Autonomous hybrid solar-heat pump for system heat-cooling in buildings

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Abstract. In this paper, there is described technical desicion of heat-cooling supply in building by using the solar heat pump system. It is possible to realize a system having high reliability in operation of the system. The solar heat pump system according to the present technical desicion has high energy efficiency while ensuring reliability, and is useful as a domestic air conditioning and heating water heater. It can also be applied to uses such as industrial heating and cooling devices. In addition, the structure of the autonomous hybrid system according is useful as a method for efficiently using PV system.

1. Introduction
The development national economy is accompanied with more and more serious world energy sources crisis, and implementation of energy-saving technologies is important. In recent years, there is continuous development of heat pump techniques, heat-pump water heater also develops rapidly [1-4]. At the same conditions, the power consumption of heat-pump water heater only is 1/3 to 1/4 part of electr consumption an electric heater, and therefore, its energy-saving potential is big. Because the energy-efficient characteristic that heat-pump water heater had, therefore, it is saves energy greatly, and can remedy inadequate natural endowments such as the existing low-density of solar water heater, discontinuity and unstability. It is a kind of round-the-clock energy-saving and environmental protection, and it is with high content of technology, and development potentiality is big. Commercial Prospect is wide to promoting that national economy sustainable development. Also it has great far-reaching social effect. This must become the main force of following water heater.

Heat pump is a kind ofly can obtain low level heat from natural air, water or soil, and through the electric power acting, output can be by the equipment of the used high-grade heat of people. Heat pump by low-temperature heat source (as the natural air of surrounding environment, underground water, river, seawater, sewage etc.) heat absorption can, be converted to the higher temperatures thermal source then and be released in the required space (or other zone).It is the heating and the hot water facility of a kind of energy-saving and environmental protection, cleaning, and heat pump techniques is the new energy technology that receives much attention in the whole world in recent years [5-6].

Heat pump assembly both can be used as heat supply heating equipment, can be used as refrigeration cool-down equipment again. Wherein, the power conversion of the source pump of heat pump assembly, it is the effect that utilizes its compressor, by consuming certain auxiliary energy (as electric energy), under the acting in conjunction of the cold-producing medium that in compressor and heat-exchanger rig, circulates, by drawing lower temperature heat energy in the environment thermal source then and be released in the required space (or other zone).It is the heating and the hot water facility of a kind of energy-saving and environmental protection, cleaning, and heat pump techniques is the new energy technology that receives much attention in the whole world in recent years [7-11]. At this, owing to the running of compressor is done manual work and has been consumed
electric energy, the running of compressor make different variable condition that the cold-producing medium of continuous circulation produces in different devices with different effects (i.e. evaporation heat absorption and condensation heat release) thus reached effect and the purpose that the recovery low-temperature heat source is produced high temperature heat source. The advantage of heat-pump water heater is: (1) conspicuous energy-saving effect; (2) can "peak load shifting", the exploitation valley power consumption; (3) can realize that hot water, heating, cooling are integrated, improve efficiency of energy utilization; Utilization, the recovery of (4) be convenient to underground heat, building low-grade energies such as used heat. Further feasibility study shows that compare with other pot-type boilers, heat-pump water heater has higher economy, and its initial cost expectation payback period is 2~3 years. With the ambient air is thermal source, and the heat pump assembly of placing the immersion coil pipe in the hot water storage tank can have a better effect [12-16].

2. Methods

The known systems for supplying consumers with heat energy, which contains solar collectors and a heat pump with circulation circuits of the coolant, closed on distributors connected by supply pipelines with a variety of consumers of heat energy of different temperature levels [17]. Solar air collectors are a low-grade heat source for heat pumps connected to the heating and hot water system. The heat pump consists of a compressor, a condenser, a throttling device, an evaporator, all connected in one circuit. It also includes an electric power source, which consists of an array of solar panels, a photovoltaic generation controller, respectively transforming from DC to AC and voltage from 12 Volts to 220 Volts an inverter to which the compressor of the heat pump installation is connected. In addition, when there is insufficient solar radiation, the heat pump requires electrical energy, which is provided by conventional energy through an inverter.

Also, a heating system is known with a regulated combination of solar collectors and a heat pump, equipped with coolant circulation circuits and control means [18]. The circulation circuit of the solar batteries is closed to a buffer storage tank, relative to which the circulation of the coolant in the circuit is provided by a circulation pump. In turn, the circulation circuit of the heat pump is connected through a three-way switching valve with a heated water tank and a heat exchanger connected to a heat energy consumer. The buffer storage tank of the solar circuit and the heat pump are connected to the earth collector via three-way changeover valves. When the difference between the initial temperature of the coolant in the solar collector circuit and the operating temperature in the heated water tank exceeds the specified limits, a heat pump is connected to the heating of the coolant in the system. The disadvantage of the known heating system is the imperfection of its layout, because the solar collector circuit does not close to the heat energy consumer, but is connected in series with the heat pump circuit, which makes the operation of solar collectors dependent on the condition and reliability of the heat pump circulation circuit equipment, the difficulty in regulating the joint operation of the circuits, which reduces the reliability and efficiency of operation systems.

A combined heat supply system containing combined solar and heat pump water heating installations with coolant circulation circuits equipped with an electronic control system and closed to a common heat storage tank is adopted as a prototype [19]. The heat storage tank is equipped with a backup peak heater and is connected to the heating and hot water supply circuit, where the heat pump water heating system circuit is connected to the heat storage tank through a three-way switching valve, and is also connected to the Earth's thermal energy source, made in the form of a ground probe or ground collector. In winter, the electronic control system measures the temperature in the storage tank and the temperature in the solar water heating circuit, at a given temperature difference, a signal is sent to the circulation pump in the solar water heating circuit, and it starts to circulate, due to which heat is transferred from the solar water heating system. installation in a storage tank. If the consumption of a heated coolant increases, for example, hot water, and the intensity of solar radiation is not enough to make up for the losses, the heat pump unit is switched on, and these two converters of thermal energy begin to work; if their heat-converting power is not enough when working together, then, to raise the temperature of the coolant to a predetermined level, there are electric heaters in the form of electric boilers in the accumulator tank and on the supply pipe of the hot water supply. During unfavorable weather conditions, when the solar water heating unit is not working, only the heat pump unit and electric heaters are involved in heating, which are turned on if necessary. In the summer period, when heating of buildings is not required, and the demand for hot water remains, the three-way changeover valve switches in the recirculation of the coolant from the storage tank to the heat pump system in such a way as to bypass the heating circuit, and leave only the hot water circuit, while the
operating mode is the same as in winter, i.e., if there is sun, then it is heated by the sun, there is not enough sun, it is warmed by the sun, there is not enough sun, then the heat pump installation is additionally switched on, the circuit of which is connected to the circuit of the source of the Earth's thermal energy. If there is not enough heat production when they work together, then an electric closer is turned on. The circuit of the heat pump unit is additionally equipped with a hydro-buffer tank for mixing the low-temperature coolant coming from the circuit of the solar water heating unit and/or the circuit of the Earth's thermal energy source. The heat exchanger can be made of a plate, which makes it possible to transfer thermal energy from the circuit of the solar water heating installation with the required temperature parameters. The system will be more durable if the circulation circuits are made of copper pipes. The circuits can be equipped with circulation pumps that circulate water and antifreeze in the pipelines of the system. The accumulated thermal energy will be stored for a long time if thermal insulation is performed on the outer wall of the storage tank. If necessary, the operation of circulation circuits and heating equipment can be controlled manually. For the accuracy and reliability of information about the operation of the system, the automatic control means are equipped with heat calculators to obtain data on the flow rate of the coolant and its temperature parameters in the supply and return pipelines of the circulation circuits. The source of thermal energy of the Earth will be ground wells, which will make the system more compact. Surplus thermal energy generated by a solar water heater can accumulate in ground boreholes. The disadvantages of the known system are the dependence on centralized power supply, incomplete use of the technical capabilities of the heat pump installation, in particular, the idle operation in the air conditioning mode in the room.

The technical task, for the solution of which the laboratory model is proposed and created, is to increase the reliability and efficiency of the hybrid heat cooling supply system, expand its capabilities in terms of autonomous power supply to the installation, improve the monitoring and control processes of the circulation circuits and equipment located in it, optimize the distribution of the heat load between the circulation circuits of the system. Expansion of its functionality for the used coolant and increased efficiency through more complete use of low-grade heat sources in addition to air conditioning systems in the hot seasons.

3. Results and discussion

3.1 Modern technical solution

This problem is solved by the proposed combined heat supply system containing solar water heating and heat pump installations with coolant circulation circuits, equipped with automatic control means and closed to a common heat storage tank, combined with a heater and connected to the circuit of the hot water supply system, while the circuit of the heat pump installation is connected to air heater of the room.

New is that the circuit of the heat pump is additionally connected to a photovoltaic station, where the circuit of the heat pump unit uses a low-temperature coolant entering from the circuit of the solar water heating unit to the storage tank, without connecting the circuit of the ground's thermal energy source. The heat pump unit can also operate during the hot period in the air conditioning mode by switching on the reverse cycle, while the indoor liquid air cooler mode is used. The heat calculators are connected to the main controller connected to a personal computer via an interface, which will allow faster transmission and processing of the received data. The processed data can be recorded by a processor and, for clarity, can be displayed on a computer monitor. The process of heating water in the heat storage tank takes place up to a temperature of 55 °C from the solar water heating system circuit. When the sensor detects this water temperature in the heat storage tank during direct heating during a period of high solar activity, the circulation pump in the solar water heating system is automatically turned off. If the temperature of the storage tank has reached, and the activity of solar radiation does not decrease, then the circulation pump of the solar water heating circuit is switched off.

In the absence of solar radiation, only electric heater 4 participates in the process of heating the heat storage tank 4. The heat pump unit extracts low-temperature coolant from the heat storage tank and then increases it to a level sufficient to heat the room air through a liquid air heater.

When the efficiency of solar radiation decreases, for example, in the evening, morning hours of the day or in the winter and autumn-spring period of the year, but the temperature in the solar water heater circuit reaches 20-25°C.
This is enough to use its coolant as a low-temperature carrier for the operation of a heat pump. If the flow rate of the heated coolant increases, and the power of the heat pump installation is insufficient, then an electric heater built into the heat transfer tank is connected to the heating process of the coolant, which raises its temperature to a predetermined level. The proposed combined heat and cooling supply system can also be used as a research and training bench for laboratory research on the use of solar energy and low-grade energy as unconventional sources of heat.

In Tashkent State Technical University (TSTU) there is created modern installation. The laboratory model relates to heating and hot water supply systems, as well as air conditioning for residential and other buildings, in particular, to combined heat and cooling supply systems using solar water heating collectors, PV and heat pump. The laboratory model is illustrated by an example of an implementation, which is shown Figure 1.

### 3.2 Principles of operation

The proposed autonomous combined heat and cold supply system contains heating means of two types: a solar water heating installation 1, consisting of solar collectors installed in the courtyard of the building, and a heat pump installation 2, consisting of a heat pump installed in the building. The units are equipped with coolant circulation circuits, where the supply and return pipelines are made of external plastic and internal copper pipes. To ensure reliable operation of the circuits, the pipelines are equipped with circulation pumps that circulate water and antifreeze in the corresponding circuits of the system. The circuits of the solar and heat pump installations 1 and 2 are closed to a common heat storage tank 3, combined with an electric heater 4 and connected to the hot water supply system 5, while the compressor of the heat pump installation 2 is electrically connected to the photovoltaic station 6, and the output through the condenser is the heat pump circuit unit 2 is connected to a liquid air heater 7. The evaporator of the heat pump unit 2 is connected through an intermediate heat exchanger 8 to a heat storage tank 3. The outlet circuit of the heat pump unit 2 is additionally equipped with a hydro-buffer tank 9 to protect against thermal expansion of the working fluid. The solar water heating system 1 circuit is closed to the common heat storage tank 3 through the heat exchanger 10. The circulation circuits are made with the possibility of automatic and/or manual control. The heating system is equipped with automatic control devices made in the form of water flow meters and temperature sensors based on resistance thermocouples installed on the supply and return pipelines of circulation circuits and electrically connected to heat meters 11, which receive data on the flow
rate of the coolant and its temperature parameters. The heat meters 11 are electrically connected to a main controller 12 connected to a personal computer (not shown) located in the room via an interface. Processing of the received data is performed on a computer using software according to a given algorithm. The processed data is recorded by the processor and displayed on the computer monitor. The process of heating water in the heat storage tank 3 is provided by the solar water heating circuit 1. The temperature sensor determines the heating temperature of the heat storage tank 3 during direct heating from the solar water heater circuit 1 during the period of high solar activity, which should not exceed 55°C. (see Figure 2).

If the water temperature in the storage tank reaches 55°C, and the activity of solar radiation does not decrease, then the circulation pump of the solar water heating system 1 circuit is turned off. In the absence of solar radiation, only electric heater 4 is involved in the process of heating the heat storage tank 3. Heat pump unit 2 extracts low-temperature coolant from the heat storage tank 3, and then increases it to a level sufficient for heating the liquid air heater 7.

When the efficiency of solar radiation decreases, for example, in the evening, morning hours of the day or in winter and autumn-spring seasons, but the temperature in the solar water heating system 1 circuit reaches 20÷25°C, then this is enough to use its coolant as a low-temperature medium for the operation of heat pump unit 2.

![Figure 2. Schem of a hybrid heat cooling supply system.](image)

The information will be in demand if the processing of the received data is performed on a computer using software according to a given algorithm (see Fig.3).

![Figure 3. Imagination in computer graphics of operating temperatures changing on time in the laboratory model:](image)
$t_0$ - temperature of boiling the coolant; $t_9$ - temperature of condensation the coolant; $t_{16}$ - temperature of air into the room; $t_3$ - temperature of coolant outgoing from air cooler, °C.

If the flow rate of the heated coolant increases, and the power of the heat pump installation 2 is not enough, then an electric heater 4, built into the heat storage tank 3, is connected to the heating process of the coolant, which raises the water temperature to a predetermined level. The proposed combined heat supply system can also be used as a research and training stand for laboratory research on the use of solar energy and low-grade energy as unconventional sources of heat. The heat pump unit 2 can also operate in the hot period in the air conditioning mode in the room by turning on the reverse cycle in it, while the unit 7 goes into the mode of the liquid air cooler.

3.3 Technical and economical evaluation
Heat and electricity are generated by solar collectors and photovoltaic panels. The cost of a heat pump with a capacity of 3 kW is $3200. The cost of a set of combined solar collector together with batteries of thermal and electric energy for 4 kW of power is $14,500. A heating (cooling) system with devices for heating (cooling) air for a 35 m² room costs $600. The economic feasibility of using heat pumps is shown by comparing different heating systems (see table 1).

| Table 1. Technical and economical comparison heat supply [20] |
|-----------------------------------------------|--------------------------|-------------------------|-------------------------|
| Fuel for heating                             | Type of installation     | Coefficient of using fuel | Fuel unit’s cost         | Cost of 30 kWh heat energy per day |
| Heating by heat pump                         |                          |                         |                         |                                    |
| Electro energy                               | Compressor heat pump with ground’s heat | COP = 3.5 | $0.085 / kWh | $0.729 |
| Electro energy                               | Compressor heat pump with ambient air’s heat | COP = 2.2 | $0.085 / kWh | $1.159 |
| Solar energy                                 | Heat pump with solar collectors, PV | COP = 0.75 | $0.000 / kWh | $0.000 |
| Heating by electro energy                    | Heater of resistance     | COP = 1.0             | $0.085 / kWh           | $2.550 |
| Heating by natural gas                       | Owen or boiler           | COP = 80%             | $0.055 / m³            | $2.074 |
| Heating by liquid fuel                       | Mazut                    | Efficiency = 80%      | $0.063 / litr           | $2.333 |

4. Conclusions
The use of solar energy in a heat pump unit with intermediate heat accumulation allows at its autonomous power supply. Also, the use of heat exchangers inside the water storage tank makes it possible to isolate temperature potentials for hot water supply and low-grade heat. The system of solar heat accumulation in a heat pump installation provides a significant reduction in dimensions without ground heat exchangers, and also smooths the modes of consumption, input and removal of thermal energy, which ensures more reliable and efficient operation of the system.

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