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(54) BINARY REFRIGERATION DEVICE

(57) Provided is a cascade refrigeration system capable of suppressing a decrease in heating performance due to a rapid startup operation. The cascade refrigeration system includes: a high-order side refrigerant circuit (2) through which a high-order side refrigerant circulates; a low-order side refrigerant circuit (3) through which a low-order side refrigerant circulates, the low-order refrigerant circuit (3) including a first circulation path (23) that performs heat-exchange with the high-order side refrigerant in a cascade heat exchanger (13), and a second circulation path (26) that performs heat-exchange with a heat medium in a low-order side heat exchanger (24); and a heat medium circuit (4) through which a heat medium circulates, the heat medium exchanging heat with the high-order side refrigerant in the high-order side heat exchanger (11) and exchanging heat with the low-order side refrigerant in the low-order side heat exchanger (24). The heat medium circuit (4) includes: a first heat medium circulation path (35) in which the heat medium circulates through the high-order side heat exchanger (11) and the low-order side heat exchanger (24); and a second heat medium circulation path (36) in which the heat medium circulates through the high-order side heat exchanger (11).

FIG. 1A

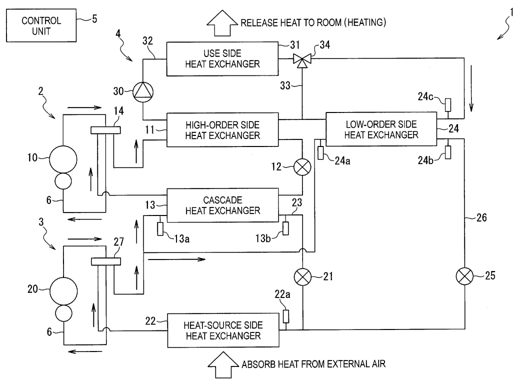


FIG. 1B

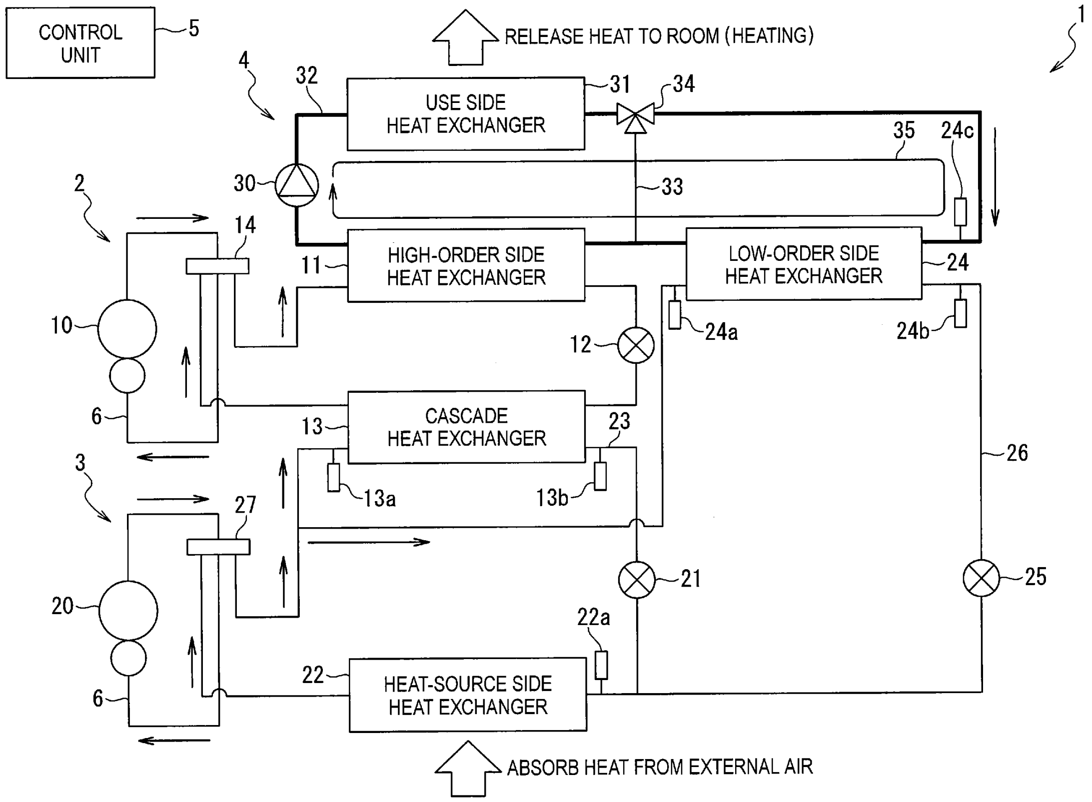
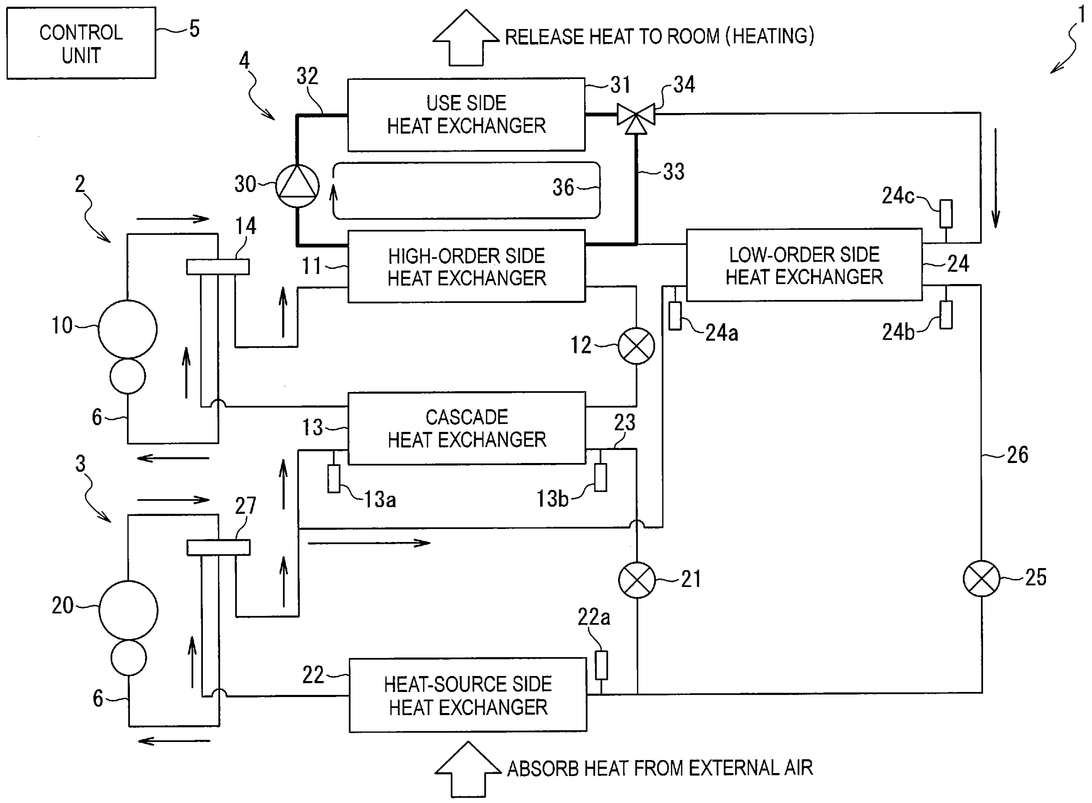

CONTROL UNIT
5
RELEASE HEAT TO ROOM (HEATING)
1
4
32
USE SIDE HEAT EXCHANGER
31
34
35
24c
30
33
2
14
HIGH-ORDER SIDE HEAT EXCHANGER
LOW-ORDER SIDE HEAT EXCHANGER
24
11
10
24a
24b
12
6
CASCADE HEAT EXCHANGER
13
23
26
3
13a
13b
27
21
25
20
22a
22
HEAT-SOURCE SIDE HEAT EXCHANGER
6
ABSORB HEAT FROM EXTERNAL AIR

FIG. 1C


CONTROL UNIT
5
RELEASE HEAT TO ROOM (HEATING)
1
4
32
USE SIDE HEAT EXCHANGER
31
34
30
36
33
2
24c
14
HIGH-ORDER SIDE HEAT EXCHANGER
LOW-ORDER SIDE HEAT EXCHANGER
11
24
10
24a
24b
12
6
CASCADE HEAT EXCHANGER
13
23
26
3
13a
13b
27
21
25
20
22a
22
HEAT-SOURCE SIDE HEAT EXCHANGER
6
ABSORB HEAT FROM EXTERNAL AIR

Description

Technical Field

[0001] The present invention relates to a cascade refrigeration system and particularly relates to a cascade refrigeration system that can restrain a decrease in heating performance.

Background Art

[0002] A cascade refrigeration system in the related art includes a high-order side refrigerant circuit and a low-order side refrigerant circuit, and the high-order side refrigerant circuit and the low-order side refrigerant circuit shares a cascade heat exchanger (an intermediate heat exchanger). A refrigerant circulating through the high-order side refrigerant circuit and a refrigerant circulating through the low-order side refrigerant circuit exchange heat in the cascade heat exchanger, and water is heated by a high-temperature side refrigerant circulating through the high-order side refrigerant circuit to generate hot water.

[0003] Such a cascade refrigeration system has a risk that an imbalance is caused between a high-order side refrigerating circuit and a low-order side refrigerating circuit in terms of a time required from startup until each refrigerating circuit enters a steady state, due to a difference in refrigerant properties, temperature conditions at startup, or the like, thereby resulting in that a compressor of the low-order side refrigerant circuit is stopped for protection. Accordingly, in a cascade refrigeration system described in PTL 1, the ratio of the rotation speed of a compressor of a high-order side refrigerating circuit to the rotation speed of a compressor of a low-order side refrigerating circuit from the startup of the cascade refrigeration system until the binary refrigerant device shifts to a steady operation (hereinafter referred to as a "startup operation") is set larger than that in a steady operation. This is to prevent the low-order side refrigerating circuit from being stopped for protection due to a high-pressure excessive increase in the startup operation.

Citation List

Patent Literature

[0004] PTL 1: JP 2013-213590 A

Summary of Invention

Technical Problem

[0005] However, in the cascade refrigeration system described in PTL 1, the ratio of the rotation speed of the compressor of the high-order side refrigerating circuit to the rotation speed of the compressor of the low-order side refrigerating circuit in the startup operation is set larger than the ratio in the steady operation. As a result, the rotation speed of the compressor of the low-order side refrigerating circuit in the startup operation is restricted, which causes such a problem that it takes time until sufficient heating performance is achieved in the startup operation.

[0006] In view of the above problem, an object of the present invention is to provide a cascade refrigeration system capable of suppressing a decrease in heating performance due to a rapid startup operation.

Solution to Problem

[0007] One aspect of the present invention is a cascade refrigeration system including: a high-order side refrigerant circuit configured such that a high-order side compressor, a high-order side heat exchanger, a high-order side pressure reduction mechanism, and a cascade heat exchanger are sequentially connected via refrigerant pipes to circulate a high-order side refrigerant through the high-order side refrigerant circuit; a low-order side refrigerant circuit including a first circulation path and a second circulation path, the first circulation path being configured such that a low-order side compressor, the cascade heat exchanger, a low-order side first pressure reduction mechanism, and a heat-source side heat exchanger are sequentially connected via refrigerant pipes to circulate a low-order side refrigerant through the first circulation path, the low-order side refrigerant exchanging heat with the high-order side refrigerant in the cascade heat exchanger, the second circulation path being configured such that a portion of the first circulation path between the low-order side compressor and the cascade heat exchanger is connected to a portion of the first circulation path between the low-order side first pressure reduction mechanism and the heat-source side heat exchanger via refrigerant pipes including a low-order side heat exchanger and a low-order side second pressure reduction mechanism such that the low-order side compressor, the low-order side heat exchanger, the low-order side second pressure reduction mechanism, and the heat-source side heat exchanger are sequentially connected via the refrigerant pipes to circulate the low-order side refrigerant through the second circulation path; a heat medium circuit including a first heat medium circulation path and a second heat medium circulation path, the first heat medium circulation path being configured such that a first circulating pump, a use side heat exchanger, the low-order side heat exchanger, and the high-order side heat exchanger are sequentially connected via pipes to circulate a heat medium through the first heat medium circulation path such that the high-order side refrigerant exchanges heat with the heat medium in the high-order side heat exchanger, and the low-order side refrigerant exchanges heat with the heat medium in the low-order side heat exchanger, the second heat medium circulation path including a first bypass path connecting a portion of the first heat medium circulation path between the use side heat exchanger and the low-order side heat exchanger to a portion of the first heat medium circulation path between the low-order side heat exchanger and the high-order side heat exchanger such that the first circulating pump, the use side heat exchanger, the first bypass path, and the high-order side heat exchanger are sequentially connected via pipes to circulate the heat medium through the second heat medium circulation path, the high-order side refrigerant and the low-order side refrigerant exchanging heat with each other in the cascade heat exchanger; a first switching unit configured to switch the heat medium circuit between a state where the heat medium flows through the first heat medium circulation path and a state where the heat medium flows through the second heat medium circulation path; and a control unit configured to control the high-order side refrigerant circuit, the low-order side refrigerant circuit, and the heat medium circuit.

Advantageous Effects of Invention

[0008] The present invention can provide a cascade refrigeration system capable of suppressing a decrease in heating performance due to a rapid startup operation.

Brief Description of Drawings

[0009]

FIG. 1A is a refrigerant circuit diagram of a cascade refrigeration system according to an embodiment of the present invention;
FIG. 1B is a view illustrating the flow of a refrigerant in a first mode operation in the cascade refrigeration system according to the embodiment of the present invention;
FIG. 1C is a view illustrating the flow of the refrigerant in a second mode operation in the cascade refrigeration system according to the embodiment of the present invention;
FIG. 2 is a control block diagram of the cascade refrigeration system according to the embodiment of the present invention;
FIG. 3 is a control flow diagram of the cascade refrigeration system according to the embodiment of the present invention;
FIG. 4A is a refrigerant circuit diagram of a cascade refrigeration system according to an alternative embodiment of the present invention;
FIG. 4B is a view illustrating the flow of a refrigerant in a first mode operation in the cascade refrigeration system according to the alternative embodiment of the present invention;
FIG. 4C is a view illustrating the flow of the refrigerant in a second mode operation in the cascade refrigeration system according to the alternative embodiment of the present invention;
FIG. 5 is a control block diagram of the cascade refrigeration system according to the alternative embodiment of the present invention; and
FIG. 6 is a control flow diagram of the cascade refrigeration system according to the alternative embodiment of the present invention.

Description of Embodiments

[0010] Embodiments of a cascade refrigeration system according to the present invention will be hereinafter described in detail with reference to the drawings. Note the present invention is not limited by the embodiments.

[0011] FIG. 1A is a refrigerant circuit diagram of a cascade refrigeration system 1 according to the present embodiment. FIG. 2 is a control block diagram of the cascade refrigeration system 1 according to the present embodiment.

Examples

[0012] Referring now to FIGS. 1A to 1C, the cascade refrigeration system 1 according to the present embodiment will be described. FIG. 1A is a refrigerant circuit diagram of the cascade refrigeration system 1 according to the present embodiment. The cascade refrigeration system 1 is a refrigeration device which can be used for a cooling operation in a case where a use side heat exchanger 31 is used as an evaporator and which can be used for an operation to make hot water or a heating operation in a case where the use side heat exchanger 31 is used as a condenser. Hereinafter, the operation to make hot water and the heating operation may be collectively called a heating operation. The present embodiment deals with a cascade refrigeration system used for the heating operation. The cascade refrigeration system 1 includes a high-order side refrigerant circuit 2, a low-order side refrigerant circuit 3, a heat medium circuit 4, and a control unit 5. The control unit 5 includes a storage unit for storing data on a target temperature or the like, software for control, and so on, and controls the cascade refrigeration system 1.

[0013] The high-order side refrigerant circuit 2 is configured such that a high-order side compressor 10, a high-order side heat exchanger 11, a high-order side expansion valve 12 as a high-order side pressure reduction mechanism, and a cascade heat exchanger 13 are sequentially connected via refrigerant pipes 6 to circulate a high-order side refrigerant through the high-order side refrigerant circuit 2. In the present embodiment, the high-order side heat exchanger 11 is a heat exchanger configured to perform heat-exchange between the high-order side refrigerant and a heat medium flowing through the heat medium circuit 4. The cascade heat exchanger 13 is a heat exchanger configured to perform heat-exchange between the high-order side refrigerant and a low-order side refrigerant flowing through the low-order side refrigerant circuit 3. Note that the high-order side heat exchanger 11 and the cascade heat exchanger 13 can be, for example, a plate-type heat exchanger or a double pipe heat exchanger, provided that they are heat exchangers that can perform heat-exchange between liquids. In the present embodiment, the high-order side heat exchanger 11 is a heat exchanger configured to perform heat-exchange between the high-order side refrigerant and the heat medium flowing through the heat medium circuit 4 but may be a heat exchanger configured to perform heat-exchange with air as the heat medium via an air-sending blower (not illustrated), for example. Arrows in the high-order side refrigerant circuit 2 indicate flows of the high-order side refrigerant in the heating operation.

[0014] In the high-order side refrigerant circuit 2, a high-order side four-way valve 14 is connected to a discharge side of the high-order side compressor 10, and the high-order side four-way valve 14 is configured to switch between a state where the high-order side refrigerant discharged from the high-order side compressor 10 flows toward the high-order side heat exchanger 11 side and a state where the high-order side refrigerant flows toward the cascade heat exchanger 13 side. The present embodiment deals with a case (the heating operation) where the high-order side four-way valve 14 causes the high-order side refrigerant discharged from the high-order side compressor 10 to flow into the high-order side heat exchanger 11 side. Accordingly, in the high-order side refrigerant circuit 2, the high-order side refrigerant discharged from the high-order side compressor 10 flows through the high-order side heat exchanger 11, the high-order side expansion valve 12, and the cascade heat exchanger 13 and is then sucked into the high-order side compressor 10.

[0015] The low-order side refrigerant circuit 3 includes a first circulation path 23 and a second circulation path 26. The first circulation path 23 is configured such that a low-order side compressor 20, the cascade heat exchanger 13 connected to the high-order side refrigerant circuit 2, a low-order side first expansion valve 21 as a low-order side first pressure reduction mechanism, and a heat-source side heat exchanger 22 are sequentially connected via refrigerant pipes 6 to circulate a low-order side refrigerant through the first circulation path 23. The heat-source side heat exchanger 22 is a heat exchanger configured to perform heat-exchange between the low-order side refrigerant and external air. The heat-source side heat exchanger 22 is provided with a condensing temperature detection sensor 22a configured to measure a condensing temperature of the low-order side refrigerant flowing through the heat-source side heat exchanger 22. The cascade heat exchanger 13 is a heat exchanger configured to perform heat-exchange between the low-order side refrigerant and the high-order side refrigerant flowing through the high-order side refrigerant circuit 2. The cascade heat exchanger 13 is provided with a condensing temperature detection sensor 13a configured to measure a condensing temperature (a refrigerant condensing temperature) of the low-order side refrigerant flowing through the cascade heat exchanger 13, and an outlet temperature detection sensor 13b configured to measure an outlet temperature of the low-order side refrigerant. Arrows in the low-order side refrigerant circuit 3 indicate flows of the low-order side refrigerant.

[0016] The low-order side refrigerant circuit 3 includes a second circulation path 26 through which the low-order side refrigerant circulates. The second circulation path 26 connects a portion between the low-order side compressor 20 and the cascade heat exchanger 13 to a portion between the low-order side first expansion valve 21 and the heat-source side heat exchanger 22 via refrigerant pipes provided with a low-order side heat exchanger 24, and a low-order side second expansion valve 25 as a low-order side second pressure reduction mechanism, such that the low-order side compressor 20, the low-order side heat exchanger 24, the low-order side second expansion valve 25, and the heat-source side heat exchanger 22 are sequentially connected via the refrigerant pipes. The low-order side heat exchanger 24 is a heat exchanger which includes a first heat accumulation unit including a heat accumulation material and which is configured to perform heat-exchange between the low-order side refrigerant and the heat medium flowing through the heat medium circuit 4. The low-order side heat exchanger 24 is provided with a condensing temperature detection sensor 24a configured to measure a condensing temperature of the low-order side refrigerant flowing through the low-order side heat exchanger 24, and an outlet temperature detection sensor 24b configured to measure an outlet temperature of the low-order side refrigerant. The low-order side heat exchanger 24 is also provided with a heat medium return temperature detection sensor 24c configured to measure a heat medium return temperature as a temperature of the heat medium flowing through the heat medium circuit 4 at the time when the heat medium flows into the low-order side heat exchanger 24. Note that the low-order side heat exchanger 24 can be, for example, a plate-type heat exchanger or a double pipe heat exchanger, provided that the low-order side heat exchanger 24 is a heat exchanger that can perform heat-exchange between liquids.

[0017] In the low-order side refrigerant circuit 3, a low-order side four-way valve 27 is connected to a discharge side of the low-order side compressor 20, and the low-order side four-way valve 27 is configured to switch between a state where the low-order side refrigerant discharged from the low-order side compressor 20 flows toward the cascade heat exchanger 13 side and the low-order side heat exchanger 24 side and a state where the low-order side refrigerant flows toward the heat-source side heat exchanger 22 side. The present embodiment deals with a case (the heating operation) where the low-order side four-way valve 27 causes the low-order side refrigerant discharged from the low-order side compressor 20 to flow toward the cascade heat exchanger 13 side and the low-order side heat exchanger 24 side. In this case, in the low-order side refrigerant circuit 3, the low-order side refrigerant discharged from the low-order side compressor 20 flows through the cascade heat exchanger 13, the low-order side first expansion valve 21, and the heat-source side heat exchanger 22 and is then sucked into the low-order side compressor 20. The low-order side refrigerant discharged from the low-order side compressor 20 also flows through the low-order side heat exchanger 24, the low-order side second expansion valve 25, and the heat-source side heat exchanger 22 and is then sucked into the low-order side compressor 20.

[0018] In the low-order side refrigerant circuit 3, the low-order side compressor 20, the heat-source side heat exchanger 22, and the low-order side four-way valve 27 are configured to be used in common for the first circulation path 23 and the second circulation path 26.

[0019] The heat medium circuit 4 is configured such that a first circulating pump 30, the use side heat exchanger 31, the low-order side heat exchanger 24, and the high-order side heat exchanger 11 are sequentially connected via pipes 32, so that water as a heat refrigerant circulates through the heat medium circuit 4. Note that nonfreezing liquid may be used instead of the water as the heat medium. The use side heat exchanger 31 is provided with an indoor unit (not illustrated) installed in a room, and air in the room flows into the use side heat exchanger 31 by an air flow generated by an air-blow fan (not illustrated). The use side heat exchanger 31 performs heat-exchange between the water as the heat medium and the air in the room provided with the indoor unit, and the air thus exchanging heat with the water as the heat medium is used for heating. The high-order side heat exchanger 11 is a heat exchanger configured to perform heat-exchange between the water as the heat medium and the high-order side refrigerant flowing through the high-order side refrigerant circuit 2. The low-order side heat exchanger 24 is a heat exchanger configured to perform heat-exchange between the water as the heat medium and the low-order side refrigerant flowing through the low-order side refrigerant circuit 3. An arrow in the heat medium circuit 4 indicates a flow of the water as the heat medium.

[0020] In addition, the heat medium circuit 4 includes a first bypass path 33 one end of which is connected to a pipe between the use side heat exchanger 31 and the low-order side heat exchanger 24 and the other end of which is connected to a pipe between the low-order side heat exchanger 24 and the high-order side heat exchanger 11. One side of the first bypass path 33 is provided with a first three-way valve 34 (a first switching unit). The first three-way valve 34 switches between a first heat medium circulation path 35 and a second heat medium circulation path 36. The water as the heat medium circulates through the first heat medium circulation path 35 in order of the first circulating pump 30, the use side heat exchanger 31, the low-order side heat exchanger 24, the high-order side heat exchanger 11, and the first circulating pump 30. The water as the heat medium circulates through the second heat medium circulation path 36 in order of the first circulating pump 30, the use side heat exchanger 31, the first bypass path 33, the high-order side heat exchanger 11, and the first circulating pump 30.

[0021] The cascade refrigeration system 1 has a first mode operation in which the heat medium flows through the first heat medium circulation path 35, and a second mode operation in which the heat medium flows through the second heat medium circulation path 36 without flowing through the low-order side heat exchanger 24. FIG. 1B illustrates a state where the heat medium circulates through the first heat medium circulation path 35 in the first mode operation. FIG. 1C illustrates a state where the heat medium circulates through the second heat medium circulation path 36 in the second mode operation. The first mode operation is a heating operation in which heat absorbed from external air by the heat-source side heat exchanger 22 of the low-order side refrigerant circuit 3 is released to the air in the room via the high-order side heat exchanger 11 of the high-order side refrigerant circuit 2 and the low-order side heat exchanger 24 of the low-order side refrigerant circuit 3. The second mode operation is an operation in which the heat medium flows through the second heat medium circulation path 36 without flowing through the low-order side heat exchanger 24. The second mode operation is performed in a case where the heat medium return temperature which is measured by the heat medium return temperature detection sensor 24c and which is a temperature of the heat medium flowing out from the use side heat exchanger 31 and flowing into the low-order side heat exchanger 24 becomes closer to a condensing temperature of the low-order side refrigerant flowing into the low-order side heat exchanger 24 which condensing temperature is measured by the condensing temperature detection sensor 24a.

[0022] The cascade refrigeration system 1 is a refrigeration device which uses latent heat of the high-order side refrigerant in the high-order side refrigerant circuit 2, which uses latent heat of the low-order side refrigerant in the low-order side refrigerant circuit 3, and which uses sensible heat of the heat medium (water) in the heat medium circuit 4. Note that, in the present embodiment, the high-order side refrigerant in the high-order side refrigerant circuit 2 is the same refrigerant as the low-order side refrigerant in the low-order side refrigerant circuit 3, but they may not necessarily be the same refrigerant. For example, the low-order side refrigerant may have a boiling point lower than that of the high-order side refrigerant. Alternatively, a refrigerant whose change in latent heat is usable for the heat medium circuit may be used. In this case, the first circulating pump 30 of the heat medium circuit 4 is replaced with a compressor, and an expansion valve or the like is provided as a pressure reduction mechanism in a path between the use side heat exchanger 31 and the low-order side heat exchanger 24.

[0023] In the cascade refrigeration system 1, the low-order side refrigerant that is turned into a low-temperature low-pressure gas phase refrigerant by absorbing heat from the external air in the heat-source side heat exchanger 22 of the low-order side refrigerant circuit 3 is compressed by the low-order side compressor 20 and turned into a high-temperature high-pressure gas phase refrigerant. The high-temperature high-pressure gas phase refrigerant is turned into a high-temperature high-pressure liquid phase refrigerant in the cascade heat exchanger 13 by releasing heat to the high-order side refrigerant circulating through the high-order side refrigerant circuit 2. A low-pressure high-order side refrigerant that absorbs heat from the low-order side refrigerant in the cascade heat exchanger 13 is compressed by the high-order side compressor 10 and turned into a high-temperature high-pressure gas phase refrigerant. The high-temperature high-pressure gas phase refrigerant releases heat, in the high-order side heat exchanger 11, to the water as the heat medium circulating through the heat medium circuit 4, so that hot water is generated. In the meantime, the low-order side refrigerant that is turned into the low-temperature low-pressure gas phase refrigerant by absorbing heat from the external air in the heat-source side heat exchanger 22 of the low-order side refrigerant circuit 3 is compressed by the low-order side compressor 20 and turned into the high-temperature high-pressure gas phase refrigerant. The high-temperature high-pressure gas phase refrigerant releases heat, in the low-order side heat exchanger 24, to the water as the heat medium circulating through the heat medium circuit 4. Accordingly, the low-order side refrigerant circulating through the low-order side refrigerant circuit 3 can be condensed by the water as the heat medium circulating through the heat medium circuit 4.

[0024] In the cascade refrigeration system in the related art, the ratio (R1/R2) of a rotation speed (R1) of a compressor of a high-order side refrigerating circuit to a rotation speed (R2) of a compressor of a low-order side refrigerating circuit in a startup operation is set larger than the ratio in a steady operation. This restrains the compressor of the low-order side refrigerant circuit from stopping for protection due to a high-pressure excessive increase caused by the refrigerant being not condensed in the low-order side refrigerating circuit. However, in the related art, the rotation speed in the startup operation of the compressor of the low-order side refrigerating circuit is restricted, and therefore, it takes time until sufficient heating performance is achieved in the startup operation. In the meantime, the cascade refrigeration system 1 in the present embodiment includes the high-order side refrigerant circuit 2, and the low-order side refrigerant circuit 3 including the first circulation path 23 and the second circulation path 26. In the first mode operation, the high-order side heat exchanger 11 of the high-order side refrigerant circuit 2 and the low-order side heat exchanger 24 in the second circulation path 26 of the low-order side refrigerant circuit 3 perform heat-exchange between the low-order side refrigerant and the heat medium circulating through the heat medium circuit 4. Thus, the low-order side refrigerant circulating through the low-order side refrigerant circuit 3 can be condensed by directly exchanging heat with the heat medium circulating through the heat medium circuit 4, thereby making it possible to immediately perform the startup operation while the protection stop of the compressor of the low-order side refrigerating circuit is restrained.

[0025] In the meantime, when the first mode operation is continued, the air exchanging heat with the heat medium in the use side heat exchanger 31 is warmed. As a result, eventually, the temperature (the heat medium return temperature) of the heat medium flowing out from the use side heat exchanger 31 and flowing into the low-order side heat exchanger 24 becomes closer to the condensing temperature of the low-order side refrigerant flowing into the low-order side heat exchanger 24. In this state, the low-order side refrigerant cannot be condensed in the low-order side heat exchanger 24. When a large amount of gas-phase refrigerant that is not condensed is distributed in the low-order side heat exchanger 24 in which a large amount of liquid-phase low-order side refrigerant is normally distributed, the liquid-phase low-order side refrigerant excessively accumulates in another path (for example, an accumulator (not illustrated) provided for the suction side of the low-order side compressor 20) instead, in the low-order side refrigerating circuit. This may cause liquid compression in the low-order side compressor 20. Besides, when the rotation speed of the low-order side compressor 20 is increased in order that the low-order side refrigerant can be condensed in the low-order side heat exchanger 24, the reliability of the low-order side compressor 20 might decrease.

[0026] However, the cascade refrigeration system 1 in the present embodiment has the second mode operation in which the heat medium flows through the second heat medium circulation path 36 without flowing through the low-order side heat exchanger 24. The second mode operation is an operation in which the heat medium circulates through the second heat medium circulation path 36 without flowing through the low-order side heat exchanger 24in a case where the heat medium return temperature of the heat medium increases and becomes closer to the condensing temperature of the low-order side refrigerant. When the second mode operation is performed, the heat medium reaching a high temperature does not flow into the low-order side heat exchanger 24, so that the low-order side refrigerant exchanges heat with surrounding air via the low-order side heat exchanger 24 or the refrigerant pipe 6. Hereby, it is possible to restrain such a situation that the low-order side refrigerant flowing into the low-order side heat exchanger 24 cannot be condensed, so that the low-order side heat exchanger 24 can be used as a condenser without increasing the rotation speed of the low-order side compressor 20. Note that, since the cascade refrigeration system 1 in the present embodiment has the second mode operation, it is preferable that the low-order side heat exchanger 24 be a double pipe heat exchanger including an outer peripheral side flow path and an inner peripheral side flow path and have a structure in which the low-order side refrigerant flows through the outer peripheral side flow path and water as the heat medium flows through the inner peripheral side flow path. Hereby, the low-order side refrigerant can easily release heat and can be easily condensed.

[0027] Next will be described a control block diagram in the cascade refrigeration system 1 according to the present embodiment with reference to FIG. 2. The control unit 5 includes a first supercooling degree calculating unit 45, a second supercooling degree calculating unit 46, and a storage unit 47. The first supercooling degree calculating unit 45 calculates a supercooling degree of the low-order side refrigerant in the cascade heat exchanger 13. The second supercooling degree calculating unit 46 calculates a supercooling degree of the low-order side refrigerant in the low-order side heat exchanger 24. The storage unit 47 stores data on a target temperature or the like, software for control, a program to calculate a supercooling degree, and so on, for example. The first supercooling degree calculating unit 45 receives a condensing temperature of the low-order side refrigerant flowing through the cascade heat exchanger 13 which condensing temperature is measured by the condensing temperature detection sensor 13a, and an outlet temperature of the low-order side refrigerant flowing through the cascade heat exchanger 13 which outlet temperature is measured by the outlet temperature detection sensor 13b. The second supercooling degree calculating unit 46 receives a condensing temperature of the low-order side refrigerant flowing through the low-order side heat exchanger 24 which condensing temperature is measured by the condensing temperature detection sensor 24a, and an outlet temperature of the low-order side refrigerant flowing through the low-order side heat exchanger 24 which outlet temperature is measured by the outlet temperature detection sensor 24b. The control unit 5 receives a target heat medium temperature. The target heat medium temperature is a target temperature of the water as the heat medium which water flows out from the first circulating pump 30 in the heat medium circuit 4. The target heat medium temperature is changed depending on an air conditioning load (a difference between the room temperature of an air-conditioning space and a set temperature determined by a user) at the time when a heating operation using the use side heat exchanger 31 is performed, for example. As the air conditioning load is larger, a larger value is set as the target heat medium temperature.

[0028] The control unit 5 also receives a heat medium return temperature measured by the heat medium return temperature detection sensor 24c, and a condensing temperature of the low-order side heat exchanger 22 which condensing temperature is measured by the condensing temperature detection sensor 22a. The first three-way valve 34 is controlled based on the heat medium return temperature and the condensing temperature of the low-order side heat exchanger 22 which are received by the control unit 5.

[0029] The control unit 5 determines respective rotation speeds of the high-order side compressor 10 and the low-order side compressor 20 based on the target heat medium temperature. The low-order side first expansion valve 21 is controlled based on the supercooling degree of the low-order side refrigerant in the cascade heat exchanger 13 which supercooling degree is calculated by the first supercooling degree calculating unit 45. The low-order side second expansion valve 25 is controlled based on the supercooling degree of the low-order side refrigerant in the low-order side heat exchanger 24 which supercooling degree is calculated by the second supercooling degree calculating unit 46.

[0030] Next will be described the control of the cascade refrigeration system 1 according to the present embodiment, with reference to a control flow diagram illustrated in FIG. 3.

[0031] First, the control unit starts a first operation mode (ST1). In the first operation mode, the first three-way valve 34 is switched to cause the heat medium to flow through the first heat medium circulation path 35. Subsequently, the first circulating pump 30 is started (ST2). Then, a startup operation is performed (ST3). In the startup operation, the high-order side compressor 10 and the low-order side compressor 20 are started, and respective openings of the high-order side expansion valve 12, the low-order side first expansion valve 21, and the low-order side second expansion valve 25 are maintained at predetermined initial openings, so that the high-order side refrigerant is circulated through the high-order side refrigerant circuit 2. The low-order side refrigerant is circulated through the first circulation path 23 and the second circulation path 26 of the low-order side refrigerant circuit 3. Here, the initial openings are respective openings of the high-order side expansion valve 12, the low-order side first expansion valve 21, and the low-order side second expansion valve 25 until the high-order side refrigerant circuit 2 and the low-order side refrigerant circuit 3 become stable after the cascade refrigeration system 1 starts its operation. The initial openings are determined based on the performance of the high-order side compressor 10 and the low-order side compressor 20 and are set in advance.

[0032] Subsequently, when a predetermined time elapses, the startup operation is ended (ST4). The predetermined time is, for example, ten minutes. The predetermined time is a necessary time to a minimum that is required until the cascade refrigeration system 1 settles to a stable operation state corresponding to a load, and the predetermined time is determined in advance by experiments or the like. After the startup operation is ended, the cascade refrigeration system 1 is switched to a normal operation (ST5). In the normal operation, the low-order side first expansion valve 21 and the low-order side second expansion valve 25 are controlled so that the low-order side refrigerant in the outlet of the cascade heat exchanger 13 and the low-order side refrigerant in the outlet of the low-order side heat exchanger 24 have respective predetermined supercooling degrees. Here, the predetermined supercooling degrees are predetermined fixed values and are set to respective values at least equal to or more than 1 deg so as to prevent a low-order side refrigerant in a two-phase state from flowing into the expansion valves. The high-order side expansion valve 12 is subjected to a suction superheat degree control such that a suction superheat degree of the high-order side compressor 10 is controlled to a target value. The target value is a predetermined fixed value and is set to a value equal to or more than 1 deg so that the high-order side refrigerant sucked in the high-order side compressor 10 is brought into an appropriate refrigerant state. Note that the high-order side expansion valve 12 may be subjected to a target discharge temperature control or a supercooling degree control, instead of the suction superheat degree control. Subsequently, it is determined whether or not the heat medium return temperature after the heat medium flows out from the use side heat exchanger 31 is lower than a predetermined value (a first predetermined temperature) (ST6). The predetermined value (the first predetermined temperature) is a variable and is a temperature lower by 2°C than the condensing temperature of the low-order side refrigerant, for example. Alternatively, the condition of step ST6 may be determined based on whether or not a difference between the heat medium return temperature after the heat medium flows out from the use side heat exchanger 31 and the condensing temperature of the low-order side refrigerant flowing into the low-order side heat exchanger 24 which condensing temperature is measured by the condensing temperature detection sensor 24a of the low-order side refrigerant circuit 3 is equal to or more than a second predetermined temperature. The second predetermined temperature is a value having such a possibility that, when the difference is lower than the second predetermined temperature, the low-order side refrigerant may not be condensed in the low-order side heat exchanger 24 and the low-order side compressor 20 may cause liquid compression. In a case where the heat medium return temperature is not lower than the predetermined value (No in ST6), the second operation mode is started (ST7). In the second operation mode, the first three-way valve 34 is switched to cause the heat medium to flow through the second heat medium circulation path 36. The case where the heat medium return temperature is not lower than the predetermined value is a case where the low-order side refrigerant in a high-temperature high-pressure gas phase which low-order side refrigerant passes through the low-order side heat exchanger 24 cannot release heat. However, by performing the second operation mode, the heat medium at a high temperature does not flow into the low-order side heat exchanger 24. As a result, the low-order side refrigerant flowing into the low-order side heat exchanger 24 releases heat by exchanging heat with the surrounding air via the low-order side heat exchanger 24 or the refrigerant pipe 6, thereby making it possible to restrain such a situation that the low-order side refrigerant cannot be condensed. Subsequently, a target supercooling degree control is performed so that the supercooling degree of the low-order side refrigerant in the outlet of the low-order side heat exchanger 24 reaches a target supercooling degree (ST8). When the target supercooling degree control is performed, the opening of the low-order side second expansion valve 25 is controlled in a closing direction so that supercooling is achieved, and the opening is finally closed or brought into a slightly open state. The target supercooling degree control is a control of the low-order side second expansion valve 25 which control is performed via the second supercooling degree calculating unit 46.

[0033] Subsequently, it is determined whether or not a defrosting start condition is established (ST9). The defrosting start condition is satisfied, for example, in a case where an outside temperature is equal to or less than 5°C and the heating operation continues for three hours or a case where a temperature detected by the condensing temperature detection sensor 22a of the heat-source side heat exchanger 22 becomes equal to or less than -15°C. When the defrosting start condition is established (Yes in ST9), the low-order side four-way valve 27 is switched to a so-called cooling cycle side, and a defrosting operation is started (ST14). After a predetermined time elapses, the defrosting operation is ended (ST15). The predetermined time is a time set in advance and is a sufficient time (for example, ten minutes) to melt frost attached to the heat-source side heat exchanger 22 by the defrosting operation. In the meantime, in a case where the defrosting start condition is not established (No in ST9), it is determined whether or not the heat medium return temperature is lower than a predetermined value (ST10). In a case where the heat medium return temperature is not lower than the predetermined value (No in ST10), the procedure returns to step ST9 and the target supercooling degree control is continued. In a case where the heat medium return temperature is lower than the predetermined value (Yes in ST10), the operation mode is switched to the first operation mode (ST11). In the first operation mode, the first three-way valve 34 is switched to cause the heat medium to flow through the first heat medium circulation path 35. As a result, the opening of the low-order side second expansion valve 25 is controlled in an opening direction from a closed or slightly open state by the target supercooling degree control (ST12). When the target supercooling degree control is performed after the operation mode is switched to the first operation mode, the low-order side refrigerant in a high-temperature high-pressure gas phase which low-order side refrigerant passes through the low-order side heat exchanger 24 can release heat and condense. Accordingly, the opening of the low-order side second expansion valve 25 is controlled in an opening direction so that the supercooling degree of the low-order side refrigerant that has passed through the low-order side heat exchanger 24 becomes a target supercooling degree. The target supercooling degree control is a control of the low-order side second expansion valve 25 which control is performed via the second supercooling degree calculating unit 46. The target supercooling degree control is continued, and the procedure returns to step ST6.

[0034] In a case where the heat medium return temperature is lower than the predetermined value (Yes in ST6), it is determined whether or not the defrosting start condition is established (ST13). The defrosting start condition is determined based on an outside temperature or a temperature detected by the condensing temperature detection sensor 22a of the heat-source side heat exchanger 22. When the defrosting start condition is established (Yes in ST13), the defrosting operation is started (ST14). After a predetermined time elapses, the defrosting operation is ended (ST15). In the meantime, in a case where the defrosting start condition is not established (No in ST13), the procedure returns to step ST6 to determine whether or not the heat medium return temperature is lower than the predetermined value (ST6).

[0035] Next will be described a cascade refrigeration system 50 according to an alternative embodiment with reference to FIGS. 4A to 4C. FIG. 4A is a refrigerant circuit diagram of the cascade refrigeration system 50 according to the alternative embodiment. FIG. 4B is a view illustrating the flow of a refrigerant in a first mode operation in the cascade refrigeration system 50 according to the alternative embodiment of the present invention. FIG. 4C is a view illustrating the flow of a refrigerant in a second mode operation in the cascade refrigeration system 50 according to the alternative embodiment of the present invention. A difference between the cascade refrigeration system 1 of the aforementioned embodiment and the cascade refrigeration system 50 is as follows. That is, the cascade refrigeration system 50 of the alternative embodiment includes a second bypass path 37 one end of which is connected to a pipe 32 between the first three-way valve 34 and the low-order side heat exchanger 24 and the other end of which is connected to a pipe 32 between the low-order side heat exchanger 24 and the first bypass path 33. Note that the other configuration is the same. In view of this, detailed descriptions of the same constituents as the constituents in the cascade refrigeration system 1 of the aforementioned embodiment are omitted. Further, the same constituents as the constituents in the aforementioned embodiment are referred to as the same reference signs as those used in the aforementioned embodiment.

[0036] The cascade refrigeration system 50 is a refrigeration device which can be used for a cooling operation in a case where the use side heat exchanger 31 is used as an evaporator and which can be used for an operation to make hot water or a heating operation in a case where the use side heat exchanger 31 is used as a condenser. Hereinafter, the operation to make hot water and the heating operation may be collectively called a heating operation. The present embodiment deals with a cascade refrigeration system used for the heating operation.

[0037] The cascade refrigeration system 50 includes the high-order side refrigerant circuit 2, the low-order side refrigerant circuit 3, the heat medium circuit 4, and the control unit 5, and the control unit 5 controls the cascade refrigeration system 50. The heat medium circuit 4 includes the first bypass path 33 and the second bypass path 37. One end of the first bypass path 33 is connected to the pipe 32 between the use side heat exchanger 31 and the low-order side heat exchanger 24, and the other end thereof is connected to a pipe between the low-order side heat exchanger 24 and the high-order side heat exchanger 11. The one end of the second bypass path 37 is connected to the pipe 32 between the first three-way valve 34 and the low-order side heat exchanger 24, and the other end thereof is connected to the pipe 32 between the low-order side heat exchanger 24 and the other end of the first bypass path 33.

[0038] In the second bypass path 37, a second three-way valve 38 as a second switching unit is provided for the other end of the second bypass path 37. Further, the second bypass path 37 includes a heat accumulation unit 39 (corresponding to a second heat accumulation unit) including a heat accumulation material, a second circulating pump 40, and a check valve 41 provided from the other end of the second bypass path 37 toward the one end thereof. The second three-way valve 38 switches between a state where water as the heat medium flows through the first heat medium circulation path 35 and a state where the water flows through a third heat medium circulation path 42. The heat accumulation unit 39 accumulates heat absorbed from the low-order side refrigerant by the low-order side heat exchanger 24, via the water as the heat medium. The heat accumulation unit 39 is provided with a temperature detection sensor 39a configured to measure a temperature of the heat accumulation unit 39. The second circulating pump 40 causes the water as the heat medium to flow from the other end of the second bypass path 37 to the one end thereof. The check valve 41 is a valve configured to cause the water as the heat medium to flow from the other end of the second bypass path 37 to the one end thereof but does not cause the water to flow from the one end to the other end.

[0039] The cascade refrigeration system 50 has a first mode operation in which the heat medium flows through the first heat medium circulation path 35, and a second mode operation in which the heat medium flows through the second heat medium circulation path 36 and the third heat medium circulation path 42. In the first mode operation, heat is absorbed from external air by the heat-source side heat exchanger 22 of the low-order side refrigerant circuit 3, the heat thus absorbed from the external air is released to the heat medium in the heat medium circuit 4 via the high-order side heat exchanger 11 of the high-order side refrigerant circuit 2 and the low-order side heat exchanger 24 of the low-order side refrigerant circuit 3. Thus, the first mode operation is an operation in which heat is released to the air in the room from the heat medium thus absorbing the heat in the heat medium circuit 4. The second mode operation is an operation in which heat is absorbed from the external air in the heat-source side heat exchanger 22 of the low-order side refrigerant circuit 3, and the heat is released to the air in the room from the heat medium of the heat medium circuit 4 via the high-order side refrigerant circuit 2. In addition, the second mode operation performs an operation in which heat is absorbed from the external air in the heat-source side heat exchanger 22 of the low-order side refrigerant circuit 3, and the heat thus absorbed from the external air is accumulated in the heat accumulation unit 39 of the heat medium circuit 4.

[0040] The first heat medium circulation path 35 is a circulation path through which the heat medium circulates in order of the first circulating pump 30, the use side heat exchanger 31, the low-order side heat exchanger 24, the high-order side heat exchanger 11, and the first circulating pump 30. The second heat medium circulation path 36 is a circulation path through which the heat medium circulates in order of the first circulating pump 30, the use side heat exchanger 31, the first bypass path 33, the high-order side heat exchanger 11, and the first circulating pump 30. The third heat medium circulation path 42 is a circulation path through which the heat medium circulates in order of the second circulating pump 40 of the second bypass path 37, the check valve 41 thereof, the low-order side heat exchanger 24, and the second circulating pump 40.

[0041] Next will be described a control block diagram in the cascade refrigeration system 50 according to the present embodiment with reference to FIG. 5. The control unit 5 includes the first supercooling degree calculating unit 45, the second supercooling degree calculating unit 46, and the storage unit 47. The first supercooling degree calculating unit 45 calculates a supercooling degree of the low-order side refrigerant in the cascade heat exchanger 13. The second supercooling degree calculating unit 46 calculates a supercooling degree of the low-order side refrigerant in the low-order side heat exchanger 24. The storage unit 47 stores data on a target temperature or the like, software for control, a program to calculate a supercooling degree, and so on, for example. As described above, the first supercooling degree calculating unit 45 receives the condensing temperature of the low-order side refrigerant flowing through the cascade heat exchanger 13 which condensing temperature is measured by the condensing temperature detection sensor 13a, and the outlet temperature of the low-order side refrigerant flowing through the cascade heat exchanger 13 which outlet temperature is measured by the outlet temperature detection sensor 13b. The second supercooling degree calculating unit 46 receives the condensing temperature of the low-order side refrigerant flowing through the low-order side heat exchanger 24 which condensing temperature is measured by the condensing temperature detection sensor 24a, and the outlet temperature of the low-order side refrigerant flowing through the low-order side heat exchanger 24 which outlet temperature is measured by the outlet temperature detection sensor 24b. The control unit 5 also receives a target heat medium temperature. The target heat medium temperature is a target temperature of the water as the heat medium which water flows out from the first circulating pump 30 in the heat medium circuit 4. The target heat medium temperature is changed depending on an air conditioning load (a difference between the room temperature of an air-conditioning space and a set temperature determined by a user) at the time when a heating operation using the use side heat exchanger 31 is performed, for example. As the air conditioning load is larger, a larger value is set as the target heat medium temperature.

[0042] The control unit 5 receives the heat medium return temperature measured by the heat medium return temperature detection sensor 24c, the condensing temperature of the low-order side heat exchanger 24 which condensing temperature is measured by the condensing temperature detection sensor 22a, and a temperature of the heat accumulation unit 39 which temperature is measured by the temperature detection sensor 39a. The first three-way valve 34, the second three-way valve 38, and the second circulating pump 40 are controlled based on the heat medium return temperature, the temperature of the low-order side heat exchanger 24, and the temperature of the heat accumulation unit 39 that are received by the control unit 5. That is, the heat medium is caused to release heat in the heat accumulation unit 39 so as to prevent the heat medium return temperature from becoming higher than the condensing temperature of the low-order side refrigerant flowing into the low-order side heat exchanger 24.

[0043] The control unit 5 determines respective rotation speeds of the high-order side compressor 10 and the low-order side compressor 20 based on the target heat medium temperature. The low-order side first expansion valve 21 is controlled via the first supercooling degree calculating unit 45 based on the condensing temperature of the high-order side refrigerant flowing through the cascade heat exchanger 13 and the outlet temperature of the high-order side refrigerant flowing through the cascade heat exchanger 13. The low-order side second expansion valve 25 is controlled via the second supercooling degree calculating unit 46 based on the condensing temperature of the low-order side refrigerant flowing through the low-order side heat exchanger 24 and the outlet temperature of the low-order side refrigerant flowing through the low-order side heat exchanger 24.

[0044] The cascade refrigeration system 50 of the present embodiment uses heat accumulated in the heat accumulation unit 39 in the second mode operation for a defrosting operation to defrost frost attached to the heat-source side heat exchanger 22. The defrosting operation is performed as follows. The high-order side compressor 10 of the high-order side refrigerant circuit 2 is stopped, and the low-order side four-way valve 27 of the low-order side refrigerant circuit 3 is switched to a so-called cooling cycle side. That is, the low-order side four-way valve 27 is switched to cause the low-order side refrigerant discharged from the low-order side compressor 20 to flow toward the heat-source side heat exchanger 22 side so as to cause the heat-source side heat exchanger 22 to function as a condenser and the cascade heat exchanger 13 and the low-order side heat exchanger 24 to function as evaporators. The low-order side first expansion valve 21 and the low-order side second expansion valve 25 are set to openings close to a full-open state. The low-order side refrigerant discharged from the low-order side compressor 20 flows into the heat-source side heat exchanger 22 and melts the frost. Part of the low-order side refrigerant flowing out from the heat-source side heat exchanger 22 flows into the low-order side heat exchanger 24 and absorbs heat from the heat medium circulating through the third heat medium circulation path 42 provided with the heat accumulation unit 39. The remaining part of the low-order side refrigerant flowing out from the heat-source side heat exchanger 22 flow into the cascade heat exchanger 13 and absorbs heat remaining in the high-order side refrigerant circuit 2 where the high-order side compressor 10 stops. The low-order side refrigerant that absorbs heat flows into the heat-source side heat exchanger 22 again via the low-order side compressor 20 and melts the frost.

[0045] With reference to a control flow diagram illustrated in FIG. 6, the control of the cascade refrigeration system 50 according to the present embodiment will be described.

[0046] First, the control unit starts the first operation mode (ST21). In the first operation mode, the first three-way valve 34 is switched to cause the heat medium to flow through the first heat medium circulation path 35. Subsequently, the first circulating pump 30 is started (ST22). Then, the startup operation is performed (ST23). In the startup operation, the high-order side compressor 10 and the low-order side compressor 20 are started, and respective openings of the high-order side expansion valve 12, the low-order side first expansion valve 21, and the low-order side second expansion valve 25 are maintained at predetermined initial openings. Hereby, the high-order side refrigerant is circulated through the high-order side refrigerant circuit 2, and the low-order side refrigerant is circulated through the first circulation path 23 and the second circulation path 26 of the low-order side refrigerant circuit 3. The initial openings are respective openings of the high-order side expansion valve 12, the low-order side first expansion valve 21, and the low-order side second expansion valve 25 until the high-order side refrigerant circuit 2 and the low-order side refrigerant circuit 3 become stable after the cascade refrigeration system 1 starts its operation. The initial openings are determined based on the performance of the high-order side compressor 10 and the low-order side compressor 20 and are set in advance.

[0047] Subsequently, when a predetermined time elapses, the startup operation is ended (ST24). The predetermined time is, for example, ten minutes. The predetermined time is a necessary time to a minimum that is required until the cascade refrigeration system 1 settles to a stable operation state corresponding to a load, and the predetermined time is determined in advance by experiments or the like. After the startup operation is ended, the cascade refrigeration system 50 is switched to a normal operation (ST25). In the normal operation, the low-order side first expansion valve 21 and the low-order side second expansion valve 25 are controlled so that the low-order side refrigerant in the outlet of the cascade heat exchanger 13 and the low-order side refrigerant in the outlet of the low-order side heat exchanger 24 become respective predetermined supercooling degrees. The predetermined supercooling degrees are predetermined fixed values and are set to respective values at least equal to or more than 1 deg so as to prevent a low-order side refrigerant in a two-phase state from flowing into the expansion valves. The high-order side expansion valve 12 is subjected to a suction superheat degree control such that a suction superheat degree of the high-order side compressor 10 is controlled to a target value. The target value is a predetermined fixed value and is set to a value equal to or more than 1 deg so that the high-order side refrigerant sucked in the high-order side compressor 10 is brought into an appropriate refrigerant state. Note that the high-order side expansion valve 12 may be subjected to a target discharge temperature control or a supercooling degree control, instead of the suction superheat degree control. Subsequently, it is determined whether or not the heat medium return temperature after the heat medium flows out from the use side heat exchanger 31 is lower than a predetermined value (a first predetermined temperature) (ST26). The predetermined value (the first predetermined temperature) is a variable and is a temperature lower by 2°C than the condensing temperature of the low-order side refrigerant, for example. Alternatively, the condition of step ST26 may be determined based on whether or not a difference between the heat medium return temperature after the heat medium flows out from the use side heat exchanger 31 and the condensing temperature of the low-order side refrigerant flowing into the low-order side heat exchanger 24 which condensing temperature is measured by the condensing temperature detection sensor 24a of the low-order side refrigerant circuit 3 is equal to or more than a second predetermined temperature. The second predetermined temperature is a value having such a possibility that, when the difference is lower than the second predetermined temperature, the low-order side refrigerant may not be condensed in the low-order side heat exchanger 24 and the low-order side compressor 20 may cause liquid compression. In a case where the heat medium return temperature is not lower than the predetermined value (No in ST26), the second operation mode is started (ST27). The second operation mode is an operation in which the first three-way valve 34 is switched to cause the heat medium to flow through the second heat medium circulation path 36, and heat absorbed from external air is accumulated in the heat accumulation unit 39 of the heat medium circuit 4. The second operation mode is performed for a predetermined time to complete heat accumulation to the heat accumulation unit 39 (ST28). Subsequently, a target supercooling degree control is performed so that the supercooling degree of the low-order side refrigerant in the outlet of the low-order side heat exchanger 24 reaches a target supercooling degree (ST29). When the target supercooling degree control is performed, the opening of the low-order side second expansion valve 25 is controlled in a closing direction so that supercooling is achieved, and the low-order side second expansion valve 25 is finally closed or brought into a slightly open state. The target supercooling degree control is a control of the low-order side second expansion valve 25 which control is performed via the second supercooling degree calculating unit 46.

[0048] Subsequently, it is determined whether or not the defrosting start condition is established (ST30). The defrosting start condition is satisfied, for example, in a case where an outside temperature is equal to or less than 5°C or less and the heating operation continues for three hours or a case where a temperature detected based on the condensing temperature detection sensor 22a of the heat-source side heat exchanger 22 becomes equal to or less than -15°C. When the defrosting start condition is established (Yes in ST30), the low-order side four-way valve 27 is switched to a so-called cooling cycle side, and the defrosting operation is started (ST35). After a predetermined time elapses, the defrosting operation is ended (ST36). The predetermined time is a time set in advance and is a sufficient time (for example, ten minutes) to melt frost attached to the heat-source side heat exchanger 22 by the defrosting operation. In the meantime, in a case where the defrosting start condition is not established (No in ST30), it is determined whether or not the heat medium return temperature is lower than a predetermined value (ST31). In a case where the heat medium return temperature is not lower than the predetermined value (No in ST31), the procedure returns to step ST30 and the target supercooling degree control is continued. In a case where the heat medium return temperature is lower than the predetermined value (Yes in ST31), the operation mode is switched to the first operation mode (ST32). In the first operation mode, the first three-way valve 34 is switched to cause the heat medium to flow through the first heat medium circulation path 35. As a result, the opening of the low-order side second expansion valve 25 is controlled in an opening direction from a closed or slightly open state by the target supercooling degree control (ST33). When the target supercooling degree control is performed after the operation mode is switched to the first operation mode, the low-order side refrigerant in a high-temperature high-pressure gas phase which low-order side refrigerant passes through the low-order side heat exchanger 24 can release heat and condense. Accordingly, the opening of the low-order side second expansion valve 25 is controlled in an opening direction so that the supercooling degree of the low-order side refrigerant that has passed through the low-order side heat exchanger 24 becomes a target supercooling degree. The target supercooling degree control is a control of the low-order side second expansion valve 25 which control is performed via the second supercooling degree calculating unit 46. The target supercooling degree control is continued, and the procedure returns to step ST26.

[0049] In a case where the heat medium return temperature is lower than the predetermined value (Yes in ST26), it is determined whether or not the defrosting start condition is established (ST34). The defrosting start condition is a condition related to the outside temperature or the temperature detected based on the condensing temperature detection sensor 22a of the heat-source side heat exchanger 22, as described above. When the defrosting start condition is established (Yes in ST34), it is determined whether or not a heat accumulation temperature in the heat accumulation unit 39 is higher than a predetermined value (ST37). The predetermined value is a temperature which is determined in advance by tests or the like and based on which it can be determined that a sufficient amount of heat that can be used for the defrosting operation is accumulated. When the heat accumulation temperature in the heat accumulation unit 39 is higher than the predetermined value (Yes in ST37), the defrosting operation is started (ST35). After a predetermined time elapses, the defrosting operation is ended (ST36). In the meantime, in a case where the heat accumulation temperature in the heat accumulation unit 39 is not higher than the predetermined value (No in ST37), the second operation mode is started (ST38). The second operation mode is an operation in which the first three-way valve 34 is switched to cause the heat medium to flow through the second heat medium circulation path, and heat absorbed from external air is accumulated in the heat accumulation unit 39 of the heat medium circuit 4. The second operation mode is performed for a predetermined time to complete heat accumulation to the heat accumulation unit 39 (ST39). Then, the defrosting operation is started (ST35), and after a predetermined time elapses, the defrosting operation is ended (ST36).

[0050] The present invention has been described referring to a limited number of embodiments, but the scope of the present invention is not limited to them, and it is obvious for a person skilled in the art that the embodiments are modifiable based on the disclosure.

Reference Signs List

[0051]

1: cascade refrigeration system
2: high-order side refrigerant circuit
3: low-order side refrigerant circuit
4: heat medium circuit
5: control unit
6: refrigerant pipe
10: high-order side compressor
11: high-order side heat exchanger
12: high-order side expansion valve
13: cascade heat exchanger
13a: condensing temperature detection sensor
13b: outlet temperature detection sensor
14: high-order side four-way valve
20: low-order side compressor
21: low-order side first expansion valve
22: heat-source side heat exchanger
22a: condensing temperature detection sensor
23: first circulation path
24: low-order side heat exchanger
24a: condensing temperature detection sensor
24b: outlet temperature detection sensor
24c: heat medium return temperature detection sensor
25: low-order side second expansion valve
26: second circulation path
27: low-order side four-way valve
30: first circulating pump
31: use side heat exchanger
32: pipe
33: first bypass path
34: first three-way valve
35: first heat medium circulation path
36: second heat medium circulation path
37: second bypass path
38: second three-way valve
39: heat accumulation unit
39a: temperature detection sensor
40: second circulating pump
41: check valve
42: third heat medium circulation path
45: first supercooling degree calculating unit
46: second supercooling degree calculating unit
47: storage unit
50: cascade refrigeration system

Claims

1. A cascade refrigeration system comprising:

a high-order side refrigerant circuit configured such that a high-order side compressor, a high-order side heat exchanger, a high-order side pressure reduction mechanism, and a cascade heat exchanger are sequentially connected via refrigerant pipes to circulate a high-order side refrigerant through the high-order side refrigerant circuit;
a low-order side refrigerant circuit including a first circulation path and a second circulation path,

the first circulation path being configured such that a low-order side compressor, the cascade heat exchanger, a low-order side first pressure reduction mechanism, and a heat-source side heat exchanger are sequentially connected via refrigerant pipes to circulate a low-order side refrigerant through the first circulation path,
the second circulation path being configured such that a portion of the first circulation path between the low-order side compressor and the cascade heat exchanger is connected to a portion of the first circulation path between the low-order side first pressure reduction mechanism and the heat-source side heat exchanger via refrigerant pipes including a low-order side heat exchanger and a low-order side second pressure reduction mechanism such that the low-order side compressor, the low-order side heat exchanger, the low-order side second pressure reduction mechanism, and the heat-source side heat exchanger are sequentially connected via the refrigerant pipes to circulate the low-order side refrigerant through the second circulation path;

a heat medium circuit including a first heat medium circulation path and a second heat medium circulation path,

the first heat medium circulation path being configured such that a first circulating pump, a use side heat exchanger, the low-order side heat exchanger, and the high-order side heat exchanger are sequentially connected via pipes to circulate a heat medium through the first heat medium circulation path such that the high-order side refrigerant exchanges heat with the heat medium in the high-order side heat exchanger, and the low-order side refrigerant exchanges heat with the heat medium in the low-order side heat exchanger,
the second heat medium circulation path including a first bypass path connecting a portion of the first heat medium circulation path between the use side heat exchanger and the low-order side heat exchanger to a portion of the first heat medium circulation

path between the low-order side heat exchanger and the high-order side heat exchanger such that the first circulating pump, the use side heat exchanger, the first bypass path, and the high-order side heat exchanger are sequentially connected via pipes to circulate the heat medium through the second heat medium circulation path,

the high-order side refrigerant and the low-order side refrigerant exchanging heat with each other in the cascade heat exchanger;
a first switching unit configured to switch the heat medium circuit between a state where the heat medium flows through the first heat medium circulation path and a state where the heat medium flows through the second heat medium circulation path; and
a control unit configured to control the high-order side refrigerant circuit, the low-order side refrigerant circuit, and the heat medium circuit.

2. The cascade refrigeration system according to claim 1, wherein
at startup of the cascade refrigeration system, the control unit starts the high-order side compressor, the low-order side compressor, and the first circulating pump and switches the first switching unit to cause the heat medium to flow through the first heat medium circulation path.

3. The cascade refrigeration system according to claim 2, wherein
the control unit switches the first switching unit to cause the heat medium to flow through the second heat medium circulation path in a case where the heat medium passing through the use side heat exchanger has a temperature exceeding a first predetermined temperature or in a case where a difference between the temperature of the heat medium passing through the use side heat exchanger and a refrigerant condensing temperature in the low-order side heat exchanger of the low-order side refrigerant circuit is less than a second predetermined temperature.

4. The cascade refrigeration system according to claim 1, comprising:
a four-way valve connected to a discharge side of the low-order side compressor in the low-order side refrigerant circuit, the four-way valve being configured to switch between a state where the low-order side refrigerant discharged from the low-order side compressor flows toward the cascade heat exchanger side and the low-order side heat exchanger side and a state where the low-order side refrigerant discharged from the low-order side compressor flows toward the heat-source side heat exchanger side.

5. The cascade refrigeration system according to claim 4, wherein
the low-order side heat exchanger includes a first heat accumulation unit including a heat accumulation material.

6. The cascade refrigeration system according to claim 5, wherein
when the heat accumulation material has a temperature equal to or more than a predetermined temperature, the control unit switches the four-way valve to the heat-source side heat exchanger side and performs a defrosting operation using heat accumulated in the heat accumulation material.

7. The cascade refrigeration system according to claim 1, comprising:

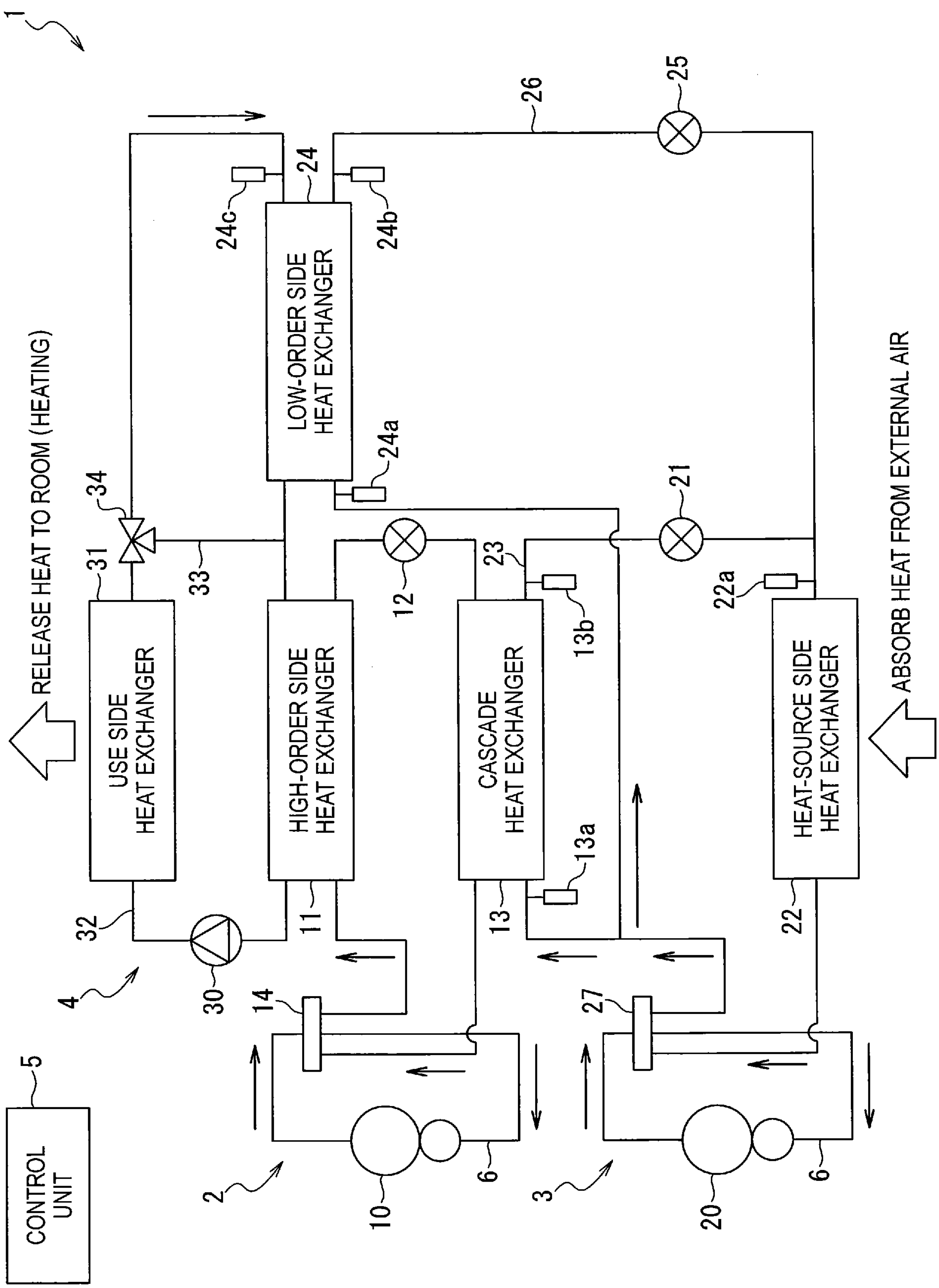
a third heat medium circulation path provided in the heat medium circuit and including a second bypass path connected in parallel to the first bypass path, the second bypass path including a check valve, a second circulating pump, and a second heat accumulation unit including a heat accumulation material, the third heat medium circulation path being configured such that the second circulating pump, the check valve, the low-order side heat exchanger, and the second heat accumulation unit are sequentially connected via refrigerant pipes to circulate the heat medium through the third heat medium circulation path;
a second switching unit configured to switch the heat medium circuit between a state where the heat medium flows through the first heat medium circulation path and a state where the heat medium flows through the third heat medium circulation path; and
a four-way valve connected to a discharge side of the low-order side compressor in the low-order side refrigerant circuit, the four-way valve being configured to switch between a state where the low-order side refrigerant discharged from the low-order side compressor flows toward the cascade heat exchanger side and the low-order side heat exchanger side and a state where the low-order side refrigerant discharged from the low-order side compressor flows toward the heat-source side heat exchanger side.

8. The cascade refrigeration system according to claim 7, wherein
at startup of the cascade refrigeration system, the control unit starts the high-order side compressor, the low-order side compressor, and the first circulat-

ing pump and switches the first switching unit and the second switching unit to cause the heat medium to flow through the first heat medium circulation path.

9. The cascade refrigeration system according to claim 8, wherein
the control unit switches the first switching unit to cause the heat medium to flow through the second heat medium circulation path and switches the second switching unit to cause the heat medium to flow through the third heat medium circulation path in a case where the heat medium passing through the use side heat exchanger has a temperature exceeding a first predetermined temperature or in a case where a difference between the temperature of the heat medium passing through the use side heat exchanger and a refrigerant condensing temperature in the low-order side heat exchanger of the low-order side refrigerant circuit is less than a second predetermined temperature.

10. The cascade refrigeration system according to claim 9, wherein
when the heat accumulation material has a temperature equal to or more than a predetermined temperature, the control unit switches the four-way valve to the heat-source side heat exchanger side and performs a defrosting operation using heat accumulated in the heat accumulation material.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ABSORB HEAT FROM EXTERNAL AIR
USE SIDE HEAT EXCHANGER
HIGH-ORDER SIDE HEAT EXCHANGER
LOW-ORDER SIDE HEAT EXCHANGER
CASCADE HEAT EXCHANGER
HEAT-SOURCE SIDE HEAT EXCHANGER
CONTROL UNIT
1
2
3
4
5
6
10
11
12
13
13a
13b
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21
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22a
23
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24a
24b
24c
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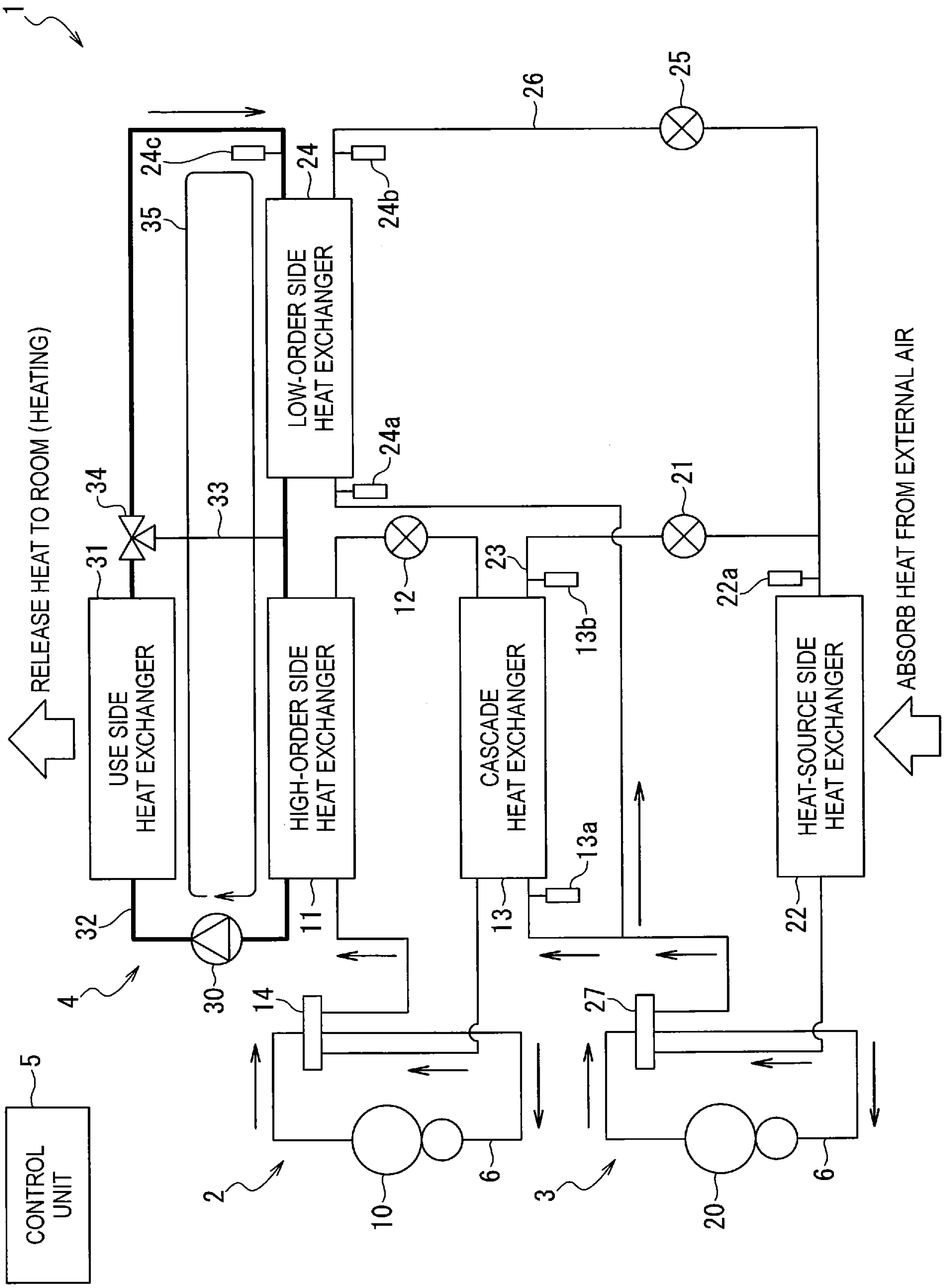
FIG. 1A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RELEASE HEAT TO ROOM (HEATING)
ABSORB HEAT FROM EXTERNAL AIR
USE SIDE HEAT EXCHANGER
HIGH-ORDER SIDE HEAT EXCHANGER
LOW-ORDER SIDE HEAT EXCHANGER
CASCADE HEAT EXCHANGER
HEAT-SOURCE SIDE HEAT EXCHANGER
CONTROL UNIT
2
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13a
13b
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22a
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24a
24b
24c
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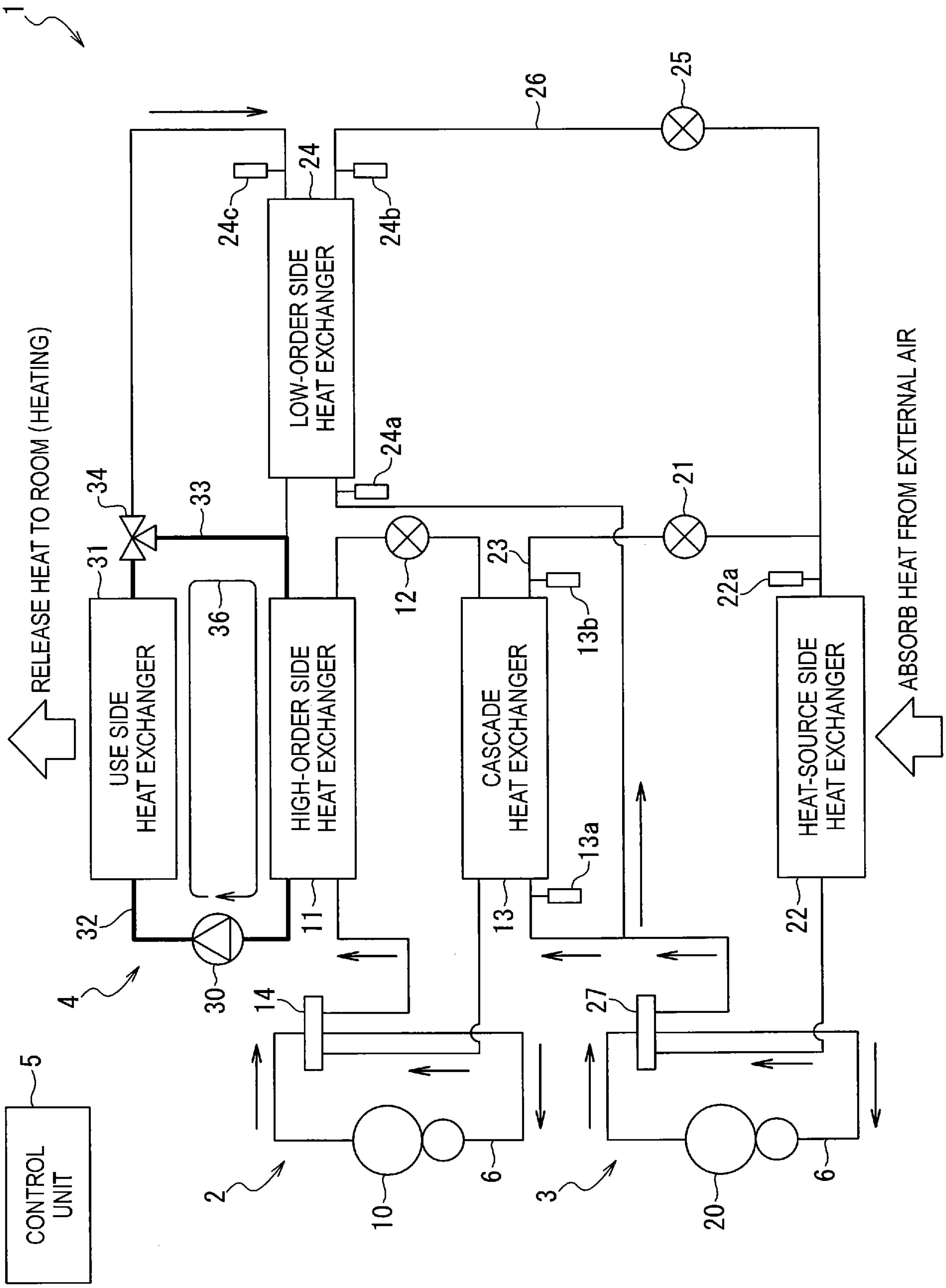
FIG. 1B

FIG. 1C


1
RELEASE HEAT TO ROOM (HEATING)
USE SIDE HEAT EXCHANGER
HIGH-ORDER SIDE HEAT EXCHANGER
LOW-ORDER SIDE HEAT EXCHANGER
CASCADE HEAT EXCHANGER
HEAT-SOURCE SIDE HEAT EXCHANGER
ABSORB HEAT FROM EXTERNAL AIR
CONTROL UNIT
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4
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6
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12
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13a
13b
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22a
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24a
24b
24c
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FIG. 2

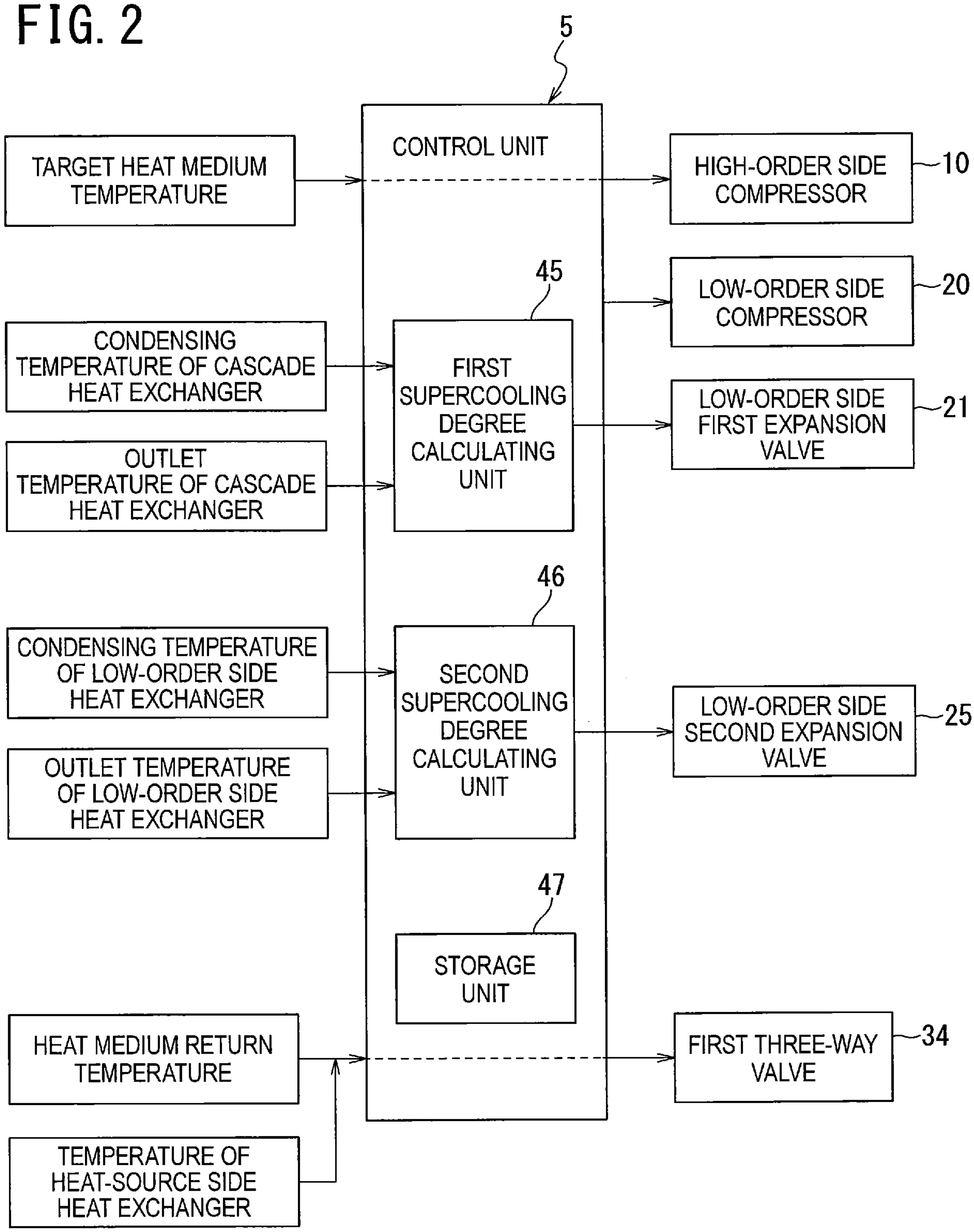
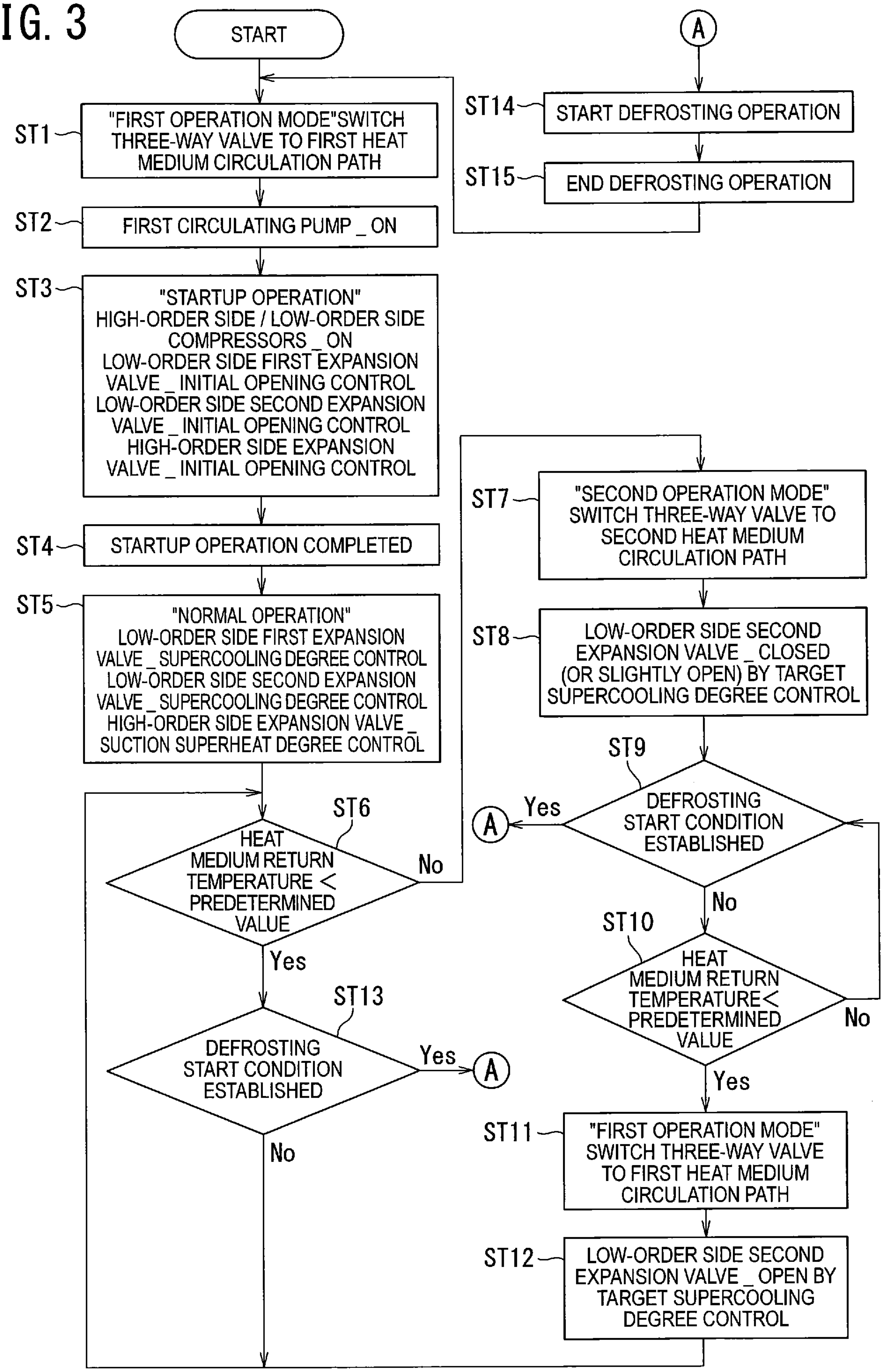
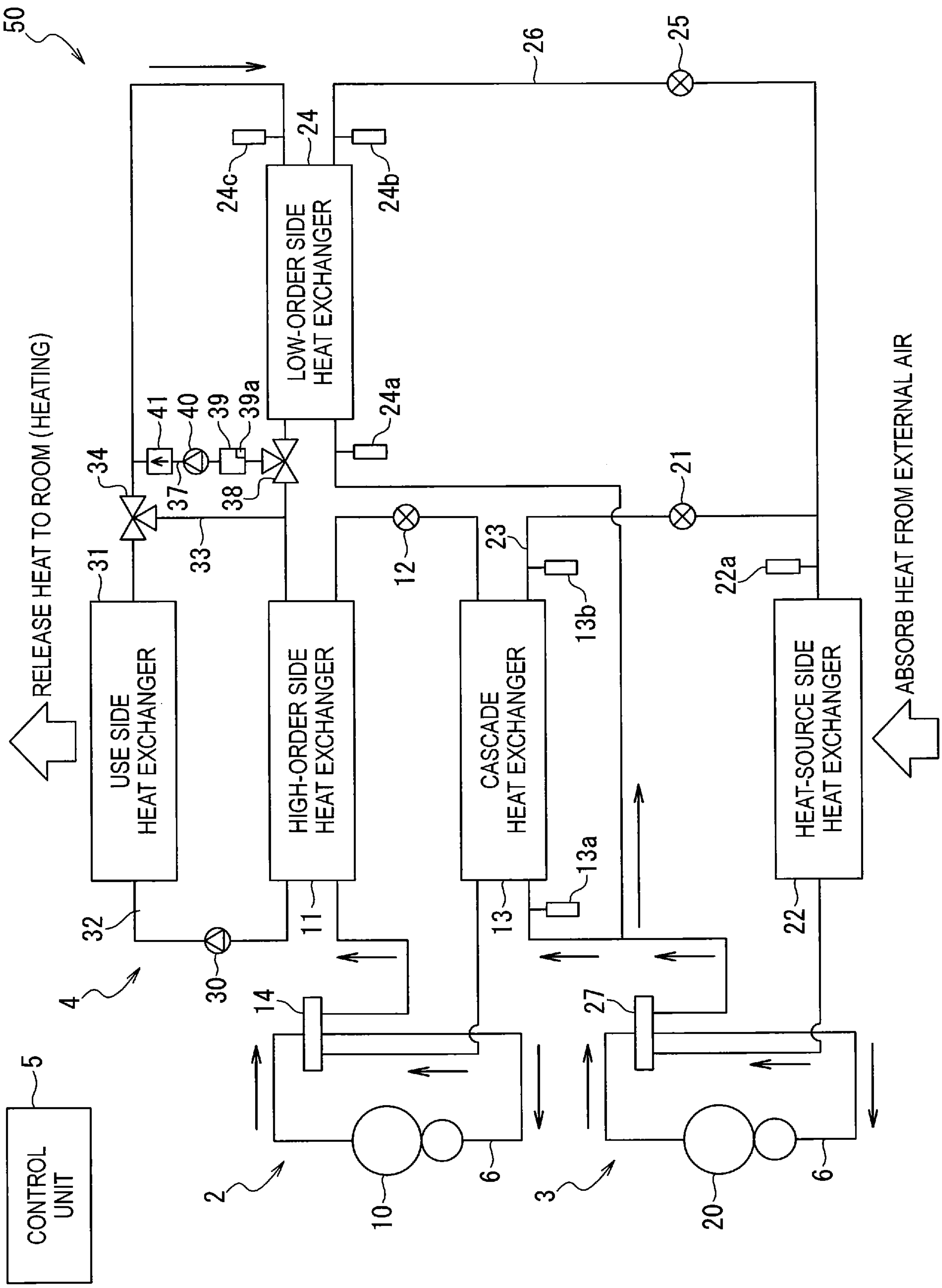

5
CONTROL UNIT
TARGET HEAT MEDIUM TEMPERATURE
HIGH-ORDER SIDE COMPRESSOR
10
45
LOW-ORDER SIDE COMPRESSOR
20
CONDENSING TEMPERATURE OF CASCADE HEAT EXCHANGER
FIRST SUPERCOOLING DEGREE CALCULATING UNIT
LOW-ORDER SIDE FIRST EXPANSION VALVE
21
OUTLET TEMPERATURE OF CASCADE HEAT EXCHANGER
46
CONDENSING TEMPERATURE OF LOW-ORDER SIDE HEAT EXCHANGER
SECOND SUPERCOOLING DEGREE CALCULATING UNIT
LOW-ORDER SIDE SECOND EXPANSION VALVE
25
OUTLET TEMPERATURE OF LOW-ORDER SIDE HEAT EXCHANGER
47
STORAGE UNIT
HEAT MEDIUM RETURN TEMPERATURE
FIRST THREE-WAY VALVE
34
TEMPERATURE OF HEAT-SOURCE SIDE HEAT EXCHANGER

FIG. 3


START
ST1 "FIRST OPERATION MODE"SWITCH THREE-WAY VALVE TO FIRST HEAT MEDIUM CIRCULATION PATH
ST2 FIRST CIRCULATING PUMP _ ON
ST3 "STARTUP OPERATION" HIGH-ORDER SIDE / LOW-ORDER SIDE COMPRESSORS _ ON LOW-ORDER SIDE FIRST EXPANSION VALVE _ INITIAL OPENING CONTROL LOW-ORDER SIDE SECOND EXPANSION VALVE _ INITIAL OPENING CONTROL HIGH-ORDER SIDE EXPANSION VALVE _ INITIAL OPENING CONTROL
ST4 STARTUP OPERATION COMPLETED
ST5 "NORMAL OPERATION" LOW-ORDER SIDE FIRST EXPANSION VALVE _ SUPERCOOLING DEGREE CONTROL LOW-ORDER SIDE SECOND EXPANSION VALVE _ SUPERCOOLING DEGREE CONTROL HIGH-ORDER SIDE EXPANSION VALVE _ SUCTION SUPERHEAT DEGREE CONTROL
ST6 HEAT MEDIUM RETURN TEMPERATURE < PREDETERMINED VALUE
Yes
No
ST13 DEFROSTING START CONDITION ESTABLISHED
Yes
No
A
ST7 "SECOND OPERATION MODE" SWITCH THREE-WAY VALVE TO SECOND HEAT MEDIUM CIRCULATION PATH
ST8 LOW-ORDER SIDE SECOND EXPANSION VALVE _ CLOSED (OR SLIGHTLY OPEN) BY TARGET SUPERCOOLING DEGREE CONTROL
ST9 DEFROSTING START CONDITION ESTABLISHED
Yes
A
No
ST10 HEAT MEDIUM RETURN TEMPERATURE< PREDETERMINED VALUE
No
Yes
ST11 "FIRST OPERATION MODE" SWITCH THREE-WAY VALVE TO FIRST HEAT MEDIUM CIRCULATION PATH
ST12 LOW-ORDER SIDE SECOND EXPANSION VALVE _ OPEN BY TARGET SUPERCOOLING DEGREE CONTROL
A
ST14 START DEFROSTING OPERATION
ST15 END DEFROSTING OPERATION



50
RELEASE HEAT TO ROOM (HEATING)
USE SIDE HEAT EXCHANGER
HIGH-ORDER SIDE HEAT EXCHANGER
LOW-ORDER SIDE HEAT EXCHANGER
CASCADE HEAT EXCHANGER
HEAT-SOURCE SIDE HEAT EXCHANGER
ABSORB HEAT FROM EXTERNAL AIR
CONTROL UNIT
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22a
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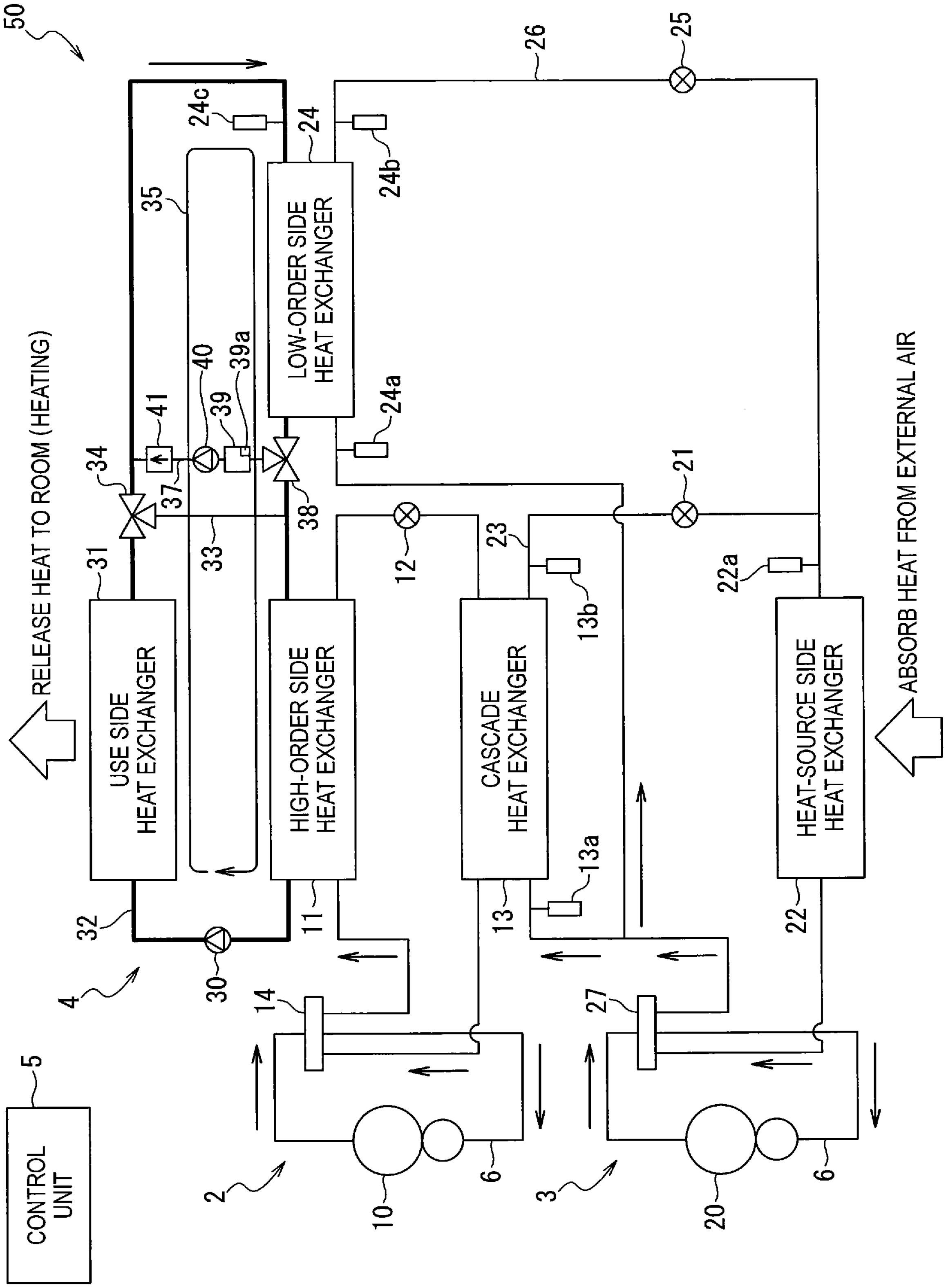
FIG. 4A

FIG. 4B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RELEASE HEAT TO ROOM (HEATING)
USE SIDE HEAT EXCHANGER
HIGH-ORDER SIDE HEAT EXCHANGER
LOW-ORDER SIDE HEAT EXCHANGER
CASCADE HEAT EXCHANGER
HEAT-SOURCE SIDE HEAT EXCHANGER
ABSORB HEAT FROM EXTERNAL AIR
CONTROL UNIT
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13b
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22a
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24b
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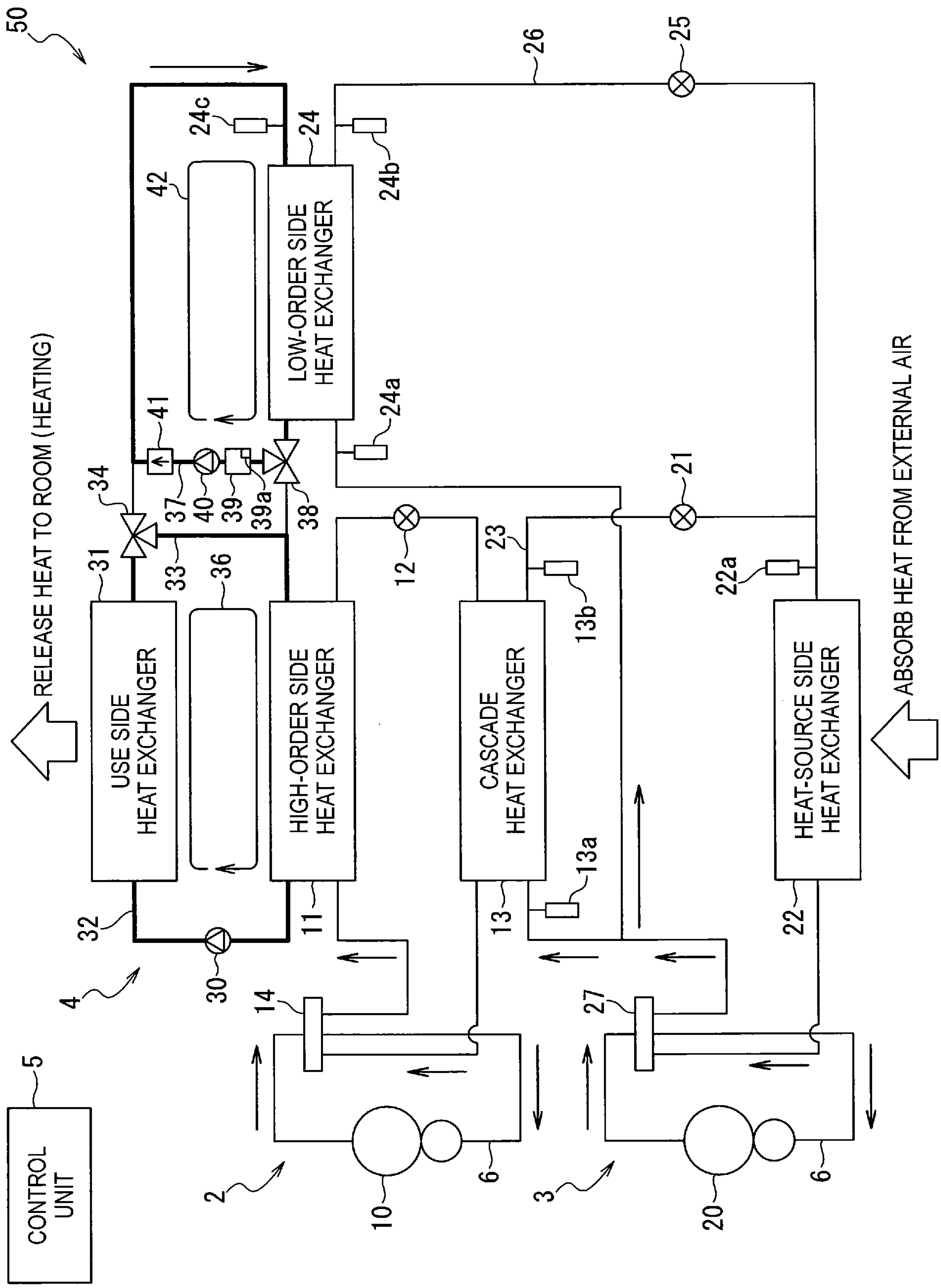

50
RELEASE HEAT TO ROOM (HEATING)
USE SIDE HEAT EXCHANGER
HIGH-ORDER SIDE HEAT EXCHANGER
LOW-ORDER SIDE HEAT EXCHANGER
CASCADE HEAT EXCHANGER
HEAT-SOURCE SIDE HEAT EXCHANGER
ABSORB HEAT FROM EXTERNAL AIR
CONTROL UNIT
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12
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13a
13b
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20
21
22
22a
23
24
24a
24b
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FIG. 4C

FIG. 5

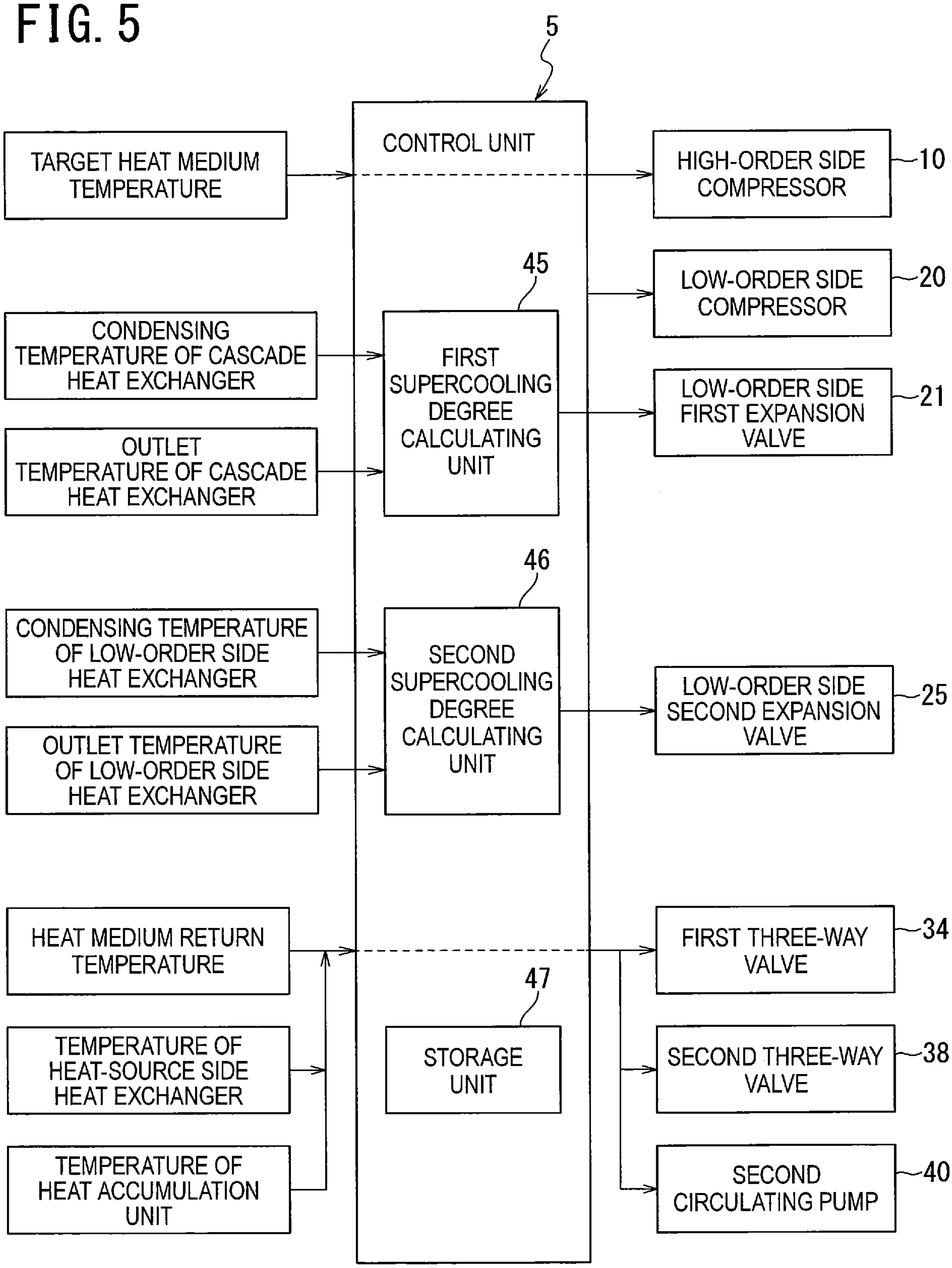
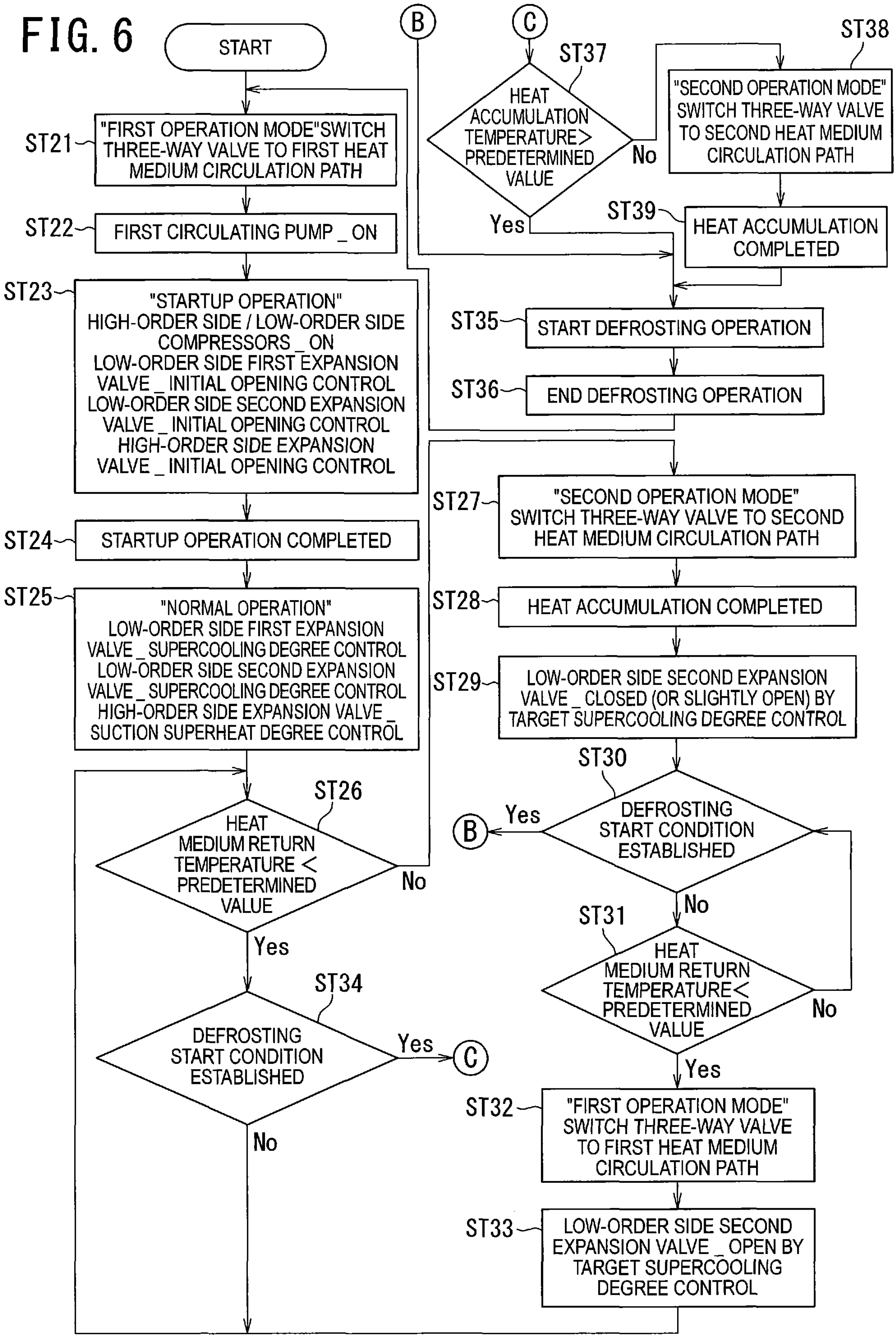

5
CONTROL UNIT
TARGET HEAT MEDIUM TEMPERATURE
HIGH-ORDER SIDE COMPRESSOR
10
45
LOW-ORDER SIDE COMPRESSOR
20
CONDENSING TEMPERATURE OF CASCADE HEAT EXCHANGER
FIRST SUPERCOOLING DEGREE CALCULATING UNIT
LOW-ORDER SIDE FIRST EXPANSION VALVE
21
OUTLET TEMPERATURE OF CASCADE HEAT EXCHANGER
46
CONDENSING TEMPERATURE OF LOW-ORDER SIDE HEAT EXCHANGER
SECOND SUPERCOOLING DEGREE CALCULATING UNIT
LOW-ORDER SIDE SECOND EXPANSION VALVE
25
OUTLET TEMPERATURE OF LOW-ORDER SIDE HEAT EXCHANGER
HEAT MEDIUM RETURN TEMPERATURE
FIRST THREE-WAY VALVE
34
47
TEMPERATURE OF HEAT-SOURCE SIDE HEAT EXCHANGER
STORAGE UNIT
SECOND THREE-WAY VALVE
38
TEMPERATURE OF HEAT ACCUMULATION UNIT
SECOND CIRCULATING PUMP
40

FIG. 6


START
ST21
"FIRST OPERATION MODE"SWITCH THREE-WAY VALVE TO FIRST HEAT MEDIUM CIRCULATION PATH
ST22
FIRST CIRCULATING PUMP _ ON
ST23
"STARTUP OPERATION" HIGH-ORDER SIDE / LOW-ORDER SIDE COMPRESSORS _ ON LOW-ORDER SIDE FIRST EXPANSION VALVE _ INITIAL OPENING CONTROL LOW-ORDER SIDE SECOND EXPANSION VALVE _ INITIAL OPENING CONTROL HIGH-ORDER SIDE EXPANSION VALVE _ INITIAL OPENING CONTROL
ST24
STARTUP OPERATION COMPLETED
ST25
"NORMAL OPERATION" LOW-ORDER SIDE FIRST EXPANSION VALVE _ SUPERCOOLING DEGREE CONTROL LOW-ORDER SIDE SECOND EXPANSION VALVE _ SUPERCOOLING DEGREE CONTROL HIGH-ORDER SIDE EXPANSION VALVE _ SUCTION SUPERHEAT DEGREE CONTROL
ST26
HEAT MEDIUM RETURN TEMPERATURE < PREDETERMINED VALUE
No
Yes
ST34
DEFROSTING START CONDITION ESTABLISHED
Yes
C
No
B
C
ST37
HEAT ACCUMULATION TEMPERATURE > PREDETERMINED VALUE
No
Yes
ST38
"SECOND OPERATION MODE" SWITCH THREE-WAY VALVE TO SECOND HEAT MEDIUM CIRCULATION PATH
ST39
HEAT ACCUMULATION COMPLETED
ST35
START DEFROSTING OPERATION
ST36
END DEFROSTING OPERATION
ST27
"SECOND OPERATION MODE" SWITCH THREE-WAY VALVE TO SECOND HEAT MEDIUM CIRCULATION PATH
ST28
HEAT ACCUMULATION COMPLETED
ST29
LOW-ORDER SIDE SECOND EXPANSION VALVE _ CLOSED (OR SLIGHTLY OPEN) BY TARGET SUPERCOOLING DEGREE CONTROL
ST30
DEFROSTING START CONDITION ESTABLISHED
Yes
B
No
ST31
HEAT MEDIUM RETURN TEMPERATURE< PREDETERMINED VALUE
No
Yes
ST32
"FIRST OPERATION MODE" SWITCH THREE-WAY VALVE TO FIRST HEAT MEDIUM CIRCULATION PATH
ST33
LOW-ORDER SIDE SECOND EXPANSION VALVE _ OPEN BY TARGET SUPERCOOLING DEGREE CONTROL

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/028293

A. CLASSIFICATION OF SUBJECT MATTER

F25B 7/00(2006.01)i; ***F25B 1/00***(2006.01)i; ***F25B 47/02***(2006.01)i
FI: F25B7/00 D; F25B1/00 321C; F25B1/00 351A; F25B1/00 399Y; F25B47/02 550F

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F25B7/00; F25B1/00; F25B47/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2012-097993 A (SANDEN CORP) 24 May 2012 (2012-05-24) entire text, all drawings	1-10
A	JP 2011-069529 A (HITACHI LTD) 07 April 2011 (2011-04-07) entire text, all drawings	1-10
A	JP 62-077554 A (TOSHIBA CORP) 09 April 1987 (1987-04-09) entire text, all drawings	1-10
A	WO 2016/059837 A1 (SANDEN HOLDINGS CORPORATION) 21 April 2016 (2016-04-21) entire text, all drawings	1-10
A	CN 111795423 A (TONGJI UNIVERSITY) 20 October 2020 (2020-10-20) entire text, all drawings	1-10

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 September 2023	**03 October 2023**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/028293

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2012-097993 A	24 May 2012	US 2013/0227979 A1	
		WO 2012/060164 A1	
		EP 2631562 A1	
		CN 103210264 A	
JP 2011-069529 A	07 April 2011	(Family: none)	
JP 62-077554 A	09 April 1987	(Family: none)	
WO 2016/059837 A1	21 April 2016	US 2017/0227260 A1	
		CN 106796062 A	
CN 111795423 A	20 October 2020	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2013213590 A **[0004]**