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(71) Applicant (for all designated States except US): **COL-IPU A/S** [DK/DK]; Nils Koppels Allé 404, 2., DK-2800 Lyngby (DK).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **PEDERSEN, Troels, Gottfried** [DK/DK]; Temevej 2, DK-2990 Nivå (DK).

(74) Agents: **HERTLING, Peter** et al.; Inspicos A/S, P.O. Box 45, Kogle Allé 2, DK-2970 Hørsholm (DK).

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(54) Title: AN ENERGY SYSTEM WITH A HEAT PUMP

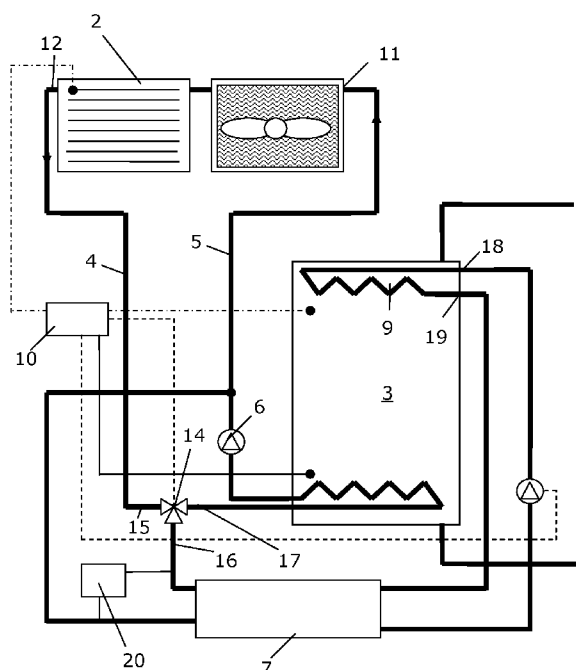


Fig. 3

(57) Abstract: The invention provides a system for collection of thermal energy, e.g. solar energy. The system comprises at least two different loops for delivering the collected energy to a reservoir. One of the loops involves the use of a heat pump for increasing a temperature difference between inlet and outlet temperature of the energy collector.



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AN ENERGY SYSTEM WITH A HEAT PUMP

Field of the invention

The present invention relates to a system for collection of thermal energy. The system comprises a heat pump, an energy collector, an energy reservoir, and a fluid flowing in several loops for collecting and distributing the thermal energy. In the following, this fluid is typically referred to as an "energy collection medium".

Background of the invention

Traditionally, energy collectors such as solar air collectors, solar water collectors, and combinations thereof have been connected to the domestic hot water system, since such energy collectors at the northern hemisphere are most efficient during summer time where the solar radiation and the outdoor temperature are high. At the same time the need for heating of the buildings is very low and sometimes non-existing. During periods with lower solar radiation and/or lower outdoor temperature, the efficiency of energy collectors are lower and their ability to collect an amount of energy which is significant compared to the amount of energy which is needed for production of domestic hot water and/or heating of the building is decreased.

Summary of the invention

It is an object of embodiments of the invention to provide an improved system for collection of thermal energy.

Thus, in a first aspect, the invention provides a system for collection of thermal energy, the system comprising

- an energy collector with a collector inlet and collector outlet for exchange of thermal energy between a fluid which flows from the collector inlet to the collector outlet and the energy collector,
- an energy reservoir with a lower reservoir inlet and lower reservoir outlet for exchange of thermal energy between a fluid which flows from the reservoir inlet to the reservoir outlet and a lower portion of the energy reservoir,

- a heat pump comprising a cold side inlet, a cold side outlet, a warm side inlet, a warm side outlet, and exchange means for exchange of thermal energy between a fluid which flows from the cold side inlet to the cold side outlet and a fluid which flows from the warm side inlet to the warm side outlet,

5 the system comprising at least a first and a second loop for flow of the fluid, wherein the first loop connects the collector outlet with the cold side inlet and the cold side outlet with the collector inlet, and the second loop connects the collector outlet with the lower reservoir inlet and the lower reservoir outlet with the collector inlet.

10 Due to the two loops, the thermal exchange may selectively be facilitated between the energy collector and one or both of the energy reservoir and the heat pump. When sufficient energy is available for the energy collector to energise the reservoir, the second loop is activated. When less energy is available, the first loop is activated either in combination with the second loop or as a replacement of the second loop. In this case, the collected energy is transported to the heat pump which can further energise the system and provide the energy
15 which is requested to the energy reservoir.

The energy reservoir may be a water reservoir with domestic hot water, a reservoir with water for heating the building, or a combined reservoir from which a part of the water is used as domestic hot water and another part is used for heating the building. In the latter
20 embodiment, the reservoir may be divided into two separate reservoirs in order to be able to circulate the water for heating without mixing it with the domestic hot water. The two separate reservoirs may thus be in thermal contact with each other, e.g. by arranging one of the reservoirs inside the other reservoir.

In embodiments with two reservoirs, both the first and the second energy reservoir may be water reservoirs.

25 However, in an alternative embodiment, the energy reservoir or the second energy reservoir need not necessary be a water reservoir, but may e.g. be a salt reservoir, a radiator, a floor heating system, a swimming pool, a ventilation duct, or a solid reservoir, e.g. in the form of a construction part, such as a wall or a floor. An advantage of using a construction part instead of a water reservoir is that the heat capacity of the construction part may be much larger
30 than the heat capacity of water.

In a further alternative, the energy reservoir may comprise different combinations of above-mentioned examples, as it may be an advantage to be able to shift between different energy reservoirs dependent e.g. on one or more of the following parameters; the weather

conditions, weather forecasts, the energy consumption, a prediction of energy consumption, the temperature of the energy collection medium, a temperature measured elsewhere in the system, etc.

The system comprises a reservoir temperature measuring device which is adapted to

5 measure the temperature of the energy reservoir, i.e. the temperature of the content of the reservoir, e.g. water, at at least one specific point in the reservoir. The temperature of the content of the energy reservoir may be different when measured at different levels in the reservoir, i.e. being warmer closer to the top of the energy reservoir than when measured closer to the bottom of the reservoir. Dependent on the layout of the system, the reservoir
10 temperature measuring device may be adapted to measure the temperature at one point in the reservoir or at a number of chosen points which each may represent the temperature at a specific level in the energy reservoir.

The energy collector may be a solar air collector, or a solar water collector. By a solar air collector is in this connection understood, an element in which air is heated by solar energy
15 when air is circulated through the element. Likewise is a solar water collector an element in which water or another suitable liquid medium is heated by solar energy when the liquid medium is circulated there through. As an example, traditional solar collectors comprising plates between which water or air may be heated can be used in the present invention.

Furthermore, vacuum solar collectors may be used. As a further example, a concave mirror
20 may be used together with a set of pipes. Alternatively, the energy collector may collect energy from e.g. sea water, the ground, from burning of oil, gas, wood, or waste, or from putrefaction e.g. in connection with composting thereby heating the energy collection medium which may be e.g. a liquid or air. The different types of energy collectors may be combined, so that at least some of them are used simultaneously or alternating e.g.

25 dependent on the weather conditions and/or the energy consumption from the energy reservoir and/or the energy consumption of the collector pump and/or heat pump.

In the following, the term 'energy collector' covers both a single energy collector and the possibility of combining a number of energy collectors being of different types or of the same type. The size of the energy collectors need not be identical. The energy collectors may be
30 arranged in parallel or in series. As an example, one energy collector may be used to cool a second collector during hot summer days, where an energy collection medium in the form of water may start boiling if not cooled. Another energy collector with an energy collection medium in the form of air may cool the water based energy collector by ensure a sufficiently high flow of air through the water based energy collector.

The energy collector may comprise an absorber in order to enhance the collection of solar energy, and thereby heating of the energy collection medium. The absorber or the energy collector may comprise a photovoltaic panel which may produce electricity based on incident solar radiation on the panel. The photovoltaic panel may be coupled to the heat pump and/or to a collector pump which circulates the fluid in the loops. The photovoltaic panel may thereby supply electricity to at least one of the heat pump and the collector pump. In some embodiments, the photovoltaic panel may be of a size which is large enough to fully cover the need for electricity of at least one of the heat pump and the collector pump. As the energy collection medium cools the energy collector, the photovoltaic panel may be cooled by the heat pump via the first loop thereby increasing the efficiency and the life time of the photovoltaic panel.

As mentioned already, the system may further comprise a collector pump for circulating the fluid in the loops. The collector pump may be a traditional liquid pump, e.g. an impeller pump, a membrane pump, or any similar traditional pump known in the art, thus allowing for circulation of an energy collection medium in the form of e.g. water. As the collector pump is adapted to control the flow rate of the energy collection medium, the collector pump may change the flow rate dependent on one or more chosen parameters such as a measured temperature of e.g. the energy collection medium or the energy reservoir, time of day, solar incident, or other parameters which influence the collection of thermal energy.

In case of a solar air collector using air as energy collection medium, the collector pump may be a fan allowing for circulation of air.

The energy collection medium may be air or a liquid medium such as water depending on the energy collector chosen. In alternative embodiments, a combination of air and a liquid medium may be used. Thus, it may in one embodiment be possible to combine air and water as energy collection medium, thereby applying two energy collection media in the system. The energy collector may in this embodiment be a combined solar air and water collector. Alternatively, two separate energy collectors may be applied, one being a solar air collector and one being a solar water collector. It may in one embodiment be possible to switch between the two energy collection media and/or the two energy collectors e.g. dependent on the need of energy. In an alternative embodiment more than two energy collectors may be applied. The energy collectors may be of different types or may be identical.

It should be understood, that the use of a liquid medium such as water as energy collection medium may require adding of an anti-freeze solution to the liquid medium in order to prevent freezing of the energy collection medium and thereby prevent damaging of the energy collector. Therefore, water as an energy collection medium may in this connection

comprise water including an anti-freeze solution. An example of a suitable anti-freeze solution may be glycol. Furthermore, for the described embodiments comprising water as an energy collection medium, the energy collection medium may likewise be another liquid medium where water with or without an anti-freeze solution is meant as an example.

- 5 When the energy collection medium is circulated between the energy reservoir and the energy collector and through the energy collector, i.e. in the second loop, it may be heated due to incident solar radiation on the energy collector and due to the temperature difference between the energy collection medium, e.g. water, and the energy collector. The heated energy collection medium is circulated back to the energy reservoir leading to a temperature
10 increase of the water in the energy reservoir.

In one embodiment, the water in the energy reservoir, e.g. water for heating a building, may be circulated through the energy collector, in which case the energy collection medium is a part of the water in the energy reservoir.

- 15 The heat pump comprises a cold side, a warm side, and exchange means for exchange of thermal energy from the cold side to the warm side. The cold and warm sides may in one embodiment be arranged so that the temperature of the fluid when flowing in the first loop is decreased and the energy collector therefore receives colder fluid than if the heat pump was not operated. The heat which is extracted from the fluid in the first loop may be delivered e.g. to the energy reservoir via a fourth or fifth loop between the warm side and
20 the reservoir. By decreasing the temperature of the cold side energy transfer from the energy collection medium to the energy reservoir may be facilitated due to the increased temperature difference between the energy collection medium and the energy reservoir.

- It should be understood, that the system may comprise more than one first loop in parallel, as the system may comprise more than one heat pump. The different first loops may be
25 active simultaneously or may be active alternating dependent on e.g. the weather conditions, the energy consumption, one or more temperature measured in the system, etc.

- In addition to the first and second loops, the system may further comprise a third loop connecting the lower reservoir inlet with the cold side outlet and the lower reservoir outlet with the cold side inlet. The third loop may be used for lowering a temperature in a lower
30 part of the reservoir, e.g. in order to move thermal energy from a lower part to an upper part of the energy reservoir.

It should be understood, that inlet and outlet of the of the energy reservoir may each be one or more openings in the energy reservoir. Dependent on the use of the system and selection

of loops the inlet opening(s) and outlet opening(s) may shift. The inlet and outlet of the heat pump may likewise shift dependent on the active loops.

Thermal energy may be delivered from the heat pump in at least two different ways. In one embodiment, the heat pump delivers the heat from the warm side to a lower portion of the reservoir. This may take place e.g. by use of a fourth loop connecting the lower reservoir inlet with the warm side outlet and the lower reservoir outlet with the warm side inlet.

Alternatively, or in combination therewith, the heat pump may deliver the thermal energy to an upper portion of the reservoir. For this purpose, the reservoir may further comprise an upper reservoir inlet and an upper reservoir outlet for exchange of thermal energy between a fluid which flows from the upper reservoir inlet to the upper reservoir outlet and an upper portion of the energy reservoir which is located at vertical distance from the lower portion of the energy reservoir. The system may also comprise a fifth loop connecting the upper reservoir inlet with the warm side outlet and the upper reservoir outlet with the warm side inlet.

The system may comprise flow communication means by which at least two of the first, second, third, fourth, and fifth loops can be connected to allow fluid communication there between. It may in one embodiment be possible to open and close the communication means, whereas the communication means in an alternative embodiment are constantly open. The fluid communication between at least two of the loops the fluid may facilitate easy emptying or filling of several loops simultaneously and thereby facilitate easy maintenance.

The system may comprise more than one of each of the first, second, third, fourth, and fifth loop in parallel, thereby allowing for simultaneous or alternating use of the first, second, third, fourth, and fifth loops dependent on different conditions associated with the system, e.g. the weather conditions, the energy consumption, one or more temperature measured in the system, etc.

It should be understood, that the temperature changes caused by activation of the different loops may both result in an increased temperature and a decreased temperature, whereby it may be possible to use at least some of the loops in connection with cooling. As an example, a construction part, such as a wall or a floor may be cooled by transferring energy via a loop to e.g. a reservoir for heating of domestic hot water which is also needed at hot summer days where it may be an advantage if construction parts can be cooled.

To control the flow between the different loops, the system may further comprise a fluid shunt valve structure allowing selection between flow of the fluid in at least two of the first,

second and third loops. As an alternative to a fluid shunt valve a number of pumps may be used to select between flow of the fluid in the loops, as opening and closing of the pumps may correspond to operation of a shunt valve if deactivation of a pump prevents flow of the fluid in one direction. As a further alternative, a valve-train or a multiple passage valve may be applied.

In one embodiment, the system includes a valve or pumps which can select between the first and second loop in such a manner, that a selectable rate of the fluid flows in the first loop and a remaining portion flows in the second loop. Similar conditions may be facilitated between the first and third and between the second and third loops. Such commercially available valves are sometimes simply referred to as shunt-valves. A valve or pumps may likewise be used to select between parallel first loops, second loop, third loops, etc.

To control the flow between the fourth and fifth loops, the system may further comprise a second shunt valve structure allowing selection between flow of the fluid in the fourth and fifth loop. This may enable selective delivery of thermal energy from the heat pump to different vertical levels in the energy reservoir.

The energy reservoir may e.g. be a floor heating system, whereby the energy may be transferred from the energy collector to the floor heating system e.g. via the heat pump etc. depending on the loop configuration.

It should be understood, that more than five different loops may be arranged dependent on the layout of the system and the use of it.

The system may further comprise a control system adapted to control the flow in at least the first and second loops, and optionally also in one or more of the third, fourth and fifth loops based on a temperature, e.g. a temperature of the energy reservoir.

The flow in the different loops may additionally or alternatively be controlled dependent on the energy consumption from the energy reservoir, the potential for energy storage in the energy reservoir, the energy price, including the costs associated with running of the heat pump, the weather conditions, including the outdoor temperature, weather forecasts, temperatures measured in the system, etc.

The system may further comprise a control system which sequentially can change flow in at least two of the first, second, third, fourth, and fifth loops. Thereby, the system may change between the loops in different time steps, so that e.g. the first loop is active in a number of steps, e.g. 4, 5, or, 6 steps, and subsequently another loop is active in step 7, 8, and 9. This

may again be followed by activation of the first loop in step 10 or by activation of another loop. In this regard, the system may choose between the loops based on different criteria defined to optimise energy consumption, capacity, etc. As an example, the system may select flow in a specific loop based on knowledge about temperature in that loop or
5 knowledge about the need for energy at a specific location in the system.

The system may further comprise a control system adapted to control the operation of the heat pump and/or the operation of the collector pump. The system may e.g. control the flow rate in the loops or the exchange rate between the cold and warm sides of the heat pump.

The control system may e.g. control the operation of the heat pump dependent on a
10 temperature of the reservoir or energy collector and/or dependent on the control of the collector pump and/or dependent on a measured temperature of the reservoir, collector or elsewhere and/or dependent on a flow rate in at least two of the loops.

The control system may e.g. be adapted to start and stop the heat pump and/or to lower and raise the output of the heat pump.

15 The control system may further be responsible for a common power supply to the collector pump and the heat pump. This may have the advantage, that close down of the whole system is facilitated in case of e.g. power blackout.

The control system may in one embodiment be responsible for selection of active loop(s), including selection of e.g. more first loops or fourth loops in parallel. Furthermore, the control
20 system may be responsible for selection between different possible energy collectors and/or different possible energy reservoirs. The selection may be based on e.g. weather conditions, one or more temperature measurements in the system, energy consumption, weather forecasts, prediction of energy consumptions, electricity costs, etc.

The selection of loops and/or energy collectors may further depend on different modes of the
25 control system, as the control system in at least one embodiment may comprise different modes which can be selected e.g. by an operator or automatically dependent on a set of selection factors.

In one embodiment the control system may comprise at least three different modes, economy mode, standard mode, and high power mode. In the economy mode saving as
30 much energy as possible is the target, i.e. the use of energy for e.g. the heat pump should be limited. High power mode is a mode in which it is the target to fulfil different temperature

requirement even though use of extra energy for e.g. the heat pump is needed. The standard mode covers the remaining situations.

In one embodiment, the reservoir temperature may be measured in the lower part of the reservoir, e.g. in the area where the energy is transferred from the energy collector to the energy reservoir via the energy collection medium. If the reservoir temperature is high it may be an advantage to lower the reservoir temperature to facilitate energy being transferred from the energy collector to the energy reservoir. This may be done by starting the heat pump to exchange heat from the cold side to the warm side, the cold side being positioned in the lower part of the energy reservoir and the warm side being positioned at the upper part of the energy reservoir or at least above the cold side, whereby the temperature gradient of the energy reservoir is increased. Consequently, the control system may be adapted to start the heat pump when the reservoir temperature exceeds a predefined value, T_{start} . It should be understood, that the reservoir temperature may not only be measured in the lower part of the reservoir, but also at other positions in the reservoir.

In one embodiment, T_{start} is in the range of 5-30 degrees Celsius. The temperature may be chosen based on the capacity of the heat pump, minimisation of heat loss from the energy reservoir, bacterial vegetation at high temperatures, etc. T_{start} need not be a constant temperature, as the system may comprise e.g. two different configurations, such as a summer configuration and a winter configuration in which configurations $T_{\text{start, summer}}$ may be different from $T_{\text{start, winter}}$. Changing from the winter configuration to the summer configuration may be carried out manually or automatically, e.g. at a specific date every year.

If the temperature of the energy reservoir is below a predefined value, energy may be transferred from the energy collector to the energy reservoir via the energy collection medium without increasing the temperature difference, and it may therefore be an advantage to stop the heat pump and thereby save energy, as the heat pump uses energy when turned on. Consequently, the control system may be adapted to stop the heat pump when the reservoir temperature is below a predefined value, T_{stop} . In one embodiment, T_{stop} is in the range of -5 to 15 degrees Celsius. T_{stop} may be changed manually or automatically like T_{start} .

In one embodiment, the control system is adapted to adjust at least one of T_{start} and T_{stop} in accordance with a set of data, whereby T_{start} and/or T_{stop} may be changed during operation of the system in accordance a chosen set of data.

The set of data may represent forecast of outdoor temperature and/or forecast of solar radiation, as the outdoor temperature and the solar incident on the energy collector influence the amount of energy which may be collected by the energy collector and thereby transferred

to the energy reservoir via the energy collection medium. In one embodiment, the control system may adjust at least one of T_{start} and T_{stop} in accordance with the forecast values. However, adjustment of T_{start} and T_{stop} may subsequently be carried out during operation of the system if the actual weather data differ from the forecast.

- 5 The control system may e.g. be connected to a wireless network to receive a set of data in the form of weather data.

The set of data may alternatively or additionally represent a reservoir temperature being measured in the energy reservoir. Dependent on the layout of the system, the reservoir temperature may be measured at one point in the reservoir or at a number of chosen points
10 which each may represent the temperature at a specific level in the energy reservoir.

If the temperature of the reservoir is measured at an upper level in the energy reservoir where water may be tapped for e.g. heating or domestic hot water, the measured temperature may indicate the level of consumption of water from the reservoir. It may be possible to adjust T_{start} dependent of this measured temperature. If the measured reservoir
15 temperature is low due to a high consumption of heat, T_{start} may be lowered to increase the energy transfer from the energy collector and still maintain a reasonable COP (Coefficient of Performance) of the heat pump.

If a predicted pattern of consumption forecasts a coming high level of consumption of heat from the reservoir, the heat pump may stay turned on even though the reservoir
20 temperature in the upper level of the energy reservoir is high in order to store a sufficient amount of heat in the energy reservoir. The predicted pattern of consumption may consequently be used as a set of data in accordance with which at least one of T_{start} and T_{stop} may be adjusted.

The set of data may represent solar incident being measured at the energy collector. The
25 solar incident may be measured by use of a light sensor.

The set of data may furthermore represent an outdoor temperature being measured outside the energy collector. The outdoor temperature may be measured close to the energy collector or at a place which is considered to have a temperature being representative for the outdoor temperature close to the energy collector.

30 It should be understood, that the above mentioned set of data only represents some of the possible data sets. Other sets may also be applicable. Furthermore, the sets of data may also be combined so that data from one set of data is combined with another set of data allowing

for a different set of data to be used. The set of data chosen may change e.g. during the day or during the season e.g. in response to change of weather or in response to energy consumption from the energy reservoir.

5 The control system may be adapted to adjust at least one of T_{start} and T_{stop} in accordance with a temperature measured in the warm side.

10 The control system may be adapted to adjust at least one of T_{start} and T_{stop} continuously. This may be based on the above mentioned set of data or on experience, such as a use pattern. Furthermore, the cost of electricity for running the heat pump may also influence the adjustment of least one of T_{start} and T_{stop} . By continuously is in the connection meant, that least one of T_{start} and T_{stop} is adjusted according to a chosen time schedule, e.g. every 5 minutes, every hour, every third hour, every 12 hour, or at another time interval. However, the interval may be changed during operation, e.g. dependent of temperature, solar incident, use pattern, etc.

15 When adjusting at least one of T_{start} and T_{stop} continuously, the primary requirement may be to achieve an optimal energy output, i.e. to optimise the use of energy of the heat pump and the collector pump relative to the energy collected in the collector and transferred to the energy reservoir.

20 A control system may further be adapted to control the flow in at least one of the first, second, third, fourth, fifth loop based on a set of data, the set of data comprising at least one of: solar incident, energy consumption, energy costs. As an alternative, the set of data may comprise forecast of at least one of: solar incident, energy consumption, energy costs. It should however be understood, that any of the above-mentioned data for adjustment of T_{start} and/or T_{stop} may also be used in connection with the control of the flow in the loops.

25 The system may further comprise a control system allowing selection between at least a first and a second operation mode, wherein the control system in the first mode automatically switches between at least two different flow rates in a at least two loops based on an optimization criteria, and wherein the control system in the second mode allows the user to specify at least certain flow conditions in selected loops.

30 In one embodiment, the heat pump may be a two-phase gas cooling type. The heat pump may comprise a compressor for compression of a refrigerant, and the compressor may have a variable compressor speed. Consequently, the heat pump may operate at different speed levels between an applicable set of T_{start} and T_{stop} . The compressor speed may be dependent

on a change of the reservoir temperature, e.g. be dependent on the speed at which the reservoir temperature changes.

Furthermore, the control system may be adapted to reduce the number of compressor starts and stops by reducing the RPM, e.g. until a constant temperature of the energy collection
5 medium in the backward flow to the energy collector can be obtained.

The gas may be R134 or another traditional coolant. Alternatively, CO₂ may be used as coolant. CO₂ is an environmentally-friendly coolant which further allows the heat pump to work more efficient in a temperature range at a higher level, e.g. 15-80 degrees Celsius, which may be an advantage in this connection.

10 Alternatively, the heat pump may e.g. be of a Peltier type, an absorption type, or a one-phase gas system based e.g. on a Stirling energy cycle.

The use of Peltier elements may be an advantage in particular when the heat pump is operating at high temperature. Running Peltier elements at maximum capacity may lower the efficiency, and it may therefore be an advantage to apply a plurality of Peltier elements, and
15 thus operate them at around medium capacity.

Furthermore, Peltier elements are well suited if the heat pump is often started and stopped. Accordingly, the system may comprise control means which changes between use of a traditional compressor and Peltier element based on a start/stop frequency.

It may even be an advantage to combine Peltier elements with a more traditional compressor
20 based heat pump and to shift between the two principles based on the temperature difference across the heat exchanger so that the Peltier elements works at temperature differences which are low and the compressor based heat pump works when the temperature difference becomes above a specific level, e.g. above 10 degrees in difference between the hot and the cold site of the heat pump. In that case, the user may benefit from silent
25 operation whenever the Peltier elements are active.

The system may further comprise a collector temperature measuring device being adapted to measure a collector temperature of the energy collector. And the control system may be adapted to calculate a temperature difference ΔT between the collector temperature and the reservoir temperature and may be adapted to control the operation of the heat pump
30 dependent of said temperature difference, ΔT .

A high temperature difference ΔT may be due to high solar incident to the energy collector allowing for a high temperature of the energy collector, whereby the energy collection medium is heated to a high temperature. It may therefore not be necessary to turn on the heat pump, as transfer of energy from the energy collector to the energy reservoir may not be facilitated significantly by use of the heat pump compared to the energy used by the heat pump.

During periods with loss of current, the collector temperature may be very high as the energy transfer from the energy collector to the energy reservoir may be decreased. This may be due to the fact that the collector pump does not run during power blackouts. Furthermore, the temperature decrease of the energy collection medium may be limited as the heat pump also stops during power blackouts. When the electricity supply is back again, the energy collection medium may be very hot due to the high collector temperature. As a too high temperature of the energy collection medium may damage the heat pump, it may be preferred that the volume of the energy collector may be less than 1/5 of the volume of the energy reservoir thereby protecting the heat pump from too high temperatures.

In particular, the heat capacity of the energy collection medium in the energy collector may be 1/5 of the heat capacity of the medium in the energy reservoir.

Furthermore, the control system may control the heat pump based on a temperature measured adjacent to the energy collector and a calculation of a dew point temperature of the energy collector. Thereby it may be ensured, that the system is operated above the dew point temperature so that moisture can be avoided. As moisture need not be a problem, this may be of particular relevance if draining of moisture and liquid is difficult or even impossible.

By calculation of the dew point temperature should be understood, that the control system calculates the dew point temperature in response to a measured temperature. In an alternative embodiment, calculation is done by interpolating between values already calculated and stored in the control system.

Examples

Examples of different control strategies for the heat pump and the system as a whole will be further described below. It should be understood, that the below examples are illustration of embodiments of the invention only, and that the invention is not limited hereto.

Example 1

The sun is shining on a more or less clear day. The temperature in the energy collector becomes high at midday, thus the control system may be set up to ensure that a second loop is formed with the domestic water reservoir.

- 5 If economic mode is selected for the control system, saving as much energy as possible is the target. The control system may receive information about high incident radiation. Furthermore, weather forecast may predict that it will be a sunny day with the possibility of transferring a high amount of energy to the energy collection medium via the energy collector without forming a first loop with the heat pump. Consequently, the control system
10 may keep the heat pump shut of even though the temperature in the top of the domestic water reservoir is below the lower limit of temperatures normally accepted.

- The second loop formed between the energy collector and the lower energy reservoir may be active for as long as energy is transferred to the energy collection medium above a predefined value. When the incident radiation falls to a lower level due to change of the
15 inclining angle towards the energy collector, the resulting radiation on the energy collector is decreased. At this stage the energy collector still produces energy, but not at a temperature high enough to support the lower part of the energy reservoir which has been heated during the day.

- The lower part of the energy reservoir is still the coolest part of the reservoir due to the
20 natural energy gradient in the reservoir. It must therefore be decided if more energy is to be transferred to the reservoir. If the production of energy during the day exceeds the predicted energy used for the following day, the control system may stop production of energy in order to keep the use of electricity at the lowest possible level.

- On the other hand the control system may foresee or be programmed to secure a sudden
25 temperature in the upper/lower part of the energy reservoir at the end of the day. If this temperature has not been achieved, the control system will start the heat pump, and form a first loop, where the inlet of the heat pump is connected to the energy collector, and the outlet of the heat pump is connected to the lower part of the reservoir or the upper part of the reservoir. Consequently, the control system will try to keep temperatures in the energy
30 collector as high as possible at the end of the day, and still heat the lower or upper part of the energy reservoir until desired temperatures are achieved.

If the control system is in standard mode, the loops formed would have been the same as in the economy mode described above, but the control system would e.g. have started the heat

pump if the temperature in the top of the reservoir became low during the start of the day. The system would then form a loop where only the top of the reservoir was kept heated as the system still would expect the sun to be active during the day heating the bottom of the energy reservoir directly through the second loop.

- 5 If the control system was in high power mode, the system would form a first loop in the beginning of the day, where the heat pump would start heating the lower part of the reservoir to a desired higher temperature, despite the forecast of high incident radiation during the day. When the minimum acceptable temperature of the reservoir is reached, the heat pump will be shut of, and only if the temperature of the energy collector through the
- 10 day exceeds that of the lower part of the reservoir, the second loop is formed to transfer energy from the energy collector to the lower part of the energy reservoir. In this mode, different loops are formed in order always to keep a minimum acceptable temperature in the whole reservoir. In this mode, the system tolerates that the temperature of the energy collector is below that of dew point, as much heat is needed, and the condensation of
- 15 moisture will boost the energy production of the energy collector.

Example 2

The system of example 2 has a radiator placed outside the building and two reservoirs to which energy can be transferred from the heat pump outlet. The present control system has only a single mode of operation.

- 20 The first reservoir is a domestic hot water reservoir and the second reservoir is a solid construction part in the form of a concrete floor of the building. The control system receives temperature data from both the lower and the upper part of the water reservoir. If the lower part of the energy reservoir has a temperature lower than that of the outside air, the system will form a second loop where energy is collected in the radiator and sent to the lower part of
- 25 the energy reservoir.

- When the temperature of the lower part of the reservoir approaches the outside temperature, the control system can stop circulation of the energy collection medium. If the floor or the upper part of the energy reservoir needs heat, the system forms a first loop where the radiator is connected to the inlet of the heat pump, and the outlet of the heat pump is
- 30 connected in a fourth or fifth loop to either the upper part of the energy reservoir, the lower part of the energy reservoir, or to the floor heating e.g. through an extra heat exchanger separating the cooling medium from water for heating the building.

If there is a need for both heating of the floor and for heating of the domestic hot water, the control system may have a priority built in or to be chosen. If heating of domestic hot water is of highest priority, the control system forms a fifth loop between the upper part of the energy reservoir and the outlet of the heat pump giving instant heating of domestic hot water. When the upper part of the energy reservoir reaches the required temperature, the control system forms another loop with the concrete floor (through a heat exchanger) and starts heating hereof. As the temperature in the concrete floor rises, e.g. measured on the outlet temperature of the concrete floor, the control system chooses to stop the heating or forms yet another fourth loop where the outlet of the heat pump is connected to the lower part of the reservoir.

Example 3

The system of example 3 has two different energy collectors adapted to supply either a heat pump, an energy reservoir, or a part of an energy reservoir together with the heating system of the building. The energy collector is an air based energy collector that collects both heat from the passing air as well as solar radiation. The control system has only one mode to be selected to simplify the example. During normal operation, the control system forms a first loop between a radiator placed outdoor to collect heat from the surrounding air, and the inlet of the heat pump. In this first loop it is refrigerant e.g. R134a from the heat pump system that carries the energy. Thus the outdoor radiator works as an evaporator. In this first loop, the system produces energy as normal and the energy may be used to heat a domestic hot water reservoir or an indoor heating system of a building. The control system selects which element should be supported first, and consequently forms sequences of loops between either the energy reservoir and the outlet of the heat pump, or between the heating system of the building and the outlet of the heat pump e.g. separated by a heat exchanger to avoid mixing of the medium used in the heat pump, Brine, and the water used in the heating system of the building.

During night time, this above-described configuration is the preferred one, giving a steady production of energy.

If the sun appears during daytime with a large amount of solar incident, the energy collector is producing much energy at a high temperature. The control system consequently chooses to form a second loop where the energy collector is connected directly to the lower part of the energy reservoir producing cheap environmental friendly energy. This is done even so that the energy collection medium used in the first loop between the collector and the heat

pump is the refrigerant of the heat pump, and the second loop formed is using an anti-freeze water solution.

During the summer, the production of energy from the energy collector may exceed the amount that is used in the building - for both domestic hot water and heating purposes. In order to protect the energy collector from overheating or in order to reduce the heating of the building, the control system may start a blower to ventilate the energy collector. This is done even so that no heat is extracted from the energy collector.

The control system is able to decide if one loop should be applied until the desired temperatures are reached, or the system should switch between a sequence of different loops and slowly but continuously reach the desired temperatures.

Example 4

The system of example 4 comprises one heat pump together with two different collectors, a solar collector and a ground source collector. Further the system comprises an energy reservoir for domestic hot water, and an air-ventilation heating/cooling system. The control system comprises only one mode in the present example.

In the standard mode, the control system is adapted to keep the room temperature inside the building on a reasonable level. This is changed manually by the user, and there is a function of night time lowering, where the temperature is lowered 2 to 3 degrees in the building in order to save heat.

The domestic reservoir is divided into a lower part and an upper part. Hot tap water is released to the building from the upper part. There is back-up heating based on a burner of gas or oil. The control system also controls start and stop of the burner based on temperatures measured in the different energy collectors and the prediction of energy consumption in the house.

During autumn, the demand for heating increases and the control system maintains a first loop between the energy collector and the heat pump inlet to use as much of the available energy during day time. During night time energy is received from the ground source. Based on forecast of cloudy, frosty weather, the control system selects between either transfer of extra energy to the energy reservoir or if the gas burner should be activated. As there is abundant of radiation during the day before the new weather situation, the control system decides to store as much energy as possible in the building and in the energy reservoir

without using the ground source. Thus, the control system forms a second loop between the energy collector and the lower part of the energy reservoir in order for it to be heated to 50 degrees Celsius. This is despite the fact that energy should not be used the same day. As more energy may be collected during the day before a frosty cloudy day, the control system

5 forms a loop between the energy collector and the ventilation system, overruling the desire of a constant temperature and increasing the temperature with e.g. 2 degrees. When the night falls, the control system will only need to form loops between the ground source and inlet of the heat pump. Due to the night time drop and overruling there is no need for using the heat pump during the night.

10 Next day, the weather does not bring any useful radiation, and the control system forms a first loop between the ground source and the inlet of the heat pump together with a loop between the outlet of the heat pump and the ventilation system. Thereby the temperature inside the building can be held constant during daytime.

When it becomes winter, the only real source of energy for heating the building is the ground

15 source. Though it may become so cold that the COP of the heat pump is no longer within an economic desirable state. Therefore the control system starts the burner in order to heat the upper part of the energy reservoir. In order to heat the building, the control system forms a loop between the upper part of the energy reservoir and the ventilation system so that heating of the building is possible. During wintertime several days with clear sky may bring

20 sunny conditions. Depending on the outside temperature and the temperature of the energy reservoir, the control system may decide to form a second loop directly between the lower part of the reservoir and the energy collector. It may also form a loop between the ventilation system and the energy collector in order to utilize as much of the free solar energy as possible and save the heat pump.

25 During summertime, the situation is different. Domestic hot water is still needed but cooling the building is also needed. In this configuration, the control system forms a loop between the ventilation system and the inlet of the heat pump and a loop between the outlet of the heat pump and the ground source. Thereby, energy is taken from the building and stored in the ground being soil, rocks or water. At the same time or in-between, the control system

30 forms a loop between the energy collector and the energy reservoir.

The loops may be established intermittently such that they repeatedly are active or de-active. More loops can be active simultaneously.

Brief description of the drawings

Embodiments of the invention will now be further described with reference to the drawings, in which:

Figs. 1-3 illustrate different embodiments of a system for collecting thermal energy according to the invention.

Detailed description of the drawings

It should be understood that the detailed description and specific examples, while indicating embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

Fig. 1 illustrates an embodiment of a system 1 for collection of thermal energy. The system 1 comprises an energy collector 2, an energy reservoir 3, and an energy collection medium (not shown) enclosed in a loop allowing fluid flow of the energy collection medium between the energy collector 2 and the energy reservoir 3 in a forward flow 4 from the energy collector 2 and in a backward flow 5 to the energy collector 2 for transferring energy between the energy collector 2 and the energy reservoir 3.

The system 1 further comprises a collector pump 6 which is adapted to control a flow rate of the energy collection medium, and a reservoir temperature measuring device (not shown). The reservoir temperature measuring device is adapted to measure a reservoir temperature, e.g. T1 or T2, of the energy reservoir 3.

Furthermore, the system 1 comprises at least one heat pump 7 comprising a cold side 8, a warm side 9, and exchange means for exchange of thermal energy from the cold side 8 to the warm side 9. The cold and warm sides 8, 9 are arranged to decrease the temperature of the energy collection medium in the backward flow 5 by operation of the heat pump 7.

The system 1 further comprises a control system 10 adapted to control the operation of the heat pump 7 and thereby an exchange rate by which thermal energy is exchanged between the energy reservoir 3 and the energy collection medium. The control system 10 is adapted to control the operation of the heat pump 7 dependent on the measured reservoir temperature, e.g. T1, T2. The dependency is illustrated by the dotted lines between the control system 10 and the points at which the reservoir temperature T1, T2 is measured.

In the illustrated embodiment, the energy collection medium is a liquid medium in the form of water with an anti-freeze solution. Accordingly, the energy collector 2 is a solar water collector through which the energy collection medium is circulated and thus heated.

It should however, be understood that the solar water collector 2 illustrated in Fig. 1 is an example of an energy collector according to the invention. The energy collector 2 may also be a solar air collector, a vacuum solar collector, a concave mirror used together with a set of pipes. Alternatively, the energy collector may collect energy from e.g. sea water, the ground, from burning of oil, gas, wood, or waste, or from putrefaction e.g. in connection with composting.

The energy collector 2 illustrated in Fig. 1 may be combined with one or more of the other examples of energy collectors, so that at least some of them are used simultaneously or alternating e.g. dependent on the weather conditions and/or the energy consumption from the energy reservoir and/or the energy consumption of the collector pump and/or heat pump.

The reservoir temperature measuring device which is adapted to measure the temperature of the energy reservoir 3, i.e. the temperature of the content of the water in the reservoir, at at least one specific point in the reservoir. The temperature of the content of the energy reservoir 3 is different when measured at different levels in the reservoir, i.e. being warmer closer to the top of the energy reservoir than when measured closer to the bottom of the reservoir. In the illustrated embodiment of the system 1, the reservoir temperature measuring device is adapted to measure the temperature close to the bottom of the reservoir T1 and close to the top of the reservoir T2, which temperatures each represent a temperature at a specific level in the energy reservoir 3.

The energy collector 2 comprises an inlet 11 and an outlet 12 for the energy collection medium to be able to circulate the energy collection medium between the energy collector 2 and the energy reservoir 3. The inlet and outlet 11, 12 are connected to each other by a set of pipes 4, 5, 13 so that the energy collector 2, the inlet 11 and the outlet 12 together with the pipes 4, 5, 13 form a closed loop being in thermal communication with the energy reservoir 3.

The energy collector 2 is connected to the forward flow path 4 via the outlet 12 and connected to the backward flow path 5 via the inlet 11. Furthermore, the forward flow path 4 and the backward flow path 5 are connected via a heat exchanger 13 which allows for thermal communication between the energy collection medium and the energy reservoir 3.

When the energy collection medium is circulated between the energy reservoir 3 and the energy collector 2 and through the energy collector 2, it can be heated due to incident solar radiation on the energy collector 2 and due to the temperature difference between the energy collection medium and the energy collector 2. The heated energy collection medium is
5 circulated back to the energy reservoir 3 leading to a temperature increase of the water in the energy reservoir 3.

Thus, the energy collector 2 is coupled to the energy reservoir 3 so that thermal energy can be transferred from the energy collector 2 to the energy reservoir 3 by circulation of the energy collection medium.

10 The heat pump 7 comprises a cold side 8, a warm side 9, and exchange means for exchange of thermal energy from the cold side to the warm side. The cold and warm sides 8, 9 are arranged to decrease the temperature of the energy collection medium in the backward flow
5 by operation of the heat pump 7. By exchange of thermal energy from the cold side 8 to the warm side 9 is in this connection understood, that the temperature of the cold side 8 is
15 decreased while the temperature of the warm side 9 is increased.

When arranging the cold and warm sides 8, 9 so that the temperature of the energy collection medium is decreased in the backward flow 5 by operation of the heat pump 7, the energy collection medium returns to the energy collector at a lower temperature, which allows for an improved efficiency of the energy collector 2. The temperature decrease takes
20 place in the energy reservoir 3 in the illustrated embodiment. Furthermore, the system 1 is arranged so that transfer of energy between the energy collector 2 and the energy reservoir 3 primarily takes place at the bottom part of the energy reservoir 3, as the heat exchanger 13 is positioned here. This allows for taking advantage of the natural temperature difference in the energy reservoir 3, as transfer of energy from the energy collector 2 to the energy
25 reservoir 3 via the energy collection medium is facilitated at a lower temperature.

As the heat pump 7 furthermore decreases the temperature of the energy collection medium in the backward flow 5, the efficiency of the system 1 is increased as the temperature gradient over the energy collector 2 is increased.

30 The control system 10 is adapted to control operation of the heat pump 7 and thereby an exchange rate by which thermal energy is exchanged between the energy reservoir 2 and the energy collection medium. Consequently, the control system 10 can start and stop the heat pump 7 and/or lower and raise the output of the heat pump 7. Operation of the heat pump 7 is dependent on the measured reservoir temperature, e.g. T1, T2 as illustrated by the dotted lines. However, other parameters also influence operation of the pump.

A collector temperature measuring device (not shown) is adapted to measure a collector temperature T3 of the energy collector 2. The control system 10 is adapted to calculate a temperature difference ΔT between the collector temperature T3 and the reservoir temperature, e.g. T1, T2, and can control the operation of the heat pump 7 dependent of said temperature difference, ΔT as illustrated by the dotted lines.

The embodiment of the system 1' illustrated in Fig. 2 is similar to the embodiment 1 illustrated in Fig. 1 except for the fact, that the energy reservoir 3' is divided into two separate energy reservoirs 3A and 3B. Furthermore, the control system 10' is integrated in the heat pump 7'.

Both illustrated embodiments are well suited for use in connection with renovation of elder solar collector systems, as the elder energy reservoir may be replaced with an energy reservoir 3, 3' of the illustrated type inclusive a heat pump 7, 7' and a control system 10, 10'.

It the energy reservoir 3, 3', the heat pump 7, 7' and the control system 10, 10' are an integrated unit a simple plug and play solution is provided, thus decreasing the installation cost associated with the renovation as no electrician is needed for installation of an integrated control system.

Fig. 3 illustrates system according to the invention where a first, second and third loop is defined by the shunt valve 14. Likewise the system in Fig. 1, the system comprises an energy collector 2, an energy reservoir 3, and an energy collection medium (not shown) enclosed in a loop allowing fluid flow of the energy collection medium between the energy collector 2 and the energy reservoir 3 in a forward flow 4 from the energy collector 2 and in a backward flow 5 to the energy collector 2 for transferring energy between the energy collector 2 and the energy reservoir 3.

The shunt 14 operates by controlling the flow between the communication ports 15, 16, and 17.

By connecting 15 to 16, the first loop wherein the collector outlet is connected with the cold side inlet on the heat pump is established. In this loop, the cold side outlet of the heat pump supplies the fluid back to the collector inlet.

By connecting 15 and 17, the second loop is established so that the collector outlet is connected to the lower reservoir inlet and the lower reservoir outlet feeds back the fluid to the collector inlet.

By connecting 16 and 17, the third loop is established where the cold outlet of the heat pump is connected to the lower reservoir inlet and the lower reservoir outlet feeds back the fluid to the cold inlet of the heat pump.

The shunt may shift between connection of communication ports 15 to 16 while 17 is completely closed, or partly flow from 15 to both 16 and 17. Same applies with respect to communication ports 16, 17 relative to communication port 15 or communication port 15, 17 relative to 16.

On the warm side of the heat pump, a fifth loop connects the warm side outlet with an inlet of an upper reservoir inlet 18 and the upper reservoir outlet 19 returns the fluid to the warm side inlet. Accordingly, the heat pump feeds the thermal energy to an upper portion of the reservoir.

In an alternative embodiment (not shown), the system may be controlled so that the heat pump can feed at least a part of the thermal energy to directly to a floor heating system or a radiator. An extra shunt may enable shifting between the upper portion of the energy reservoir and direct feeding of a heating system, such as a floor heating system or a radiator.

When the shunt 14 enables communication between ports 16 and 17, the heat pump simply moves thermal energy from the bottom of the reservoir to the top of the reservoir.

When the shunt 14 enables communication between ports 15 and 16, the heat pump increases the temperature difference between the fluid which is received from the energy collector and the fluid which is returned to the energy collector.

When the shunt 14 enables communication between ports 15 and 17, the heat pump is disabled and the energy collector communicates thermal energy directly with the energy reservoir.

As indicated, the shunt 14 can be controlled by the control system 10.

In addition, the system comprises a safety shunt 20 which may bypass the heat pump, e.g. if the temperature of the fluid at port 16 is too cold or warm.

CLAIMS

1. A system for collection of thermal energy, the system comprising

– an energy collector with a collector inlet and collector outlet for exchange of thermal energy between a fluid which flows from the collector inlet to the collector outlet and the energy collector,

– an energy reservoir with a lower reservoir inlet and lower reservoir outlet for exchange of thermal energy between a fluid which flows from the reservoir inlet to the reservoir outlet and a lower portion of the energy reservoir,

– a heat pump comprising a cold side inlet, a cold side outlet, a warm side inlet, a warm side outlet, and exchange means for exchange of thermal energy between a fluid which flows from the cold side inlet to the cold side outlet and a fluid which flows from the warm side inlet to the warm side outlet,

the system comprising at least a first and a second loop for flow of the fluid, wherein the first loop connects the collector outlet with the cold side inlet and the cold side outlet with the collector inlet, and the second loop connects the collector outlet with the lower reservoir inlet and the lower reservoir outlet with the collector inlet.

2. A system according to claim 1, the system further comprising a third loop, connecting the lower reservoir inlet with the cold side outlet and the lower reservoir outlet with the cold side inlet.

3. A system according to any of the preceding claims, further comprising a fourth loop connecting the lower reservoir inlet with the warm side outlet and the lower reservoir outlet with the warm side inlet.

4. A system according to any of the preceding claims, wherein the reservoir further comprising an upper reservoir inlet and an upper reservoir outlet for exchange of thermal energy between a fluid which flows from the upper reservoir inlet to the upper reservoir outlet and an upper portion of the energy reservoir which is located at vertical distance from the lower portion of the energy reservoir, the system comprising a fifth loop connecting the upper reservoir inlet with the warm side outlet and the upper reservoir outlet with the warm side inlet.

5. A system according to any of the preceding claims, further comprising a fluid shunt valve structure allowing selection between flow of the fluid in at least two of the first, second and third loops.

5 6. A system according to any of the preceding claims, further comprising a second shunt valve structure allowing selection between flow of the fluid in the fourth and fifth loop.

7. A system according to any the preceding claims, further comprising a control system facilitating change of flow rate in at least one of the first, second, third, fourth, and fifth loops.

10 8. A system according to any of the preceding claims, further comprising a control system facilitating fluid flow in a combination of at least two of the first, second, third, fourth, or fifth loops.

15 9. A system according to any of the preceding claims, further comprising a control system adapted to control the flow in at least one of the first, second, third, fourth, fifth loop based on a set of data, the set of data comprising at least one of: solar incident, energy consumption, energy costs.

10. A system according to any of the preceding claims, further comprising a control system adapted to control the flow in at least one of the first, second, third, fourth, fifth loop based on a set of data, the set of data comprising forecast of at least one of: solar incident, energy consumption, energy costs.

20 11. A system according to any of the preceding claims, further comprising a control system allowing selection between at least a first and a second operation mode, wherein the control system in the first mode automatically switches between at least two different flow rates in at least two loops based on an optimization criteria, and wherein the control system in the second mode allows the user to specify at least certain flow conditions in selected loops.

25 12. A system according to any of the preceding claims, further comprising a control system which sequentially can change flow in at least two of the first, second, third, fourth, and fifth loops.

13. A system according to any of the preceding claims, wherein the heat pump comprises one or more Peltier elements.

14. A system according to any of the preceding claims, further comprising a collector pump adapted to control a flow rate of the fluid in at least one of the loops.

15. A system according to any of the preceding claims, further comprising a control system adapted to control the operation of the heat pump.

5 16. A system according to claims 14 and 15, wherein the control system is adapted also to control the collector pump.

17. A system according to claim 16, wherein the control system is adapted to control the operation of the heat pump dependent on a temperature of the reservoir or energy collector.

10 18. A system according to claim 16 or 17, wherein the control system is adapted to control the operation of the heat pump dependent on the control of the collector pump.

19. A system according to any of claims 16-18, wherein the control system is adapted to control the operation of the heat pump dependent on the control of the collector pump and dependent on a measured temperature.

15 20. A system according to any of claims 16-19, wherein the control system is adapted to control the operation of the heat pump or the collector pump dependent on a flow rate in at least two of the loops.

21. A system according to any of the preceding claims, wherein the energy collector comprises a photovoltaic panel.

20 22. A system according to any of the preceding claims, comprising flow communication means by which at least two of the first, second, third, fourth, and fifth loops can be connected to allow fluid communication there between.

23. A system according to any of claims 1-21, wherein the heat pump comprises a compressor for compression of a refrigerant, and wherein the refrigerant flows in at least one of the first, third, fourth, or fifth loop.

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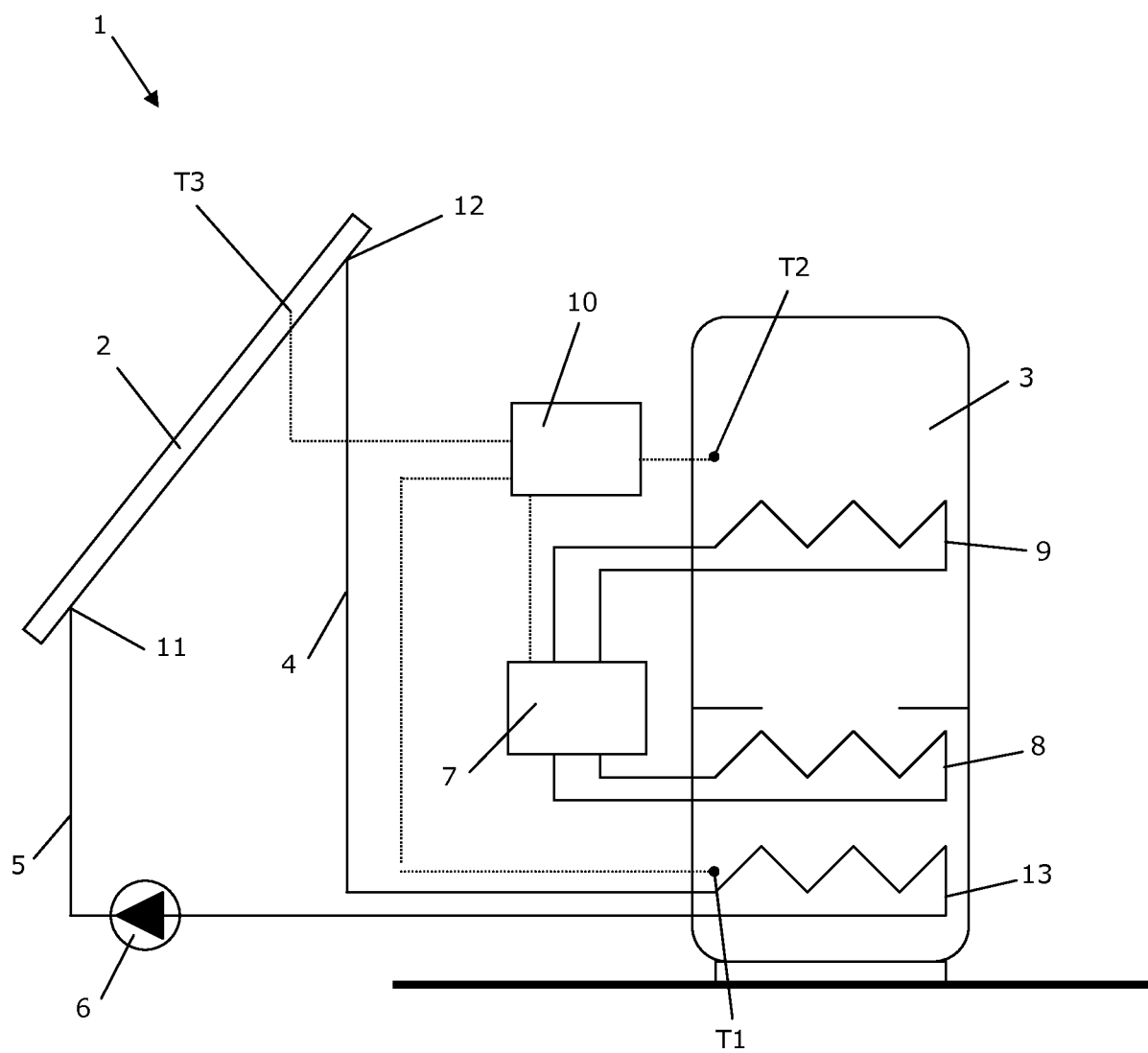


Fig. 1

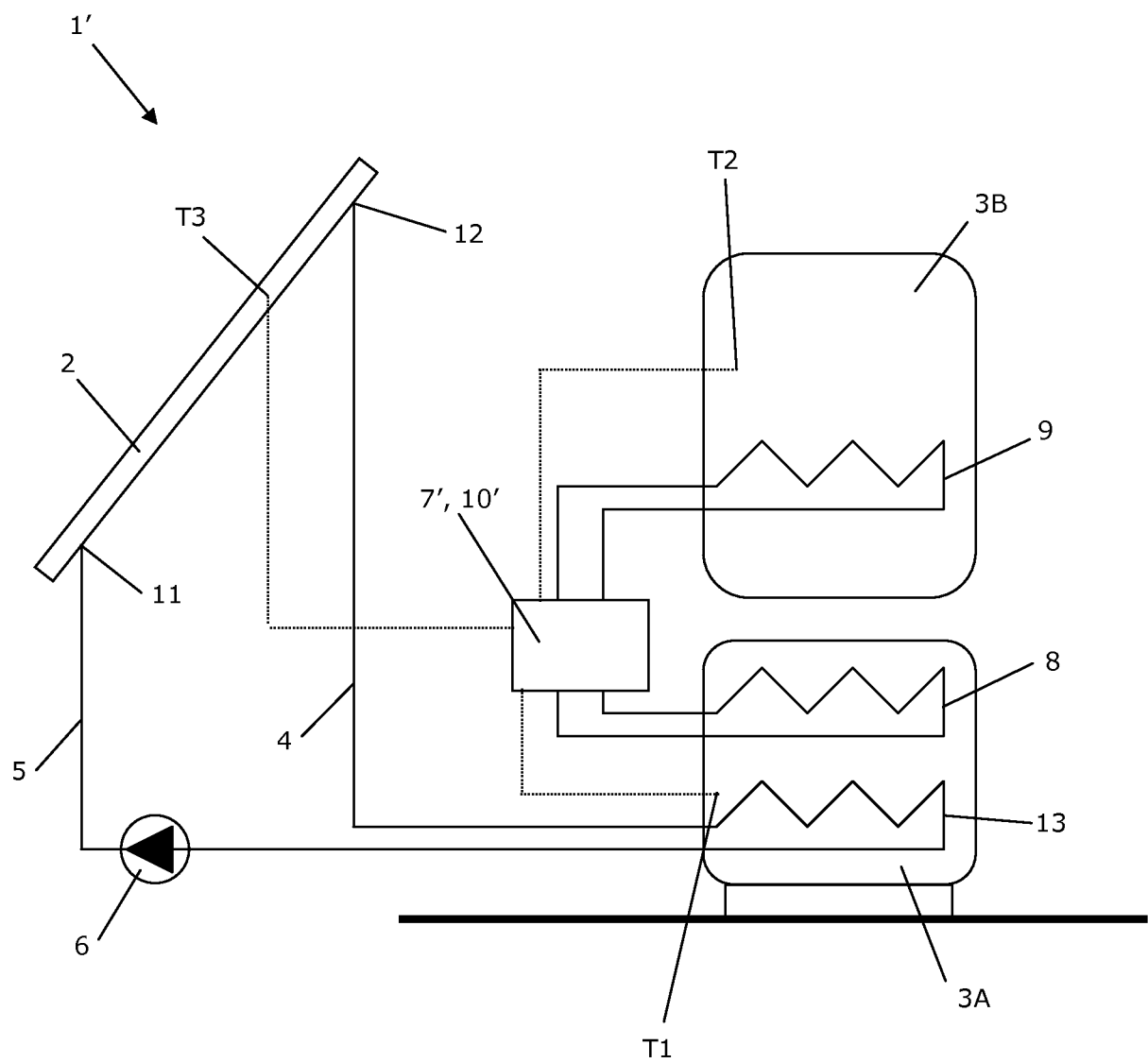


Fig. 2

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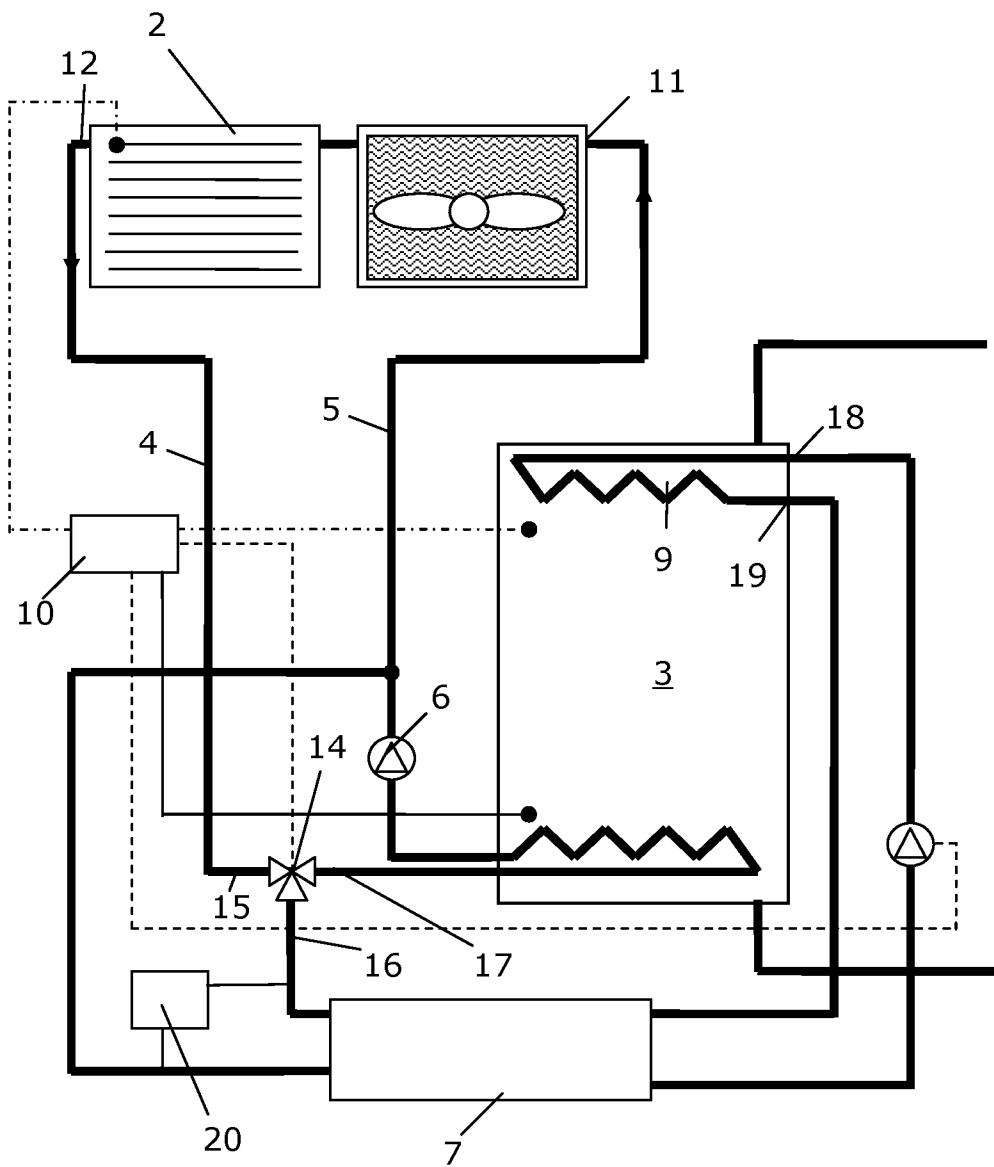


Fig. 3