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(54) METHODS AND APPARATUSES FOR OPERATING HEAT PUMPS IN HOT WATER SYSTEMS

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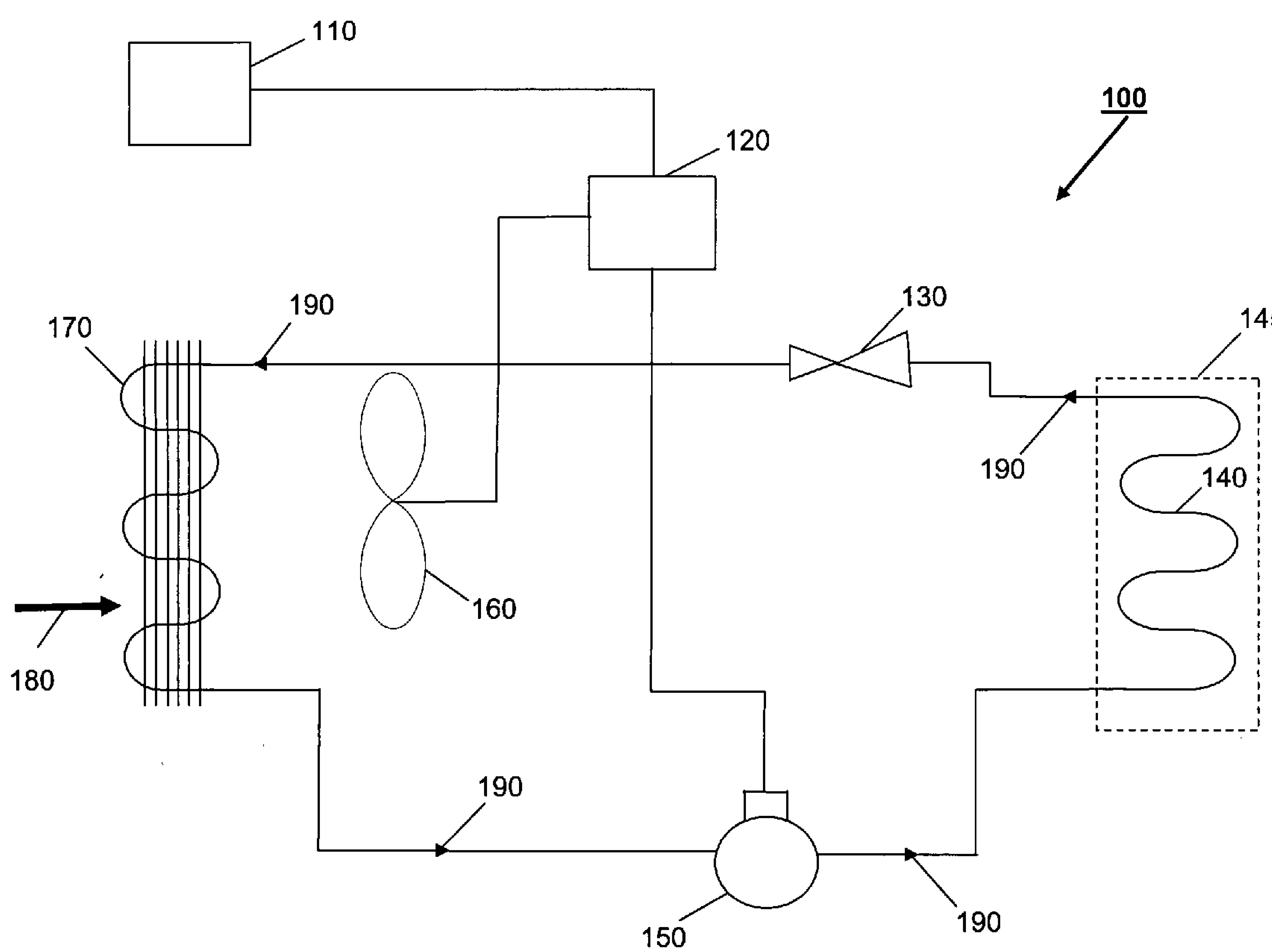
(57) **ABSTRACT**

A method for operating a heat pump (**100**) in low ambient air temperatures comprises periodically or temporarily halting flow of refrigerant through an evaporator (**170**) of the heat pump (**100**) and providing forced airflow across the evaporator (**170**) while the refrigerant flow is halted. The method enables operation of the heat pump (**100**) at low ambient temperatures and provides a means for de-icing the evaporator (**170**) when operating at low ambient temperatures. The method is particularly applicable to heat pumps having an evaporator located outdoors, such as domestic and industrial water heating systems.



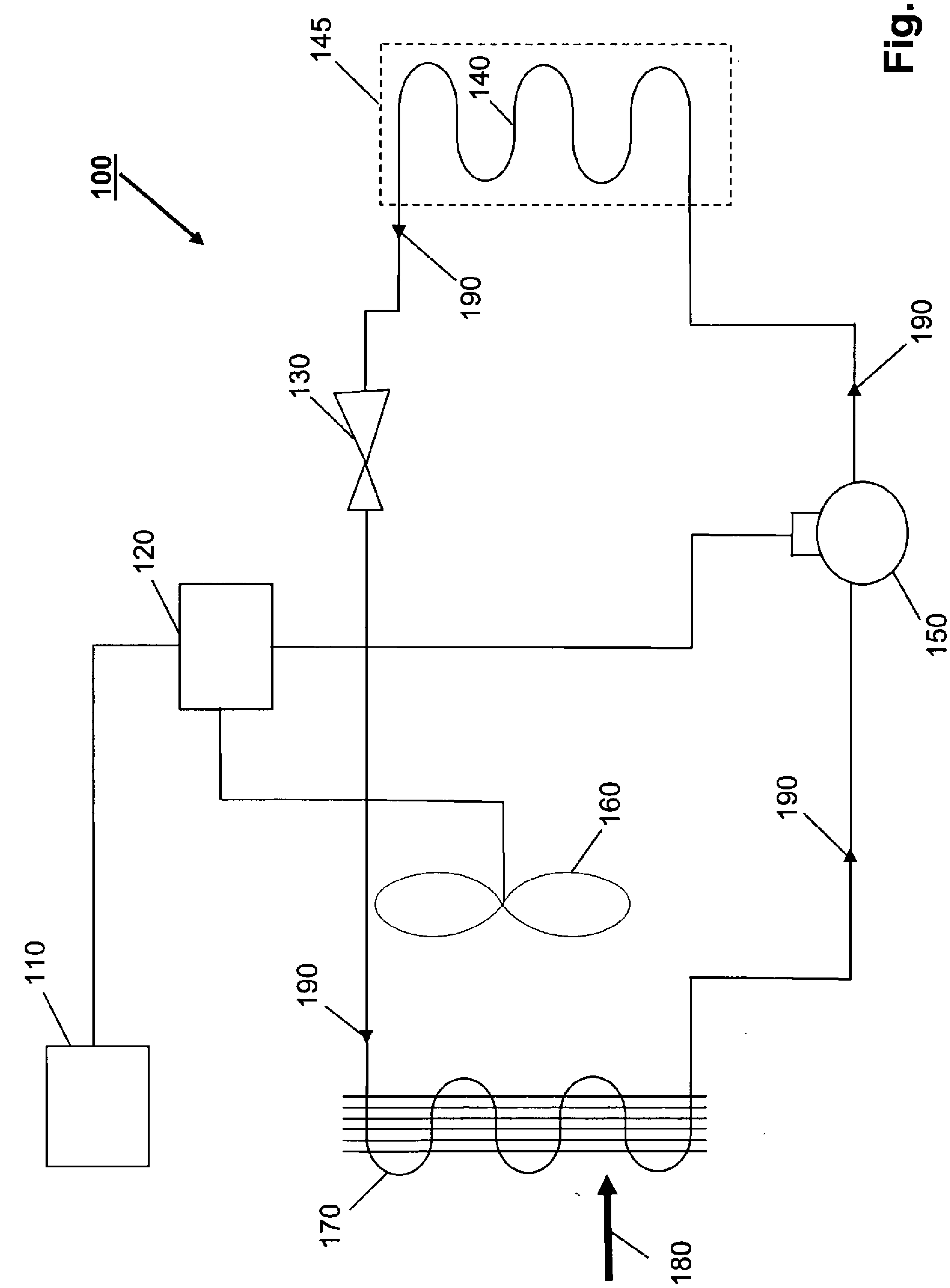
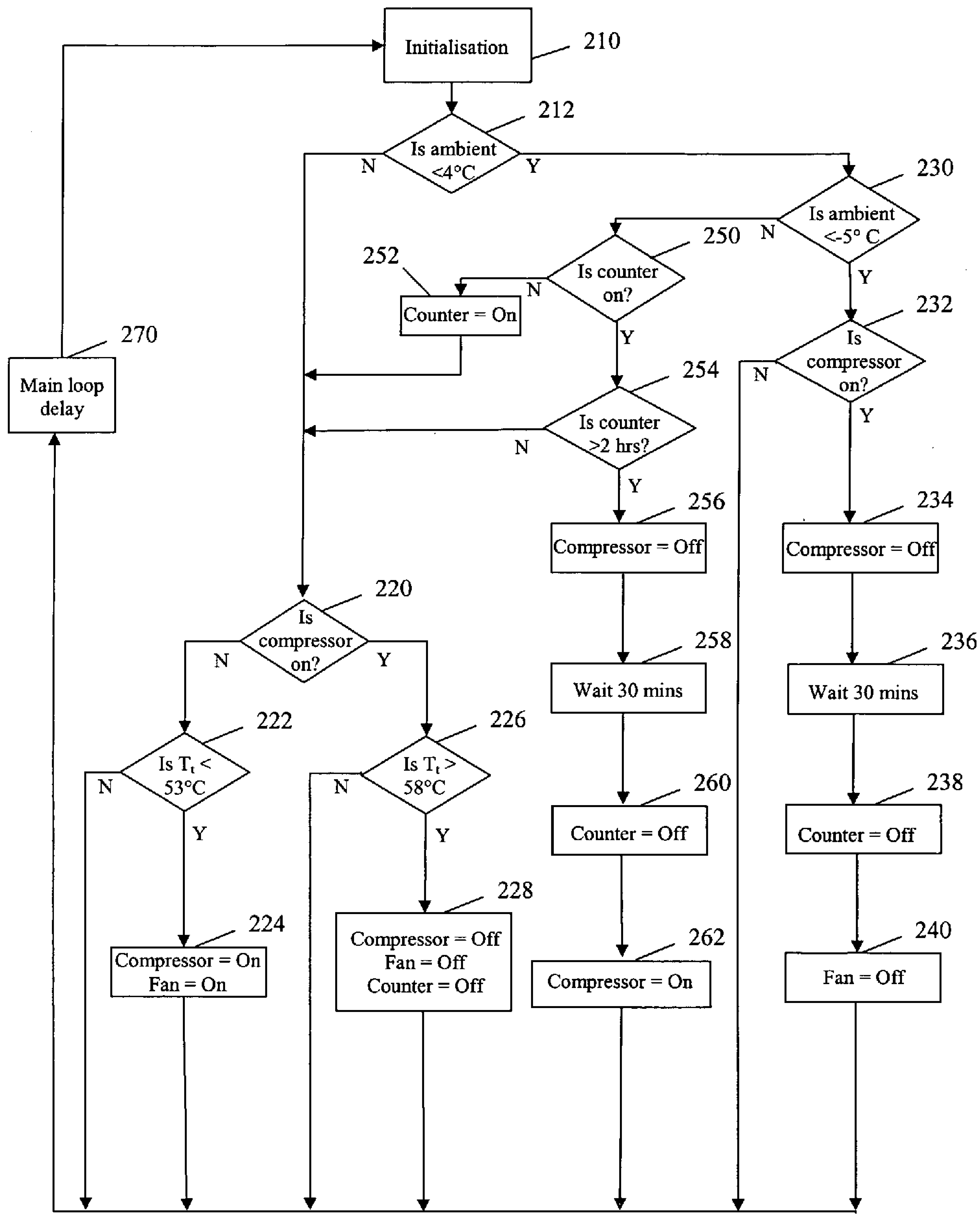


Fig. 1



Initialisation
210
212
Is ambient <4°C
N
Y
230
Is ambient <-5° C
250
N
252
Is counter on?
N
Counter = On
Y
270
Main loop delay
Y
232
Is compressor on?
N
Y
254
Is counter >2 hrs?
N
Y
256
Compressor = Off
234
Compressor = Off
220
Is compressor on?
N
Y
258
Wait 30 mins
236
Wait 30 mins
222
Is T_t < 53°C
N
Y
226
Is T_t > 58°C
N
Y
260
Counter = Off
238
Counter = Off
228
Compressor = Off
Fan = Off
Counter = Off
224
Compressor = On
Fan = On
262
Compressor = On
240
Fan = Off

Fig. 2

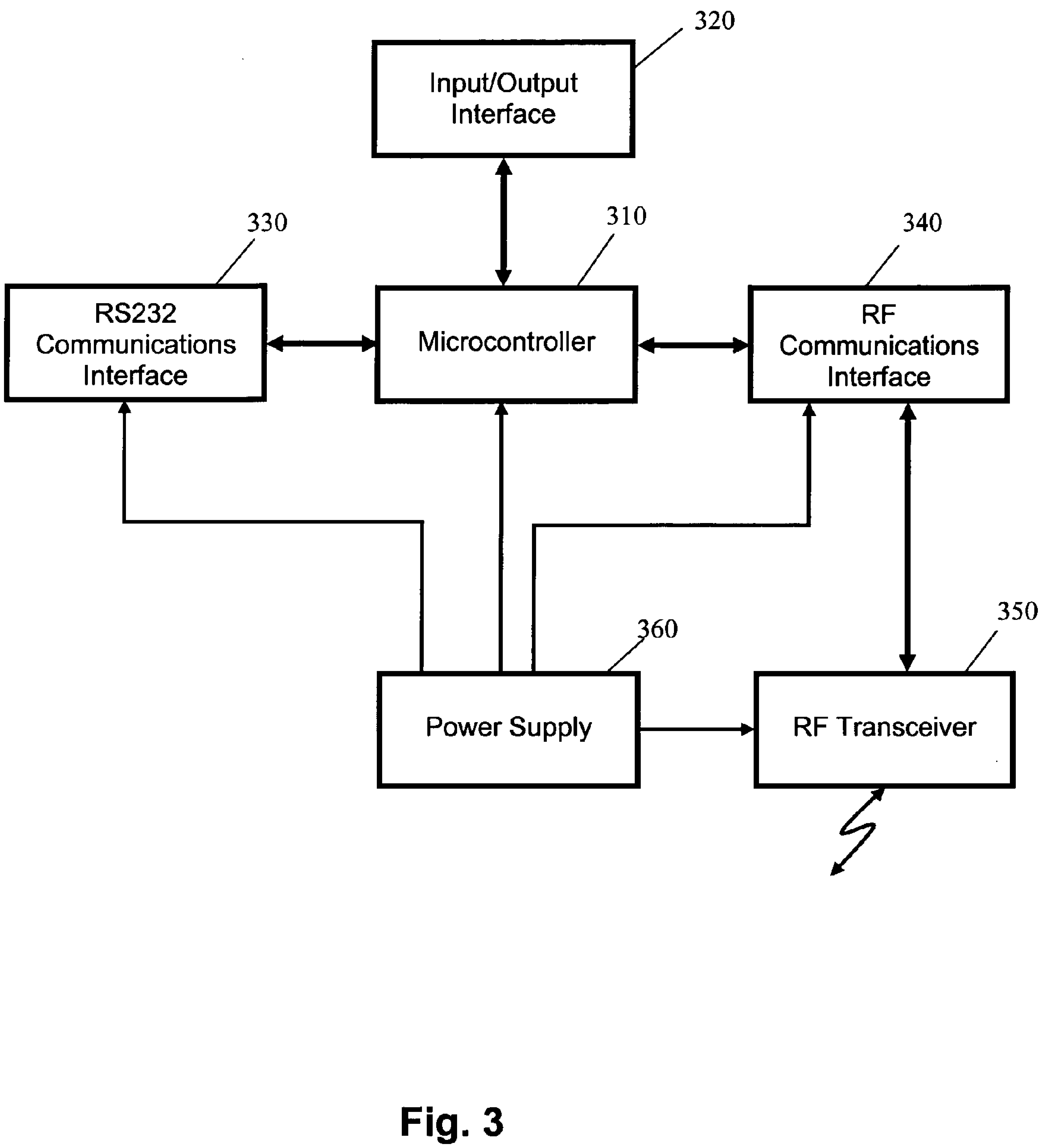

320
Input/Output Interface
330
310
340
RS232 Communications Interface
Microcontroller
RF Communications Interface
360
350
Power Supply
RF Transceiver

Fig. 3

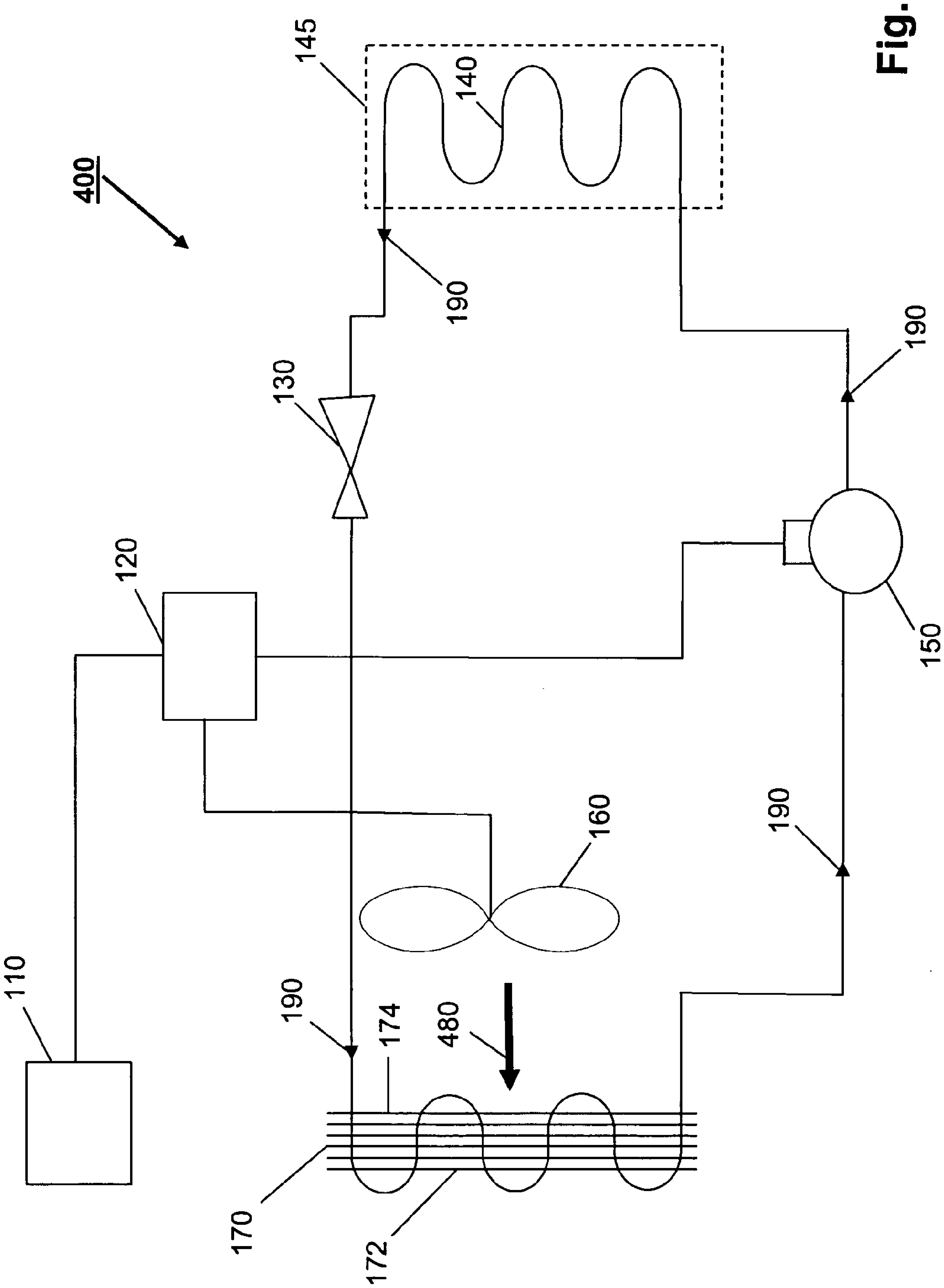


Fig. 4

METHODS AND APPARATUSES FOR OPERATING HEAT PUMPS IN HOT WATER SYSTEMS

RELATED APPLICATIONS

[0001] The present application claims priority from Australian Provisional Patent Application No. 2008900409, filed on 30 Jan. 2008, and Australian Provisional Patent Application No. 2008904653, filed on 8 Sep. 2008. The contents of Australian Provisional Patent Application No. 2008900409 and Australian Provisional Patent Application No. 2008904653 are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to the operation of heat pumps that may be used in hot water systems and more particularly to the operation of such heat pumps under low ambient temperature conditions.

BACKGROUND

[0003] Heat pumps are devices or systems that move heat from a 'source' location to a 'sink' location using work. Heat pumps operate by exploiting the physical properties of an evaporating and condensing fluid known as a refrigerant. The refrigerant, in a pressurised gaseous state, is circulated through the heat pump circuit by a compressor. On the discharge side of the compressor, hot and highly pressurised gas is cooled in a heat exchanger known as a condenser until the gas condenses into a high pressure liquid at a relatively more moderate temperature. The condensed refrigerant then passes through a pressure-lowering device such as a thermostatic expansion valve or capillary tube, which passes the low pressure, barely liquid, refrigerant to another heat exchanger, known as an evaporator, where the refrigerant evaporates into a gas via heat absorption. The refrigerant is then returned to the compressor and the cycle is repeated.

[0004] In a hot water system that employs a heat pump to heat a body of water, the greater the difference between the water temperature and the ambient air temperature, the greater the pressure difference and amount of energy required to compress the refrigerant fluid. Coefficient of Performance (COP) is a measure used to describe energy efficiency, that is, the amount of heat moved per unit of work. COP values are thus relatively higher when the ambient air temperature is much less or much greater than the water temperature in a hot water system. When the ambient air temperature is substantially lower or substantially higher than the actual or demanded water temperature (i.e., at relatively higher COP values), the heat pump becomes subject to excessive strain. One conventional method of operating under such temperature conditions is to turn off the heat pump and employ a booster (e.g., an auxiliary electric heating element) to heat the water.

[0005] Another disadvantageous effect that is manifested when the ambient air temperature is substantially lower than the water temperature is that moisture in the air condenses and forms ice on the evaporator. This is particularly significant in hot water systems on account of the evaporator typically being located outdoors. Switching to boosted operation, as described above, ameliorates this problem However, boosters require continuous power and are contrary to the environmental motivation for using a heat pump in the first place. Furthermore, electric heating elements are susceptible to corrosion when installed in the water tank of a hot water system.

[0006] A need thus exists to provide alternative and/or improved methods and apparatuses for operating heat pumps under extreme ambient temperature conditions and particularly under low ambient temperature conditions.

SUMMARY

[0007] According to one aspect of the present invention, there is provided a method for operating a heat pump in low ambient air temperatures. The method comprises the steps of: periodically or temporarily halting flow of refrigerant through an evaporator of the heat pump; and providing forced airflow across the evaporator while the refrigerant flow is halted.

[0008] The step of periodically or temporarily halting flow of refrigerant through an evaporator may comprise the step of repeatedly turning a compressor of the heat pump off for a first predetermined time period and on for a second predetermined time period. The second predetermined time period is greater than the first predetermined time period.

[0009] Another aspect of the present invention provides an apparatus comprising: a heat pump circuit comprising a compressor, a condenser, a pressure-lowering device, and an evaporator; a fan adapted to generate airflow across the evaporator; a temperature sensor adapted to measure ambient air temperature; and an electronic controller coupled to the compressor, the fan and the temperature sensor. The heat pump circuit is adapted to hold a charge of refrigerant. The electronic controller is adapted to: obtain ambient air temperature values from the temperature sensor; repeatedly turn the compressor on and off while the ambient air temperature values are lower than a first predetermined temperature value; and operate the fan to provide forced airflow across the evaporator while the compressor is turned off.

[0010] The electronic controller may be adapted to cyclically operate the compressor by repeatedly turning the compressor off for a first predetermined time duration and on for a second predetermined time duration. The second predetermined time duration is greater than the first predetermined time duration.

[0011] Another aspect of the present invention provides a hot water system, comprising: a water tank for storing water; a heat pump circuit comprising a compressor, a pressure-lowering device, an evaporator, and a condenser in a heat exchanging relationship with the water in the water tank; a fan adapted to generate airflow across the evaporator; a first temperature sensor adapted to determine ambient air temperature; and an electronic controller coupled to the compressor, the fan and the first temperature sensor. The electronic controller is adapted to: obtain ambient air temperature values from the temperature sensor; repeatedly turn the compressor on and off while the ambient air temperature values are lower than a first predetermined temperature value; and operate the fan to provide forced airflow across the evaporator while the compressor is turned off.

[0012] The hot water system may further comprise a second temperature sensor coupled to the electronic controller and adapted to determine temperature of water in the water tank. In this instance, the electronic controller is further adapted to: obtain water temperature values from the second temperature sensor; and turn off the compressor and the fan when the water temperature exceeds a third predetermined temperature.

[0013] The electronic controller may be adapted to cyclically operate the compressor by repeatedly turning the compressor off for a first predetermined time duration and on for a second predetermined time duration. The second predetermined time duration is greater than the first predetermined time duration.

[0014] Another aspect of the present invention provides a method for operating a heat pump in a hot water system. The method comprises the steps of: providing forced airflow across an evaporator of the heat pump while the heat pump is operational to heat water in a tank of the hot water system; and temporarily halting flow of refrigerant through the evaporator and reversing the direction of the forced airflow across the evaporator while ambient air temperature is lower than a predetermined temperature value. The step of temporarily halting flow of refrigerant through the evaporator and reversing the direction of the forced airflow across the evaporator may be performed periodically while the heat pump is operational to heat water in the tank of the hot water system and ambient air temperature is lower than a predetermined temperature value. The flow of refrigerant through the evaporator may be halted and the direction of the fan reversed for a period of approximately 30 minutes every 2 hours. The direction of the fan may be reversed to provide forced airflow onto a side of the evaporator that is less susceptible to icing.

[0015] Another aspect of the present invention provides a hot water system comprising: a water tank for storing water; a heat pump circuit comprising a compressor, a pressure-lowering device, an evaporator, and a condenser in a heat exchanging relationship with said water in the water tank; a fan adapted to provide forced airflow across the evaporator; a temperature sensor adapted to determine ambient air temperature; and an electronic controller coupled to the compressor, the fan and the temperature sensor. The electronic controller is adapted to: obtain ambient air temperature values from the temperature sensor; operate the fan to provide forced airflow across the evaporator while the heat pump is operational to heat water in the water tank; and temporarily halt flow of refrigerant through the evaporator and reverse the direction of the forced airflow across the evaporator while ambient air temperature is lower than a predetermined temperature value.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Embodiments are described hereinafter, by way of example only, with reference to the accompanying drawings in which:

[0017] FIG. **1** is a schematic block diagram of an embodiment of a heat pump;

[0018] FIG. **2** is a flow diagram of a method for operating a heat pump, such as the heat pump of FIG. **1**, in a hot water system;

[0019] FIG. **3** is a schematic block diagram of an electronic controller for operating a heat pump, such as the heat pump of FIG. **1**; and

[0020] FIG. **4** is a schematic block diagram of another embodiment of a heat pump.

DETAILED DESCRIPTION

[0021] Embodiments of methods and apparatuses are described hereinafter for operating a heat pump under low ambient temperature conditions. Although the embodiments are described with reference to a heat pump used to heat water in a hot water system, it is not intended to limit the present invention in this manner. For example, the embodiments described hereinafter may have application for operating heat pumps used for other purposes such as heating systems for buildings (e.g., reverse cycle air conditioning).

[0022] References to hot water systems in this specification are intended to include both domestic and industrial water heating systems.

[0023] FIG. **1** shows an embodiment of a heat pump **100**. Referring to FIG. **1**, the heat pump **100** has a heat pump circuit comprising an evaporator **170**, a compressor **150**, a condenser **140** and a pressure reducing device **130** such as a thermostatic expansion valve (TX valve). The heat pump circuit is configured such that the outlet of the compressor **150** is coupled to an inlet of the condenser **140**, an outlet of the condenser **140** is coupled to the inlet of the pressure reducing device **130**, the outlet of the pressure reducing device **130** is coupled to an inlet of the evaporator **170**, and an outlet of the evaporator **170** is coupled to an inlet of the compressor **150**. The heat pump circuit is adapted to hold a charge of refrigerant that is circulated through the heat pump circuit by the compressor **150** in a direction shown by the arrows **190**. The foregoing components of the heat pump **100** operate to produce a refrigeration cycle, as is well known to persons skilled in the art.

[0024] A fan **160** is used to generate airflow **180** across the evaporator **170**. The fan **160** may comprise a single, multi or variable speed fan. Operation of the compressor **150** and the fan **160** is controlled by an electronic controller **120**, which is coupled to a source of electricity (not shown), typically mains power. A temperature sensor **110** is also coupled to the electronic controller **120**, for determining and providing the electronic controller **120** with ambient temperature values. When the heat pump **100** is used in a hot water system, the condenser **140** is typically positioned in a heat exchanging relationship with a body of water contained in a tank **145** of the hot water system.

[0025] As described hereinbefore, the heat pump **100** may become subject to excessive strain when the ambient air temperature is substantially lower or substantially higher than the actual or demanded water temperature. Furthermore, when the ambient air temperature is substantially lower than the water temperature, moisture in the air condenses and forms ice on the evaporator and other refrigerant bearing components used to couple the evaporator to the heat pump circuit.

[0026] An embodiment of the present invention provides a method for operating the heat pump **100** in low ambient air temperatures. The method comprises temporarily or periodically halting the flow of refrigerant through the evaporator **170** of the heat pump **100** and providing forced airflow from the fan **160** across the evaporator **170** while the refrigerant flow is halted. Forced airflow from the fan **160** is preferably provided for the entire duration the refrigerant flow is halted. However, this is not essential as the forced airflow may only need to be maintained for a substantial portion of the time the refrigerant flow is halted. The refrigerant flow through the evaporator **170** may be halted by switching off the compressor **150**. An effect of halting the flow of refrigerant is that the forced airflow from the fan **160** causes the static refrigerant in the evaporator **170** to heat up. This causes the difference in temperature between the refrigerant and the ambient air to reduce significantly, which in turn causes any ice build-up on the evaporator **170** and associated coupling components to melt. De-icing is assisted by the use of a single wall evaporator structure.

[0027] In the embodiment described hereinbefore with reference to FIG. **1**, the fan **160** is adapted to draw air to heat the refrigerant in the evaporator **170**. In other words, the direction of forced airflow as indicated by arrow **180** in FIG. **1** is across the evaporator **170** towards the fan **160**. In this configuration, the forced airflow first strikes the side of the evaporator **170** that is most susceptible to icing as a consequence of low ambient temperature conditions.

[0028] However, the inventor has discovered that operating the fan **160** in the reverse direction to cause forced airflow from the fan **160** towards the side of the evaporator **170** less susceptible to icing (i.e., forced airflow in a direction opposite to that indicated by the arrow **180** in FIG. **1**) while the flow of refrigerant through the evaporator **170** is temporarily halted, substantially improves the efficiency of de-icing as opposed to operating the fan **160** in the direction indicated by the arrow **180** in FIG. **1**. This, in turn, improves the overall heating efficiency of the heat pump **100**.

[0029] In one embodiment, the fan **160** is adapted to provide forced air flow in the direction of arrow **180** during normal (i.e., non-de-icing) operation and is reversed during de-icing operation to provide forced air flow in the direction opposite to arrow **180**.

[0030] In another embodiment, the fan **160** may be adapted to always provide forced airflow in the direction opposite to arrow **180** (i.e., during both normal and de-icing operation). Although the effect of the moving refrigerant during normal operation (i.e., compressor **150** operating) may result in increased icing of the evaporator **170**, the forced airflow may additionally be caused to pass in close proximity to the compressor **150**, thereby providing forced airflow at an increased temperature which will assist de-icing.

[0031] FIG. **2** is a flow diagram of a method for operating a heat pump, such as the heat pump **100** of FIG. **1**. The method of FIG. **2** may be practiced as a computer program executed by the electronic controller **120** of FIG. **1**.

[0032] The method begins at step **210**, during which hardware and/or software of the electronic controller **120** is initialised. For example, a counter may be initialised for time duration measurement purposes.

[0033] The main program loop includes step **270** and is executed approximately once per minute. However, those skilled in the art will appreciate that other main program loop delay intervals may alternatively be practiced.

[0034] At step **212**, a determination is made whether the ambient air temperature is less than a predetermined temperature value of 4° C., below which de-icing is performed. If not (N), the de-icing is not required and normal operation of the heat pump proceeds at step **220**.

[0035] At step **220**, a determination is made whether the compressor is on. If not (N), a determination is made at step **222** whether the temperature of the water in the water tank of the hot water system is less than a predetermined value of 53° C. As a temperature differential typically exists across the water tank and hot water is drawn off the top of the water tank for consumption purposes, the water temperature used for the determination in step **222** is preferably the temperature of water near the top of tank (T_t).

[0036] If the temperature of the water in the water tank of the hot water system is less than a predetermined value of 53° C. (Y), the water in the tank requires heating and the compressor and the fan are both turned on at step **224**. Step **224** effectively turns on the heat pump. The method then proceeds to step **270** of the main loop. If the water in the tank does not require heating (N), at step **222**, the method proceeds directly to step **270** of the main loop without turning the heat pump on.

[0037] If the compressor is on (Y), at step **220**, a determination is made at step **226** whether the water temperature at the top of the water tank of the hot water system (T_t) is greater than a predetermined value of 58° C. If so (Y), the water in the tank does not require further heating and the compressor, fan and counter are turned off at step **228**. Step **228** effectively turns off the heat pump. The method then proceeds to step **270** of the main loop. If the water in the tank does require further heating (Y), at step **226**, the method proceeds directly to step **270** of the main loop without turning the heat pump off.

[0038] Returning now to step **212**, if the ambient air temperature is less than a predetermined value of 4° C., de-icing is required and the method proceeds at step **230**. At step **230**, a determination is made whether the ambient air temperature is less than a predetermined value of −5° C. If so (Y), the heat pump is effectively turned off from step **232** onwards. A determination is made, at step **232**, whether the compressor is on. If so (Y), the compressor is turned off at step **234**. After waiting for a delay of 30 minutes at step **236**, the counter is turned off at step **238** and the fan is turned off at step **240**. Thereafter, the method proceeds to step **270** of the main loop. If the compressor is already off (N), at step **232**, the method proceeds directly to step **270** of the main loop.

[0039] If the ambient temperature is not less than the predetermined value of −5° C. (N), at step **230**, de-icing is performed. A determination is made at step **250** whether the counter is on. If not (N), the counter is turned on at step **252** and processing continues at step **220** as described hereinbefore. However, if the counter is on (Y), at step **250**, a determination is made, at step **254**, whether the counter indicates that more than 2 hours has elapsed since last being turned on. If more than 2 hours have not elapsed (N), processing continues from step **220** as described hereinbefore. On the other hand, if more than 2 hours have elapsed (Y), the compressor is turned off at step **256**. After waiting for a delay of 30 minutes at step **258**, the counter is turned off at step **260** and the compressor is turned on again at step **262**. Thereafter, the method proceeds to step **270** of the main loop.

[0040] As described hereinbefore with reference to FIG. **2**, the compressor is turned on for 2 hours and off for 30 minutes in a repeating cycle when de-icing is performed (i.e., when the ambient air temperature is less than 4° C. and greater than or equal to −5° C. The fan is, however, kept turned on during the entire de-icing cycle. In ambient air temperatures of 4° C. or greater, de-icing is not required. In ambient air temperatures below −5° C., the heat pump is completely turned off (i.e., both the compressor and the fan), as heat pump operation in such low temperatures is not viable.

[0041] Those skilled in the art will appreciate that the values and ranges (e.g., of temperatures and times) referred to in the description hereinbefore relating to FIG. **2** are for purposes of describing a particular embodiment of the present invention only and that other predetermined values and/or ranges may alternatively be practiced. For example, de-icing may be performed over a different range of ambient air temperatures. Furthermore, those skilled in the art will appreciate that the on and off times for operating the compressor during de-icing operation may vary from the 2 hours and 30 minutes, respectively, used in the embodiment of FIG. **2**. Times for de-icing (i.e., compressor on and off times) depend on humidity and typically range from 15 to 30 minutes. De-icing can be accelerated by increasing airflow across the evaporator, which can be implemented by use of a multi-speed fan. A multi-speed fan may also be used to assist heat pump performance at high ambient or water temperatures by decreasing airflow and consequently reducing refrigerant pressure. Forced airflow from the fan is preferably maintained for the entire duration the compressor is turned off. However, this is not essential as the forced airflow may only need to be maintained for a substantial portion of the time the compressor is turned off.

[0042] As described hereinbefore, the fan may be adapted to blow air onto the side of the evaporator most susceptible to icing during de-icing to improve the efficiency of de-icing. This may be achieved by reversing the direction of the fan during de-icing or by having the fan blow air onto the inside surface of the evaporator during normal operation and de-icing.

[0043] FIG. **3** is a schematic block diagram of an embodiment of the electronic controller **120** in FIG. **1**. Control of the heat pump **100** is performed by a software control program resident in the memory of the microcontroller **310**. In one particular embodiment, the microcontroller **310** comprises a Microchip PIC16F676 CMOS 8-bit microcontroller. The PIC16F676 has 1,792 bytes of flash-based program memory, 64 bytes of RAM and 128 bytes of EEPROM and also includes an on-board 10-bit analog-to-digital (A/D) converter. However, as would readily be appreciated by those skilled in the art, other microcontrollers or microprocessors may alternatively be practiced in the controller **310**. Various memory and peripheral configurations may also be practiced, such as a combination of on-board and off-board memory.

[0044] The microcontroller **310** controls components of the heat pump **100** via output ports that are interfaced to the devices by means of input/output interface circuitry **320**. In one embodiment, the compressor **150** and the fan **160** are controlled via relays, which form part of the input/output interface circuitry **320**. However, alternative control elements may also be practiced, including solid state switches such as thyristors and triacs. In certain embodiments, the relays or control elements for the fan enable reversing of the direction of the fan.

[0045] The microcontroller **310** obtains data from components of the heat pump **100** and/or hot water system via input ports that are interfaced to the devices by means of input/output interface circuitry **320**. For example, ambient air temperature data is obtained from the temperature sensor **110** of FIG. **1**. Furthermore, the microcontroller **310** may also obtain data relating to the temperature of the water at the top and/or bottom of the hot water tank **145** (T_t and T_b, respectively) from temperature sensors (not shown in FIG. **1**) coupled via the input/output interface circuitry to input ports of the microcontroller **310**. Thus, the microcontroller **310** is able to control the compressor **150** and the fan **160** in accordance with external variables such as water temperature, ambient air temperature, etc.

[0046] The microcontroller **310** may also be coupled to an RF transceiver **350** via an RF communications interface **340** for receiving information from and/or transmitting information to a remote entity. Such information may, for example, be used to remotely monitor system performance (e.g., hot water temperature) and/or hot water consumption. The RF transceiver **350** may comprise a communications module for cellular telephone type communication (e.g., GSM, GPRS or CDMA). Other types of communications transceivers may alternatively be practiced, which may use communications channels such as the ultra-high frequency (UHF), very-high frequency (VHF) or microwave bands. Still further, a receiver only may be practiced in place of the RF transceiver **350**. The RF transceiver may be used to communicate with fixed or mobile, hand-held RF communication devices.

[0047] The microcontroller **310** may also be coupled to an RS-232 communications interface **330** to provide a communication link to a computer apparatus (not shown). Various other types of communications interfaces may be practiced in place of the RS-232 interface, such as a RS-485 interface, a parallel interface, an infra-red interface, a Universal Serial Bus (USB) interface, or any other commonly available or proprietary communications interfaces. The computer apparatus may comprise a Personal Computer (PC), a Personal Digital Assistant (PDA), a mobile telephone, or any other off-the-shelf or proprietary computer apparatus. Parameters for operation of the controller **310** may be adjusted by, and/or downloaded to, the controller **310** from such a computer apparatus via the RS-232 communications interface **330**. In certain embodiments, bootstrap loader software installed in the program memory of the microcontroller **310** enables downloading of new and/or revised control software to the controller **310** via the RS-232 communications interface **330**.

[0048] The microcontroller **310**, RF communications interface **340**, the RF transceiver **350** and the RS-232 communications interface **330** are powered by a power supply **360**, which typically receives input power from the mains supply.

[0049] Those skilled in the art will appreciate that electronic controller described hereinbefore with reference to FIG. **3** is an example of an electronic controller that may be used to practice embodiments of the present invention. Various other types of electronic controllers may alternatively be practiced, including an electronic circuit that does not include a microprocessor or microcontroller.

[0050] FIG. **4** shows another embodiment of a heat pump **400**. The heat pump **400** is similar to the heat pump **100** of FIG. **1** in that components having the same reference designators in FIGS. **1** and **4** are similar or substantially identical. For example, the evaporator **170**, the fan **160**, the compressor **150**, the condenser **140** and the pressure reducing device **130** in FIGS. **1** and **4** are equivalent or similar in functionality. However, the fan **160** in the embodiment of FIG. **4** is adapted to blow air in the direction of the arrow **480** towards the evaporator **170**. The evaporator **170** comprises two main operational sides or surfaces for heat exchanging, namely sides **172** and **174**. One of the sides is generally more susceptible to icing, for example, on account of being exposed to lower ambient temperatures. The forced airflow from the fan **160** strikes the side **174** of the evaporator **170** that is less susceptible to icing. That is, the side **172** of the evaporator **170** is more susceptible to icing.

[0051] In a particular embodiment, the fan **1670** is operated to blow air in the direction of the arrow **480** for a 0.5 hour period every 2 hours to perform de-icing. However, those skilled in the art will appreciate that other periods and/or values may alternatively be practiced.

[0052] In certain embodiments of the present invention, the fan **160** is typically only turned on to provide forced airflow across the evaporator **170** during water heating to heat the refrigerant in the evaporator **170**. However, when the ambient air temperature drops lower than a predetermined temperature value (e.g., 8° C.), icing of the evaporator **170** becomes possible. As a consequence, the flow of refrigerant through the evaporator **170** is temporarily halted (e.g., the compressor

150 is turned off) and the direction of the fan **160** is temporarily reversed (e.g., to provide or direct forced airflow in the direction of arrow **480** in FIG. **4**). Halting the flow of refrigerant through the evaporator **170** and reversing the direction of the fan **160** (i.e., the direction of forced airflow across the evaporator **170**) is typically performed periodically while the heat pump is operational to heat water in the tank of the hot water system and the ambient air temperature is lower than the predetermined temperature value.

[0053] In a particular embodiment, flow of refrigerant through the evaporator **170** is halted and the direction of the fan **160** is reversed for a period of approximately 30 minutes every 2 hours.

[0054] During the period in which the direction of the fan **160** is reversed, forced airflow is provided or directed onto a side of the evaporator **170** that is less susceptible to icing (e.g., with reference to FIG. **4**, the direction of forced airflow indicated by the arrow **480** onto the side **174** of the evaporator **170** that is less susceptible to icing, compared to the side **172** of the evaporator **170** that is more susceptible to icing).

[0055] Embodiments described hereinbefore advantageously enable operation of a heat pump at low ambient temperatures. Embodiments described hereinbefore also provide a means for de-icing components of a heat pump (e.g., an evaporator), when operating at low ambient temperatures. A significant advantage of the embodiments described is that no supplementary de-icing equipment or energy is required. The embodiments are particularly applicable to heat pumps having an evaporator located outdoors, such as domestic and industrial water heating systems.

[0056] The foregoing detailed description provides exemplary embodiments only, and is not intended to limit the scope, applicability or configurations of the invention. Rather, the description of the exemplary embodiments provides those skilled in the art with enabling descriptions for implementing an embodiment of the invention. Various changes may be made in the function and arrangement of elements without departing from the spirit and scope of the invention as set forth in the claims hereinafter. Where specific features, elements and steps referred to herein have known equivalents in the art to which the invention relates, such known equivalents are deemed to be incorporated herein as if individually set forth. Furthermore, features, elements and steps referred to in respect of particular embodiments may optionally form part of any of the other embodiments unless specifically stated to the contrary.

[0057] In the context of this specification, the word "comprising" means "including principally but not necessarily solely" or "having" or "including", and not "consisting only of". Variations of the word "comprising", such as "comprise" and "comprises" have correspondingly varied meanings.

1. A method for operating a heat pump in low ambient air temperatures, said method comprising the steps of:

periodically halting flow of refrigerant through an evaporator of said heat pump; and

providing forced airflow across said evaporator while said refrigerant flow is halted.

2. The method of claim **1**, wherein said step of periodically halting flow of refrigerant through an evaporator comprises the step of repeatedly turning a compressor of said heat pump off for a first predetermined time period and on for a second predetermined time period, said second predetermined time period greater than said first predetermined time period.

3. The method of claim **1**, wherein said method is performed when the ambient air temperature falls below a predetermined temperature value.

4. The method of claim **1**, wherein said heat pump in used to heat water in a hot water system and a condenser of said heat pump is positioned in a heat exchanging relationship with a body of water in said hot water system.

5. An apparatus comprising:

a heat pump circuit comprising a compressor, a condenser, a pressure-lowering device, and an evaporator, said heat pump circuit adapted to hold a charge of refrigerant;

a fan adapted to generate airflow across said evaporator;

a temperature sensor adapted to measure ambient air temperature; and

an electronic controller coupled to said compressor, said fan and said temperature sensor, said electronic controller adapted to:

obtain ambient air temperature values from said temperature sensor;

repeatedly turn said compressor on and off while said ambient air temperature values are lower than a first predetermined temperature value; and

operate said fan to provide forced airflow across said evaporator while said compressor is turned off.

6. The apparatus of claim **5**, wherein said electronic controller is adapted to cyclically operate said compressor by repeatedly turning said compressor off for a first predetermined time duration and on for a second predetermined time duration, said second predetermined time duration greater than said first predetermined time duration.

7. The apparatus of claim **5**, wherein said electronic controller is further adapted to turn said compressor off an said fan off when said ambient air temperature values are less than a second predetermined temperature value.

8. The apparatus of claim **5**, wherein said electronic controller is further adapted to operate said fan and said compressor continuously while said ambient air temperature values are greater than or equal to said first predetermined temperature value.

9. The apparatus of claim **5**, wherein said pressure-lowering device comprises a thermostatic expansion valve (TX valve).

10. A hot water system, comprising:

a water tank for storing water;

a heat pump circuit comprising a compressor, a pressure-lowering device, an evaporator, and a condenser in a heat exchanging relationship with said water in said water tank;

a fan adapted to generate airflow across said evaporator;

a first temperature sensor adapted to determine ambient air temperature; and

an electronic controller coupled to said compressor, said fan and said first temperature sensor, said electronic controller adapted to:

obtain ambient air temperature values from said temperature sensor;

repeatedly turn said compressor on and off while said ambient air temperature values are lower than a first predetermined temperature value; and

operate said fan to provide forced airflow across said evaporator while said compressor is turned off.

11. The hot water system of claim **10**, further comprising a second temperature sensor coupled to said electronic controller and adapted to determine temperature of water in said water tank, and wherein said electronic controller is further adapted to:

obtain water temperature values from said second temperature sensor; and

turn off said compressor and said fan when said water temperature exceeds a third predetermined temperature.

12. The hot water system of claim **10**, wherein said electronic controller is adapted to cyclically operate aid compressor by repeatedly turning said compressor off for a first predetermined time duration and on for a second predetermined time duration, said second predetermined time duration greater than said first predetermined time duration.

13. The hot water system of claim **10**, wherein aid electronic controller is further adapted to turn said compressor off and said fan off when said ambient air temperature values are less than a second predetermined temperature value.

14. The hot water system of claim **10**, wherein said electronic controller is further adapted to operate said fan and said compressor continuously while said ambient air temperature values are greater than or equal to said first predetermined temperature value.

15. The hot water system of claim **10**, wherein said pressure-lowering device comprises a thermostatic expansion valve (TX valve).

16. A method for operating a heat pump in low ambient air temperatures, said method comprising the steps of:

temporarily halting flow of refrigerant through an evaporator of said heat pump; and providing forced airflow across said evaporator while said refrigerant flow is halted.

17. The method of claim **1**, wherein the step of providing forced airflow comprises forcing airflow onto a side of said evaporator that is less susceptible to icing.

18. The apparatus of claim **5**, wherein said electronic controller is adapted to control said fan to blow air onto a side of said evaporator that is less susceptible to icing.

19. The hot water system of claim **10**, wherein said electronic controller is adapted to control said fan to blow air onto a side of said evaporator that is less susceptible to icing.

20. A method for operating a heat pump in a hot water system, said method comprising the steps of:

providing forced airflow across an evaporator of said heat pump while said heat pump is operational to heat water in a tank of said hot water system; and

temporarily halting flow of refrigerant through said evaporator and reversing the direction of said forced airflow across said evaporator while ambient air temperature is lower than a predetermined temperature value.

21. The method of claim **20**, wherein said step of temporarily halting flow of refrigerant through aid evaporator and reversing the direction of said forced airflow across said evaporator is performed periodically while said heat pump is operational to heat water in said tank of said hot water system and ambient air temperature is lower than a predetermined temperature value.

22. The method of claim **21**, wherein said flow of refrigerant through said evaporator is halted and the direction of said fan is reversed for a period of approximately 30 minutes every 2 hours.

23. The method of claim **20**, wherein the direction of said fan is reversed to provide forced airflow onto a side of said evaporator that is less susceptible to icing.

24. A hot water system, comprising:

a water tank for storing water;

a heat pump circuit comprising a compressor, a pressure-lowering device, and evaporator, and a condenser in a heat exchanging relationship with said water in aid water tank;

a fan adapted to provide forced airflow across said evaporator;

a temperature sensor adapted to determine ambient air temperature; and

an electronic controller coupled to said compressor, aid fan and said temperature sensor, said electronic controller adapted to:

obtain ambient air temperature values from said temperature sensor;

operate said fan to provide forced airflow across said evaporator while said heat pump is operational to hot water in said water tank; and

temporarily halt flow of refrigerant through said evaporator and reverse the direction of said forced airflow across said evaporator while ambient air temperature is lower than a predetermined temperature value.

25. The hot water system of claim **24**, wherein said electronic controller adapted to periodically halt flow of refrigerant through said evaporator and reverse the direction of said forced airflow across said evaporator while said heat pump is operational to heat water in said water tank and ambient air temperature is lower than a predetermined temperature value.

26. The hot water system of claim **25**, wherein said flow of refrigerant through said evaporator is halted and the direction of said fan is reversed for a period of approximately 30 minutes every 2 hours.

27. The hot water system of claim **24**, wherein the direction of said fan is reversed to provide forced airflow onto a side of said evaporator that is less susceptible to icing.

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