International Journal of Science and Technology

International Journal of Science and Technology, 2025, 11–16

doi: 10.70728/tech.v02.i17.002
Volume 02, Issue 17
ISSN: 3030-3443
Paper

PAPER

IMPROVING THE ENERGY EFFICIENCY OF HEAT PUMP UNITS

Toshmamatov Bobir Mansurovich[1,*], Ruzikulov Gulom Yusupovich [1], Aminov Fakhriddin [2]

[1]Karshi State Technical University, Ass. Prof., PhD
[2]Karshi State Technical University, 2nd year Master's degree

* bobur160189@mail.ru

Abstract

In the world, traditional energy resources are depleting and the ecological burden on the environment is increasing, so production from existing energy sources will solve the problem. So, this paper investigates the energy performance of an autonomous solar-assisted heat pump (HP) system designed for heating and cooling applications in rural regions with a sharply continental climate, such as Uzbekistan. The proposed integrated system combines a network of solar thermal collectors, a hot-water storage tank and a mechanically driven heat pump. Solar radiation is absorbed in the collector field and stored as medium-temperature water, which is then used as a stable low-potential heat source for the evaporator. A thermodynamic model of the heat pump cycle was developed based on heat and mass balance equations, compressor isentropic efficiency and logarithmic mean temperature difference in the evaporator and condenser. Hourly ambient air and storage-tank temperatures were obtained for the heating season; ambient air varies between 7÷15 °C, whereas storage temperature is maintained between 3÷40 °C. The coefficient of performance (COP) of the conventional air-source HP was compared with that of the solar-assisted configuration. Numerical results show that the average COP increases from 4.1 for the basic HP to 6.2 for the HP with solar collectors, corresponding to an efficiency gain of about 50 %. The findings demonstrate that solar-assisted heat pumps can significantly reduce electricity consumption and greenhouse-gas emissions in decentralized heating systems.

Key words: heat pump, solar thermal collectors, storage tank, coefficient of performance (COP), integrated heating system, continental climate, energy efficiency, renewable energy.

Introduction

The consistent depletion of conventional fuel–energy resources worldwide and the increasing

Compiled on: December 16, 2025.

ecological burden caused by technogenic and anthropogenic impacts have made the rational use and conservation of existing energy sources a highly urgent and strategically significant issue. Ensuring energy security and sustainable development requires large-scale modernization of the global energy infrastructure and the extensive integration of environmentally friendly and renewable energy sources into energy systems [1].

In regions characterized by sharply continental climates and abnormal climatic fluctuations, a number of complex technical and technological challenges arise in ensuring autonomous heating–cooling supply and uninterrupted energy provision, especially for facilities located in rural areas such as residential households, educational institutions, agricultural structures, greenhouse farms, farming infrastructures, poultry complexes, and food and textile industry enterprises [2].

In such facilities, the systems responsible for heating, cooling, hot-water supply, and electricity are required to operate in an integrated manner and must remain stable, reliable, and uninterrupted even under emergency conditions, fuel shortages, or disruptions in energy supply. Additionally, high variability in daily and seasonal energy loads, the low exergy efficiency of traditional heating systems, and the necessity to supply energy effectively and consistently during extremely cold and hot seasons represent major challenges that need to be addressed [3-5].

One of the scientific and technical solutions to these challenges is the introduction of an integrated autonomous heating–cooling supply system that serves as an alternative to conventional thermal supply infrastructures. This system is based on the optimal structural integration of the region's geothermal energy potential, renewable energy sources, and heat pump technologies, and is regarded as an innovative and highly efficient approach [6-8].

According to the prognostic assessments of the International Energy Agency, by the middle of this century at least 40% of the global energy balance is expected to be supplied by renewable energy sources. Achieving such a balance between renewable and conventional energy sources is projected to stabilize atmospheric SO_2 concentrations by 2050 and significantly reduce them by 2100 [9].

In this context, the development of energy-efficient devices and innovative technologies that utilize alternative and renewable energy sources, as well as the creation of competitive and environmentally friendly energy technologies, are becoming strategic priorities for the energy sector over the next 15÷20 years. Within this process, the wide deployment of heat pump–based heating systems, enhancement of their energy efficiency, ensuring stable operation under various climatic conditions, and their optimal integration with renewable energy sources (geothermal, air–water, water–water, ground–water systems) play a crucial role.

Heat pump technologies have become key technological drivers in reducing carbon footprints, lowering dependence on conventional fuels, and establishing reliable thermal supply infrastructures, as they enable the transfer of low-potential heat to high-temperature consumers with high efficiency. Therefore, improving the structural design of heat pump units, increasing the exergy efficiency of compressors and heat exchange modules, developing integrated control algorithms, and ensuring their effective combination with renewable energy sources will remain essential directions for enhancing energy security and sustainable development in the coming years.

One of the major advantages of heat pump systems and geothermal energy is their ability to provide an environmentally safe and sustainable source of energy with minimal environmental impact. Geothermal resources, which are continuous, renewable, and characterized by nearly constant temperatures throughout the year, offer significant advantages in ensuring energy stability.

Studies show that electricity generation from high-temperature geothermal resources releases only 13 to 380 grams of CO_2 per kWh. This is substantially lower than emissions from traditional hydrocarbon fuels, particularly coal-based power generation, which emits an average of up to 1042 grams of CO_2 per kWh-approximately 3 to 80 times higher than geothermal technologies.

Furthermore, when heat pumps are combined with geothermal resources, their coefficient of performance (COP) increases significantly, allowing 1 kW of electrical energy to deliver 3–5 kW or more of thermal energy to consumers. This not only enhances energy efficiency but also contributes to a sharp reduction in the carbon footprint of heating systems. As a result, geothermal heat pump systems are considered not only economically viable but also an essential component of global energy strategies aimed at mitigating climate change [8].

A heat pump is a device that extracts low-grade heat energy and delivers it to consumers in the form of heated water or air. One of its key features is that for every 1 kW of electrical energy consumed, it can supply 3÷4 kW of thermal energy. In principle, a heat pump operates similarly to a refrigerator: in a refrigerator, the internal chamber is cooled while the extracted heat is released into the surrounding air. Conversely, a heat pump absorbs heat from a low-temperature source and transfers it to a high-temperature system. This process is facilitated by a refrigerant, whose circulation between the compressor and the evaporator requires electrical energy input [9].

The coefficient of performance (⊠ or COP) increases as the temperature difference (T_1 - T_0) decreases. Therefore, heat pumps are especially efficient in systems where only a moderate increase in temperature is required, such as in domestic hot water supply systems (from 20 °C to 50 °C). However, if the temperature at the heat source remains constant, an increase in outlet temperature T_1 significantly reduces the economic efficiency of the system. This issue becomes particularly evident in climates with large seasonal variations in heat demand. In sharply continental climates, peak heating loads may be nearly twice the average load, requiring the production of hot water at temperatures up to 90 °C. In some cases, heating networks demand water heated up to 150 °C, however, achieving such temperatures using conventional heat pumps is fundamentally impossible.

Today, heat pump technologies are increasingly becoming an essential component of new heating systems in many countries. Due to growing political and economic support for decarbonizing heating systems, heat pumps are being rapidly adopted as one of the most important technologies in the global transition toward clean energy. In 2021, approximately 190 million heat pump units were used worldwide for building heating. The global demand for heat pumps has continued to grow steadily, particularly due to major markets in North America, Europe, and East and Northeast Asia. In 2021, sales of heat pumps reached record levels in Europe, China, and the United States [10]. Methods and materials.

The energy efficiency of heat pumps (HPs) is evaluated based on their coefficient of performance (COP) and overall exergy efficiency. Improving the energy efficiency of heat pump systems can be achieved through various constructive, technological, and operational solutions. One of the most effective approaches to increasing COP is to ensure a relatively high inlet temperature, since the smaller the temperature difference (T_1 - T_0), the lower the energy consumption of the heat pump. Therefore, the use of stable low-potential heat sources-such as ground-source wells, river or lake water, soil heat, and other similar resources-significantly increases COP. In this study, the method of enhancing heat pump energy efficiency through the application of solar collectors is investigated.

The structural configuration of solar-collector-based systems mainly consists of the hydraulic network of the solar collectors and a thermal storage unit. Within the scope of this research, a hybrid heat pump system integrated with a solar collector installation is examined as the primary heat source. In this hybrid configuration, the low-potential heat required for heat pump operation is supplied by the thermal energy collected by the solar collectors and accumulated in the storage tank. The design methodology of the hybrid system begins with analyzing the initial process data related to heat balances. Energy integration is conducted using thermodynamic Pinch analysis, which enables the determination of the minimum heating demand, surplus heat, optimal ΔTmin value, as well as the optimal surface area of the solar collectors and the capacity of the thermal storage tank. As a result, the overall energy efficiency of the system increases, a stable thermal source is ensured for year-round heat pump operation, and both capital and operating costs of the solar thermal subsystem are reduced. A heat pump transfers heat from a low-temperature source to a higher-temperature medium through mechanical compression. Designing such a system requires accurate knowledge of the heating load, process operating temperatures, and the evaporation temperature of the working fluid. These parameters determine the amount of work performed by the compressor and allow the selection of an appropriate refrigerant.

The evaporator of the heat pump must superheat the refrigerant sufficiently to ensure that it enters the compressor in a fully vapor state. This prevents liquid droplets from entering the compressor and damaging it. The degree of superheating is directly related to the adiabatic compression process. In practice, the isentropic efficiency of compressors typically ranges between 80÷90% for the proposed system, an efficiency of 85% is adopted.

In the condenser, heat is released due to desuperheating, condensation, and subcooling of the refrigerant. The subcooling process ensures that the refrigerant entering the expansion valve is fully in liquid form, preventing vapor formation that could adversely affect the mass flow rate of the refrigerant. During expansion, a sharp pressure drop occurs, producing a liquid–vapor mixture at the evaporation temperature.

Results and Discussion

In the proposed hybrid system, the solar collector array and the thermal storage tank provide the continuous low-potential heat required for the evaporator of the heat pump. As a result of adiabatic compression, both the pressure and temperature of the refrigerant increase, enabling it to deliver heat at the desired process temperature.

A logarithmic mean temperature difference (LMTD) of 10 °C is assumed for the evaporator and condenser. The heat released by the heat pump in the condenser can be utilized for various purposes depending on the specific system integration. The thermal schematic of the solar-assisted heat pump system developed by the authors to enhance heat pump performance is presented in Fig. 1.

This system consists of a solar thermal subsystem (solar collectors and a thermal storage tank) integrated with a heat pump unit, and it operates in the following sequence:

Solar radiation is absorbed by the solar collector array, causing the heat-transfer fluid inside the collectors to heat up. The heated fluid is then delivered to the thermal storage tank, where it is stored. The medium-temperature hot water accumulated in the storage tank serves as a stable heat source for the evaporator of the heat pump. Using a circulation pump, the heated water is supplied to the evaporator of the heat pump system (HPS). In the evaporator, the refrigerant absorbs heat from the thermal storage water, undergoes evaporation, and becomes vapor, thereby preparing it for compression from low to high pressure.

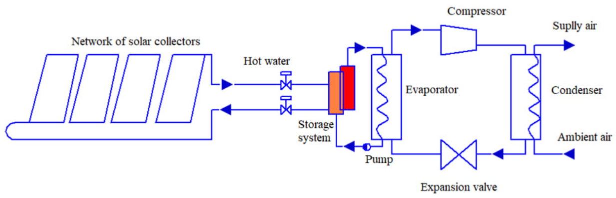

Рис. 1. Figure 1. Thermal diagram of a heat pump device with solar collectors.

The vapor-phase refrigerant enters the compressor, where it is compressed, resulting in a significant increase in both pressure and temperature. Consequently, the high-temperature, high-pressure refrigerant gas is directed to the condenser. In the condenser, the refrigerant transfers heat to the ambient air, and during this process it condenses back into liquid form. The heated air exits the system as "supply air" and is delivered to the environment or the designated thermal load [10].

The condensed liquid refrigerant then flows into the expansion valve, where a sharp drop in pressure occurs. This pressure reduction causes the refrigerant to transform into a liquid–vapor mixture at its corresponding saturation temperature. The refrigerant mixture subsequently returns to the evaporator, and the thermodynamic cycle repeats from the beginning. The heat transfer processes within the heat pump system are evaluated using the following equations:

The amount of heat transferred from the heat-transfer fluid (cold source) to the refrigerant in the evaporator is calculated using [11,12]:

$$Q_{ev} = m_{heat} C_p (T_1 - T_0)$$

or, The amount of heat recovered by the refrigerator is calculated using the following equation:

$$Q_{ev} = m_{ref} (h_1 - h_4)$$

The heat balance of the evaporator is expressed as $Q_{ev} = m_{heat} C_p (T_1 - T_0)$, where m_{heat} and m_{ref} are the mass flow rates of the working fluid (kg/s), C_p

is the heat capacity of the heat carrier (kJ/(kg·K)), T_1 and T_0 are the inlet and outlet temperatures of the evaporator (K), and h_1 and h_4 are the enthalpy values of the refrigerant at points 1 and 4 (kJ/kg), respectively.

The evaporator heat load can also be written as $Q_{ev} = m_{ref}(h_1 - h_4)$.

The electric power of the compressor is given by $W_C = m_{ref}(h_2 - h_1)$, where h_2 and h_1 are the enthalpy values of the refrigerant at points 2 and 1 (kJ/kg), respectively.

The adiabatic efficiency of the compressor is defined as $\eta_C = \frac{h_{2,s} - h_1}{h_2 - h_1}$, where $h_{2,s}$ is the enthalpy of the refrigerant after ideal adiabatic compression (kJ/kg).

The heat transferred to the air in the condenser is calculated as $Q_{Cond} = m_{air} C_p (T_{h,air} - T_{a,air})$, where m_{air} is the mass flow rate of air through the condenser (kg/s), and $T_{h,air}$ and $T_{a,air}$ are the outlet and inlet air temperatures (K).

The condenser heat removal rate is expressed as $Q_{Cond,h} = m_{ref}(h_2 - h_3) = W_A + Q_{col}$, where W_A is the compressor work rate (W) and Q_{col} is the additional heat supplied from an external source (W).

Finally, the coefficient of performance of the heat pump is defined as $COPHP = \frac{QCond}{W_C}$.

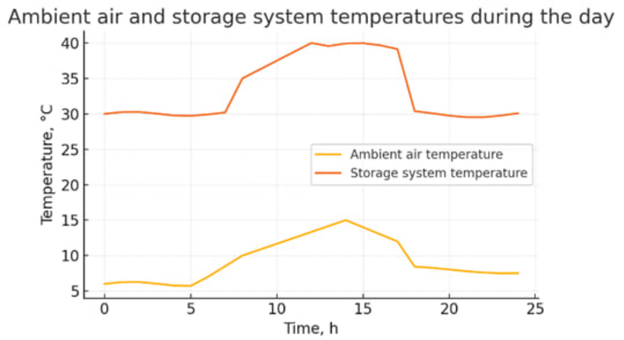

Рис. 2. Figure 2. Experimental results of the storage system and ambient air temperatures.

As shown in Figure 2, the ambient air temperature in the natural climatic conditions of Uzbekistan (characterized by a sharply continental climate) varies throughout the day such that between 08:00 and 14:00 it increases from approximately 10 °C to 15 °C, and between 14:00 and 17:00 it decreases from 15 °C to around 12 °C. During the remaining hours of the day, the ambient temperature remains within the range of 7÷9 °C. The storage system temperature remains at approximately 30 °C between 00:00÷08:00 and 17:0÷24:00. Between 08:00 and 12:00, it increases from 35 °C to 40 °C, and during 12:00÷17:00 it is maintained at a relatively high level within the range of 35÷40 °C.

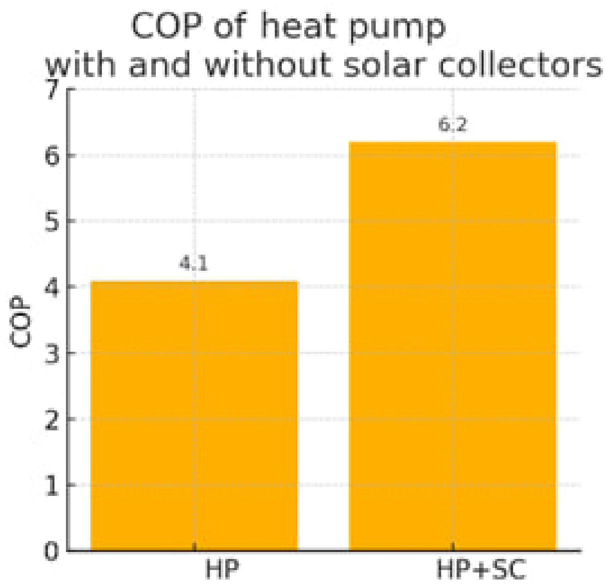

Рис. 3. Figure 2. Experimental results of the storage system and ambient air temperatures.

Conclusion

The results of the study demonstrate that utilizing medium-temperature water supplied by solar collectors as the heat source for the evaporator significantly enhances the energy efficiency of the heat pump system. While the average COP of a conventional heat pump (HP) is 4.1, the solar-assisted configuration (HP+SC) increases this value to 6.2. This improvement is attributed to the higher inlet temperature delivered to the evaporator, which reduces the electrical energy consumption of the compressor and increases the amount of heat released in the condenser.

The integration of a solar collector system with the heat pump also ensures more stable operation throughout the year by reducing sensitivity to fluctuations in ambient air temperature. As a result, the overall thermal efficiency of the system can be increased by up to 50%, further strengthening the economic and environmental benefits of utilizing renewable energy sources.

These findings indicate that solar-assisted heat pump systems can operate efficiently even in low-temperature climatic conditions and have strong potential for widespread application in residential and industrial facilities.

References

1. Узаков Г. Н., Базаров О. Ш., Давланов Х. А., Тошмаматов Б. Научно-инновационные разработки Каршинского инженерно-экономического института по использованию возобновляемых источников энергии Беларусь-Узбекистан: формирование рынка инновационной продукции Сборник материалов научно практической конференции (Минск, 14–15 марта 2023 г.), стр. 353-356.
2. Узаков Г.Н., Давланов Х.А., Тошмаматов Б.М. Энергоэффективные системы и технологии с использованием альтернативных источников энергии //Альтернативная энергетика. 2021. Т. 1. С. 7-19.
3. Узаков Г.Н., Алиярова Л.А., Ибрагимов У.Х., Тошмаматов Б.М. Исследование комбинированного водовоздушного солнечного коллектора при ламинарном гидродинамическом режиме//Альтернативная энергетика. 2021. Т. 1. С. 33-40.
4. Узаков Г.Н., Давланов Х.А., Тошмаматов Б.М. Анализ гибридных систем отопления жилых зданий, использующие ВИЭ//Альтернативная энергетика. Научно-технический журнал. 2023. Т. 8. № 1. С. 9-15.
5. Узаков Г.Н., Давланов Х.А., Камолов Б.И., Тошмаматов Б.М. Интегрированные автономные системы энергоснабжения объектов, расположенных в сельской местности//Алтернативная энергетика. Научно-технический журнал. №2, 03.07.2023-г. Стр. 9-14.
6. Zakhidov R.A., Tajiyev U.A., Kiseleva E.I., Saliev G.S., Gorobtsov S.I. On the Possibility of Sustainable Energy and Water Supply of Low-Rise Residential Buildings Located in Areas with an Arid Climate using Combined Wind and Solar Photovoltaic Power Complexes of Low Power. Applied Solar Energy (English translation of Geliotekhnika) this link is disabled, 2022, 58(1), pp. 159–164.
7. Uzakov G.N., Toshmamatov B.M., Kamolov B.I. Selection of rational heat carriers and thermal accumulators in a hybrid heating system for a rural house//International journal of advanced research in science, engineering and technology. Vol. 11, Issue 10, October 2024. PP. 22450- 22456.
8. Toshmamatov B.M., Muradov I. and Khusenov A.A. Choosing an efficient heat accumulator for solar air heating collectors with flat reflectors//International journal of advanced research in science, engineering and technology. Vol. 11, Issue 10, October 2024. PP. 22445- 22449.
9. Toshmamatov B., Kodirov I., and Davlonov Kh. Determination of the energy efficiency of a flat reflector solar air heating collector with a heat accumulator//E3S Web of Conferences 402, 05010 (2023).
10. Gajdzik, B.; Jaciow, M.; Wolniak, R.; Wolny, R.; Wes Grebski, W. Energy Behaviors of Prosumers in Example of Polish Households. Energies 2023, 16, 3186.
11. J. Li, S. Wei, Y. Dong, X. Liu, V. Novakovic, Technical and economic performance study on winter heating system of air source heat pump assisted solar evacuated tube water heater, Appl. Therm. Eng. 221 (2023) 119851.
12. A.D. Chiasson, C. Yavuzturk, Assessment of the viability of hybrid geothermal heat pump systems with solar thermal collectors, Build. Eng. 109 (2003) 487.