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(54) **PROPER DEICING END DETECTION AND DEFROST CYCLE OPTIMIZATION**

(57) A method (300) of defrost operation optimization in a heat pump includes launching (305) a heating mode after completion of a performed defrost operation, measuring (310), after launching the heating mode, a heat transfer capability, determining (315) if the measured heat transfer capability is less than or equal to a predetermined heat transfer capability limit for a non-iced condition, and reinforcing (320) a next defrost operation if the measured heat transfer capability is greater than the predetermined gap limit.

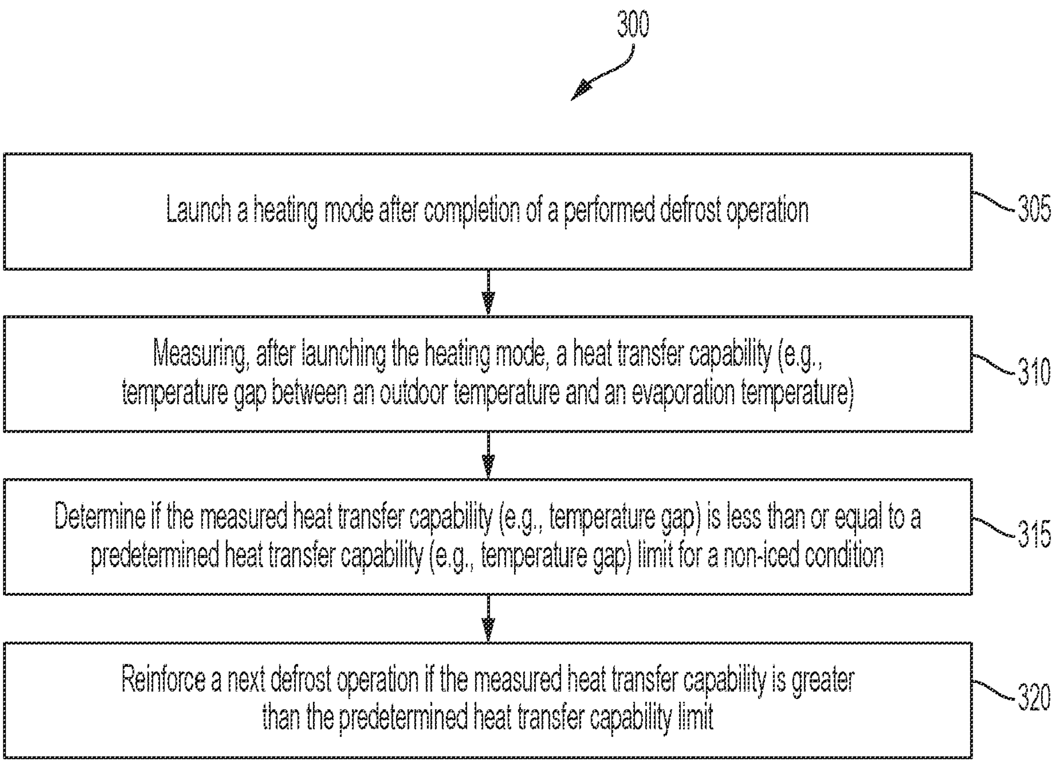

FIG. 3

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Description

TECHNICAL FIELD

[0001] This application relates generally to heating, ventilation, and air conditioning (HVAC) systems and more particularly, but not by way of limitation, to managing defrost operations in a heat pump.

BACKGROUND

[0002] This section provides background information to facilitate a better understanding of the various aspects of the disclosure. It should be understood that the statements in this section of this document are to be read in this light, and not as admissions of prior art.

[0003] Heat pumps may be utilized as part of an air conditioning system that provides heated air and cooled air to a location. During cold ambient temperatures, an outside heat exchanger and/or fan may be subject to icing. The icing may cause heating power drops, energy efficiency drops, reduce air flow rate, and/or mechanical failure (e.g., including pre-failure events such as wear on parts).

[0004] Defrost cycles may be utilized to reduce ice accumulation on surfaces and/or to inhibit ice formation. The defrost cycle may including reversing the flow of refrigerant such that hot refrigerant is provided to the outside heat exchanger and the temperature of the heat exchanger and/or fan is raised.

SUMMARY

[0005] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not necessarily intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of claimed subject matter.

[0006] An exemplary method of defrost operation optimization in a heat pump includes launching a heating mode after completion of a performed defrost operation, measuring, after launching the heating mode, a temperature gap between an outdoor temperature and an evaporation temperature, determining if the measured temperature gap is less than or equal to a predetermined gap limit for a non-iced condition, and reinforcing a next defrost operation if the measured temperature gap is greater than the predetermined gap limit.

[0007] Another exemplary method of defrost operation optimization in a heat pump includes launching a heating mode after completion of a performed defrost operation, the performed defrost operation consisting of a single defrost cycle, measuring, within about 30 seconds and 300 seconds after launching the heating mode, a heat transfer capability of the heat pump, determining if the measured heat capability transfer is less than or equal to a predetermined heat transfer capability limit for a non-iced condition, and reinforcing a next defrost operation if the measured heat transfer capability is greater than the predetermined heat transfer capability limit.

[0008] Another exemplary method of defrost operation optimization in a heat pump includes launching a heating mode after completion of a performed defrost operation, measuring, after launching the heating mode, an air pressure differential across an outdoor heat exchanger, determining if the measured air pressure differential is less than or equal to a predetermined differential limit for a non-iced condition, and reinforcing a next defrost operation if the measured air pressure differential is greater than the predetermined differential limit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The disclosure is best understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of various features may be arbitrarily increased or reduced for clarity of discussion.

FIGURE 1 illustrates an implementation of an exemplary heat pump;

FIGURE 2 illustrates another implementation of an exemplary heat pump;

FIGURE 3 illustrates an implementation of an exemplary process for defrost operation optimization;

FIGURE 4 is graphical illustration of an exemplary temperature gap mapping performed in a laboratory setting to implement parameters in the heat pump control settings;

FIGURE 5 illustrates an implementation of an exemplary process for defrost operation optimization;

FIGURE 6 illustrates an implementation of an exemplary process for defrost operation optimization; and

FIGURE 7 illustrates an implementation of an exemplary process for defrost operation optimization.

DETAILED DESCRIPTION

[0010] Various embodiments will now be described more fully with reference to the accompanying drawings. The disclosure may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

[0011] Heat pumps may be utilized in a variety of applications, such as air conditioning and refrigeration systems. During operation, some portions of the heat pump, such as fan(s), housing(s), and heat exchanger(s) may be subject to conditions that cause an ice event (e.g., ice and/or frost accumulation). Frost/ice accumulation may cause heating power drops, energy efficiency drops and/or inhibited operation of at least a portion of the heat pump (e.g., reduction in heat capacity provided by a heat exchanger and/or ice accumulation may restrict air flow rate due to increased air pressure drop of the heat exchanger).

[0012] FIGS. 1 and 2 illustrate implementations of an example heat pump 100. As illustrated, the heat pump 100 includes one or more heat exchangers 105, 110. The heat exchangers may include a first heat exchanger 105 and a second heat exchanger 110. The first heat exchanger 105 and/or the second heat exchanger may be capable of operating as an evaporator and/or a condenser. The first heat exchanger may be exposed to ice accumulation conditions (e.g., disposed in an environment in which ice may accumulate during operation, such as when disposed outside and/or positioned in an environment that may be cold, moist, and/or windy).

[0013] The heat pump may include a compressor 115. Any appropriate compressor 115 may be utilized. The heat pump 100 may include valves. As illustrated, the heat pump may include a reversing valve 120 (e.g., a valve capable of changing the direction of flow) and/or an expansion valve 125.

[0014] A controller 130 (e.g., a computer) may be coupled (e.g., communicably, such as by wires or linked by Wi-Fi) to component(s) of the heat pump 100 and control various operations of the component(s) and/or system. For example, the controller 130 may include management modules, such as a defrost module to perform various operations of the heat pump 100. The management modules may control operations of the heat pump, such as receiving requests for operation, determining whether to respond to requests for operation, responding to requests for operation, and/or operating various components (e.g., compressors, reversing valves, and/or expansion valves). The defrost module may perform various operations to reduce and/or inhibit the accumulation of frost on portions of the heat pump. For example, primary defrost module may determine properties and/or changes in properties of the heat pump (e.g., heat exchanger temperatures, ambient temperatures, ambient humidity, operation times, time between operations, and/or other properties), determine whether to allow defrost operations, determine what properties to utilized in determining whether to allow a defrost operation, determine what type of defrost operations to allow, transmit a signal to allow a defrost operation, restrict a defrost operation, allow a heat pump to respond to user requests, resume operation(s) of a heat pump, suspend operation(s) of a heat pump, etc.

[0015] Lines 135 (e.g., tubing) may couple various components and allow refrigerant to flow in and/or out of various components of the heat pump 100. Fans 140, 145 may cause air to flow through heat exchangers 105, 110 disposed proximate the fans. One or more of the fans may be disposed in a housing with a heat exchanger. For example, a fan 140 may be disposed in a housing with the first heat exchanger 105.

[0016] In some implementations, a portion of the heat pump 100 may be disposed outside a building (e.g., an "outdoor portion" on the ground proximate a building and/or on a roof of the building) and a portion of the heat pump may be disposed inside or outside the building (e.g., an "indoor portion") with an air path connected inside the building (air supply and/or air return). For example, an outdoor portion 150 may include heat exchanger 105 and fan 140 and an indoor portion 155 may include heat exchanger 110 and fan 145. The outdoor portion 150 and/or the indoor portion 155 may be at least partially disposed in housing(s).

[0017] The heat pump may include sensor(s) adapted to measure properties of the heat pump. For example, the sensor(s) may monitor properties, such as temperature (e.g., coil temperatures), ambient temperatures, change in temperature, outdoor heat exchanger air pressure differential, etc. The controller (e.g., a defrost module or defrost optimization module) may determine a measured heat transfer capability, e.g., a temperature gap between the coil temperature (e.g., evaporation temperature) and the outdoor temperature and/or air pressure differential across the first heat exchanger. The controller may determine a difference between the measured heat transfer capability and a predetermined heat transfer capability limit. Predetermined heat transfer capability limits for non-iced conditions may be stored in a memory of the heat pump.

[0018] FIGS. 1 and 2 illustrate exemplary temperature sensors 160, 165. Temperature sensor 160 is positioned to monitor and measure an outdoor temperature proximate first heat exchanger 105. Temperature sensor 160 may be position proximate a fresh air intake to the indoor area. Temperature sensor 165 is positioned to measure the refrigerant temperature at the first heat exchanger. For example, during a heating cycle or mode sensor 165 measures an evaporation temperature. Sensors 160, 165 as well as other sensors are traditionally present in heat pumps.

[0019] FIG. 2 illustrates the addition of an air pressure differential sensor 170 positioned at first heat exchanger 105. As ice increases the air pressure drop across first heat exchanger 105 increases.

[0020] A heat pump 100 may allow operations with heating and cooling modes or cycles. During a cooling mode, cool air may be provided by blowing air (e.g., from a fan 145) at least partially through a second heat exchanger 110 (e.g., in the indoor portion). The second heat exchanger may act as an evaporator to evaporate liquid refrigerant in the second heat exchanger. Heat may be removed from the air provided by the fan 145 and transferred at least partially to the liquid refrigerant to evaporate the refrigerant. Thus, a temperature of the air may be reduced, and the cool air may be provided to a location (e.g., via ducting). The gaseous refrigerant may exit the second heat exchanger 110, be compressed by a compressor 115, and delivered to a first heat exchanger 105 (e.g., outdoor portion), which acts as a condenser. The second heat exchanger 105 may condense the gaseous refrigerant, for example, by blowing air (e.g., from a fan 140) at least partially through the second heat exchanger 105 to remove heat from the gaseous refrigerant.

[0021] To operate the heat pump 100 in the heating mode, heat pump 100 may include a reversing valve 120 to change the direction of refrigerant flow through the heat pump such that the refrigerant flows in the opposite direction as the direction in which the refrigerant flows in the cooling cycle. For example, hot air may be provided by blowing air (e.g., using a fan 145) across the second heat exchanger 110. The second heat exchanger 110 may act as a condenser and condense gaseous refrigerant in the second heat exchanger 110. Heat from the condensation may be transferred from the refrigerant to the air provided by the fan 145. Thus, the temperature of the air may be elevated, and heated air may be provided (e.g., via ducting) to a location. The condensed refrigerant may be provided to the first heat exchanger 105 through expansion valve 125. The second heat exchanger 105 (e.g., in the outdoor portion) may act as an evaporator. Air from the fan 140 may be provided to the first heat exchanger (e.g., at least a portion of the first heat exchanger may at least partially surround the fan) and may transfer heat to the refrigerant in the first heat exchanger 105. As heat is transfer to the refrigerant, the refrigerant may be evaporated. The temperature of the air, provided by fan 140, may be cooler leaving the second heat exchanger 105 than when entering the second heat exchanger 105.

[0022] When a heat pump 100 is exposed to cold and moist air, frost (e.g., frost and/or ice) may accumulate on surfaces and/or other portions of component(s) of the heat pump 100. For example, when the first heat exchanger 105 and/or fan 140 are subject to moist and/or cold air, frost may accumulate on surfaces of the fan housing, fan blade, fan orifice, heat exchanger housing, and/or heat exchanger coil (e.g., coil tubing and/or fins). The frost accumulation may inhibit operation of at least a portion of the heat pump (e.g., reduced heat capacity provided by a heat exchanger and/or the air flow rate may be inhibited from air pressure drop increase due to ice accumulation in the heat exchanger) and/or may cause energy efficiency drops. Thus, one or more defrost operations of the heat pump may be allowed to reduce and/or inhibit ice accumulation on portions of the heat exchanger and/or fan.

[0023] Currently, to ensure good deicing of the outdoor heat exchanger, several defrosting or deicing cycles are performed consecutively before the heat pump is switched back to heating mode. However, in many cases, only one deicing cycle is needed to deice the coil. Thus, the heat pump is consuming energy without any benefit. Further, the excess deicing cycles unnecessarily cool the building.

[0024] Disclosed are exemplary systems and methods implementing a deicing check to determine or validate if a defrost operation was properly completed. In an exemplary process, the deicing check is performed after a single deicing cycle has been performed and the heat pump is launched in heating mode. The deicing check is performed during heating mode restart in determined operating conditions to obtain a stable measurement of the outdoor coil heat transfer capability. The measurement of the outdoor coil heat transfer capability is compared to a predetermined heat transfer capability value of the heat pump without ice at corresponding operating conditions. In an exemplary embodiment, the predetermined heat transfer capability values (e.g., temperature gap, air pressure drop) for a non-iced condition are determined in a laboratory type environment at ambient temperatures and at nominal operating conditions, e.g., indoor and outdoor fan speeds. During heating mode restart, the heat pump is set at, or approximate, the nominal conditions used to determine the predetermined heat transfer capability values and limits.

[0025] FIG. 3 illustrates an exemplary implementation of an example process 300 for detecting a proper deicing end and defrost operation optimization. The need to deice may be determined in various manners as is well known in the industry. For example, the heat pump may be started in heating mode during icing conditions, i.e., ambient temperature less than about 5 C. The proper deicing check may be launched to validate that the first heat exchanger is well deiced prior to the first start in heating mode.

[0026] At block 305 the heat pump is launched in heating mode. Heating mode launch may occur on startup of the heat pump, for example during icing conditions, or after the completion of a defrost operation.

[0027] A proper deicing, or deiced, check is performed after the heating mode is launched. At block 310, with the heat pump in heating mode, the heat exchanger heat transfer capability is measured. The heat transfer capability measurement is primarily described in terms of a temperature gap between the ambient outdoor temperature (sensor 160) and the evaporation temperature (sensor 165). This measurement provides an accurate heat transfer capability determination and utilizes sensors typically implemented in heat pumps. However, according to an exemplary process, the heat transfer capability measurement may be a heat exchanger air pressure drop utilizing a sensor 170 such as implemented in the heat pump illustrated in FIG. 2.

[0028] Measuring the heat transfer capability in terms of a temperature gap may include measuring the outdoor temperature via sensor 160 and the refrigerant evaporation temperature via sensor 165 and determining, for example with the processor and/or defrost optimization module, the difference between the outside temperature and the evaporation temperature. The heat transfer capability is measured during heating mode startup when conditions are stable. For example, the measurement is performed after a sufficient delay for the heat pump to stabilize and within a time limit sufficient to serve as a check of the validity of the completed defrost operation. In an exemplary process, measuring the temperature gap is preformed within about thirty seconds to five minutes (about 30 to 300 seconds) of launching the heating mode. In some processes, the temperature gap is measured within about one minute to four minutes (about 60 to 240 seconds) of launching the heating mode. In another example, the temperature gap is measured within about two minutes to about three minutes (about 120 to 180 seconds) of launching the heating mode. In one exemplary embodiment, the temperature gap is measured at about three minutes (about 180 seconds) of launching the heating mode.

[0029] At block 315, the measured heat transfer capability (e.g., temperature gap) is compared to a predetermined heat transfer capability limit for corresponding ambient conditions to determine if the measured heat transfer capability is less than or equal to the predetermined heat transfer capability limit. In this example, a measured temperature gap, or pinch, is compared to a predetermined gap limit. The predetermined gap limits may be stored in the heat pump memory. The predetermined gap limit corresponds with and is based on a temperature gap value of the heat pump without ice that was determined at ambient temperatures corresponding with the block 310 ambient temperature. In an exemplary embodiment, the temperature gap values for a non-iced heat pump are determined in a laboratory setting with controlled and known ambient temperatures and operating the heat pump at nominal operating values. At block 305, the heating mode may be launched with the nominal operating values used to determine the predetermined gap limits. As will be understood by those in the industry with benefit of this disclosure, the predetermined gap limit may be the gap value corresponding to the non-iced condition or the gap value with a tolerance, for example an additional 10 to 15 percent.

[0030] The performed defrost operation is determined to be proper if the measured temperature gap is less than or equal to the predetermined gap limit for the ambient conditions. If the performed defrost operation is determined to be proper, the next defrost operation will be nominal (i.e., same as the performed defrost operation).

[0031] At block 320, the next defrost operation is reinforced if the measured temperature gap is greater than the predetermined gap limit. Because the heat pump is operating in the heating mode, it is the next defrost operation that is changed. Reinforcing the next defrost operation may include, for example, one or more of increasing, relative to the performed defrosting operation, a number of deicing cycles, a condensing temperature, and a deicing time. Reinforcing the next defrost operation is implemented by adjusting the defrost operation parameters in the processor and/or defrost optimization module.

[0032] Figure 4 graphically illustrates heat transfer capability mapping, in terms of temperature gap mapping, performed in a laboratory to determine gap values for a heat pump without ice. The values illustrated in Figure 4 are exemplary and for the purpose of demonstration and are not limiting. The temperature gap between the evaporation temperature and outdoor temperature is graphed versus the ambient temperatures, i.e., outdoor, and indoor (e.g., recycled air) temperatures. In a laboratory setting, unlike in the field, the ambient temperatures are known and can be accurately controlled. In order to respect the compressor operating map, nominal air flow rates (indoor and outdoor fans) can be different according to the indoor and/or outdoor temperature. These temperature gap values, and the heat pump operating parameters may be implemented as predetermined gap limits in the heat pump control setting. The heat pump operating parameters corresponding to the predetermined gap values may be implemented, or substantially implemented, as the determined operating parameters of the heat pump during the deicing cycle end check.

[0033] The predetermined gap limits may be set at or based on the determined gap values for a heat pump without ice. In an exemplary embodiment, the predetermined gap limits include a tolerance added to the determined gap value. For example, and without limitation, the predetermined gap limits include a tolerance of about 10 to 15 percent added to the determined value. As will be understood by those skilled in the industry with benefit of this disclosure, the predetermined values and limits may be presented in terms of the heat exchanger air pressure differential instead of a temperature gap.

[0034] Figure 5 illustrates another exemplary implementation of an example process 500 for detecting a proper deicing end and defrost operation optimization. At block 505, the heat pump is turned on in heating mode. The heat pump is initiated with a deicing cycle counter at one (block 510) and the predetermined heat transfer capability limits (block 515).

[0035] At block 520 a defrost operation is started. The need to deice, or defrost, may be determined in various manners as is well known in the industry. For example, the heat pump may be started in a heating mode during icing conditions, i.e., ambient temperature less than about 5 C. To start the defrost operation the compressor is turned off, a delay is implemented to allow the pressure to stabilize, and then the compressor is turned on.

[0036] At block 525 the reversing valve is set to initiate or launch the cooling mode for a defrost operation. In this exemplary process, the defrost operation comprises performing one or more deicing cycles. The deicing cycle counter (j) is set at zero (block 530). The high-pressure temperature of the refrigerant is monitored, e.g., sensor 165, (blocks 535, 545). When the high-pressure temperature meets or exceeds an ice melting temperature (block 535) the outdoor fan 140 is turned on (block 540). The ice melting temperature may be selected from a range, for example of about 40 to 50 C. The fan eliminates the water droplets from the melted ice. The fan also moves cold ambient air across the heat exchanger cooling the refrigerant. When the high-pressure refrigerant temperature reaches a low temperature limit (block 545), the outdoor fan is turned off (block 550). The low temperature limit may be, for example, in a range of about 32 C and 40 C. A single deicing cycle is completed, and the cycle performed counter (j) is increased by one (block 560). At block 565, performance of another deicing cycle is determined. In this example, the performed defrost operation consists of a single deicing cycle and the defrosting operation is complete.

[0037] At block 570 the heat pump is transitioned to heating mode. The compressor is turned off and a delay is implemented to allow for pressure stabilization.

[0038] The heat pump is launched in heating mode at block 575. The compressor, indoor fan, outdoor fan, and reversing valve are turned on. The heat mode is launched with the compressor, indoor fan, and outdoor fan operating at determined operating values correlating with the nominal operating values used to determine the heat transfer capability value for the heat pump without ice and on which the predetermined heat transfer capability limit is based. The operating values may be for example, 100% recycle air, or 100% fresh air for moderate ambient temperatures, the indoor fan at nominal indoor flow rate, and the outdoor fan at nominal speed, or perhaps 60-80% of the nominal speed.

[0039] The defrost operation validation check is then performed at 585. A delay (block 580) may be implemented after launching the heating mode and before performing the check to allow the heat pump to stabilize. For example, delay 580 may within a range of about thirty seconds to five minutes. The validation check includes measuring (block 590) a heat transfer capability, e.g., a temperature gap between the refrigerant evaporation temperature (sensor 165) and the ambient outdoor temperature (sensor 160) or an air pressure differential (sensor 170) across the outdoor heat exchanger. At block 595, the measured heat transfer capability is compared to the predetermined heat transfer capability limit to determine if the performed defrost operation was proper. The defrost operation is determined proper if the measured heat transfer capability is less than or equal to the predetermined heat transfer capability limit for the corresponding ambient temperature. If the defrost operation is determined as proper (block 597), the initial cycle counter (block 590) remains at one or is decreased. If the defrost operation is determined not proper (block 599), the next defrost operation is reinforced by increasing the number of deicing cycles (counter i).

[0040] Figure 6 illustrates another exemplary implementation of an example process 600 for detecting a proper deicing end and defrost operation optimization. At block 605, the heat pump is turned on in heating mode.

[0041] The heat pump is initiated with a deicing cycle counter at one (block 610), a counter (j) is set at a condenser temperature (sensor 165) designated as the ice melting temperature, and the predetermined heat capability transfer limits (block 620). An exemplary ice melting temperature range may be, for example, 40 C to 65 C. For the purpose of description, the initial counter may be set at a condenser temperature of 50 C. Subsequent defrost cycles may be reinforced (block 690) for example by increasing the ice melting temperature.

[0042] At block 625 a defrost operation is started. The need to deice, or defrost, may be determined in various manners as is well known in the industry. For example, the heat pump may be started in a heating mode during icing conditions, i.e., ambient temperature less than about 5 C. To start the defrost operation the compressor is turned off, a delay is implemented to allow the pressure to stabilize, and then the compressor is turned on.

[0043] At block 630 the reversing valve is set to initiate or launch the cooling mode for a defrost operation. In this exemplary process, the defrost operation is based on condenser temperature, i.e., the outdoor heat exchanger during defrost operations. The high-pressure temperature of the refrigerant is monitored, e.g., sensor 165, (blocks 635, 645). When the high-pressure temperature meets or exceeds the selected ice melting temperature (block 635), the outdoor fan 140 is turned on (block 640). The fan eliminates the water droplets from the melted ice. The fan also moves cold ambient air across the heat exchanger cooling the refrigerant. When the high-pressure refrigerant temperature reaches a low temperature limit (block 645), the outdoor fan is turned off (block 650). The low temperature limit may be, for example, in a range of about 32 C and 40 C. The defrost operation, or cycle, is complete.

[0044] At block 655 the heat pump is transitioned to heating mode. The compressor is turned off and a delay is implemented to allow for pressure stabilization.

[0045] The heat pump is launched in heating mode at block 660. The compressor, indoor fan, outdoor fan, and reversing valve are turned on. The heat mode is launched with the compressor, indoor fan, and outdoor fan operating at determined operating values corresponding to the nominal operating values used in the determination of the heat transfer capability value for the heat pump without ice at the corresponding ambient temperatures and upon which the predetermined heat transfer capability limit is based. The operating values may be for example, 100% recycle air, or 100% fresh air for moderate ambient temperatures, the indoor fan at nominal indoor flow rate, and the outdoor fan at nominal speed, or perhaps 60-80% of the nominal speed.

[0046] The defrost operation validation check is then performed at 670. A delay (block 665) may be implemented after launching the heating mode and before performing the check to allow the heat pump to stabilize. The validation check includes measuring (block 675) a heat transfer capability, e.g., temperature gap between the refrigerant evaporation temperature (sensor 165) and the outdoor temperature (sensor 160), or air pressure differential (sensor 170). At block 680, the measured heat transfer capability is compared to the predetermined heat transfer capability limit (block 620) corresponding with the ambient temperature(s) to determine if the performed defrost operation was proper and deicing was successful. If the measured heat transfer capability is less than or equal to the predetermined heat transfer capability limit the defrost operation is determined as proper. If the defrost operation is determined proper (block 685), the initial condenser temperature counter (block 615) remains at the initial ice melting temperature, or the temperature may be decreased by an incremental value. If the defrost operation is determined not proper, the next defrost operation is reinforced by increasing the initial condenser temperature counter (counter j).

[0047] Figure 7 illustrates another exemplary implementation of an example process 700 for detecting a proper deicing end and defrost operation optimization.

[0048] At block 705 the heat pump is launched in heating mode. Heating mode launch may occur on startup of the heat pump, for example during icing conditions, or after the completion of a defrost operation.

[0049] At block 710, with the heat pump in heating mode, the heat exchanger heat transfer capability is measured. In this exemplary process, the heat exchanger measurement is a heat exchanger air pressure drop measurement. For example, with reference to FIG. 2, the air pressure differential across outdoor heat exchanger 105 is measured with sensor 170.

[0050] The air pressure differential is measured during heating mode startup when conditions are stable. For example, the measurement is performed after a sufficient delay for the heat pump to stabilize and within a time limit sufficient to serve as a check of the validity of the completed defrost operation. In an exemplary process, the measuring is preformed within about thirty seconds to five minutes (about 30 to 300 seconds) of launching the heating mode. In some processes, the pressure differential is measured within about one minute to four minutes (about 60 to 240 seconds) of launching the heating mode. In another example, the pressure differential is measured within about two minutes to about three minutes (about 120 to 180 seconds) of launching the heating mode. In one exemplary embodiment, the differential pressure is measured at about three minutes (about 180 seconds) of launching the heating mode.

[0051] At block 715, the measured air pressure differential is compared to a predetermined differential limit to determine if the measured air pressure differential is less than or equal to the predetermined differential limit. The predetermined differential limit may be stored in the heat pump memory. In an exemplary embodiment, the predetermined differential limits are based on values determined in a laboratory setting for a heat pump without ice at controlled and known outdoor and indoor temperatures and operating at nominal operating values. At block 705, the heating mode may be launched with the nominal operating values that were used to determine differential value for a heat pump without ice. As will be understood by those in the industry with benefit of this disclosure, the predetermined differential limit may be the differential value corresponding to the non-iced condition or the value with a tolerance, for example an additional 10 to 15 percent.

[0052] The performed defrost operation is determined to be proper if the measured air pressure differential is less than or equal to the predetermined differential limit. If the performed defrost operation is determined to be proper, the next defrost operation will be nominal (i.e., same as the performed defrost operation).

[0053] At block 720, the next defrost operation is reinforced if the measured temperature gap is greater than the predetermined gap limit. Because the heat pump is operating in the heating mode, it is the next defrost operation that is changed in the control settings. Reinforcing the next defrost operation may include, for example, one or more of increasing, relative to the performed defrosting operation, a number of deicing cycles, a condensing temperature, and a deicing time. Reinforcing the next defrost operation may be implemented by adjusting the defrost operation parameters in the processor and/or defrost optimization module.

[0054] The term "substantially" is defined as largely but not necessarily wholly what is specified (and includes what is specified; e.g., substantially 90 degrees includes 90 degrees and substantially parallel includes parallel), as understood by a person of ordinary skill in the art. In any disclosed embodiment, the terms "substantially," "approximately," "generally," and "about" may be substituted with "within a percentage of' what is specified, where the percentage is a range as understood by a person of ordinary skill in the art.

[0055] For purposes of this disclosure, the term computer-readable storage medium encompasses one or more tangible computer-readable storage media possessing structures. As an example and not by way of limitation, a computer-readable storage medium may include a semiconductor-based or other integrated circuit (IC) (such as, for example, a field-programmable gate array (FPGA) or an application-specific IC (ASIC), a hard disk, an HDD, a hybrid hard drive (HHD), an optical disc, an optical disc drive (ODD), a magneto-optical disc, a magneto-optical drive, a floppy disk, a floppy disk drive (FDD), magnetic tape, a holographic storage medium, a solid-state drive (SSD), a RAM-drive, a SECURE DIGITAL card, a SECURE DIGITAL drive, a flash memory card, a flash memory drive, or any other suitable tangible computer-readable storage medium or a combination of two or more of these, where appropriate.

[0056] Particular embodiments may include one or more computer-readable storage media implementing any suitable storage. In particular embodiments, a computer-readable storage medium implements one or more portions of a controller as appropriate. In particular embodiments, a computer-readable storage medium implements RAM or ROM. In particular embodiments, a computer-readable storage medium implements volatile or persistent memory. In particular embodiments, one or more computer-readable storage media embody encoded software.

[0057] In this patent application, reference to encoded software may encompass one or more applications, bytecode, one or more computer programs, one or more executables, one or more instructions, logic, machine code, one or more scripts, or source code, and vice versa, where appropriate, that have been stored or encoded in a computer-readable storage medium. In particular embodiments, encoded software includes one or more application programming interfaces (APIs) stored or encoded in a computer-readable storage medium. Particular embodiments may use any suitable encoded software written or otherwise expressed in any suitable programming language or combination of programming languages stored or encoded in any suitable type or number of computer-readable storage media. In particular embodiments, encoded software may be expressed as source code or object code. In particular embodiments, encoded software is expressed in a higher-level programming language, such as, for example, C, Python, Java, or a suitable extension thereof. In particular embodiments, encoded software is expressed in a lower-level programming language, such as assembly language (or machine code). In particular embodiments, encoded software is expressed in JAVA. In particular embodiments, encoded software is expressed in Hyper Text Markup Language (HTML), Extensible Markup Language (XML), or other suitable markup language.

[0058] Depending on the embodiment, certain acts, events, or functions of any of the algorithms described herein can be performed in a different sequence, can be added, merged, or left out altogether (e.g., not all described acts or events are necessary for the practice of the algorithms). Moreover, in certain embodiments, acts or events can be performed concurrently, e.g., through multi-threaded processing, interrupt processing, or multiple processors or processor cores or on other parallel architectures, rather than sequentially. Although certain computer-implemented tasks are described as being performed by a particular entity, other embodiments are possible in which these tasks are performed by a different entity.

[0059] Conditional language used herein, such as, among others, "can," "might," "may," "e.g.," and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment.

[0060] While the above detailed description has shown, described, and pointed out novel features as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the devices or algorithms illustrated can be made without departing from the spirit of the disclosure. As will be recognized, the processes described herein can be embodied within a form that does not provide all of the features and benefits set forth herein, as some features can be used or practiced separately from others. The scope of protection is defined by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

Claims

1. A method of defrost operation optimization in a heat pump (100), the method comprising:

launching (305) a heating mode after completion of a performed defrost operation;
measuring (310), after launching the heating mode, a temperature gap between an outdoor temperature and an evaporation temperature;
determining (315) if the temperature gap is less than or equal to a predetermined gap limit for a non-iced condition; and
reinforcing (320) a next defrost operation if the temperature gap is greater than the predetermined gap limit.

2. The method of claim 1, wherein the heat pump (100) comprises:

a heat exchanger (105) exposed to ice accumulation conditions;
one or more sensors (160, 165) to monitor the outdoor temperature and the evaporation temperature;
a memory storing the predetermined gap limit;
a defrost optimization module to measure the temperature gap between the outdoor temperature and the evaporation temperature, and to compare the temperature gap to the predetermined gap limit; and
a processor to execute the defrost optimization module.

3. The method of claim 1 or claim 2, wherein the reinforcing comprises one or more of increasing, relative to the performed defrost operation, a number of defrost cycles, a condensing temperature, and a defrost time.

4. The method of any one of claims 1 to 3, wherein the performed defrost operation consists of a single defrost cycle.

5. The method of any one of claims 1 to 4, wherein the measuring is performed:

during a stable time after the launching the heating mode;
within about 30 seconds and 300 seconds after the launching the heating mode; or
at about 180 seconds after the launching the heating mode.

6. The method of any one of claims 1 to 5, wherein the measuring the temperature gap is performed at determined operating conditions; and
the predetermined gap limit is based on a temperature gap value of the heat pump without ice determined at operating conditions corresponding with the determined operating conditions.

7. The method of any one of claims 1 to 6, wherein the predetermined gap limit is based on a temperature gap value of the heat pump (100), determined in a laboratory, without ice.

8. The method of claim 7, wherein the temperature gap value is determined:

at known ambient temperatures; or
with the heat pump (100) operating at nominal operating parameters, and the launching the heating mode comprises operating the heat pump (100) at determined operating parameters substantially corresponding to the nominal operating parameters, wherein the operating parameters comprise a compressor capacity, indoor fan speed, and outdoor fan speed.

9. The method of claim 8, wherein the reinforcing comprises one or more of increasing, relative to the performed defrost operation, a number of defrost cycles, a condensing temperature, and a defrost time, the measuring being optionally performed within about 30 seconds and 300 seconds after the launching the heating mode.

10. A method (300) of defrost operation optimization in a heat pump (100), the method comprising:

launching (305) a heating mode after completion of a performed defrost operation, the performed defrost operation consisting of a single defrost cycle;
measuring (310), within about 30 seconds and 300 seconds after launching the heating mode, a heat transfer capability of the heat pump (100);
determining (315) if the heat transfer capability is less than or equal to a predetermined heat transfer capability limit for a non-iced condition; and
reinforcing (320) a next defrost operation if the measured heat transfer capability is greater than the predetermined heat transfer capability limit.

11. The method of claim 10, wherein the measuring the heat transfer capability is performed in determined operating conditions; and
the predetermined heat transfer capability limit is based on a heat transfer value of the heat pump (100) without ice determined at operating conditions corresponding to the determined operating conditions.

12. The method of claim 11, wherein the determined operating conditions comprise an outdoor temperature and a fan speed.

13. The method of claim 11, wherein the heat transfer capability is a temperature gap between an outdoor temperature and an evaporation temperature or an air pressure differential across a heat exchanger (105).

14. A method (700) of defrost operation optimization in a heat pump (100), the method comprising:

launching (705) a heating mode after completion of a performed defrost operation;
measuring (710), after launching the heating mode, an air pressure differential across an outdoor heat exchanger (105);
determining (715) if the air pressure differential is less than or equal to a predetermined differential limit for a non-iced condition; and
reinforcing (720) a next defrost operation if the air pressure differential is greater than the predetermined differential limit.

15. The method of claim 14, wherein the measuring the air pressure differential is performed in determined operating conditions; and
the predetermined differential limit is based on an air pressure differential value of the heat pump (100) without ice determined at operating conditions corresponding to the determined operating conditions.

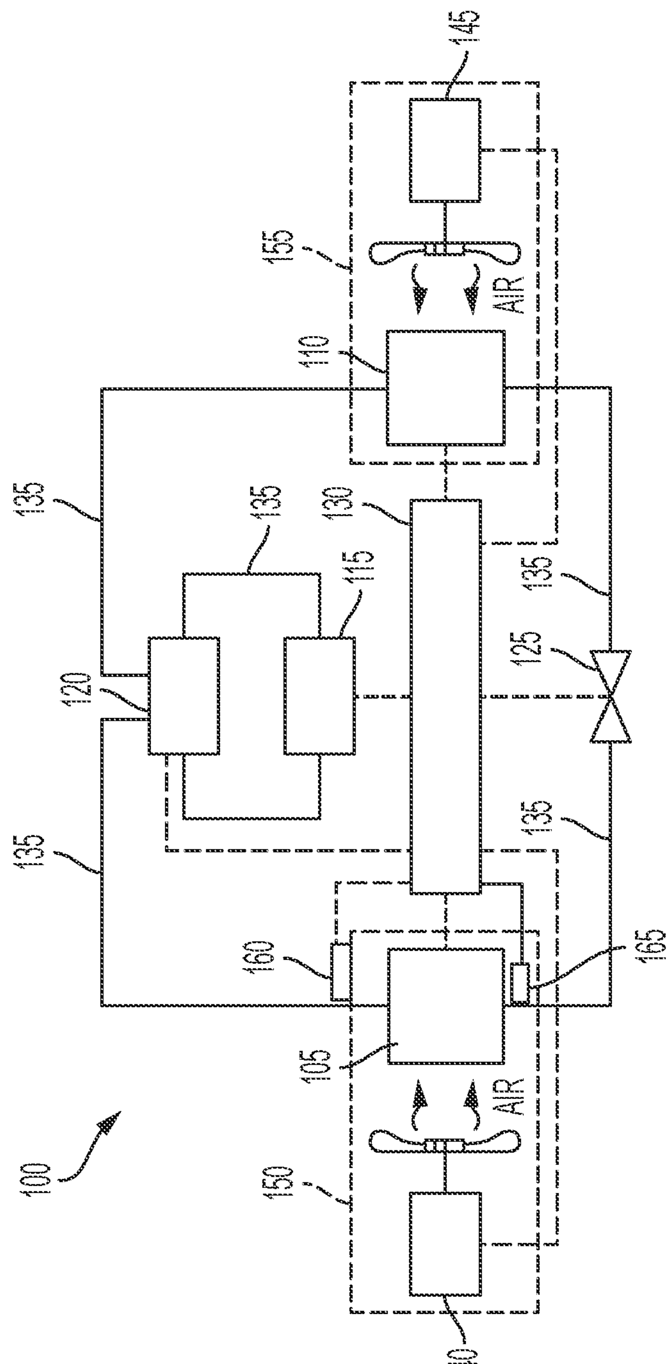
100
105
110
115
120
125
130
135
135
135
135
135
140
145
150
155
160
165
AIR
AIR

FIG. 1

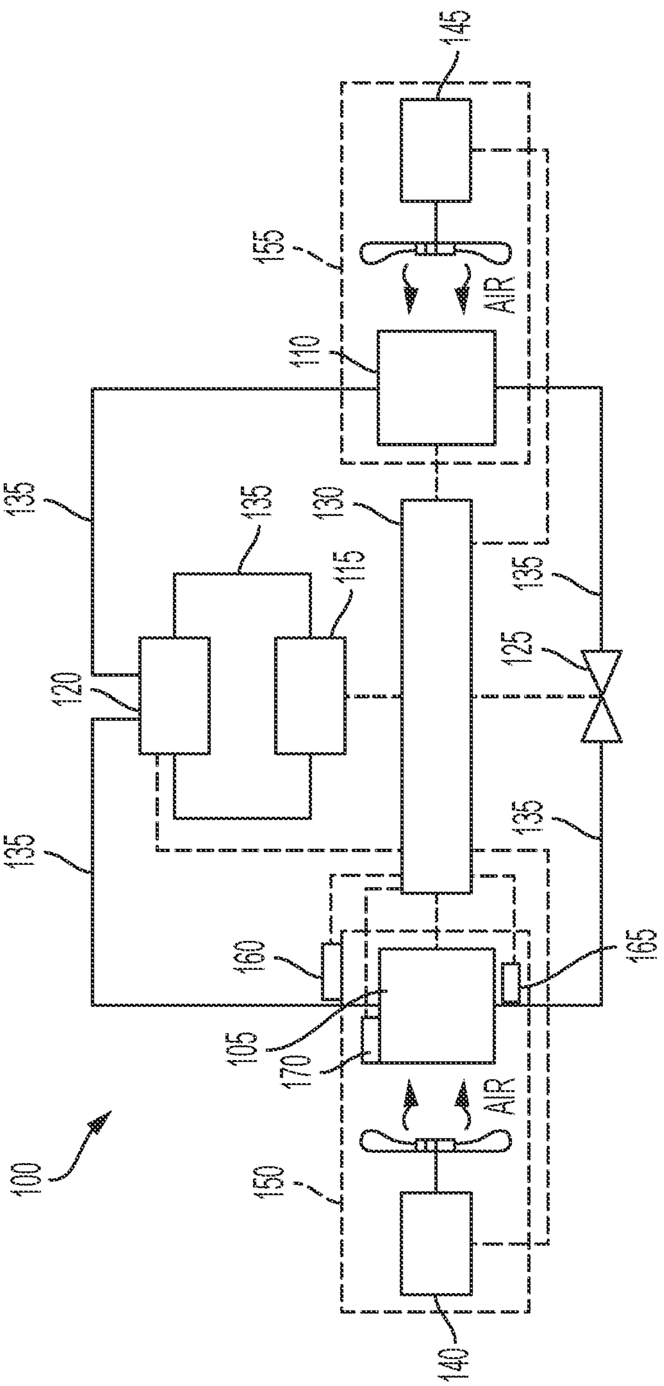
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
AIR
AIR

FIG. 2

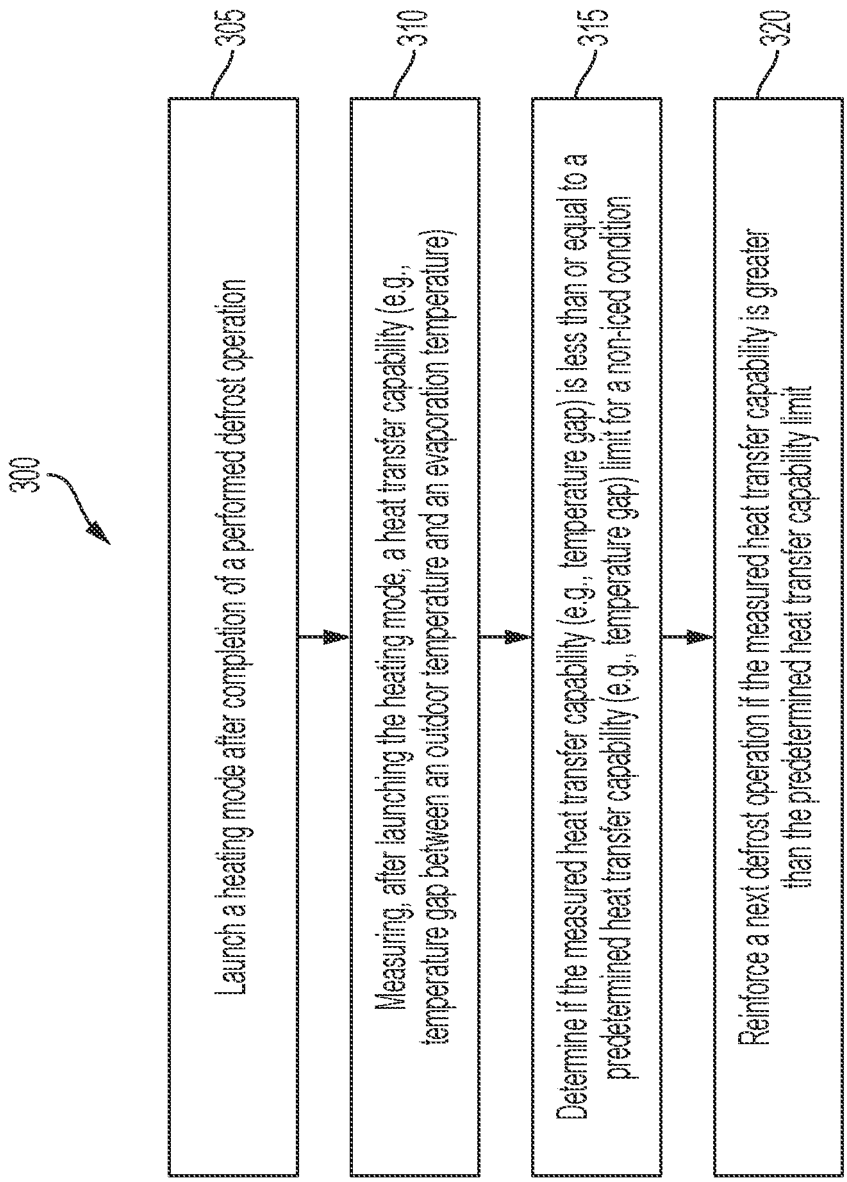
300
305
Launch a heating mode after completion of a performed defrost operation
310
Measuring, after launching the heating mode, a heat transfer capability (e.g., temperature gap between an outdoor temperature and an evaporation temperature)
315
Determine if the measured heat transfer capability (e.g., temperature gap) is less than or equal to a predetermined heat transfer capability (e.g., temperature gap) limit for a non-iced condition
320
Reinforce a next defrost operation if the measured heat transfer capability is greater than the predetermined heat transfer capability limit

FIG. 3

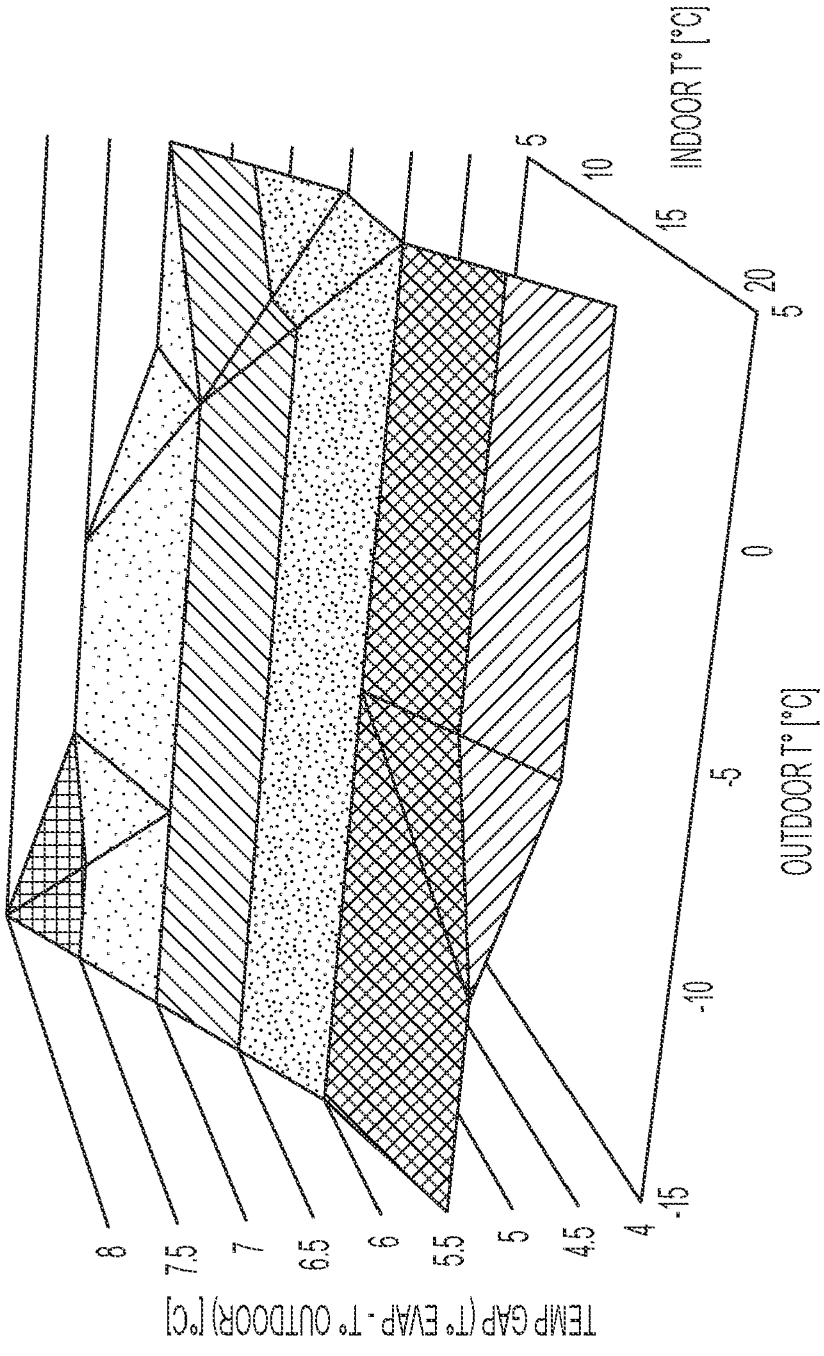
TEMP GAP (T° EVAP - T° OUTDOOR) [°C]
8
7.5
7
6.5
6
5.5
5
4.5
4
OUTDOOR T° [°C]
-15
-10
-5
0
5
INDOOR T° [°C]
5
10
15
20

FIG. 4

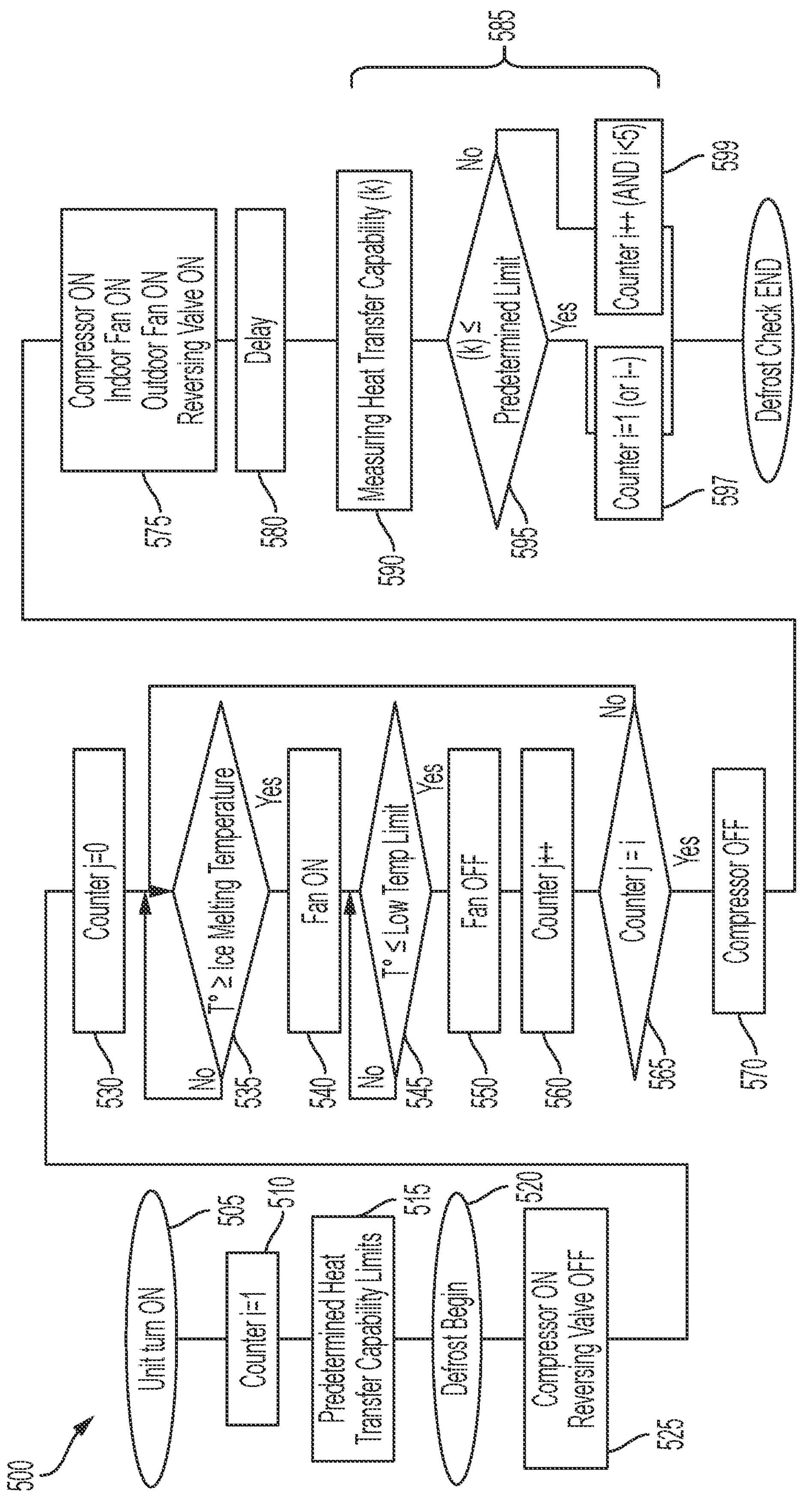
500
Unit turn ON
505
Counter i=1
510
Predetermined Heat Transfer Capability Limits
515
Defrost Begin
520
Compressor ON Reversing Valve OFF
525
Counter j=0
530
T° ≥ Ice Melting Temperature
No
Yes
535
Fan ON
540
T° ≤ Low Temp Limit
No
Yes
545
Fan OFF
550
Counter j++
560
Counter j = i
No
Yes
565
Compressor OFF
570
Compressor ON Indoor Fan ON Outdoor Fan ON Reversing Valve ON
575
Delay
580
Measuring Heat Transfer Capability (k)
590
(k) ≤ Predetermined Limit
No
Yes
595
Counter i=1 (or i--)
597
Counter i++ (AND i<5)
599
585
Defrost Check END

FIG. 5

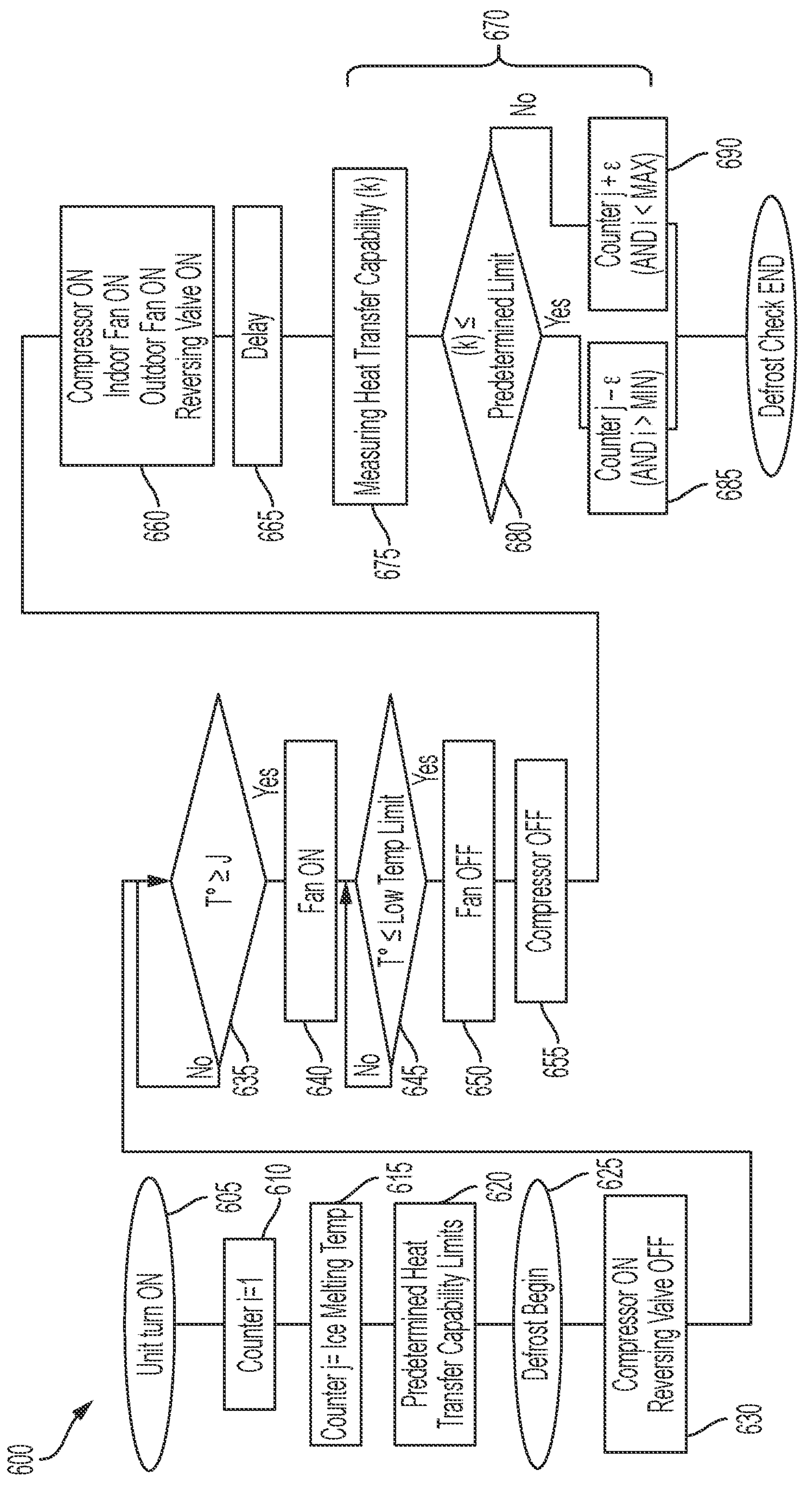
600
Unit turn ON
605
Counter i=1
610
Counter j= Ice Melting Temp
615
Predetermined Heat Transfer Capability Limits
620
Defrost Begin
625
Compressor ON Reversing Valve OFF
630
T° ≥ J
No
Yes
635
Fan ON
640
T° ≤ Low Temp Limit
No
Yes
645
Fan OFF
650
Compressor OFF
655
Compressor ON Indoor Fan ON Outdoor Fan ON Reversing Valve ON
660
Delay
665
Measuring Heat Transfer Capability (k)
675
(k) ≤ Predetermined Limit
Yes
No
680
Counter j – ε (AND i > MIN)
685
Counter j + ε (AND i < MAX)
690
670
Defrost Check END

FIG. 6

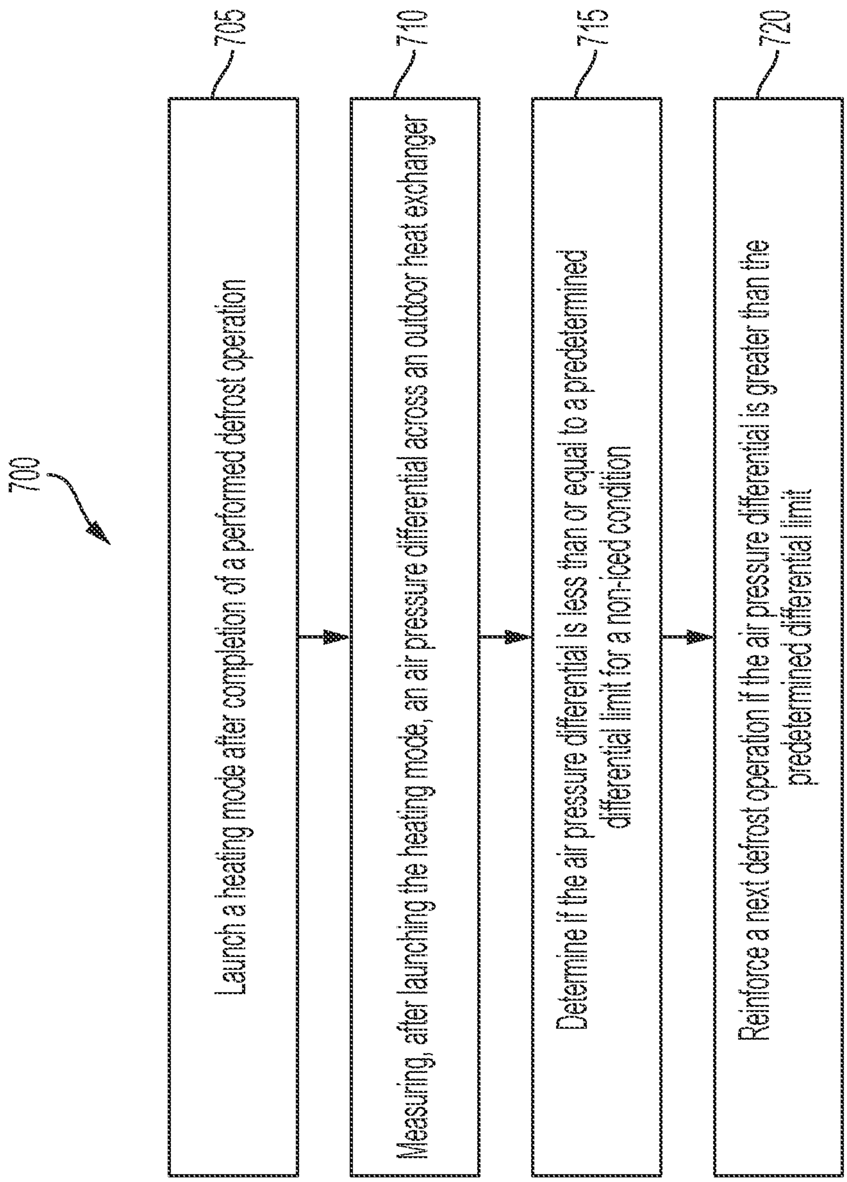
700
705
Launch a heating mode after completion of a performed defrost operation
710
Measuring, after launching the heating mode, an air pressure differential across an outdoor heat exchanger
715
Determine if the air pressure differential is less than or equal to a predetermined differential limit for a non-iced condition
720
Reinforce a next defrost operation if the air pressure differential is greater than the predetermined differential limit

FIG. 7