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doi:10.15199/48.2024.09.46

Analysis of the Efficiency of the Bivalent Parallel Mode of Operation of Heat Pumps in an Individual Residential Building: a Study of the Operating Modes of the Heat Supply System

***Abstract:** The article uses computer modeling to study the use of ground heat pumps from alternative energy sources in the heat supply of the city of Kelbajar. For this purpose, the experience of developed countries was studied and a diagram of the heat supply system of the object under study was selected using computer modeling. The bivalent-parallel operating mode of the heat pump system was adopted and studied, and the conversion coefficient of the heat pump was calculated. The storage tank and its parameters for heat accumulation are selected. An auxiliary boiler was selected to meet the heating demand during the peak period and its characteristic parameters were determined. A solar collector was used as an additional heat source. The quantity, geometric dimensions and other parameters of the solar collector have been determined. The characteristics of the soil probe are given in the table. It is accepted that the working fluid of the probe is a 25% water-glycol solution. The temperature of the soil around the probe, the temperature of the working fluid at the inlet and outlet of the heat pump are determined and specified in the form of a graph. For the heating system, the heat load of the heat pump, solar collector, auxiliary boiler into the system and the conversion coefficient of the heat pump are graphically shown. As a result of the simulation, the energy produced (annual), losses (annual), energy used (annual), solar circuit, the required power and presented in the form of a table. The influence of the heat pump system on the environment is studied and it is shown that it is an environmentally friendly heat and cold supply system.*

***Streszczenie:** W artykule wykorzystano modelowanie komputerowe do zbadania zastosowania gruntowych pomp ciepła wykorzystujących alternatywne źródła energii w zaopatrzeniu w ciepło miasta Kelbajar. W tym celu wykorzystano doświadczenia krajów rozwiniętych i za pomocą modelowania komputerowego wybrano schemat systemu zaopatrzenia w ciepło badanego obiektu. Przyjęto i zbadano biwalentno-równoległy tryb pracy układu pompy ciepła oraz obliczono współczynnik konwersji pompy ciepła. Dobiera się zasobnik i jego parametry akumulacji ciepła. Do zaspokojenia zapotrzebowania na ciepło w okresie szczytowym dobrano kocioł pomocniczy i określono jego parametry charakterystyczne. Jako dodatkowe źródło ciepła zastosowano kolektor słoneczny. Określono ilość, wymiary geometryczne i inne parametry kolektora słonecznego. Charakterystykę sondy gruntowej podano w tabeli. Przyjmuje się, że czynnikiem roboczym sondy jest 25% roztwór wody i glikolu.Temperaturę gruntu wokół sondy, temperaturę płynu roboczego na wlocie i wylocie pompy ciepła określa się i podaje w postaci wykresu. Dla układu grzewczego przedstawiono graficznie obciążenie cieplne pompy ciepła, kolektora słonecznego, kotła pomocniczego w systemie oraz współczynnik konwersji pompy ciepła.W wyniku symulacji wytworzona energia (rocznie), straty (rocznie)), zużytą energię (rocznie), obwód fotowoltaiczny, wymaganą moc i przedstawiono w formie tabeli.Bada się wpływ systemu pompy ciepła na środowisko i wykazano, że jest to przyjazny dla środowiska system zaopatrzenia w ciepło i chłód . (**Analiza efektywności biwalentnego, równoległego trybu pracy pomp ciepła w indywidualnym budynku mieszkalnym: badanie trybów pracy systemu zaopatrzenia w ciepło**)*

Key Words: heat supply, heat pump, bivalent-parallel mode, soil probe, solar collector, computer modeling, storage tank
Słowa kluczowe: zaopatrzenie w ciepło, pompa ciepła, tryb biwalentno-równoległy, sonda glebowa, kolektor słoneczny, modelowanie komputerowe, zbiornik akumulacyjny

Introduction

The increasing demand for energy in the world, the problem of limited mineral reserves, including the problem of environmental protection, are pushing humanity to save energy. One of the main directions in this area is the use of systems using renewable energy sources.

Heat pumps, being one such system, are most often used in water supply processes for heating, ventilation, air conditioning systems of industrial and residential buildings in developed countries. Heat pumps are used both as individual heat pump units and as heat pump systems consisting of other devices and equipment. While a heat pump installation includes devices for collecting low-grade energy, heat pump systems include a heat pump and various devices for collecting low-grade energy from various media, as well as control and automation devices.

The characteristics that characterize heat pumps are thermal, energy and economic characteristics. These characteristics also depend on the characteristics of the heat sources. The task of an ideal source is to provide the heat consumer with a constant temperature throughout the entire period of heat supply. It must also be minimally corrosive and non-polluting to the surrounding area, as well as being cost-effective and economical. As a heat source, thermal energy is obtained from outdoor and exhaust air, as well as from soil and groundwater. At the same time, highly efficient systems receive heat from sea, lake and river water, as well as from geothermal sources and groundwater. Rural residents use wells for drinking and domestic water supply to their homes and farms. Well water can be used as a low potential source in a heat pump system to heat a home.

Formulation of the problem

The soil of the upper layers of the earth, like the external air, is a heat accumulator of unlimited capacity, collecting energy from the Sun. The efficiency of using soil heat mainly depends on its annual temperature regime, composition and humidity, air temperature, etc. it depends. The soil has high thermal stability, which increases with increasing depth.

The operating principle of a heat pump is based on the evaporation of refrigerant in a low pressure and low temperature heat exchanger and its condensation in a high pressure and high temperature heat exchanger, transferring energy.

During the process, the compressor consumes electricity. For every kilowatt-hour of electricity consumed, the heat pump produces 2.5-5 kilowatt-hours of thermal energy. The ratio of the thermal energy generated to the electrical energy consumed is called the style conversion ratio. The efficiency of a heat pump is determined by the conversion factor ε. The conversion factor is the ratio of the thermal energy Q produced to the electrical energy P used.

$$\varepsilon = \frac{Q}{P} \quad (1)$$

By using low-grade heat from the earth, heat pumps can operate at conversion rates greater than 100% because the heat load transferred by the heat pump from the external source to the room greatly exceeds the electrical energy expended to transfer the heat.

This value depends on the difference between the temperature levels in the evaporator and condenser: the greater the difference, the smaller this value.

Therefore, when designing a heat supply system using a heat pump, the following condition should be taken into account: the mass of the low-temperature heat source must be greater than the mass of the heated part. This will allow you to avoid overcooling the low temperature source and maintain the required temperature difference.

The heat pump has several operating modes: monovalent mode, monoenergetic mode, bivalent variable mode, bivalent parallel mode.

Soil is the most stable environment in terms of temperature. The upper layers of the earth are subject to temperature fluctuations, especially in the freezing depth zone. The depth of freezing is different for each region. The low-grade heat removal system has two designs: horizontal and vertical.

The horizontal system is a network of closed pipelines laid below the freezing depth of the soil. The vertical system is a complex of vertical pipelines and probes placed in wells with a depth of 20 to 200 meters. The probe consists of pipes that ensure unhindered descent to the required depth. Probes are manufactured as two-pipe, four-pipe, coaxial. Currently, four-tube probes are widely used.

For research and application in the climatic zone of Karabakh, heat pumps using low-potential heat sources with vertical probes were studied using computer modeling.

To ensure efficient operation of the heat pump installation, it is necessary to ensure the relative temperature stability of the low-potential heat source and sufficient heat capacity of the source for the entire period of operation of the system.

Solution of problems

The article presents a computer simulation model of the heat pump system of heat supply of a private residential house in Kalbajar. The simulation was carried out using GeoTSOL software. This software is a professional tool for planning and designing heat pump systems. With the help of this program, it is possible to select different system types and components and calculate energy and costs. This program:

• If necessary, models heat pump systems with solar thermal collectors and conventional boilers.

• The heat pump selects the medium: geothermal probes, geothermal collectors, air, groundwater.

• Selects the heat pump operating medium: salt water/water, water/water, air/water.

• Calculates seasonal performance coefficients, energy consumption, losses, solar share, efficiency and more for the entire heat pump system using computer simulations throughout the year.

• Conducts financial analysis: heat pump system heat price and comparisons are calculated over the entire life of the system.

Taking these positive factors into account, the heat pump heating system for a private residential building in Kelbajar is presented in Figure 1.

A heat pump system for heating a private home consists of a geothermal probe, a heat pump, a solar collector, a storage tank, an auxiliary boiler, a hot water supply system and a heating system.

In the presented diagram, soil is taken as a heat source. The soil temperature around the probe and the temperature of the working fluid at the inlet and outlet of the heat pump were determined as a result of modeling for the city of Kelbajar by month (Fig. 2).

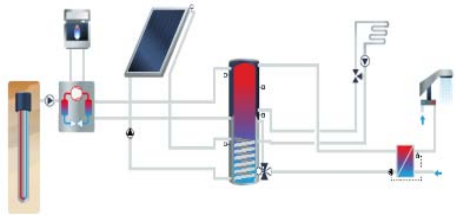

Fig. 1. Heat pump system for heating a private home

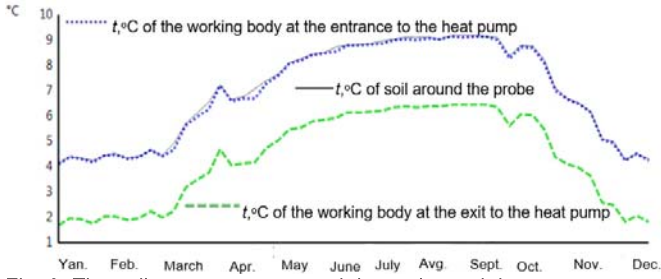

Fig. 2. The soil temperature around the probe and the temperature of the working fluid at the inlet and outlet of the heat pump in the city of Kelbajar by month

Ground-based probes use heat accumulated at depths ranging from a few meters to 100 meters. In addition, soil probes are filled with a mixture of brine and water and are designed to absorb stored heat from the soil and transfer it to the heat pump. The parameters of the ground probe used as a heat source for a private house in Kelbajar, calculated as a result of the simulation, are shown in Table 1:

Table 1. Results by soil zone

Parameter	Price	Parameter	Price
Number of wells	3 units	Type of construction	double U-tube
Drilling depth	76,6 m	Solution pump integration	114 W
The diameter of the well	150 mm	Solution flow from the pump	1390 l/hour

The working body moves along the first circuit and transfers the heat received from the ground to the second circuit - the heat pump. The main elements of a heat pump are: compressor, control valve, condenser and evaporator. The condenser and evaporator are the heat exchangers of the heat pump. Heat from a low-potential source is transferred through the working fluid to the refrigerant in the evaporator. The refrigerant evaporates in the evaporator. The refrigerant vapor is compressed in the compressor and acquires higher parameters. After this, the heat of the refrigerant in the condenser is transferred to the water going to the consumer. The refrigerant is liquefied through the control valve and returned to the cycle.

Heat pumps of this type are factory-manufactured and their power varies from 4 kW to 650 kW. R410A, R407C, R134a are used as refrigerants. The rated thermal power of the heat pump selected as a result of the simulation is 6 kW. The heat pump operating mode is bivalent parallel. In Figure 3, the schedule of operating modes of the heat pump system is determined as a result of modeling.

The heat pump works alone up to BV temperature. When the ambient temperature drops below the BV temperature, the heat pump and auxiliary boiler both operate simultaneously. Here, 1-heat pump, 2-auxiliary boiler, P-heat load, P_H – heat load transferred by heat pump, BV-bivalent point, $\Phi_{HL,B}$ – building heat load, T_a –

ambient temperature, T_L – heating temperature limit, approx. 20°C, T_{aux} – start-up temperature of auxiliary boiler, T_{off} – heat pump shut-off temperature, T_e-standard ambient temperature, approx. – (- 15°C).

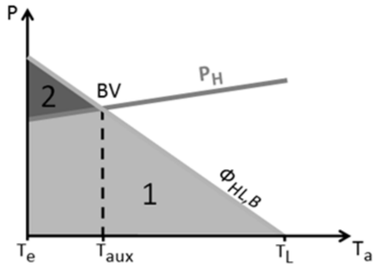

Fig. 3. Heat pump system operating mode chart

The heat load for heating and hot water supply of the building is mainly covered by the heat pump and solar collector. In case of peak loads, which is December, January, February, an additional boiler is turned on. The estimated boiler power is 10 kW.

Solar energy plays an important role in the energy saving system, which is due to the large amount of solar energy entering the Earth, its inexhaustibility, availability and compatibility with the environment. The most common are small solar systems used for heating homes. Such systems include solar collectors, storage tanks, circulation pumps and other auxiliary equipment. The specific characteristics of the solar collector calculated using computer modeling for the city of Kalbajar are shown in Table 2 below:

Table 2. Results related to the solar collector

Parameter	Price	Parameter	Price
Solar faction	20,5%	The energy provided by the collector circuit	2857kWh
Solar fraction for hot water supply	35,5%	The energy provided by the collector	3247kWh
The useful work factor of the solar system	29,1%	The model of the collector	Standard flat plate
Active solar system radiation	9733 kVt/saat	The number of collector	6 units

It is necessary to use a storage tank to even out fluctuations in the consumption and production of solar energy both throughout the year and during the day in frequency [1]. The estimated capacity of the storage tank is 750 l. Hot water in the storage tank comes from both the heat pump and the solar collector, as well as from the boiler during operation of the boiler.

When studying the efficiency of the existing solar heating system, it was found that low-potential solar energy is used less during periods of low solar insolation, as well as when the water temperature in the storage tank decreases [2]. Taking this into account, in the proposed heat supply scheme (Fig. 4), water from the storage tank is also supplied to the heat pump for heating. When the storage tank temperature drops below the required threshold, the heat pump system stops working and the consumer receives energy from a backup heat source. This mode of operation allows maximum use of the energy stored in solar collectors. At the same time, the efficiency of solar collectors increases as a result of a decrease in the temperature of the coolant at the inlet to the collector.

In the bivalent parallel mode heat pump system, during the peak time, in December, January, February, the solar collector and the heat pump together cannot meet the heat demand. Therefore, the auxiliary boiler starts, it works in parallel with the solar collector and the heat pump. From mid-March to December, the auxiliary boiler does not work. From the end of May to the beginning of October, the heat pump works with minimal load, so the results obtained through the heat simulation are shown in table 3.

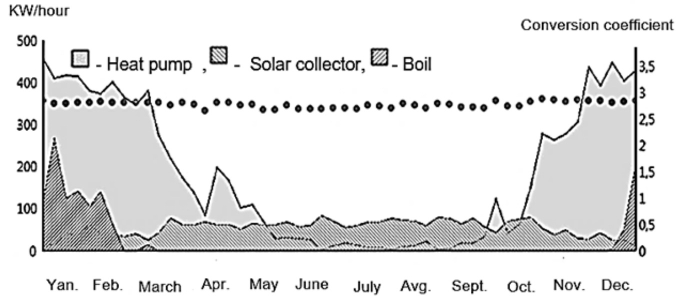

Fig. 4 Heat pump, solar collector, auxiliary boiler heat load to the system and heat pump conversion factor for the heat supply system by month.

Table 3. The results obtained as a result of the simulation

Parameter	Price	Parameter	Price
Produced energy (annually): With a heat pump With boiler With a solar collector	 9465 kWh (70%) 1256 kWh (9%) 2808 kWh (21%)	**Losses (annual)** From the storage tank From a solar tank From the solar collector pipe in the room From the outer tube of the solar collector	 378 kWh 49 kWh 315 kWh 75 kWh
Energy used (annual) Autonomous heating Hot water supply	 8509 kWh (64%) 4736 kWh (35%)	**Solar outline:** Solar share Solar share in hot water supply The useful work factor of the solar system Active solar system radiation The energy provided by the collector	 20.5% 35.5% 29.1% 9733kWh 3247kWh
Required power: Heat pump Auxiliary energy Solar contour pump Boiler	 3204 kWh (65%) 186 kWh (4%) 149 kWh (3%) 1328 kWh (28%)		

Increased environmental pollution and disruption of the thermal balance of the atmosphere gradually leads to global climate change. Global climate change, in turn, causes various natural disasters. Increasing CO_2 levels in the atmosphere are one of the contributing factors to these problems. By using a heat pump system for the heating equipment of a private residential building in Kelbajar, 8956 kWh of energy was saved. In addition, 2,217 kg of CO_2 were prevented from being released into the atmosphere.

A heat pump system is an environmentally friendly heating and cooling system. During its operation, minerals, or rather organic fuel, are not burned, and as a result, harmful gases such as CO, CO_2, NO_X, SO_2, PbO_2 are not released into the atmosphere. Based on the calculation results, the implementation of this system will reduce the amount of greenhouse gases and heavy metals, harmful emissions, and we can say that this will have the most positive impact on the environmental situation of the region. The heat pump used also does not pose an environmental hazard to people living in this environment. Thus, it operates more quietly than a conventional refrigerator and does not emit any allergenic emissions into the cooled or heated room.

The heat pump is durable and does not require much attention. The service life of factory-made soil probes reaches 100 years. The service life of the main unit of the heat pump - the compressor - is 30 years and is easily replaced. The heat pump system ensures maximum comfortable conditions in buildings, minimal fluctuations in temperature and humidity, noise levels, and also allows the heating and cooling process to be carried out using the same equipment. The heating system using a heat pump is completely explosion and fireproof. It does not require special maintenance and is easy to operate [4].

Result

A review of the experience of developed foreign countries in the operation of heat pumps for heating individual residential buildings confirms their technical and energy efficiency, and, under certain conditions, profitability. [5-9] Thus, heat pumps are the only way to obtain natural thermal energy with economic and environmental benefits. If we take into account the annual increase in heat carrier tariffs by 10-15%, the payback period of the heat pump system will decrease. The use of a heat pump will significantly reduce the cost of heating in winter and cooling buildings in summer [10-19]. Taking into account the pace of low-rise construction in the Karabakh zone, forecasts for the growth of electricity, gas and inflation rates, we can come to the conclusion that the region will have a large demand for heating residential buildings in the near future with the introduction of heat pumps.

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