціальні й загальні методи наукового пізнання: математичної формалізації – для побудови математичної моделі задачі теплопостачання ВМ і виявлення витоків теплоносія; індукції й дедукції – для вибору та обґрунтування доцільності використання обладнання для СТ ВМ; аналізу й синтезу – для розробки схемного рішення СТ ВМ.

Результати. Обґрунтовані варіанти рішень щодо вибору теплогенеруючого обладнання для модернізації СТ ВМ. Запропонована комбінована система за використання котелень і сонячних колекторів. Для комбінованої системи розроблене схемне рішення інтеграції обладнання в єдину автономну СТ ВМ і економний варіант автоматичного керування системою. Для котелень комбінованої системи запропоновано використовувати дешеве й доступне паливо – пеллети. Розроблена математична модель пошуку ефективного системного рішення СТ ВМ і виявлення витоків теплоносія.

Наукова новизна. Сформульовані особливі вимоги до СТ ВМ: автономність; високий рівень надійності, живучості; гнучкість у забезпеченні обсягів постачання тепла протягом доби, тижня, сезону; мінімізація вартості обладнання й палива для нього; можливість недорогого ремонту та оновлення. Проаналізовані варіанти модернізації СТ ВМ, розроблене схемне рішення інтегрованої СТ ВМ за комбінованого використання генеруючого обладнання.

Практична значимість. Розроблена математична модель і схемне рішення СТ ВМ, запропоновані варіанти використання обладнання й палива для нього дозволяють забезпечити належний рівень виконання особливих вимог до СТ ВМ.

Ключові слова: *термомодернізація, військові містечка, військові інфраструктурні комплекси, теплові мережі, енергоефективність*

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