Substantiation of Optimal Parameters for Managing a Hybrid Heat Pump Scheme

Hennadii OLISHEVSKYI[1)], Illia OLISHEVSKYI[2)], Ivan LUTSENKO[3)], Yevhenii KOSHELENKO[4)], Yuliya PAZYNICH[5)]

[1)] PhD, Associate professor, Associate Professor of the Department of Electric Power Engineering, Faculty of Electrical Engineering, Dnipro University of Technology, 19 Dmytra Yavornytskyi Avenue, Dnipro, Ukraine; https://orcid.org/0000-0001-9576-7527, email: olishevskyi.h.s@nmu.one;
[2)] PhD, Associate professor of the Department of Information Security and Telecommunications, Faculty of Information Technologies, Dnipro University of Technology, 19 Dmytra Yavornytskyi Avenue, Dnipro, Ukraine; https://orcid.org/0000-0001-8573-3366, email: olishevskiyih@gmail.com;
[3)] PhD, Associate professor, Professor of the Department of Electric Power Engineering, Faculty of Electrical Engineering, Dnipro University of Technology, 19 Dmytra Yavornytskyi Avenue, Dnipro, Ukraine; https://orcid.org/0000-0001-6406-2364, email: lutsenko.i.m@nmu.one;
[4)] PhD, Associate professor, Associate Professor of the Department of Electric Power Engineering, Faculty of Electrical Engineering, Dnipro University of Technology, 19 Dmytra Yavornytskyi Avenue, Dnipro, Ukraine; https://orcid.org/0000-0003-3600-1550, email: Koshelenko.ye.v@nmu.one;
[5)] PhD, Dr Associate professor of the Department of Business and Enterprise Management, Faculty of Management, AGH University of Krakow, al. Mickiewicza 30, PL-30059 Krakow, Poland; Ph.D, Associate Professor of the Department of Philosophy and Pedagogy, Dnipro University of Technology, 19 Dmytra Yavornytskyi Avenue, UA-49005 Dnipro, Ukraine; https://orcid.org/0000-0003-2516-8638; email: jpazynich@ukr.net

https://doi.org/10.29227/IM-2025-02-04-020

Submission date: 23-11-2025 | Review date: 11-12-2025

Abstract

This study examines and refines non-traditional heating approaches based on the integration of heat pump technology with renewable energy sources. A critical analysis of both existing implementations and proposed designs of energy-efficient heating systems has been conducted, emphasizing the potential for performance improvement through hybrid configurations. A novel solution is proposed involving the incorporation of solar collectors and thermal accumulators into a heat pump-based heating system, enabling efficient utilization of solar energy as a supplementary heat source. An algorithmic framework and a set of analytical expressions have been developed to determine the optimal values of key design parameters, including the effective surface area of the solar collector and the volume of the thermal accumulator. These parameters serve as the foundation for calculating the core thermodynamic and operational characteristics of the proposed hybrid system. To ensure the technical soundness of the solution, a mathematical model has been constructed to simulate thermodynamic and heat-exchange processes within the hybrid configuration. An automated calculation procedure has been implemented to support system design and parameter optimization, allowing for robust performance assessments under varying operational conditions. The simulation and analytical results confirm that the proposed hybrid heat pump heating scheme achieves up to 1.5 times greater energy efficiency compared to conventional ground-source heat pump systems. The findings substantiate the rationality of integrating renewable sources into heat pump systems and demonstrate a viable pathway for enhancing energy performance in sustainable building heating applications.

Keywords: *energy saving, conversion factor, solar collector, thermal pump, heat accumulator, renewable energy source, automated control*

1. INTRODUCTION

As early as 1973 during the first world oil crisis, all the industrialized countries adopted the global energy-saving strategy for each industry and corresponding technology [1]. The tendency remained unchangeable over following decades, which were accompanied by further regular world crises in the energy sector as well as in the global economy [2]. Unfortunately, for the moment nothing has changed for the better in this matter; moreover, such new challenges as military conflicts have been added complicating heavily the problems in the energy sector [3]. In Ukraine being under the conditions of full-scale invasion, the problem of any deficit in energy type generation is among the most urgent issues. Such a situation needs more and more measures as for saving of electric and thermal energy; gas; oil; and other power resources [1, 3, 4].

Use of renewable energy sources (RESs) as well as application of non-traditional power generation is among the most important trends in the policy of energy saving [5]. In a long time, the European Union has set a course for comprehensive development of 'green energy', and its percentage achieving up to the substantial value in the general energy generation balance to replace the traditional power production share impacting negatively the environment. In this connection, the EU enacts routinely additional regulatory acts favouring progress of the sector as well as other aspects of energy-saving policy [1, 6].

As a member of the community of the developed European countries, Ukraine always participates actively in all international energy-saving programs and implementation of non-traditional power generation. For the purpose, it timely joined and ratified appropriate international laws and agreements and provided own regulatory framework for the development and implementation of new, progressive and environmentally friendly alternative energy [1, 6, 7]. So, within

Tab. 1. Climatic data on Dnipro City

Tab. 1. Dane klimatyczne miasta Dniepr

Parameter	Oct	Nov	Dec	Jan	Feb	Mar
Average temp., °C	9	2	-2	-4	-3	3
Solar insolation, kWh/(m2 per day)	2.27	1.2	0.96	1.21	1.99	2.98
No of sunny days	15	10	3	4	3	7
No of cloudy days	7	13	21	22	19	15

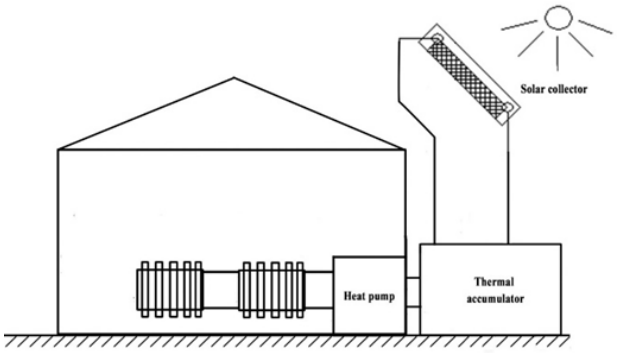


Fig. 1. Analytical scheme of a hybrid thermal pump warming system

Rys. 1. Schemat analityczny hybrydowego systemu ogrzewania z pompą cieplną

the framework of Paris Agreement 2015, Ukraine assumed following obligations to 2030: to increase a percentage of renewable energy sources in power industry up to 30% (as of the end of 2019, the RESs share was 10.9%); to reduce the number of coal TPPs; to implement gradual closure of coal mines in the complex with programs of coal region transformation; to increase heat generation by 30% while using biofuel (in 2018, amount of all RESs in heat supply was 8% in Ukraine); to carry out thermal modernization of buildings at a level of 1.3% of the total amount of houses annually; and to replace fossil energy sources with the renewable ones [1, 8].

As for vehicles, a share of electric cars should be increased up to 15% of all number of transport facilities; the process is quite successful today [1]. Since 2010, rapid construction of solar power plants has started [9]. The year before, the Green Tariff program was launched to stimulate electricity generation from alternative energy sources [1, 10]. This initiative aims to encourage investment in renewable energy by offering favourable rates for electricity sold to the grid [11]. Under the tariff system, the government purchases electricity produced by small hydroelectric power stations, as well as by wind and solar power plants [12]. Additionally, the program supports energy generated by facilities that convert biomass into fuel, promoting a broader shift toward sustainable energy production [13].

The integration of a vortex heat generator into a heat pump warming system enhances thermal efficiency by converting mechanical energy into heat through controlled translational–rotational gas flow dynamics [14]. Within the working chamber, the incompressible gas flow forms a stable vortex structure that intensifies heat transfer without direct combustion or harmful emissions [15]. This process increases the system's coefficient of performance (COP), allowing for effective low-temperature heat recovery and reducing dependence on traditional fossil fuels [14, 16]. By optimizing the hydrodynamic conditions of the vortex motion, the heat pump can operate more reliably under variable environmental conditions [17]. The system also contributes to environmental protection by minimizing greenhouse gas emissions and utilizing clean mechanical-to-thermal energy conversion [18]. As a result, the proposed hybrid design represents a sustainable and energy-efficient approach to residential and industrial heating.

In such a way, it is the mechanism intended to encourage the population for generating electricity using alternative energy sources. In 2010, solar power plants (SPPs) were put into operation which total capacity was 3 MW; in 2020, the performance was 6320 MW. In the first quarter of 2021, the share of SPPs in the general Ukrainian power generation was almost 6%. Consequently, a portion of power generation by RESs before the full-scale invasion achieved 12.5% in the overall energy balance of the country. Moreover, the power generation also includes hydroelectric power stations (9.2%) and pumped storage power plants (1.3%) [19].

Hence, the national energy sector was developing successfully until the full-scale invasion began. Unfortunately, over the past three years, a substantial portion of the country's power generation capacity, particularly thermal power plants and hydroelectric facilities, has been severely damaged or destroyed. As a result, the role of alternative energy sources and the corresponding infrastructure has become increasingly critical for maintaining energy security [1, 20]. This shift also underscores the growing importance of modern thermal generation systems, such as heat pumps, in ensuring stable and efficient energy supply [21].

Currently, there are numerous non-traditional power plants using RESs, namely solar power stations; solar collectors; wind generators; heat pumps; tidal power stations; geothermal power plants etc [22]. Each of the devices has its own undeniable advantages and disadvantages. Solar plants cannot operate in the nighttime; moreover, together with wind generators, they depend completely upon weather [23]. Application place and time are important since their efficiency and productivity depend heavily upon the factors. Relevant comments can be found concerning other types of non-traditional power plants [3, 24]. Thermal pumps for indoor heating are far from having the highest efficiency indicators; in addition, rather often they operate under the minimum permissible indicators of a conversion factor at an unfavourable temperature ratio between the heat source and the ambient temperature

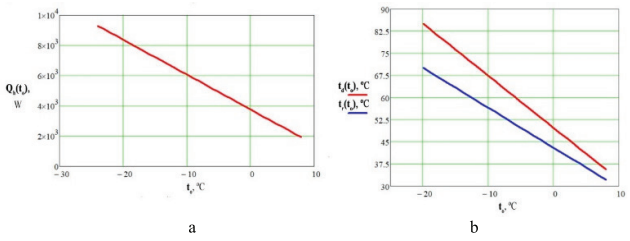


Fig. 2. Thermal loading of the warming system (a) and water temperature in a straight and return pipelines (b)
Rys. 2. Obciążenie cieplne układu grzewczego (a) i temperatura wody w rurociągach prostym i powrotnym (b)

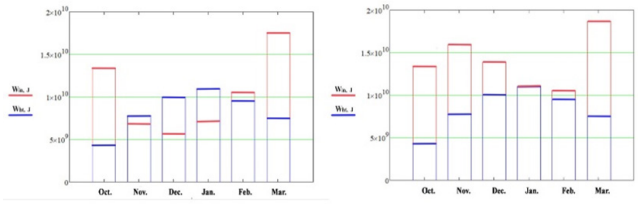


Fig. 3. Monthly heat by the solar collector W_{in} and heat consumed by the warming system
Rys. 3. Miesięczne ciepło z kolektora słonecznego W_{in} i ciepło pobierane przez instalację grzewczą

[5, 25]. Hence, a tendency is available currently as for the improvement of one plant efficiency at the expense of its use as a part of non-traditional facility of another type [26]. The idea is rather topical under the difficult power generation conditions of today [27].

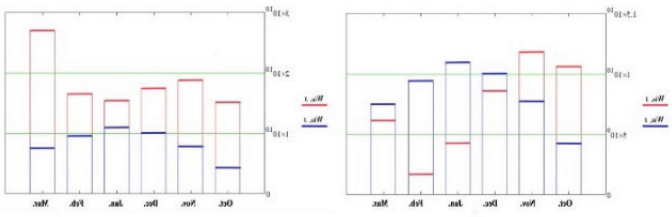
Consequently, the primary objective of this research is to substantiate the optimal parameters for a heat pump-based heating system. This system also incorporates a solar collector and a thermal accumulator, which together function as an integrated artificial renewable energy source (RES). The study aims to enhance the overall efficiency and sustainability of thermal energy supply by optimizing the interaction of these components under varying operational conditions.

2. ANALYSIS OF THE RESEARCH PROBLEM

Currently, thermal pumps are common. They are widely used and their application increases not only in the industrialized countries as it used to be but also all over the world. The number of the mounted facilities is tens of millions [2]. Plans to erect new thermal pumps in Europe are grandiose since it set as a goal to improve energy indicators of 35 000 000 buildings up to 2030 for achieving decarbonization purposes [2-3, 28]. If the size of the market for thermal pumps used in heating is determined by the volume of available financing, then their share in the heating sector is expected to grow significantly [29]. Under such a scenario, thermal pumps could account for up to 80% of the heating market by 2030. This projected growth reflects increasing investments in energy-efficient technologies and the global shift toward sustainable and low-carbon heating solutions [28-30]. Classification of thermal pumps is rather diverse and well-known. Depending upon the ratio between the heat source environment and environment to be heated, they may be thermal pumps from a ground-water type for the most powerful warming systems to an air-air type for less loaded systems. Currently, numerous proposals are available as well as already implemented schemes of thermal pump use for indoor heating. They can be either the most common basic schemes where heat is removed from the traditional low-potential thermal sources and transferred to water- or air-based warming systems or various original schemes to use or utilize various flows of thermal energy being within easy reach. For example, paper [6] considers the possibilities to utilize conditioning system heat for hot water supply needs in summer; here not only the heat removed from premises is applied with benefit but also energy consumption by a compressor drive drops significantly. Paper [4] describes use of heat by the consumed air of ventilation system in winter for hot water supply needs; the abovementioned also results in real energy saving to compare with electric boiler. Thermal accumulators were applied for the schemes. Paper [5] studied the possibility to reverse an operating mode of a ground heat pump in summer cooling mode without thermal accumulator use adding blowing of radiator ribs which can factor into 18% of energy saving to compare with air conditioner + thermal accumulator scheme. Moreover, it becomes popular to use large thermal accumulators (with a heat pump and without it) storing differently the thermal energy in a warm period to be used for heating in winter. Paper [6] analyses use of large seasonal thermal accumulators in a heat pump warming system, which accumulated thermal energy from air conditioning in a warm period. The results have shown 39% of reference fuel economy compared to a scheme where thermal accumulator was not available, and 79% compared with boiler + conditioner scheme. Paper [7] describes methods to identify optimal parameters of a control over a thermal pump operation used by our research while developing models.

A decision has been made to analyse the possibility of a thermal accumulator use for heat energy storing. Only solar collectors were involved. It was decided to assume one month as the basic period for study of power balances of a warming system. In such a way, the system will operate in a dynamic thermal mode practically without previous energy accumulation during a heating period. Thermal accumulator will act as a RES energized by solar collectors recommended regularly in the context of different hybrid schemes [8, 20-22].

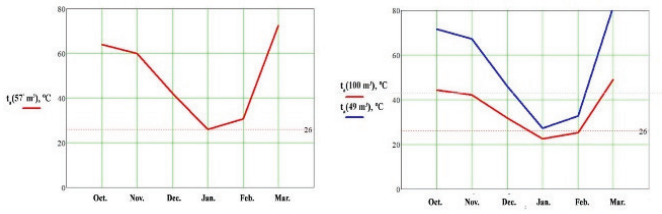
Use of thermal pumps to remove calorific energy from different sources is a promising technique the research by the world scientists is focused on [23, 25]. Not only thermody-



a b

Fig. 4. Ratio between the thermal balance components of the heating system if the solar collector useful area is less than the rational value (a) and more than it (b)

Rys. 4. Stosunek składników bilansu cieplnego instalacji grzewczej w przypadku, gdy powierzchnia użytkowa kolektora słonecznego jest mniejsza od wartości racjonalnej (a) i większa od niej (b)



a b

Fig. 5. Water temperature change in a thermal accumulator under rational value of its amount (a) and under other values of the accumulator volume (b)

Rys. 5. Zmiana temperatury wody w akumulatorze cieplnym przy racjonalnej wartości jej objętości (a) i przy innych wartościach objętości akumulatora (b)

namic aspects of the processes being the basis of power benefit of the technology generate interest but also the possibilities for optimal control of the system parameters helping achieve the peak accuracy of the set parameters while minimizing energy resource consumption [24, 26-27] and maximizing solar energy attraction both electrically and thermally [31].

Hence, the research objective is to substantiate the rational parameters for thermal pump warming system in terms of average in size cottage under the conditions of Dnipro City with the use of a thermal accumulator and solar collector [32]. For the purpose, automated methods were developed to calculate rational parameters of a non-traditional heating system based upon mathematical modelling of thermodynamic processes taking place in the warming facilities.

3. THE RESEARCH METHODOLOGY AND METHODS FOR OPTIMAL PARAMETERS OF THE HYBRID HEAT PUMP

The research methodology is based on a comprehensive theoretical and computational analysis aimed at optimizing the operational and structural parameters of a hybrid heat pump heating system that integrates renewable energy sources [33]. A systems engineering approach is applied to evaluate the interaction between key components of the system, including the heat pump unit, solar collector, and thermal accumulator [34]. The overall focus is placed on enhancing energy efficiency and reducing environmental impact through rational system management and optimal parameter selection [34, 35].

The research methods include several interrelated techniques. Analytical modelling was used to develop mathematical descriptions of the thermodynamic and heat-exchange processes occurring within the hybrid system, accounting for energy balance, mass flow rates, thermal losses, and solar energy input [36]. Parametric optimization was carried out using a dedicated algorithm to determine the most effective values for critical design parameters, such as the area of the solar collector and the volume of the thermal accumulator, with objectives centred on maximizing efficiency and minimizing cost [37]. Computational simulation supported model verification and performance analysis, using tools like MATLAB and other specialized engineering software to solve nonlinear systems and conduct iterative calculations [38,39].

The comparative efficiency analysis was conducted to benchmark the performance of the proposed hybrid system against conventional ground-source heat pump configurations, using metrics such as the coefficient of performance (COP), total energy consumption, and renewable energy contribution [39, 40]. To support practical implementation, an automated calculation procedure was developed, allowing users to select system parameters based on real-world data and design goals [38-41]. This methodological framework offers a robust foundation for substantiating rational design and management strategies in the development of advanced hybrid heat pump heating systems [37]

Algorithm of automated calculation methods for non-traditional heating systems:

- determination of the geometrical and heat engineering characteristics of the building, climatic data of the area, and physical parameters of heat-transport medium and coolant;
- formation of the functions of thermal loading of the building, and calculation of temperature functions in a straight and return pipelines of the heating system depending upon the ambient temperature;
- formation and introduction of the functions of the coolant enthalpy depending upon condensation temperature using four basic points of a refrigeration cycle for the set evaporation temperatures (relying upon p and i being a diagram of the selected coolant);
- formation of the functions of the specific characteristics of the refrigeration cycle (i.e. cooling capacity, condenser load, and theoretical compressor operation) depending upon condensation temperature for

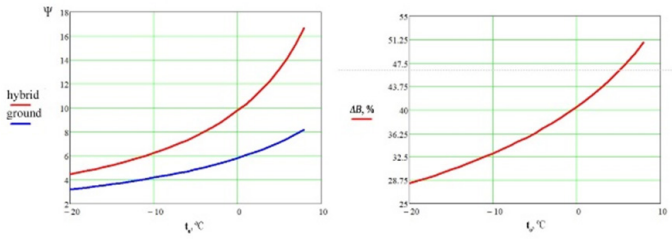


Fig. 7. Dependencies of energy conversion ratios Ψ for the hybrid and ground heating systems upon the ambient temperature to
Rys. 7. Zależności współczynników konwersji energii Ψ dla hybrydowego i gruntowego systemu grzewczego od temperatury otoczenia

the set evaporation temperatures;

- formation of the functional dependencies of power parameters of a heat pump (i.e. mass coolant flow, capacity consumed by a compressor drive, cooling capacity, energy conversion factor, and refrigerant condensation temperatures) upon thermal loading of the heating system as well as upon the ambient temperature for the set temperatures of the coolant evaporation;
- formation of a functional dependence of thermal energy quantity generated by the solar collector upon its useful area $W_{ins}(f_a)$ for the period from a heating season start to a month with average air temperature inclusive, and determination of thermal energy quantity to be consumed by a warming system of the building for the same period W_h;
- determination of rational value of the solar collector useful area f_a^* if following power balance equation is implemented

$$W_{ins}(f_a) = W_h, J; \quad (1)$$

- formation of the functions of terminal water temperature in a thermal accumulator for each month of a heating season depending upon water volume in it;
- determination of the rational water volume in a thermal accumulator (i.e. its rational volume in conversion) if water temperature in a thermal accumulator is equal to the minimum permissible value in the most loaded month. The value is identified based upon the results of study of terminal water temperature in a thermal accumulator formed in the previous paragraph of the methods; and
- determination of all power parameters of the complex heat pump warming system relying upon the defined rational values of the solar collector useful area, thermal accumulator volume, and other output data.

4. RESULTS AND DISCUSSION FOR MANAGING A HYBRID HEAT PUMP

The development of the methods involved both analytical techniques and numerical modeling to comprehensively understand the system's behavior. These approaches allowed for detailed examination of thermodynamic and heat transfer processes within the hybrid heat pump system. The numerical models were specifically implemented using the Mathcad Professional software environment, which provided robust tools for symbolic calculations and numerical analysis. This environment facilitated the creation of flexible and accurate simulation models that could be easily adjusted for different system configurations. Figure 1 illustrates the basic analytical scheme of the plant, highlighting the key components and their interactions. The scheme serves as a visual representation of the system layout and forms the basis for the mathematical modeling efforts. Together, these methods enable precise parameter estimation and performance evaluation critical to optimizing the heating system. This schematic serves as the foundation for the subsequent modeling and analysis processes.

Substantiating the rational parameters of the hybrid thermal pump warming system. The abovementioned methods have been applied to study energy efficiency of the hybrid scheme of a thermal pump warming system for a private house which average size is 15x12 m and ceiling height is 2.5 m. The climatic conditions are typical for Dnipro City. Table 1 explains the basic climatic parameters used for calculation in accordance with corresponding months of a heating season [1].

The thermal pump plant is of a vapour-compression type operating in terms of the basic refrigeration cycle; water is applied as an accumulating substance. Owing to the use of a thermal accumulator, evaporation temperature of the heat pump is raised up to 20°C. Condensation temperature is regulated by a warming control system depending upon thermal loading on the heating and being determined by the ambient temperature.

The house has the current thermal characteristics as for heat losses to the environment. Internal air temperature is 21°C. According to the methods, dependencies of thermal loading Q_h on the heating system upon the ambient temperature t_o were obtained as well as graphs of temperature dependencies in a straight $t_d(t_o)$ and return $t_r(t_o)$ pipelines of water radiator heating system (Fig. 2), and other basic parameters of the system.

Further, (1) was applied to identify rational value of the solar collector useful area $f_a^* = 53$ m^2. In this regard, the methods take into consideration month-by-month change in the solar collector efficiency depending upon insolation. Following step is demonstration of monthly energy ratios generated by the solar collector. The energy should be consumed by the thermal pump heating system without use of a thermal accumulator (Fig. 3). The months show imbalances varying in value and signs. Hence, it is possible to state that continuous operation of the heating system is impossible if the solar collector energy redistribution between months does not take place in the thermal accumulator. Namely, through the thermal accumulator, the solar energy excess will be stored in some months to be used in other ones where solar insolation is less. The methods help demonstrate the abovementioned relying upon the results of corresponding calculations taking

into consideration the thermal accumulator use. The mode complies with the rational value of the solar collector useful area f_a^*. Right in January, the complete energy balance of the system is achieved, i.e. energy input into a thermal accumulator is equal to the energy consumption.

Fig. 4 demonstrates episodes of energy balance when useful area values of the solar collector are more and less than the rational value f_a^*. It is seen that in the context of the episodes, the solar energy is not sufficient for the most loaded month (i.e. January) or excessive solar energy input takes places for all months. Hence, the methods are correct as for the rational value f_a^* definition.

Then, the developed methods helped substantiate and identify a rational value of the required water amount in the thermal accumulator or in conversion, its rational amount (i.e. 57* m^3). In this regard, in early October water temperature was 18°C; during following fourteen days it warmed up. After that, the heating system switched on and operated in accordance with its thermal loading (Fig.2). Relevant functions, formed according to the methods, were involved. To avoid decrease in the terminal temperature in the thermal accumulator below 26°C in the most loaded month (i.e. January), the rational water amount has been defined as well as the thermal accumulator volume. Fig. 5 shows temporal graph of changes in the terminal monthly water temperature t_a in the accumulator for rational value of the accumulator amount (a), and for greater (100 m^3) and smaller (49 m^3) amount values (b). It should be mentioned that if accumulator amount is more than rational one then minimum terminal temperature in January will be less than 26°C. In such a way, violation of thermal exchange between evaporator and accumulator will happen. If the amount is less than the rational one then water temperature increase takes place, which cannot be completely provided by rather cloudy climatic conditions of the area. Hence, we assume rather low level of the basic water temperature values; as for more sunny days, the scheme efficiency has obvious tendencies to be improved.

Consequently, having determined the important rational parameters of the hybrid heating system (i.e. useful area of the solar collector, and the thermal accumulator volume) and relying upon the developed methods, each basic power parameter of the thermal pump plant turns out to be formed according to relevant functions. In addition, the improved energy efficiency of the hybrid heating system has been identified for the case to compare with the standard ground thermal pump plant. Taking into consideration the fact that in terms of such a facility, a coolant evaporation temperature is about 4°C, the methods helped obtain relevant graphs of energy conversion ratio Ψ dependence upon the ambient temperature t_o (Fig. 6). In addition, dependence of reference fuel economy of the hybrid heating system ΔB upon the ambient temperature has been identified to compare with a ground plant (Fig. 7). Having analyzed the dependencies, it becomes possible to draw a conclusion on the high efficiency of the proposed hybrid thermal pump plant which may substantially (on average one and a half times) increase energy saving of the available non-traditional heating system if only rational values of the system parameters are defined correctly.

The developed methods combining analytical techniques and numerical modeling successfully substantiated the rational parameters for managing a hybrid heat pump heating system under typical climatic conditions of Dnipro City. The research demonstrated that integrating a thermal accumulator with a solar collector significantly stabilizes the system's energy balance throughout the heating season, enabling continuous operation even during months with low solar insolation. The identification of the optimal useful area of the solar collector and the appropriate thermal accumulator volume was critical for achieving a balanced thermal energy supply and demand. Thermal performance analyses showed that deviations from these optimal parameters lead either to energy shortages during peak demand or excessive solar energy input, which reduces overall efficiency. Comparative evaluations confirmed that the hybrid system outperforms conventional ground-source heat pumps, providing on average a 1.5-fold increase in energy efficiency and fuel savings. These results validate the proposed methodology as an effective tool for designing and managing energy-efficient, renewable-integrated heating systems tailored to specific climatic conditions.

5. CONCLUSION

This study presents a comprehensive investigation into the optimization and management of a hybrid heat pump heating system integrating renewable energy components. Through the development of advanced analytical and numerical methods tailored to the specific system configuration, the research addresses critical parameters such as the solar collector area and thermal accumulator volume. Emphasizing dynamic energy exchange and practical implementation, the findings offer valuable insights into improving energy efficiency and operational reliability. The following conclusions summarize the key outcomes and implications of this work, highlighting the system's potential advantages over conventional heating solutions.

1. The proposed hybrid heat pump system is efficient and promising for practical application, allowing effective control and management of system parameters while comparing favourably to natural renewable energy sources.

2. Using a monthly period as the fundamental timeframe for energy exchange within the thermal accumulator enables the hybrid system to operate dynamically, effectively redistributing thermal energy between months and avoiding the need for large seasonal accumulators.

3. The developed automated calculation methods demonstrate high adequacy and precision, focusing specifically on the chosen non-traditional heating scheme rather than relying on generalized or approximate approaches commonly used in heating equipment design.

4. The reliability of the calculations is ensured through detailed mathematical modelling of the thermodynamic and heat-exchange processes occurring within the hybrid system, tailored to the specific plant scheme.

5. Analytical research confirms the soundness of the mathematical models and assumptions used in the algorithm to determine optimal values for the solar collector's useful area and the thermal accumulator's volume.

6. Comparative studies show that the hybrid heat pump system significantly outperforms conventional ground-source heat pump setups, providing on average 1.5 times higher efficiency and a mean reference fuel saving of approximately 40%.

Literatura – References

1. Pivnyak, G., Olishevska, V., Olishevskiy, H., Lutsenko, I., Lysenko, A., & Sala, D. (2024). Comprehensive study on electric vehicles and infrastructure for sustainable development in Ukraine. E3S Web of Conferences, 567, 01025. https://doi.org/10.1051/e3sconf/202456701025
2. Lewicka, D. (2010). The impact of HRM on creating proinnovative work environment. International Journal of Innovation and Learning, 7(4), 430. https://doi.org/10.1504/ijil.2010.032932
3. Vladyko, O., Maltsev, D., Gliwiński, Ł., Dychkovskyi, R., Stecuła, K., & Dyczko, A. (2025). Enhancing Mining Enterprise Energy Resource Extraction Efficiency Through Technology Synthesis and Performance Indicator Development. Energies, 18(7), 1641. https://doi.org/10.3390/en18071641
4. Olishevskiy, G., & Olishevskiy, I. (2021). Rational heat recovery technologies of ventilation systems for heating building systems. Journal of Rocket-Space Technology, 28(4), 164–174. https://doi.org/10.15421/452022
5. Olishevskyi, I., & Olishevskyi, H. (2021). Automated method of calculation of parameters for non-traditional heating technologies and conditioning of buildings. Electrical Engineering and Power Engineering, (3), 40–47. https://doi.org/10.15588/1607-6761-2021-3-4
6. Olishevskyi, I. H. (2024). Results of development and research of the technology for automated energy-efficient control of heat pump systems by means of computer experiment. Herald of Khmelnytskyi National University. Technical Sciences, 335(3(1)), 419–428. https://doi.org/10.31891/2307-5732-2024-335-3-58
7. Moroz, B. I., Shvachych, H. H., Selehei, A. M., Krekoten, M. A., Olishevskyi, I. H., & Zhamanbayev, B. U. (2024). Model for optimal control of charge loading parameters of metal-reducing plants. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, (6), 129–135. https://doi.org/10.33271/nvngu/2024-6/129
8. Dychkovskyi, R., Falshtynskyi, V., Saik, P., Lozynskyi, V., Sala, D., Hankus, Ł., Magdziarczyk, M., & Smoliński, A. (2025). Control of contour evolution, burn rate variation, and reaction channel formation in coal gasification. Scientific Reports, 15(1). https://doi.org/10.1038/s41598-025-93611-3
9. Lin, Y., Bu, Z., Yang, W., Zhang, H., Francis, V., & Li, C.-Q. (2022). A review on the research and development of solar-assisted heat pump for buildings in China. Buildings, 12(9), 1435. https://doi.org/10.3390/buildings12091435
10. Rehman, O. A., Palomba, V., Frazzica, A., Charalampidis, A., Karellas, S., & Cabeza, L. F. (2023). Numerical and experimental analysis of a low-GWP heat pump coupled to electrical and thermal energy storage to increase the share of renewables across Europe. Sustainability, 15(6), 4973. https://doi.org/10.3390/su15064973
11. Polyanska, A., Pazynich, Y., Petinova, O., Nesterova, O., Mykytiuk, N., & Bodnar, G. (2024). Formation of a Culture of Frugal Energy Consumption in the Context of Social Security, pp. 60-87. The Journal of the International Committee for the History of Technology, 29(2), 60–87. https://doi.org/10.11590/icon.2024.2.03
12. Beshta, O. S., Beshta, O. O., Khudolii, S. S., Khalaimov, T. O., & Fedoreiko, V. S. (2024). Electric vehicle energy consumption taking into account the route topology. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 2, 104–112. https://doi.org/10.33271/nvngu/2024-2/104
13. Fedoreiko, V.S., Zahorodnii, R.I., Lutsyk, I.B., & Rutylo, M.I. (2017). Modeling of block of electricity generation of cogeneration system for heat generator. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, (2), 87–92.
14. Nikolsky, V., Dychkovskyi, R., Cabana, E. C., Howaniec, N., Jura, B., Widera, K., & Smoliński, A. (2022). The Hydrodynamics of Translational–Rotational Motion of Incompressible Gas Flow within the Working Space of a Vortex Heat Generator. Energies, 15(4), 1431. https://doi.org/10.3390/en15041431
15. Pavlychenko, A., Sala, D., Pyzalski, M., Dybrin, S., Antoniuk, O., & Dychkovskyi, R. (2025). Utilizing Fuel and Energy Sector Waste as Thermal Insulation Materials for Technical Buildings. Energies, 18(9), 2339. https://doi.org/10.3390/en18092339
16. Nikolsky, V., Dychkovskyi, R., Lobodenko, A., Ivanova, H., Cabana, E.C. & Shavarskyi, Ja. (2022). Thermodynamics of the Developing Contact Heating of a Process Liquid. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 2, 48 – 53. https://doi.org/10.33271/nvngu/2022-2/048
17. Vetel, J., Plourde, F., & Doan-Kim, S. (2000). Influence of hydrodynamic conditions on the vortex shedding phenomenon. 6th Aeroacoustics Conference and Exhibit, 1-12. https://doi.org/10.2514/6.2000-2000
18. Nikolsky, V., Kuzyayev, I., Dychkovskyi, R., Alieksandrov, O., Yaris, V., Ptitsyn, S., Tikhaya, L., Howaniec, N., Bak, A., Siudyga, T., Jura, B., Cabana, E., Szymanek, A., & Smoliński, A. (2020). A Study of Heat Exchange Processes within the Channels of Disk Pulse Devices. Energies, 13(13), 3492. https://doi.org/10.3390/en13133492
19. The New Voice of Ukraine. (2025, February 25). Ukraine restores up to 5 GW of lost power capacity since 2022 — report. https://english.nv.ua/business/ukraine-restores-5-gw-of-power-capacity-lost-since-2022-but-energy-imports-remain-critical-50518150.html
20. Dychkovskyi, R., Tabachenko, M., Zhadiaieva, K., & Cabana, E. (2019). Some aspects of modern vision for geoenergy usage. E3S Web of Conferences, 123, 01010. https://doi.org/10.1051/e3sconf/201912301010

21. Rivas-Cruz, F., Hernández-Martínez, E. G., & Papadimitriou-Suarez del Real, L. E. (2022). Heating and cooling with heat pumps – Projects developed in Mexico. Renewable Energy, Biomass & Sustainability, 3(2), 94–108. https://doi.org/10.56845/rebs.v3i2.59

22. Widiatmojo, A., Chokchai, S., Takashima, I., Uchida, Y., Yasukawa, K., Chotpantarat, S., & Charusiri, P. (2019). Ground-source heat pumps with horizontal heat exchangers for space cooling in the hot tropical climate of Thailand. Energies, 12(7), 1274. https://doi.org/10.3390/en12071274

23. Zhang, H., & Lao, J. (2022). Economic analysis of two heat pumps to recover heat from circulating water. E3S Web of Conferences, 358, 01009. https://doi.org/10.1051/e3sconf/202235801009

24. Beshta, O., Albu, A., Balakhontsev, A., & Fedoreyko, V. (2015). Universal model of the galvanic battery as a tool for calculations of electric vehicles. Power Engineering, Control and Information Technologies in Geotechnical Systems, 7–11. https://doi.org/10.1201/b18475-2

25. Conrad, J., & Greif, S. (2019). Modelling load profiles of heat pumps. Energies, 12(4), 766. https://doi.org/10.3390/en12040766

26. Derii, V. O., Sokolovska, I. S., & Teslenko, O. I. (2021). Prospects for using heat pumps in district heating systems around the world and Ukraine. The Problems of General Energy, 2021(3), 43–52. https://doi.org/10.15407/pge2021.03.043

27. Di Schio, E. R., Ballerini, V., & Valdiserri, P. (2022). The bin method to investigate the effect of climate conditions on the SCOP of air source heat pumps: The Italian case. WSEAS Transactions on Heat and Mass Transfer, 17, 124–130. https://doi.org/10.37394/232012.2022.17.13

28. Witkowska, A., Krawczyk, D. A., & Rodero, A. (2021). Analysis of the heat pump market in Europe with a special regard to France, Spain, Poland, and Lithuania. Environmental and Climate Technologies, 25(1), 840–852. https://doi.org/10.2478/rtuect-2021-0063

29. Polyanska, A., Sala, D., Psyuk, V., & Pazynich, Y. (2025). A Multicriteria Approach to the Study of the Energy Transition Results for EU Countries. https://doi.org/10.20944/preprints202509.0758.v1

30. Niemierka, E. (2018). The residential heat pumps' impact on national CO2 emission. E3S Web of Conferences, 44, 00123. https://doi.org/10.1051/e3sconf/20184400123

31. Parus, E., Blinov, I., Rybina, O., Olefir, D., Sala, D., Tora, B., & Dychkovskyi, R. (2025). Improving the Electricity Market Participation Management of Hydropower Plants in Ukraine. Inżynieria Mineralna, 1(1). https://doi.org/10.29227/im-2025-01-26

32. Lapshyn, Y. (2025). Feasibility of Fine Classification in Processing Watered Coal Sludge from Storage: A Case Study of the Dnipro Coke Chemical Plant. Acta Montanistica Slovaca, 100. https://doi.org/10.46544/ams.v30i1.07

33. Shcherba, A., Vinnychenko, D., Suprunovska, N., Roziskulov, S., Dyczko, A., & Dychkovskyi, R. (2025). Management of Mobile Resonant Electrical Systems for High-Voltage Generation in Non-Destructive Diagnostics of Power Equipment Insulation. Electronics, 14(15), 2923. https://doi.org/10.3390/electronics14152923

34. Bashynska, I., Niekrasova, L., Ivliev, D., Dudek, M., Kosenkov, V., & Yakimets, A. (2024). Justification for Transitioning Equipment to Direct Current for Smart Small Enterprises with Sustainable Solar Power Autonomy. 2024 IEEE 5th KhPI Week on Advanced Technology (KhPIWeek), 1–6. https://doi.org/10.1109/khpiweek61434.2024.10878001

35. Hepbasli, A., & Kalinci, Y. (2009). A review of heat pump water heating systems. Renewable and Sustainable Energy Reviews, 13(6–7), 1211–1229. https://doi.org/10.1016/j.rser.2008.08.015

36. Wang, S., & Ma, Z. (2008). Supervisory and optimal control of building HVAC systems: A review. HVAC&R Research, 14(1), 3–32. https://doi.org/10.1080/10789669.2008.10390991

37. Kalogirou, S. A. (2004). Solar thermal collectors and applications. Progress in Energy and Combustion Science, 30(3), 231–295. https://doi.org/10.1016/j.pecs.2004.02.001

38. MATLAB. (2020). MATLAB user guide. MathWorks. https://www.mathworks.com

39. Chua, K. J., Chou, S. K., & Yang, W. M. (2010). Advances in heat pump systems: A review. Applied Energy, 87(12), 3611–3624. https://doi.org/10.1016/j.apenergy.2010.06.014

40. Blinov, I., Radziukynas, V., Shymaniuk, P., Dyczko, A., Stecuła, K., Sychova, V., Miroshnyk, V., & Dychkovskyi, R. (2025). Smart Management of Energy Losses in Distribution Networks Using Deep Neural Networks. Energies, 18(12), 3156. https://doi.org/10.3390/en18123156

41. Bashynska, I. (2025). Ethical aspects of AI use in the circular economy. AI & SOCIETY, 1–19. https://doi.org/10.1007/s00146-025-02436-1

Uzasadnienie optymalnych parametrów zarządzania hybrydowym systemem pompy ciepła

W niniejszym badaniu analizowane i udoskonalane są niekonwencjonalne metody ogrzewania oparte na integracji technologii pomp ciepła z odnawialnymi źródłami energii. Przeprowadzono krytyczną analizę zarówno istniejących wdrożeń, jak i proponowanych projektów energooszczędnych systemów grzewczych, podkreślając potencjał poprawy wydajności poprzez konfiguracje hybrydowe. Zaproponowano nowatorskie rozwiązanie obejmujące integrację kolektorów słonecznych i akumulatorów ciepła w systemie grzewczym opartym na pompie ciepła, co umożliwia efektywne wykorzystanie energii słonecznej jako dodatkowego źródła ciepła. Opracowano ramy algorytmiczne i zestaw wyrażeń analitycznych w celu określenia optymalnych wartości kluczowych parametrów projektowych, w tym efektywnej powierzchni kolektora słonecznego i objętości akumulatora ciepła. Parametry te stanowią podstawę do obliczenia podstawowych charakterystyk termodynamicznych i eksploatacyjnych proponowanego systemu hybrydowego. Aby zapewnić techniczną poprawność rozwiązania, skonstruowano model matematyczny symulujący procesy termodynamiczne i wymiany ciepła w konfiguracji hybrydowej. Wdrożono zautomatyzowaną procedurę obliczeniową wspomagającą projektowanie systemu i optymalizację jego parametrów, umożliwiającą rzetelną ocenę wydajności w zmiennych warunkach eksploatacyjnych. Wyniki symulacji i analiz potwierdzają, że proponowany hybrydowy system ogrzewania z pompą ciepła osiąga nawet 1,5-krotnie wyższą efektywność energetyczną w porównaniu z konwencjonalnymi systemami gruntowych pomp ciepła. Wyniki te uzasadniają racjonalność integracji odnawialnych źródeł energii.

Słowa kluczowe: *oszczędność energii, współczynnik konwersji, kolektor słoneczny, pompa cieplna, akumulator ciepła, odnawialne źródło energii, sterowanie automatyczne*