DETERMINING THE EFFICIENCY OF SCHEME SOLUTIONS OF HEAT-AND-ELECTRICITY GENERATING AGGREGATES BASED ON LIQUID-VAPOR JET DEVICES

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DOI: 10.17973/MMSJ.2026_06_2026009

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The aim of the research is to assess the energy efficiency of proposed heat, electricity and hot water supply systems for apartment buildings. Schematic solutions of heat and power generating units based on liquid-vapor jet devices. The proposed schemes are improved solutions for mini-TPP and heat pump unit, and fundamentally new decisions have been developed, the so-called combined scheme of heat-&-electricity power generating aggregate, which has all the advantages of the previous two schemes. For the studied building, the parameters determining the heating system operation were previously determined, including hot water consumption based on the number of residents and electricity consumption defining the required turbine power. To determine feasibility of using heat-&-electricity power generating aggregate based on liquid-vapor jet devices, thermodynamic, exergetic and thermoeconomic analyses were performed. As a result of thermodynamic analysis, the load and power of devices included in proposed scheme solutions were determined, as well as the values of the main material flows participating in the energy conversion process in the proposed schemes. As a result of the exergetic analysis, the efficiency of the proposed schemes was determined. The most effective was the combined scheme, which is 23% better than the heat pump unit and 11% better than the mini-TPP. According to the results of the thermoeconomic analysis, the tariffs at which residents will receive heat, hot water and electricity were determined and compared with the current state ones. The combined scheme turned out to be the best. For it, the tariffs are on average 32-35% lower than the state ones for civil consumers.

KEYWORDS

heat-&-electricity generating aggregate, liquid-vapor jet device, mini-TPP, heat pump unit, efficiency, affordable and clean energy, sustainable cities and communities

1 INTRODUCTION

According to the Distributed Generation Development Strategy until 2035, developed in accordance with the requirements of Directive (EU) 2019/944 of the European Parliament and the Council of the European Union dated 5 June 2019 on common rules for the internal electricity market and amending Directive 2012/27/EU (recast), Ukraine is expected to establish a system of distributed heat-and-electricity generation facilities to protect consumers from continuous attacks on critical infrastructure during martial law conditions [Bobrov 2025, Fesenko 2018, Razumkov Centre 2022]. Such an approach is intended to increase the level of energy security, reduce dependence on centralized energy sources, and promote the implementation of renewable energy sources. However, the initial steps toward implementing this Strategy have revealed a number of challenges. The most significant among them include the limited number of ready-to-operate decentralized heat and electricity supply facilities, their technical obsolescence, and low efficiency [Cukr.city 2024, Kostenko 2023].

One of the promising solutions to these problems, which would facilitate the development of decentralized heat and electricity supply systems, is the implementation of heat-and-electricity generating aggregates (HEGA) based on liquid-vapor jet devices (LVJD) [Sharapov 2024]. The specific features of the LVJD operating process allow for a substantial increase in the efficiency of existing heat and power generation facilities, as well as enabling the design and construction of new high-efficiency plants [Zidek 2024]. Their wide range of operating parameters makes it possible to develop HEGA units capable of supplying heat, domestic hot water, and electricity even to a single residential building. This approach nearly eliminates energy losses within power grids, which are characteristic of centralized systems, especially under wartime conditions.

Therefore, the authors aim to evaluate the energy efficiency of the proposed heat, electricity, and domestic hot water supply systems for a multi-apartment residential building.

2 LITERATURE REVIEW

Attempts to develop decentralized energy supply systems for both residential and industrial consumers date back to the mid-20th century [Babak 2020, Yang 2017]. This was driven by rapid industrial growth, when new cities were formed near newly built plants, factories, and industrial enterprises. These facilities could be located tens of kilometers away from the nearest settlement and therefore required their own sources of heat-and-electricity generation.

The first mini combined heat and power plants (mini-TPP s) were equipped with internal combustion engines combined with turbines, whose overall efficiency rarely exceeded 15–20%. Efforts to improve their performance have followed two main approaches: modification of the structural scheme of mini-TPP s and regulation of operating parameters to achieve maximum turbine and condenser productivity [Rahvard 2022, Tashtoush 2019].

Studies [Tashtoush 2020a, Wang 2023] examined the possibility of using steam-jet units to optimize the structural scheme of mini-TPP s and enhance turbine efficiency. The authors demonstrated the feasibility of such modernization, achieving a 2–3% increase in overall efficiency. However, the issue of generating the working steam required for the operation of the steam-jet compressor remained unresolved.

Other works [Aghaei 2021, Nikbakht Naserabad 2019] proposed an alternative approach to optimizing mini-TPP performance by selecting optimal steam parameters upstream of the turbine. This makes it possible to accurately determine the effective operating range of the turbine and increase the amount of electricity generated. Nevertheless, the authors did not address the selection of optimal compressor parameters, which in the proposed schemes is mounted on the same shaft as the turbine and directly affects its efficiency.

In study [Sefiddashti 2021], the idea of abandoning steam-jet ejectors as inefficient and outdated units was proposed for the first time. Such ejectors are typically multi-stage and require additional equipment, including filters and condensers. The authors suggested considering dynamic compressors instead. However, this leads to several drawbacks, including increased mini-TPP capacity and, consequently, the need to connect a larger number of consumers to a single station. Works [Assari 2022, Filkoski 2020] explored the use of such TPP plants primarily for large industrial facilities, with residential consumers connected as secondary users. Although this approach is energy-efficient and allows enterprises to offset part of their heat and electricity costs through residential payments, it is not fully practical. Industrial demand may significantly decrease or increase within short periods, resulting in interruptions in energy supply to residential consumers, who are not the primary users in such systems.

In studies [Horskyi 2023, Maliarenko 2020, Uusitalo 2024], schematic solutions based on heat pump technology were proposed. However, the working fluids in such installations are refrigerants, which are subject to increasingly strict environmental and safety requirements. A possible alternative is the use of liquid-vapor jet devices (LVJD) operating on the principle of jet thermocompression. The working fluid in such systems is water, and the generation of working steam occurs inside the LVJD itself, specifically in the primary flow nozzle. If working steam is required, it is only needed for the heat exchanger-heater of the primary flow working fluid; this component can also be replaced by an electric boiler or water heater.

The sources analyzed above do not provide a definitive answer as to which schematic solution is optimal for implementing distributed generation and creating energy-efficient aggregates. Therefore, the authors conducted a study of schematic solutions based on mini- TPP, heat pump units, and a combined scheme, and evaluated the feasibility of their implementation in distributed generation systems.

3 RESEARCH METHODOLOGY

3.1 Initial Data

The study was conducted for a three-storey residential building consisting of 15 apartments, located in Sumy, Ukraine (50°54′43″N, 34°48′10″E). The initial data used for the analysis are presented in Tab. 1.

Table 1. Initial data for research

No	Parameter	Value
1	Total heated area (m^2)	376.5
2	Total heated volume (m^3)	997.725
3	Average air temperature during the heating period (°*C)*	-5.1
4	Lowest air temperature during the heating period (°*C)*	-16.6
5	Average relative air humidity during the heating period *(%)*	81.76
6	Duration of the heating period, *months*	6
7	Temperature in living rooms (bedroom, living room, office, kitchen-dining room, etc.) (°*C)*	22±2
8	Temperature in non-residential rooms (kitchen, toilet, wardrobe, etc.) (°*C)*	19.5±2
9	Temperature in the bathroom (°*C)*	25±2
10	Quantity of residents in the house, people	25
11	Heat losses through the building's enclosing structures (kW*)*	48.708
12	Average monthly hot water consumption (m^3/month*)*	75
13	Average electricity consumption (kW · hour)	45
14	Maximum electricity consumption (kW · hour)	85

3.2 Object, subject and tasks of research

The object of the study is the energy parameters of heat, electricity, and domestic hot water supply systems for a multi-apartment residential building.

The subject of the study is the efficiency indicators of the proposed heat, electricity, and domestic hot water supply systems for a multi-apartment residential building.

To achieve the stated objective, the following tasks were accomplished:

1. A thermodynamic analysis of the proposed schemes was carried out, resulting in the determination of heat loads and power consumption of the units included in the heat- and electricity-generating aggregates, as well as the thermodynamic efficiency indicators of the cycles.
2. An exergetic analysis of the proposed schemes was performed, allowing the determination of the exergetic efficiency indicators for each schematic solution.
3. A thermoeconomic analysis was conducted, resulting in the determination of tariffs for heat, domestic hot water, and electricity for each variant of the heat- and electricity-generating aggregate.
4. A comparative analysis of the proposed schematic solutions and state-regulated tariffs for heat, domestic hot water, and electricity was carried out.

The thermodynamic analysis was performed according to the methodology described in [Bergantini Botamede 2023]. The exergetic analysis was conducted based on previous studies and the methodology presented in [Sharapov 2020, Szablowski 2021] for similar schemes. The thermoeconomic analysis was carried out based on [Tashtoush 2020b] and supplemented with tariff calculations for the main energy flows presented in [Elmorsy 2022, Sharapov 2024 & 2025].

3.3 Schemes and Diagrams

Mini-TPP (Thermal Power Plant) Based Scheme

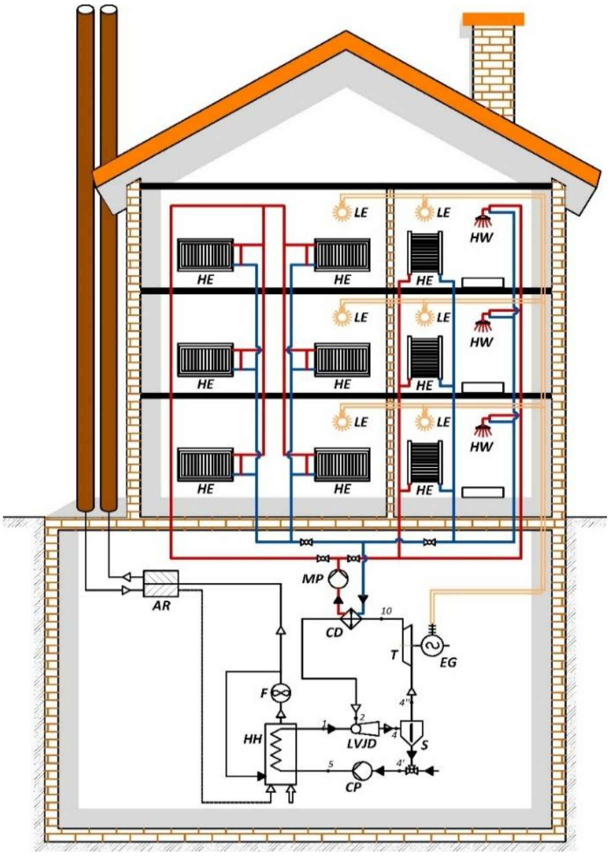

Figure 1. Scheme of HEGA based on mini-TPP

LVJD – liquid-vapor jet device,
S – separator,
CP – circulation pump,
HH – heat exchanger-heater,
F – fan,
AR – air regenerator,
T – turbine,
EG – electric generator,
MP – mains pump; CD – condenser,
HE – heating system element,
HW – hot water supply system element,
LE – lighting system element,
SS – solar collector system.

The schematic diagram of the heat- and electricity-generating aggregate based on a mini-TPP is shown in Fig. 1, and the thermodynamic cycle in p–h coordinates is presented in Fig. 2. In this configuration, the LVJD operates in the compressor mode. Its thermodynamic parameters are equivalent to those of a conventional mini-TPP, which makes it possible, under real operating conditions, to replace the steam-jet compressor with the LVJD without additional system adjustments.

Electricity in this configuration is generated in the electric generator EG, which is driven by the turbine T. The working steam for the turbine is supplied from the separator S. Water for the heating and domestic hot water systems is heated to the required parameters by the steam–water mixture in the mixing condenser CD.

In the mixing condenser, the condensation process is partial rather than complete, which allows additional regulation of the temperature in the heating and domestic hot water systems.

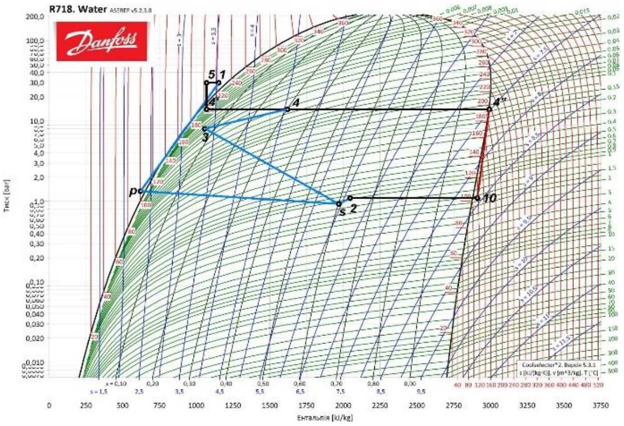

Figure 2. P,h-diagram of process in HEGA based on mini-TPP (adapted from [Danfoss Systems 2026])

Heat Pump Based Scheme

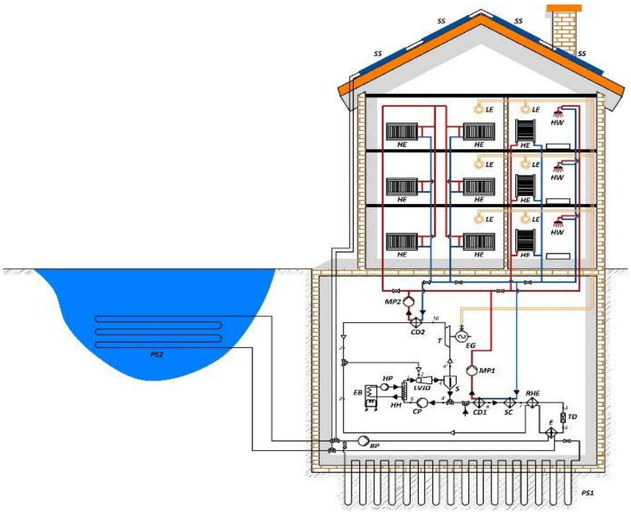

Figure 3. Scheme of HEGA based on heat pump unit

LVJD – liquid-vapor jet device,
S – separator,
CP – circulation pump,
HH – heat exchanger-heater,
EB – electric boiler,
HP – coolant pump,
CD1, CD2 – condenser,
T – turbine,
EG – electric generator,
MP1, MP 2 – mains pump,
SC – subcooler,
RHE – regenerative heat exchanger,
TD – throttle device,
E – evaporator,
P – brine pump,
PS1, PS2 – probe system,
HE – heating system element,
HW – hot water supply system element,
LE – lighting system element,
SS – solar collector system.

The schematic diagram of the heat- and electricity-generating aggregate based on the heat pump unit is shown in Fig. 3, and its thermodynamic cycle in p–h coordinates is presented in Fig. 4. In this configuration, the LVJD operates in a vacuum mode.

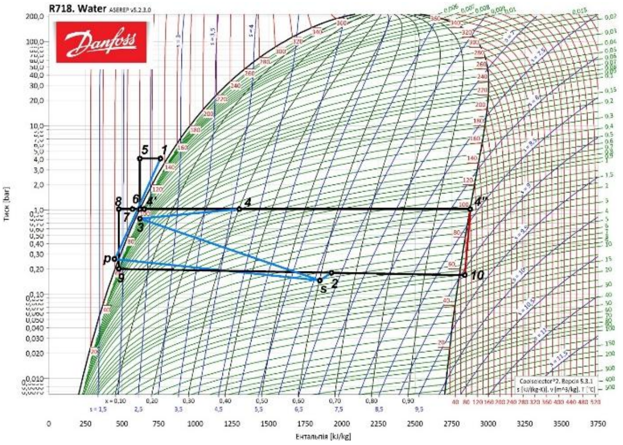

Figure 4. P,h-diagram of process in HEGA based on heat pump unit (adapted from [Danfoss Systems 2026])

Electricity generation, as in the mini-TPP-based scheme, is carried out in the electric generator EG driven by the turbine T. The heat released during steam condensation in the mixing condenser CD1 is utilized to heat a portion of the water for the heating and domestic hot water systems. The remaining portion of water for the heat and electricity supply system is heated by the heat released in condenser CD2 and the subcooler SC. Such a configuration reduces the load on the equipment, distributes water flows, and enables smooth system regulation.

The presented scheme can utilize heat extracted from the ground, water from a nearby reservoir (if available), and solar energy. For this purpose, the system includes probe systems PS1 and PS2, as well as solar panels SS installed on the roof of the building. If all heat sources are available, such a combined system can be implemented. Alternatively, depending on local conditions, configurations such as “ground probes + solar collector,” “ground probes only,” or “solar collector only” may be used.

This scheme is structurally more complex than the mini-TPP-based configuration; however, the transition to vacuum operating mode allows a further increase in system efficiency. This reduces the required work of the components included in the scheme and, consequently, their power consumption. This effect is clearly illustrated by the graphical comparison of the cycles shown in Fig. 2 and Fig. 4.

Combined Scheme

The schematic diagram of the combined heat-and-electricity generating aggregate is shown in Fig. 5, and its thermodynamic cycle in p–h coordinates is presented in Fig. 6. In this configuration, the LVJD can operate in either compressor mode or vacuum mode.

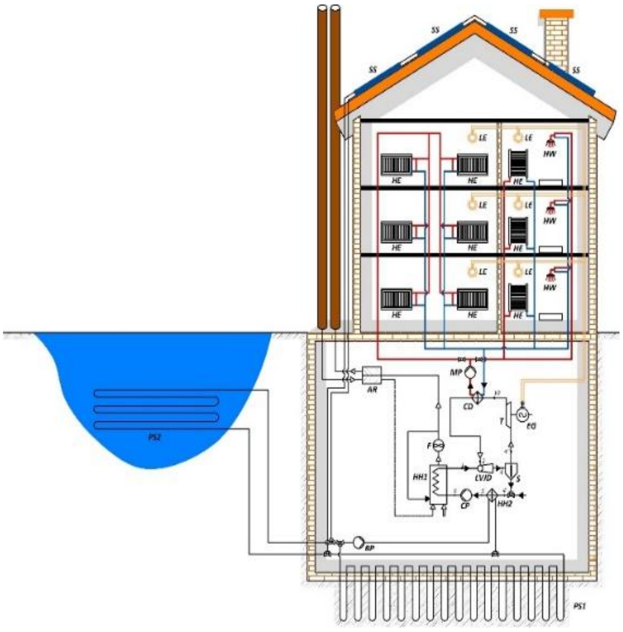

Figure 5. Scheme of combined HEGA

LVJD – liquid-vapor jet device,
S – separator,
CP – circulation pump,
HH1, HH2 – heat exchanger-heater,
F – fan,
AR – air regenerator,
T – turbine,
EG – electric generator,
MP – mains pump,
CD – condenser,
BP – brine pump,
PS1, PS2 – probe system,
HE – heating system element,
HW – hot water supply system element,
LE – lighting system element,
SS – solar collector system.

This scheme combines the advantages of the two previously described configurations. It is more efficient than the mini-TPP-based scheme due to the flexible operating mode, while being structurally simpler than the heat pump-based installation.

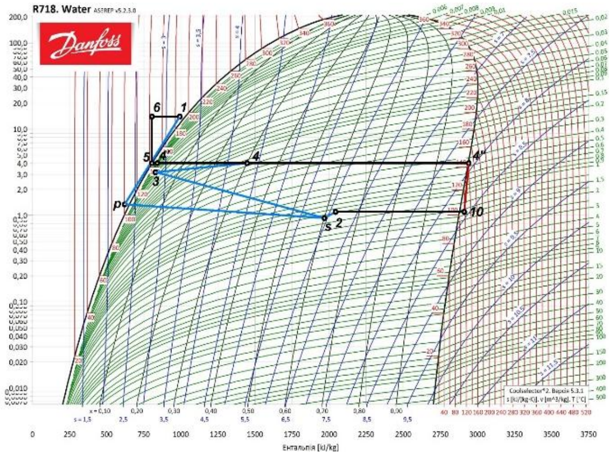

Figure 6. P,h-diagram of process in combined HEGA (adapted from [Danfoss Systems 2026])

In this scheme, electricity generation is similar to the previous configurations. The use of an additional heat-exchanger preheater HH2 allows for a reduction in the load on the main preheater HH1 and enables smoother regulation of the system under different operating modes (compressor, vacuum, or atmospheric).

Like the heat pump-based installation, the combined HEGA scheme can be implemented in various configurations («PS1 + PS2 + SS», «PS1/PS2 + SS», «PS1+PS2», «PS1/PS2», or «SS»), depending on the available heat sources.

$$\varepsilon_{ex} = \frac{(E_{2w}-E_{1w})+N_T}{(E_{1u}-E_{2u})+\sum N_P} \qquad (1)$$

4 RESULTS AND DISCUSSION

The purpose of the thermodynamic calculation is to determine the heat loads and power requirements of the main equipment included in the HEGA scheme solutions. Tab. 2 presents the results of the thermodynamic analysis for the proposed HEGA scheme solutions.

Table 2 shows that the combined HEGA scheme is the most efficient configuration as it exhibits the highest COP. It is 4.5% higher than the mini-TPP-based scheme and 9.75% higher than the heat pump-based scheme. This is achieved due to the simplification of the design compared to the heat pump installation and the reduction of operating parameters in the apparatuses compared to the mini-TPP-based scheme.

The purpose of the exergy analysis is to determine the exergy of the product and fuel streams, as well as the overall exergy efficiency of the system.

Table 2. Results of thermodynamic analysis of schemes of HEGA

No	Parameter	Mini-TPP HEGA	Heat pump HEGA	Combined HEGA
1	Inlet pressure of primary flow in LVJD. bar	30	4	16
2	Inlet temperature of primary flow in LVJD. °C	204	126	180
3	Inlet pressure of secondary flow in LVJD. bar	1	0.2	4
4	Outlet pressure in LVJD. bar	15.55	1	1
5	Mas flow rate of secondary flow in LVJD. kg/sec	0.678	0.763	0.623
6	Volume flow rate in water supply system. m3/hour	15		
7	Volume flow rate in heating system. m3/hour	1		
8	Heat loads of the devices. kW - condenser* - evaporator - regenerative heat exchanger - subcooler - separator - heat exchanger-heater**	 21.31 – – – 5.83 4.33	 16.47 11.98 3.85 1.64 2.03 2.62	 17.88 – – – 5.66 3.14
9	Powers of devices. kW - LVJD - turbine - summary power of pumps	 6.32 10.4 3.52	 7.11 10.5 4.19	 5.8 10.2 3.69
10	Coefficient of performance (COP) of the cycle	2.91	2.77	3.04

* For scheme shown on Fig. 3 indicated the summary power of condensers CD1 and CD2;
** For scheme shown on Fig. 5 indicated the summary power of heat exchanger-heaters HH1 and HH2

According to the method of exergetic analysis by J. Tsatsaronis, exergy efficiency is determined by the formula:

$$\boldsymbol{\varepsilon}_{\mathbf{ex}} = \frac{(\mathbf{E_{2w}}-\mathbf{E_{1w}})+\mathbf{N_T}}{(\mathbf{E_{1u}}-\mathbf{E_{2u}})+\sum \mathbf{N_P}}, \tag{1}$$

where E_{1w} is exergy of mains water at the inlet to condenser (Fig. 1, 5) or to subcooler (Fig. 3). E_{2w} is exergy of mains water at the outlet of condenser. E_{1u} is exergy of brine at the inlet to evaporator. E_{2u} is exergy of brine at the outlet of evaporator, N_T is power of turbine; $\sum N_P$ is summary power of rumps. The results of the exergy analysis are given in Tab. 3.

As seen in Tab. 3, the most efficient configuration is the combined HEGA scheme, whose exergy efficiency is 12% higher than that of the mini-TPP-based scheme and 23% higher than that of the heat pump-based scheme. This confirms the results of the thermodynamic analysis.

The purpose of the thermoeconomic analysis is to determine the costs of the main streams involved in the energy conversion process and to define the tariffs at which they will be delivered to consumers.

Table 3. Results of exergetic analysis

No	Parameter	Mini-TPP HEGA	Heat pump HEGA	Combined HEGA
1	Exergy of product flow, *kW*	265.38	265.48	265.18
2	Exergy of fuel flow, *kW*	853.31	925.02	751.22
3	Exergetic efficiency	0.311	0.287	0.353

The system of equations that used for the thermoeconomic analysis:

$$\begin{cases} c_{P,LVJD} \cdot E_{P,LVJD} = c_{F,LVJD} \cdot E_{F,LVJD} + Z_{LVJD} \\ c_{P,HH} \cdot E_{P,HH} = c_{F,HH} \cdot E_{F,HH} + Z_{HH} \\ c_{P,S} \cdot E_{P,S} = c_{F,S} \cdot E_{F,S} + Z_S \\ c_{P,T} \cdot E_{P,T} = c_{F,T} \cdot E_{F,S} + Z_T \\ c_{P,CD} \cdot E_{P,CD} = c_{F,CD} \cdot E_{F,CD} + Z_{CD} \\ c_{P,SC} \cdot E_{P,CS} = c_{F,CS} \cdot E_{F,CS} + Z_{CS} \\ c_{P,RHE} \cdot E_{P,RHE} = c_{F,RHE} \cdot E_{F,RHE} + Z_{RHE} \\ c_{P,E} \cdot E_{P,E} = c_{F,E} \cdot E_{F,E} + Z_E \\ c_{P,P} \cdot E_{P,P} = c_{F,P} \cdot E_{F,P} + Z_P \end{cases}, \tag{2}$$

where $c_{P,LVJD}$, $c_{F,LVJD}$ – price of the product flow and fuel for liquid-vapor jet device. Z_{LVJD} – cost of capital investment for liquid-vapor jet device. $c_{P,HH}$, $c_{F,HH}$ – price of the product flow and fuel for heat exchanger-heater. Z_{HH} – cost of capital investment for heat exchanger-heater. $c_{P,S}$, $c_{F,S}$ –price of the product flow and fuel for separator. Z_S –cost of capital investment for separator. $c_{P,T}$, $c_{F,T}$ – price of the product flow and fuel for turbine. Z_T – cost of capital investment for turbine. $c_{P,CD}$, $c_{F,CD}$ – price of the product flow and fuel for condenser. Z_{CD} – cost of capital investment for condenser. $c_{P,SC}$, $c_{F,SC}$ – price of the product flow and fuel for subcooler (for schemes Fig. 1, 5 $c_{P,SC} = c_{F,SC}=0$). Z_{SC} – summary cost of capital investment for subcooler (for schemes Fig. 1, 5 $Z_{SC}=0$). $c_{P,RHE}$, $c_{F,RHE}$ – price of the product flow and fuel for regenerative heat exchanger (for schemes Fig. 1, 5 $c_{P,RHE} = c_{F,RHE}=0$). Z_{RHE} – cost of capital investment for regenerative heat exchanger (for schemes Fig. 1, 5 $Z_{RHE}=0$), $c_{P,E}$, $c_{F,E}$ –price of the product flow and fuel for evaporator (for schemes Fig. 1, 5 $c_{P,E} = c_{F,E}=0$). Z_E – cost of capital investment for evaporator (for schemes Fig. 1, 5 $Z_E=0$). $c_{P,P}$, $c_{F,P}$ – summary price of the product flow and fuel for pumps. Z_P – summary cost of capital investment for pumps.

Fig. 7 shows the results of the thermoeconomic analysis presented as a comparison between the tariffs for energy carriers produced using the proposed HEGA schemes and the tariffs paid by consumers at state-regulated prices. The data on state tariffs were obtained from publicly available sources of utility companies in the city of Sumy (LLC "Sumyteploenergo" and JSC "Sumyoblenergo").

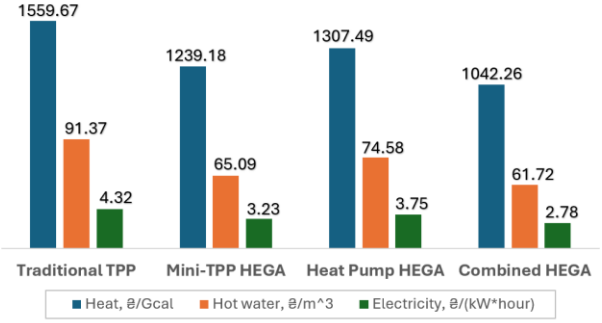

Figure 7. Results of comparative analysis of heat, hot water and electricity tariffs for HEGA scheme solutions

As can be seen from Fig. 7, all considered scheme solutions are efficient, since the tariffs for energy carriers produced by them are lower than the national average tariffs. The most efficient solution is the combined HEGA scheme, as the heat, hot water, and electricity produced by this system will be supplied to consumers at the lowest tariffs, which are on average 32–35% lower than the state tariffs for residential consumers. By conducting the study on the feasibility of implementing heat-and-electricity generating aggregates based on liquid–vapor jet devices, the authors were able to address the main problems that represented key disadvantages of the existing schemes described in [Filkoski 2020, Horskyi 2023, Jasiulewicz-Kaczmarek 2023, Maliarenko 2020, Nikbakht Naserabad 2019, Sefiddashti 2021, Tashtoush 2020a]. The replacement of the steam-jet compressor with an LVJD in the mini-TPP scheme made it possible to increase the efficiency of the installation described in [Tashtoush 2020b]. Due to structural modifications, the efficiency of the mini-TPP increased by nearly 15%.

The use of a mixing condenser instead of a conventional condenser in the schemes presented in [Nikbakht Naserabad 2019, Sefiddashti 2021] made it possible to use wet steam as a secondary flow in the LVJD. The reduction of thermodynamic parameters of the LVJD working process reduced the load on the components of the mini-TPP. This optimization provided an additional efficiency increase of approximately 8%.

The modernization of heat pump installations described in [Horskyi 2023, Maliarenko 2020]. made it possible to convert them into cogeneration systems capable of producing not only thermal energy for heating and domestic hot water supply but also electricity. Although the modernization increased structural complexity, the transition to vacuum operating mode and proper selection of LVJD operating parameters enabled an average efficiency to increase of approximately 11%.

The conducted study includes several assumptions. The main ones relate to the accuracy of determining the cycle parameters at nodal points of the HEGA cycles and the mass flow rates of the main streams involved in the energy conversion process. Simplifications adopted in the calculations include assuming a constant wind velocity along the building height (since the building height does not exceed 10 m), identical heat carrier flow rates for both corner and internal rooms, calculation of the total heat carrier flow rate based on ambient temperature and required indoor temperature and neglecting individual room temperature regulation for occupant comfort.

The analysis of the calculation results showed that the error does not exceed 4–5% compared to real values, which is within acceptable limits for engineering calculations.

5 CONCLUSIONS

Based on the analysis of the proposed HEGA schemes, their implementation in distributed generation systems can be considered justified, since the tariffs for energy carriers produced by these systems are lower than state-regulated tariffs.

The thermodynamic analysis determined the efficiency of the proposed HEGA schemes using the coefficient of performance (COP). The combined HEGA scheme demonstrated the highest COP, exceeding that of the mini-TPP-based scheme by 4.5% and the heat pump scheme by 9.75%.

The exergy analysis determined the exergy efficiency of the proposed schemes. The highest exergy efficiency was observed in the combined scheme, reaching 0.353, which is 12% higher than that of the mini-TPP-based scheme and 23% higher than that of the heat pump scheme.

The thermoeconomic analysis provided calculated tariffs for heat, hot water, and electricity for the proposed schemes. The lowest tariffs were obtained for the combined scheme. It should also be noted that tariffs for all proposed schemes are lower than national average tariffs.

This study represents an initial stage, as it includes a primary analysis of HEGA schemes based on LVJD technology. Further optimization and efficiency improvement may be achieved by determining the optimal passive flow temperature at the LVJD inlet (state point 2), which affects the degree of passive flow condensation in the mixing condenser. For the heat pump scheme, critical parameters include the distribution of network water between condensers, which determines their load. Another important parameter influencing condenser and subcooler performance is the optimal selection of network water temperature between these components.

Thus, the above considerations define the directions for further research necessary for the implementation of these schemes in distributed generation systems.

ACKNOWLEDGMENTS

This publication was created within the project Research of advanced technologies for increasing the efficiency of multivalent energy systems for sustainable industrial development, ITMS21+ code: 401101C504, co-funded by the European Union under the Programme Slovakia. The projects VEGA 1/0551/26 and KEGA 004TUKE-4/2026 were granted by the Ministry of Education, Research, Development, and Youth of the Slovak Republic.

REFERENCES

[Aghaei 2021] Aghaei, A.T. and Saray, R.K. Optimization of a combined cooling, heating, and power (CTPP) system with a gas turbine prime mover: A case study in the dairy industry. Energy, 2021, Vol. 229, 120788.

[Assari 2022] Assari, M.R., et al. Numerical study of water-air ejector using mixture and two-phase models. International Journal of Engineering, 2022, Vol. 35, No. 2.

[Babak 2020] Babak, V., et al. Systems, Decision and Control in Energy I. Cham: Springer International Publishing, 2020.

[Bergantini Botamede 2023] Bergantini Botamede, B. and Oliveira Salviano, L. Thermodynamic analysis of concentrated solar energy layouts integrated with combined power system. Applied Thermal Engineering, 2023, Vol. 229, 120618.

[Bobrov 2025] Bobrov, Ye. Economic challenges of distributed generation development in Ukraine under the conditions of energy transformation in 2025. Vcheni zapysky Universytetu KROK, 2025, Vol. 2, No. 78, pp. 23-34. (in Ukrainian)

[Cukr.city 2024] Cukr.city. How to heat high-rise buildings in winter if CHPs are destroyed? Cukr.city, 2024 [online]. [cited 8 April 2026]. Available from https://cukr.city/city/2024/beztec/ (in Ukrainian)

[Danfoss Systems 2026] Danfoss Systems. Coolselector®2, v.5.6.11 database 130. Danfoss Systems, 2026 [online]. [cited 8 April 2026]. Available from https://coolselectoronline.danfoss.com

[Elmorsy 2022] Elmorsy, L., et al. Comparative exergoeconomic evaluation of integrated solar combined-cycle (ISCC) configurations. Renewable Energy, 2022, Vol. 185, pp. 680-691.

[Fesenko 2018] Fesenko, A., et al. Prospects of Using Hydrodynamic Cavitation for Enhancement of Efficiency of Fluid Working Medium Preparation Technologies. Periodica Polytechnica Mechanical Engineering, 2018, Vol. 62, No. 4, pp. 269-276.

[Filkoski 2020] Filkoski, R., et al. Steam system optimization of an industrial heat and power plant. Thermal Science, 2020, Vol. 24, No. 6, Part A, pp. 3649-3662.

[Horskyi 2023] Horskyi, V. and Maliarenko, O. Use of Improved Methodology to Determine the Total Power Efficiency of Energy Products in Their Co-production at Combined Heat and Power Plant. In: Systems, Decision and Control in Energy 4. Cham: Springer International Publishing, 2023, pp. 291-307.

[Jasiulewicz-Kaczmarek 2023] Jasiulewicz-Kaczmarek, M., et al. Industry 4.0 Technologies for Sustainable Asset Life Cycle Management. Sustainability, 2023, Vol. 15, No. 7, 5833.

[Kostenko 2023] Kostenko, G. and Zgurovets, O. Current State and Prospects for Development of Renewable Distributed Generation in Ukraine. System Research in Energy, 2023, Vol. 2, No. 73, pp. 4-17.

[Maliarenko 2020] Maliarenko, O., et al. An Improved Approach to Evaluation of the Efficiency of Energy Saving Measures Based on the Indicator of Products Total Energy Intensity. In: Systems, Decision and Control in Energy 1. Cham: Springer International Publishing, 2020, pp. 201-216.

[Nikbakht Naserabad 2019] Nikbakht Naserabad, S., et al. Multi-objective optimization of feed-water heater arrangement options in a steam power plant repowering. Journal of Cleaner Production, 2019, Vol. 220, pp. 253-270.

[Rahvard 2022] Rahvard, A. J., et al. An applicable surface heating in a two-phase ejector refrigeration. European Physical Journal Plus, 2022, Vol. 137, No. 2.

[Razumkov Centre 2022] Razumkov Centre. The renewable energy sector of Ukraine before, during and after the war. Razumkov Centre [online]. [cited 8 April 2026]. Available from razumkov.org.ua/statti/sektor-vidnovlyuvanoyi-energetyky-ukrayiny-do-pid-chas-ta-pislya-viyny (in Ukrainian)

[Sefiddashti 2021] Sefiddashti, A.R., et al. Efficiency Enhancement of Gas Turbine Systems with Air Injection Driven by Natural Gas Turboexpanders. Sustainability, 2021, Vol. 13, 10994.

[Sharapov 2020] Sharapov, S., et al. Analysis of the possibility of using R718 for a heat pump of a heating system based on a liquid-vapor ejector. Eastern-European Journal of Enterprise Technologies, 2020, Vol. 6, No. 8, pp. 39-44.

[Sharapov 2024] Sharapov, S., et al. Heat Utilization in Boiler Plants by Using Liquid-Vapor Jet Apparatus. Journal of Engineering Sciences, 2024, Vol. 11, No. 2, pp. G1-G8.

[Sharapov 2025] Sharapov, S., et al. Improving the efficiency of evaporation plants that produce condensed milk by applying liquid-vapor jet units. Eastern-European Journal of Enterprise Technologies, 2025, Vol. 5, No. 11, pp. 6-14.

[Szablowski 2021] Szablowski, L., et al. Exergy Analysis of Adiabatic Liquid Air Energy Storage (A-LAES) System Based on Linde–Hampson Cycle. Energies, 2021, Vol. 14, No. 4, 945.

[Tashtoush 2019] Tashtoush, B. M., et al. A comprehensive review of ejector design, performance, and applications. Applied Energy, 2019, Vol. 240, pp. 138-172.

[Tashtoush 2020a] Tashtoush, B. and Nayfeh, Y. Energy and economic analysis of a variable-geometry ejector in solar cooling systems for residential buildings. Journal of Energy Storage, 2020, Vol. 27.

[Tashtoush 2020b] Tashtoush, B., et al. Exergy and Exergoeconomic Analysis of a Cogeneration Hybrid Solar Organic Rankine Cycle with Ejector. Entropy, 2020, Vol. 22, No. 6, 702.

[Uusitalo 2024] Uusitalo, A. and Jaatinen-Varri, A. Centrifugal compressor design analysis for large-scale systems and cycle integration. Appl. J. Turbomach. Energy Eng., 2024, Vol. 257, 124355.

[Wang 2023] Wang, Y., et al. A high-efficiency multi-function system based on thermal desalination and absorption cycle for water, water-cooling or water-heating production. Energy Conversion and Management, 2023, Vol. 284.

[Yang 2017] Yang, X., et al. The urban cool island phenomenon in a high-rise high-density city and its mechanisms. Int J Climatol, 2017, Vol. 37, No. 2, pp. 890-904.

[Zidek 2024] Zidek, K., Duhancik, M., Hrehova., S. Real-Time Material Flow Monitoring in SMART Automated Lines using a 3D Digital Shadow with the Industry 4.0 Concept. In: 2024 25th International Carpathian Control Conference (ICCC), Krynica Zdroj, Poland, 2024, pp. 1-6. DOI: 10.1109/ICCC62069.2024.10569500

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