IMPROVING THE EFFICIENCY off-line HEAT PUMP SYSTEM FOR HEATING RURAL HOUSE IN THE COLD DAYS

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Summary: This article presents methods and means of increasing an efficiency of heat pump system and hot water supply for residential houses on the base of using of the heat pumps «air-water», solar collector of energy and ground heat exchangers. The technological scheme of energy saving heat pump system of the rural house taking into account local climatic conditions is described. The study determines typical temperature parameters hybrid heat pump system's elements at cold days in heating season. The expediency of use of solar energy and heat of ground for preliminary heating of the cold external air arriving to the thermal pump «air-water» is proved.

KEYWORDS: HEATING, THERMAL PUMP, AIR SOLAR COLLECTOR, SOIL HEAT EXCHANGER, WARMTH ACCUMULATION.

1. Introduction

Distinctive feature of agricultural objects of Republic of Kazakhstans is their rather small individual capacity and significant dispersion on extensive territory that creates the certain difficulties in construction of the effective centralized systems of heating and hot water supply (HHWS). At the same time local climatic conditions of this country favour to development of independent hybrid systems HHWS with use of renewed energy sources (RES), in particular, to energy of the Sun, a wind and heat of a ground. The last provides use of popular thermal pumps (TP) or their combination with other types of power sources. The choice of updating of TP depends on climatic conditions of the district and technical and economic indicators of the equipment. The solution of questions of a choice of TP type, scales and areas of their rational use in the different countries is far not equivalent. As a rule, geothermal TP «water-water» were extended in the northern countries, and in southern - TP «air-water». The price of the last for 30-40 % is cheaper than geothermal TP at comparability of capacity and quality of the equipment. This difference essentially increases at carrying out difficult earthwork, drilling of wells (by depth of 60-100 m) and a laying of geothermal probes [1].

In the majority of regions of Kazakhstan it is more preferable to use low-potential warmth of atmospheric air, that is to apply to HHWS of rural houses the thermal pumps «air-water» (TPAW). Wide circulation of TPAW is connected with relative simplicity of installation and low cost concerning other types of thermal pumps. Weakness of TPAW is reduction of thermal capacity at decrease in temperature of external air lower – 15 °C [2].

Considering that decrease in temperature of external air (below – 15 °C) in the majority of regions of Kazakhstan is observed rather short time (10-15 days of the winter period), arises practical interest to search of possibility of increase of overall performance of heat pump system of a heat supply (HPHS) of rural houses during this period of time taking into account use of local resources.

In this article it is offered some ways of increase of overall performance of HPHS of rural houses in cold days at the expense of preliminary heating of the external air arriving in TPAW, by means of the thermal blocks accumulating warmth of solar energy (in the afternoon) and soil air lines (at night).

2. Materials and research methods

2.1 Preconditions of use of solar energy and warmth of soil for HHWS of the rural house. The main indicator of overall performance of TP is the factor of transformation of the thermal *pumps COP* (coefficient of preformance) which is defined by the relation of capacity of received useful heat to the capacity spent for a drive of the compressor [1,2].

For calculation *of COP* the formula [1] is used:

$$COP = \frac{Q_н}{W},$$

where $Q_н$ – received useful heat, J;
W - power consumption, J.

TPAW, as a rule, have optimum values *COP* = 3,5 … 4,0 at temperature of external air t=2 °C [1]. With increase in temperature of a source of low-potential heat and reduction of temperature of heating factor *COP* increases and can reach 4, 5 and more values. Fall of temperature of air during winter time considerably reduces *COP* and leads to an inefficiency of use TPAW.

Key question on which efficiency of application of TP substantially depends, the question of temperature increase of a source of low-potential heat, that is the air arriving in TPAW is. Considering short duration of the coldest days in the southern and western regions of Kazakhstan (10-15 days) for achievement of the specified purpose in rural areas it is possible to find separate ways and means. For example, previously to pass cold external air through the adapted economic constructions, cellars, etc.

At a complete set of hybrid HPHS for rural houses of Kazakhstan, first of all, it is necessary to consider use of solar energy (especially in the afternoon). It gives essential reduction of consumption of electric energy TPAW with 25 to 15 % from the general development [3,4].

Irrespective of a geographical arrangement of the republic, resources of solar energy in the country are stable and accepted, thanks to favourable dry climatic conditions. The quantity of a sundial makes 2200-3000 hours in a year, and energy of sunlight of 1300-1800 kW on metre a year. Total day radiation under various conditions on the republic makes 3,8-5,2 kWh/sq.m. Average monthly temperature of external air, for example, in Almaty area during winter time does not decrease below – 11 °C. In some cases this temperature can decrease to – 25 °C (in a current of 3-5 days).

In rural areas of the majority of regions of Kazakhstan and attractive use of warmth of soil as its temperature, on depth of 1,3-1,5 metres, practically do not change and keeps in limits 7-10 °C heat is available. When laying soil air lines on this depth and the admission through them cold external air from the subsequent giving in TPAW it is possible to increase in addition efficiency of its work in cold days.

Considering stated in this article one of ways of increase of efficiency of TPS of the rural house at the expense of preliminary heating of the external cold air arriving in TPAW, in the heat exchangers accumulating solar heat and warmth of soil is offered.

2.2 Block diagramme of the HHWS hybrid system. Widespread devices for transformation
solar energy in thermal are concentrating and directly absorbing a solar stream - solar collectors and absorbers or panels. As solar

collectors serves гелиосистема, including a transparent roof from the metal plate established under it with the wavy profile which outer side is painted by a selective absorbing covering.

For increase of efficiency of use of solar radiation гелиосистема it can be supplied with the heatheat-sink design accumulating warmth of solar energy. Use of the accumulators charged in the minimum power consumption and discharged in the maximum requirement, essentially increases reliability and overall performance of HPHS. By means of such set of heliosystem the heat-carrier temperature in primary contour of solar absorbers and in a contour of the evaporator of the thermal pump during the winter period can be raised to 3 … 7 wasps in relation to temperature of external air.

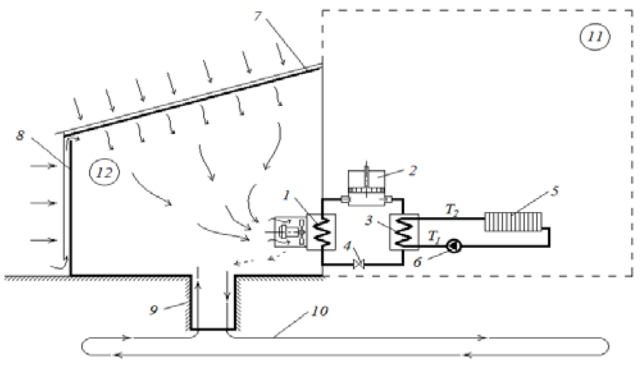
Heliothermal pump installation can work in two modes - summer and winter. In the summer period (April-October) hot water supply of a house becomes covered completely by the warmth received from solar collectors. The thermal pump as the additional power source, can work in cloudy days and, if necessary, at night. During the winter period thermal loading for heating of a house becomes covered by heatpump installation which uses as a source of low-potential energy warmth of external air warmed-up with solar absorbers and a heatheat-sink design.

We developed the hybrid HPS of the rural house consisting of air solar collectors, the soil heat exchanger and the warmth accumulator which can be used for preliminary heating of the cold external air arriving in evaporator TPAW.

In the picture 1 the block diagramme of energy saving HPS of the rural house which includes evaporator TPAW (1), the compressor (2), the condenser (3), a throttle dilator (4), system of heating (5), the circulating pump (6), an inclined solar collector (7), a vertical solar collector (8), the heataccumulator (9), soil the heat exchanger (10), a heated room (11) and thermal point (12) is presented.

From picture 1 follows that basic elements for preliminary heating of the external air arriving in a contour of evaporator TPAW, are: the air solar collectors integrated into a roof and the southern facade of thermal point, the soil heat exchanger (air line) and the warmth accumulator.

For effective use of the RES thermal resources the system of collecting low-potential heat takes place indoors which is attached to a heated building as thermal point (TP).



Picture 1 *- Scheme of collecting low-potential heat and work of energy saving HPHS of the rural house*

The arrangement of TP minimises quantity of air lines and reduces heatlosses at transformation of thermal energy. As TP can serves utility rooms, garages, etc.

The experimental module of thermal point given in the picture 2, includes a room in the area 25 sq.m and height of 2,2 m which is divided by the horizontal heatisolated ceiling into two parts: top and bottom, reported among themselves ventilating hatches.

Picture 2 *- The experimental module of thermal point attached to the rural house*

The top part of thermal point contains a transparent roof from cellular polycarbonate in thickness δ = 10,0 mm, and under it the absorbing plate with the wavy profile "П" of a figurative form is established.

Feature of thermal point is that all elements of system of collecting low-potential heat are built in TP and through it automatic control of consumed warmth in heating systems depending on change of temperature of external air is carried out.

In a roof and the southern facade of TP the inclined and vertical air solar collectors consisting of a tight, heatisolated metal or wooden frame and a black metal plate, absorbing warmth take place. From above this frame is blocked by a transparent covering: glass or two-layer cellular polycarbonate. Properly sized square of a collector should be not less than 1,0 sq.m. The relation of length of a collector to its width should be in a range 5:1 … 3:1.

In the lower part of thermal point external block TPAW of the Toshiba Estia brand (HWS-803XWHM3-E) is attached to the general wall heated a room. The hydroblock (HWS-803H-E) of the thermal pump is connected to a heat-insulated floor and the heating devices bringing and taking-away pipelines. Management of modes of heating is carried out from the panel (HWS-AMS11E).

The offered design of the soil heat exchanger has the fan which takes away used in a contour of evaporator TPAW the heat-carrier (air) and banishes it through the pipes of the soil heat exchanger laid in a trench. Soil the heat exchanger is given in the picture 3 also represents the heat exchanger executed from two-layer goffered polyethylene, external diameter of a pipe of 110 mm, laid in a trench depth of 1,6 m and in the length of 66 m on perimetre of the rural house.

a. б.

a – trench with the heat exchange pipe;
б – the heat exchange pipe in the viewing hole

Picture 3 *– General view of the soil heat exchanger*

The heat-carrier (air) circulating in the soil heat exchanger selects warmth from soil and submits it to the heat exchanger of evaporator TPAW.

Regulation of the direction of circulation of the heat-carrier fulfilled in a contour of the evaporator, is carried out by means of a box with the cut-out air pipes, the thermal pump established on the external block, as is shown in the picture 4.

***Picture 4** – Directing box of the heat-carrier, fulfilled in TPAW*

From picture 4 it is visible that on the open end of a box there is a rotary latch by means of which the adjustable suction of the air fulfilled in TPAW is made. In case of a negative difference of the air temperatures, evaporator TPAW fulfilled in a contour, and the external air, the fulfilled air is circulated through pipes of the soil heat exchanger. Otherwise, when the temperature of external air is lower fulfilled, the last will circulate on a vicious circle, i.e. through air solar collectors.

For the purpose of the accounting of an expense of the heat-carrier on submitting pipelines of primary and distributive contours flowmeters СГВ-15 are established.

The heatheat-sink design is formed in TP in the form of a hole in volume not less than 5 m^3. As heatheat-sink weight nonfreezing liquids (antifreeze, antifreeze, etc.) or firm materials (magnesite, talc chlorite, chamotte, etc.), possessing a high thermal capacity can be applied. The heatheat-sink design is reported on a contour of circulation by the solar water collectors established along the edges by a transparent roof, solar energy accumulating warmth.

In TP the external block TPAW using air, warmed up by the warmth utilised by system of collecting low-potential power sources takes place.

2.3 Principle of work of heatpump system. Hybrid HPS of the rural house works as follows. In the coldest days of the heating period, before receipt in evaporator TPAW, external cold air passes through vertical and inclined air solar collectors, it is warmed up and arrives in TP. Further the heated-up external air arrives in the evaporator of external block TPAW. Warmth thermotransformation to higher temperature level occurs by warmth transfer from the warm low-potential heat-carrier to a coolant circulating in a contour of the evaporator. Further the coolant evaporates, pairs of coolant are compressed in compressor TPAW, and its warmth is transferred circulating via the condenser of the thermal pump to water of system of heating. Water of system of heating heats up in the thermal pump to some temperature defined by conditions of economic work TPAW and by means of the circulating pump moves in heating system (in a heat-insulated floor or heating devices).

Cooled in a contour of evaporator TPAW the heat-carrier (air) by means of the fan moves in the soil heat exchanger. Passing through the goffered pipes laid in a trench of the soil heat exchanger cooled air, takes away warmth of soil on depth of a nonfreezing layer of earth and again comes back back to TP. It allows to circulate the most part of air in an internal contour (TP, TPAW and the soil heat exchanger) without external cooling.

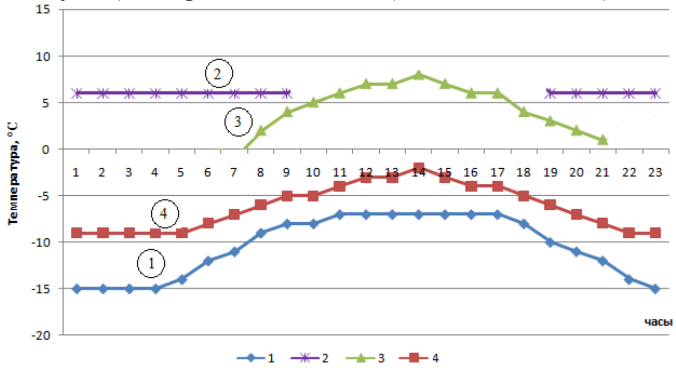
Accumulation of warmth occurs in TP where the heatheat-sink weight (9) specified in the picture1 takes place. At night, the warmth accumulated in a warm and heat-sink design warms up external air before its giving in a contour of evaporator TPAW.

3 Results and discussion

We carried out natural tests and the main are defined temperature characteristics in knots and elements HPS of the rural house in climatic conditions of Almaty area of the Republic of Kazakhstan.

During experiences temperatures were measured: external air, thermal point (at height of 1 m from a floor) and in a soil air line. Measurements were carried out according to a technique [5].

In the picture 5 dynamics of change of temperatures in the HPHS various elements of the rural house (Kargala's settlement of Almaty area) during cold time is shown (on December 8, 2014).



***Picture 5** – Dynamics of change of temperatures in elements HPHS of the rural house during cold time*

Daily change of temperature of external air it is provided by dark blue colour (schedule 1). The temperature in a soil air line (depth of 1,6 m), shown by violet colour (schedule 2), practically did not change and was near + 6 ^{o}C.

Air temperature in thermal point, at its heating by air solar collectors (during the period from 7^{00} to 18^{00} hours), was measured at height of 1 metre from a floor (schedule 3). Despite a sunset (approximately in 18^{20} of hours) warm air in TP keeps approximately till 20^{00} o'clock.

The TP air intended for TPAW, periodically passed heating in a soil air line by run by the special fan. At work of air solar collectors (from 7^{00} to 18^{00} o'clock) soil air lines are disconnected and collect heat from surrounding soil.

In the picture 5 red colour (schedule 4) gave a resultant the average air temperature, arriving in evaporator TPAW. This temperature develops at the expense of preliminary heating of cold external air in thermal point which is in turn warmed up by air solar collectors and a soil air line.

In the considered technological scheme of HPS of the rural house, in cold days of winter, there is a preliminary heating of the external air arriving in TPAW. It allows to support factor of transformation *COP* in effective limits of 3-4 units. At more high temperatures of external air (higher than -5 ^{o}C) the soil air line is disconnected from the scheme. Air solar collectors become more active in the afternoon that allows to minimise operating time TPAW.

If the temperature of external air is lower, than the temperature of the heat-carrier fulfilled in evaporator TPAW, soil the heat exchanger works in the closed mode. Thus, the fulfilled heat-carrier is banished through the integrated systems of air solar collectors and soil air lines, is warmed up and moves in TPAW. Such way of heating of a low-potential source of warmth is much more effective.

Conclusion

The offered technological scheme of an independent heat supply of the rural house of the settlement of Kargaly of Almaty area allows to increase factor of transformation of heat *COP* of the thermal pump «air-water» with 2-2,5 to 3,5-4 at temperature of external air during the winter period from – 14 °C to – 20 °C. Thus, use of solar energy reduces in the afternoon electricity consumption TPAW approximately for 15-18 %.

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