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(54) **REFRIGERANT SYSTEM WITH WATER HEATING**

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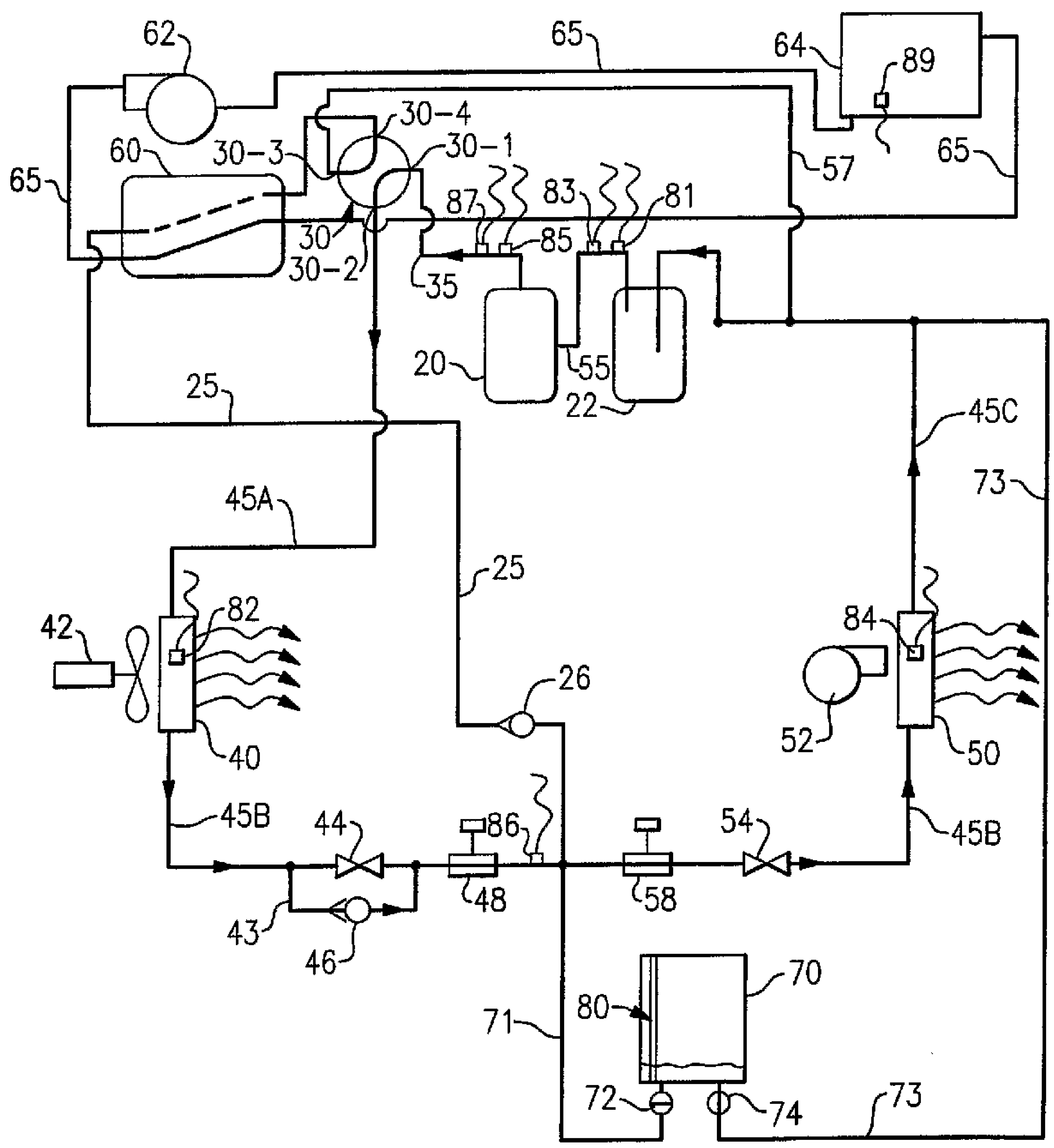
(57) **ABSTRACT**

A heat pump system (**10**) includes a compressor (**20**), a reversing valve (**30**), an outdoor heat exchanger (**40**) and an indoor heat exchanger (**50**) coupled via refrigerant lines (**35**, **45**) in a conventional refrigeration circuit, and a refrigerant-to-water heat exchanger (**60**). In the air cooling with water heating mode, the air heating with water heating mode and the water heating only mode, water from a water reservoir (**64**), such as a storage tank or swimming pool, is passed through heat exchanger (**60**) in heat exchange relationship with refrigerant passing through an additional refrigerant line (**27**) that establishes a fluid flow path through the heat exchanger (**60**) into the refrigerant circuit intermediate the outdoor heat exchanger (**40**) and indoor heat exchanger (**50**). A refrigerant reservoir (**70**) may be provided for use in refrigerant charge control.



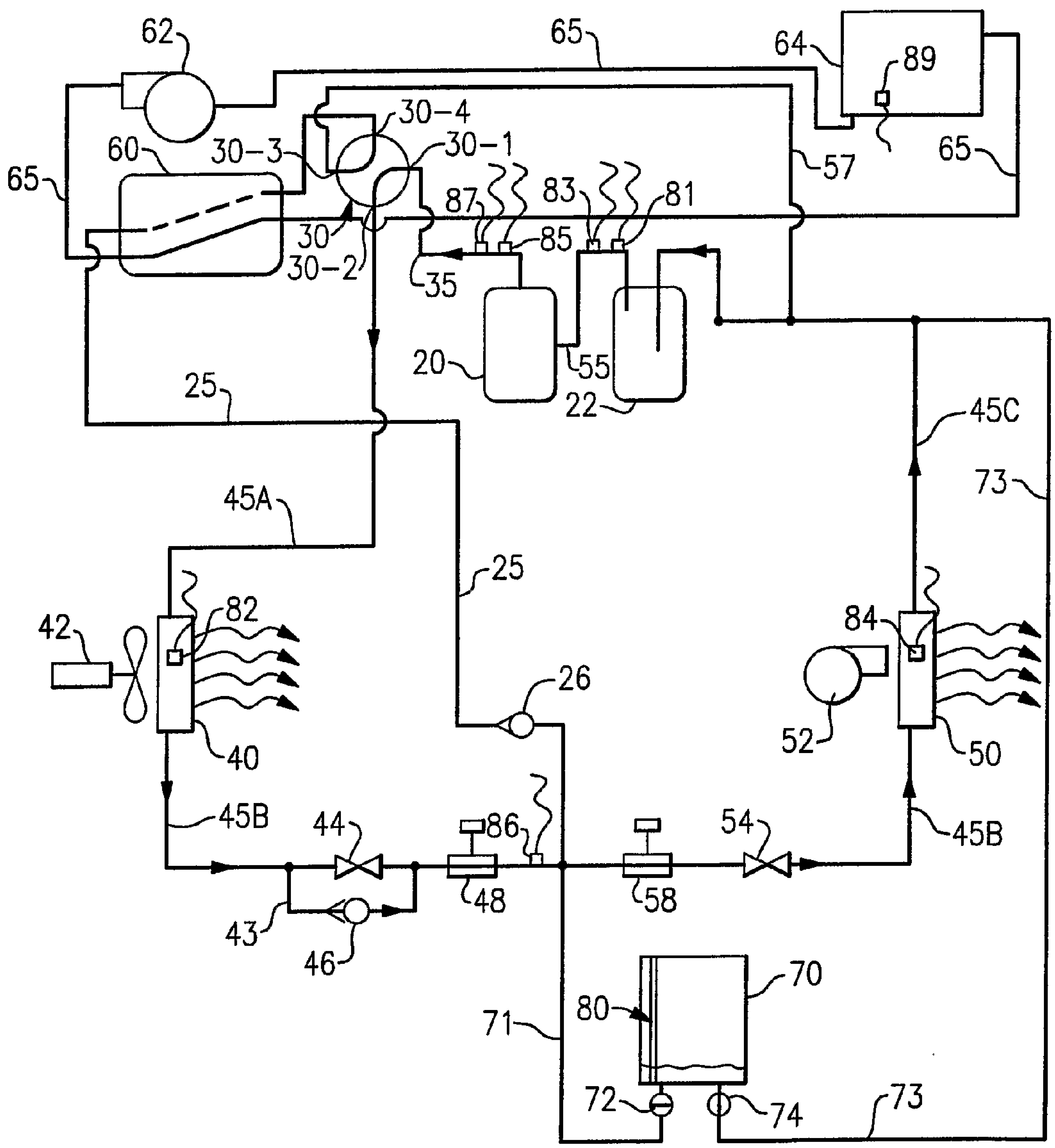

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FIG.1

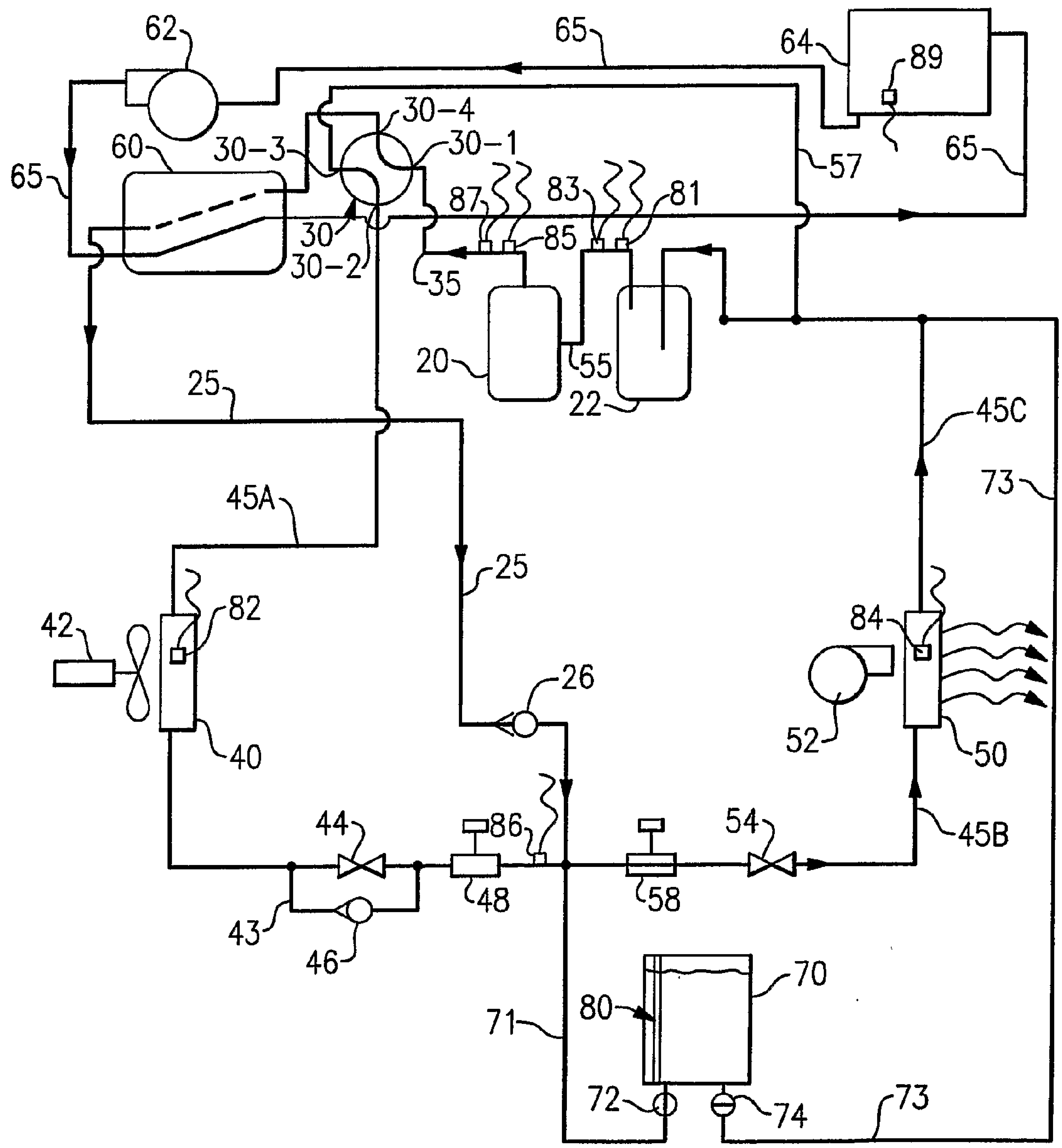
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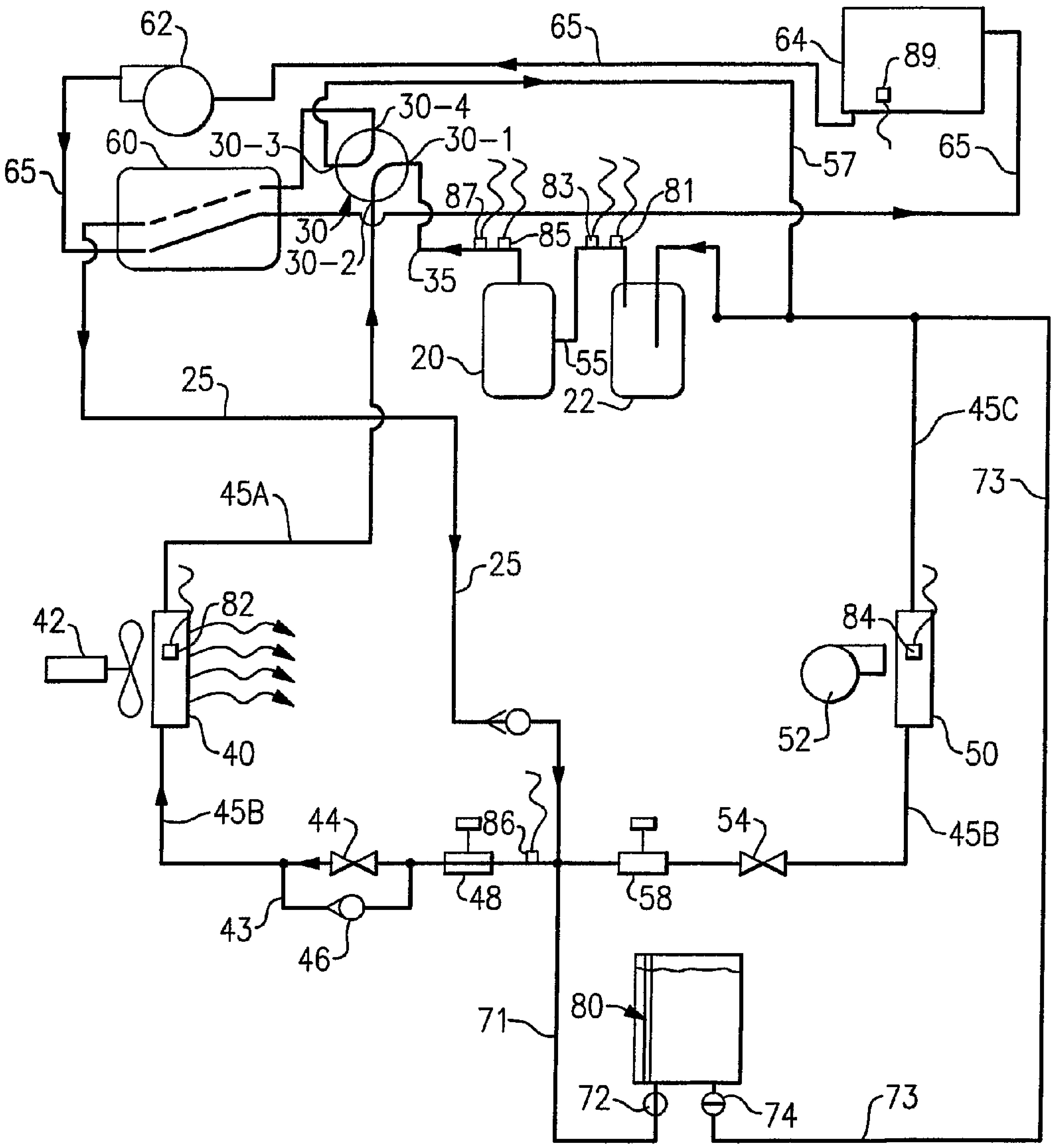
FIG.2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45A
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82
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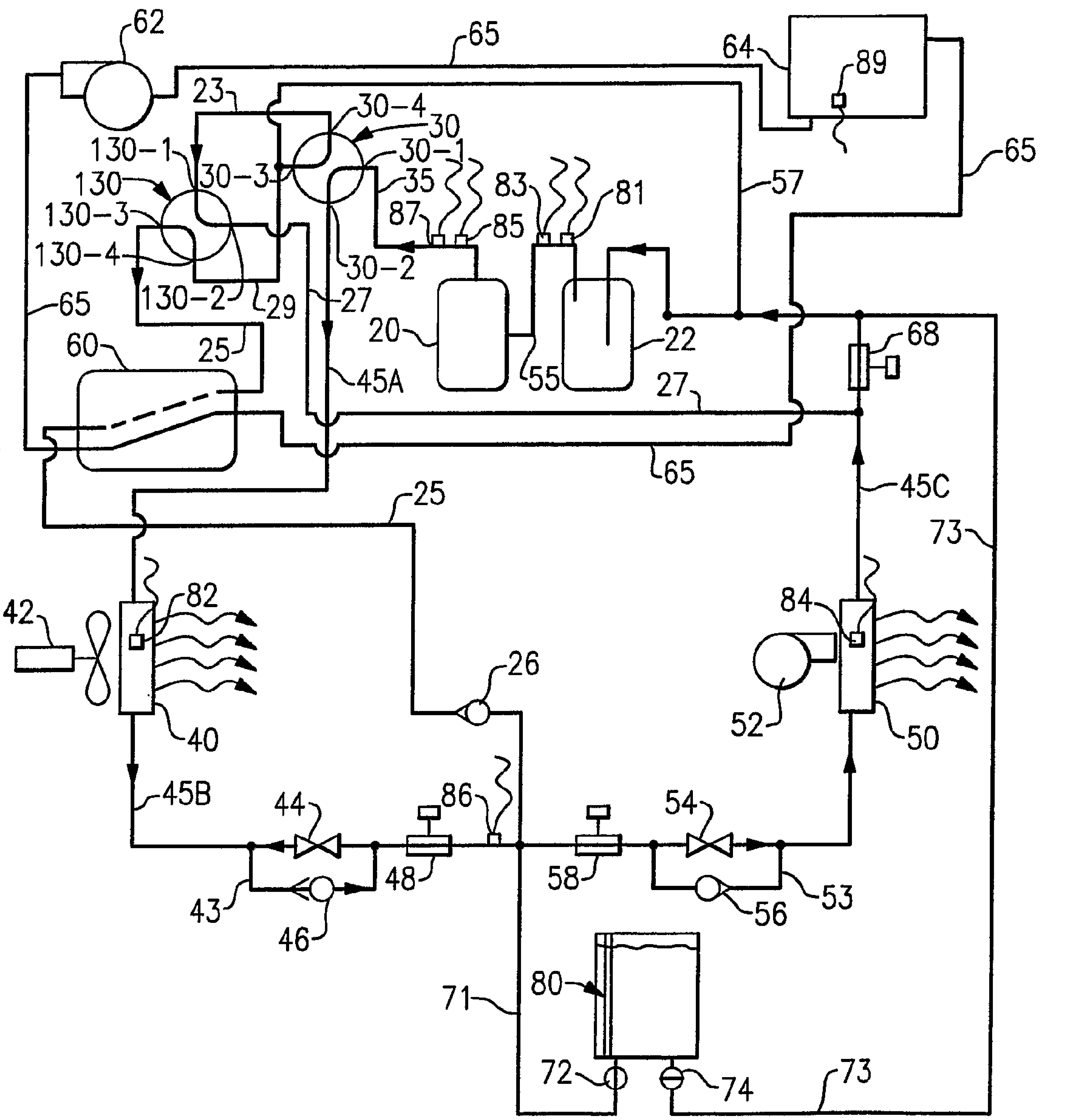
FIG.3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130-4
30-2
65
130-2
29
27
20
22
68
60
25
45A
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45C
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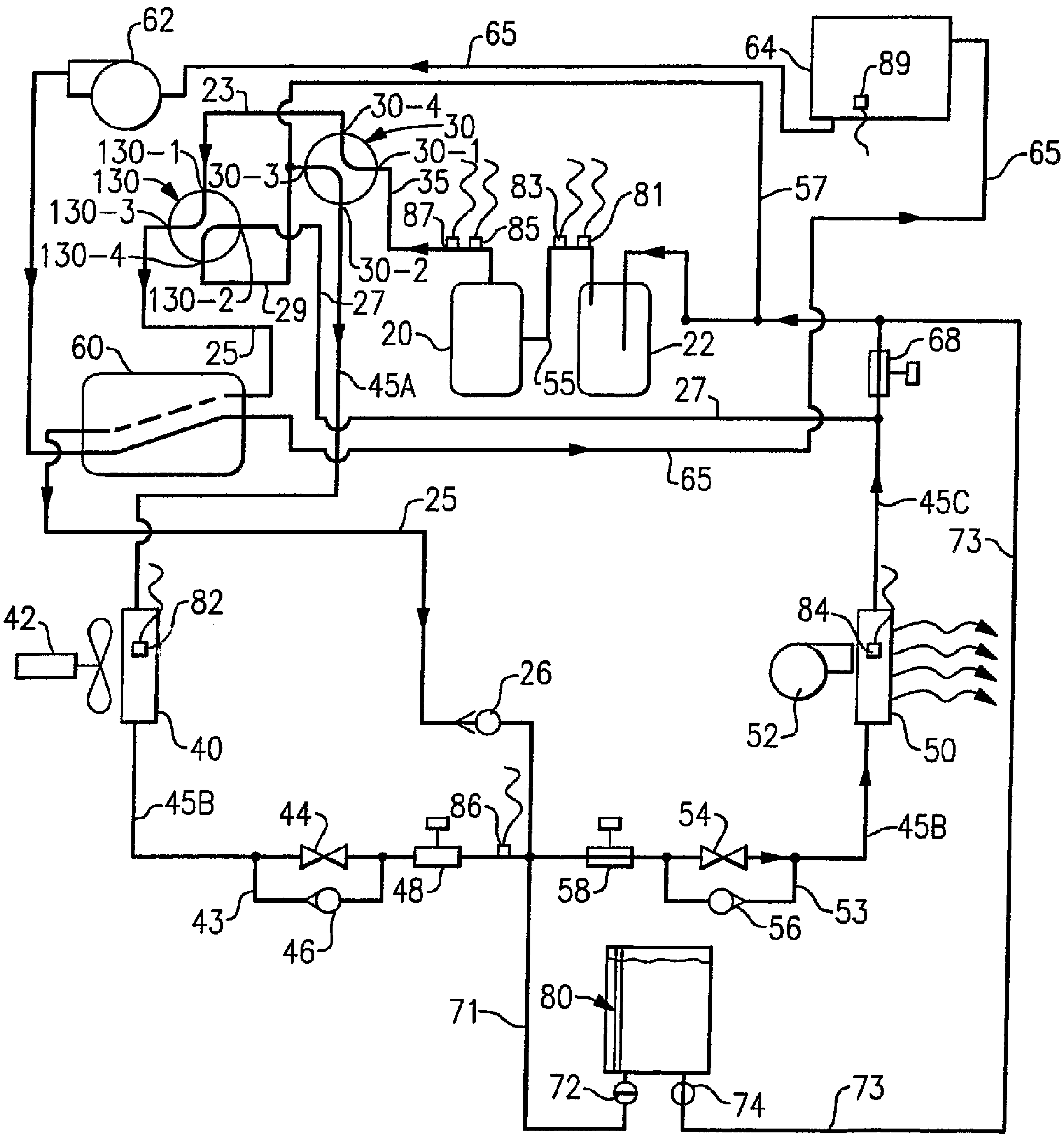
FIG.4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130-4
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130-2
29
27
20
22
68
60
25
45A
55
27
65
25
45C
73
42
82
84
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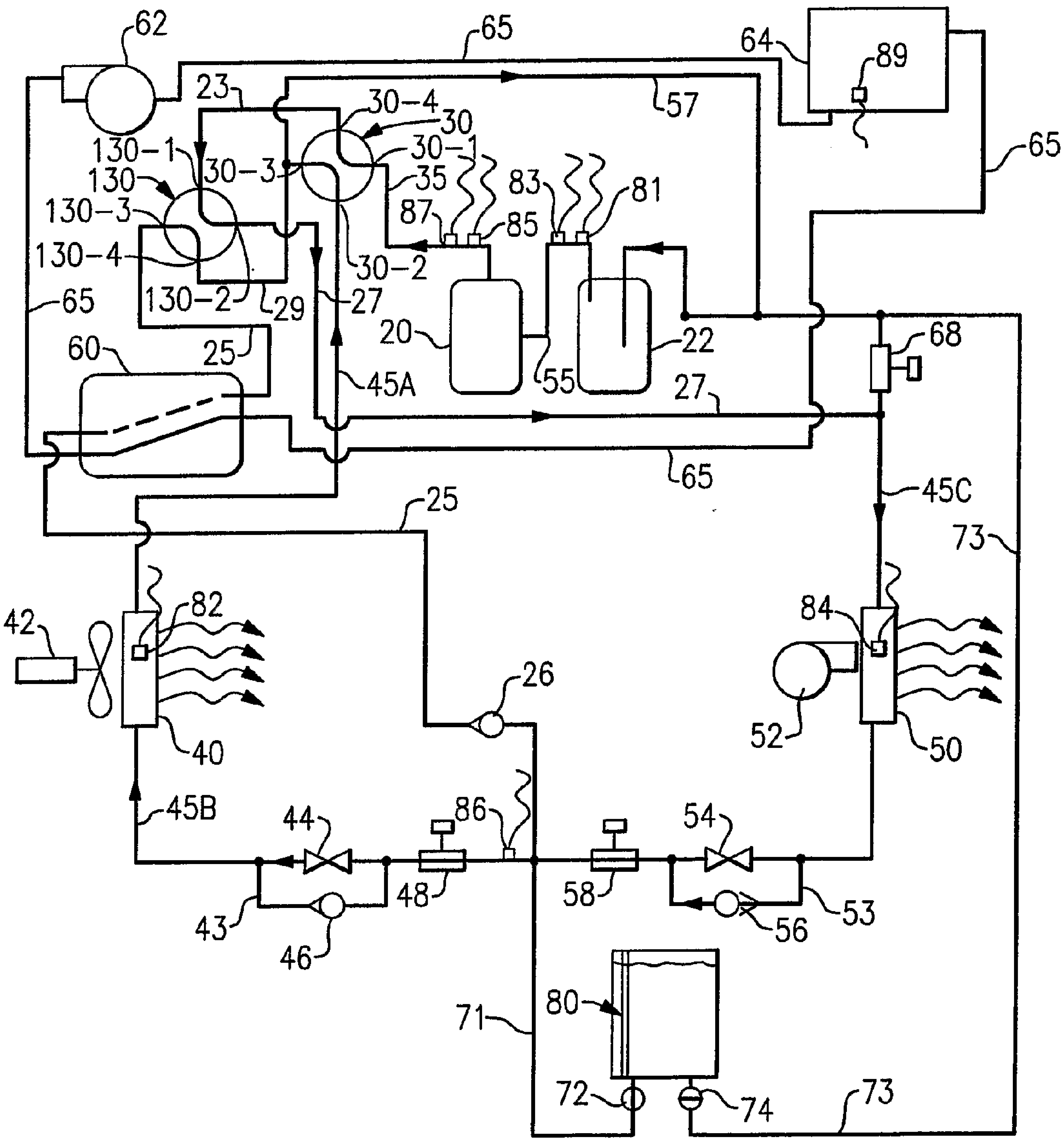
FIG.5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20
22
68
60
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45A
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27
65
25
45C
73
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42
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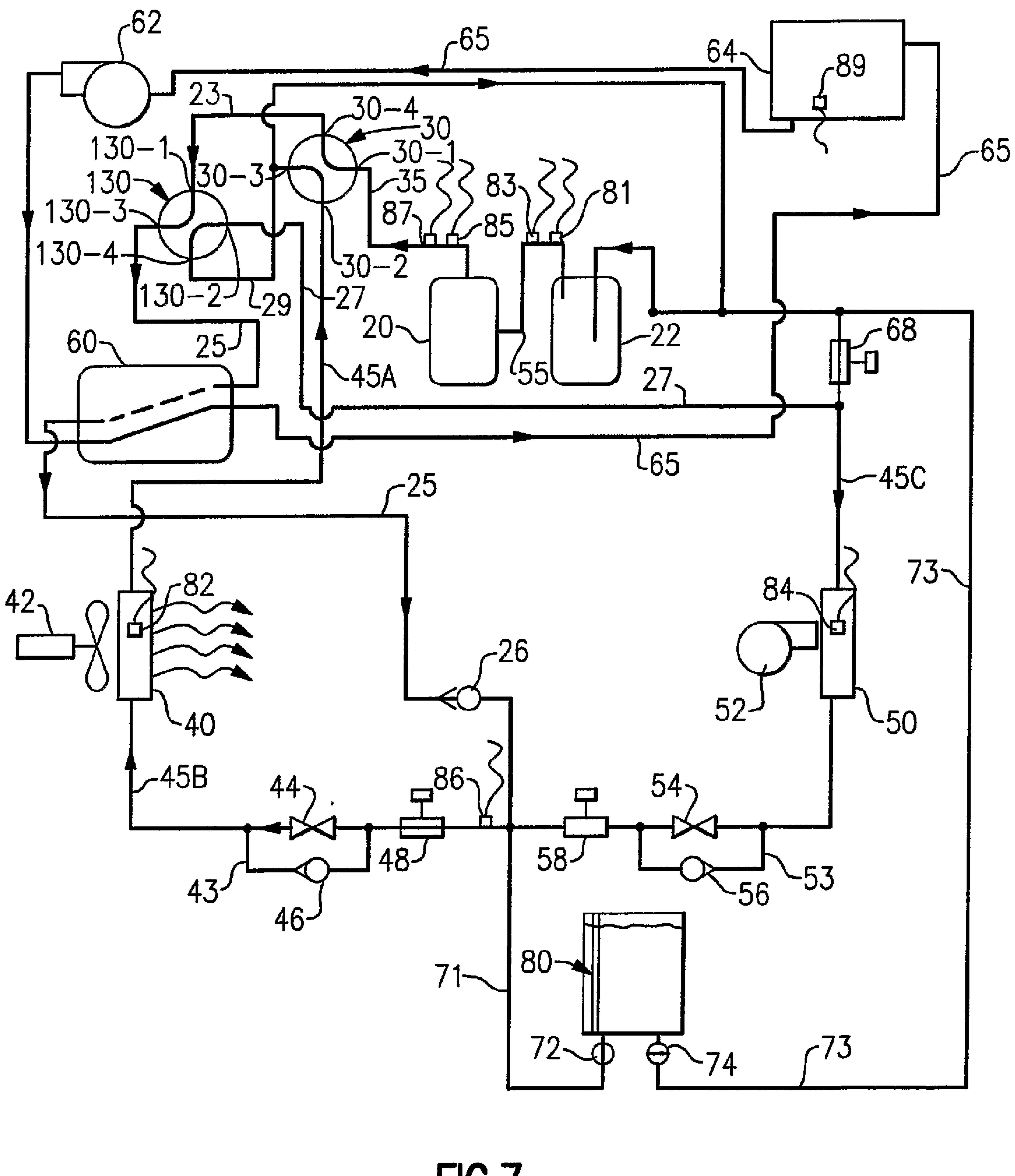
FIG.6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27
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FIG.7

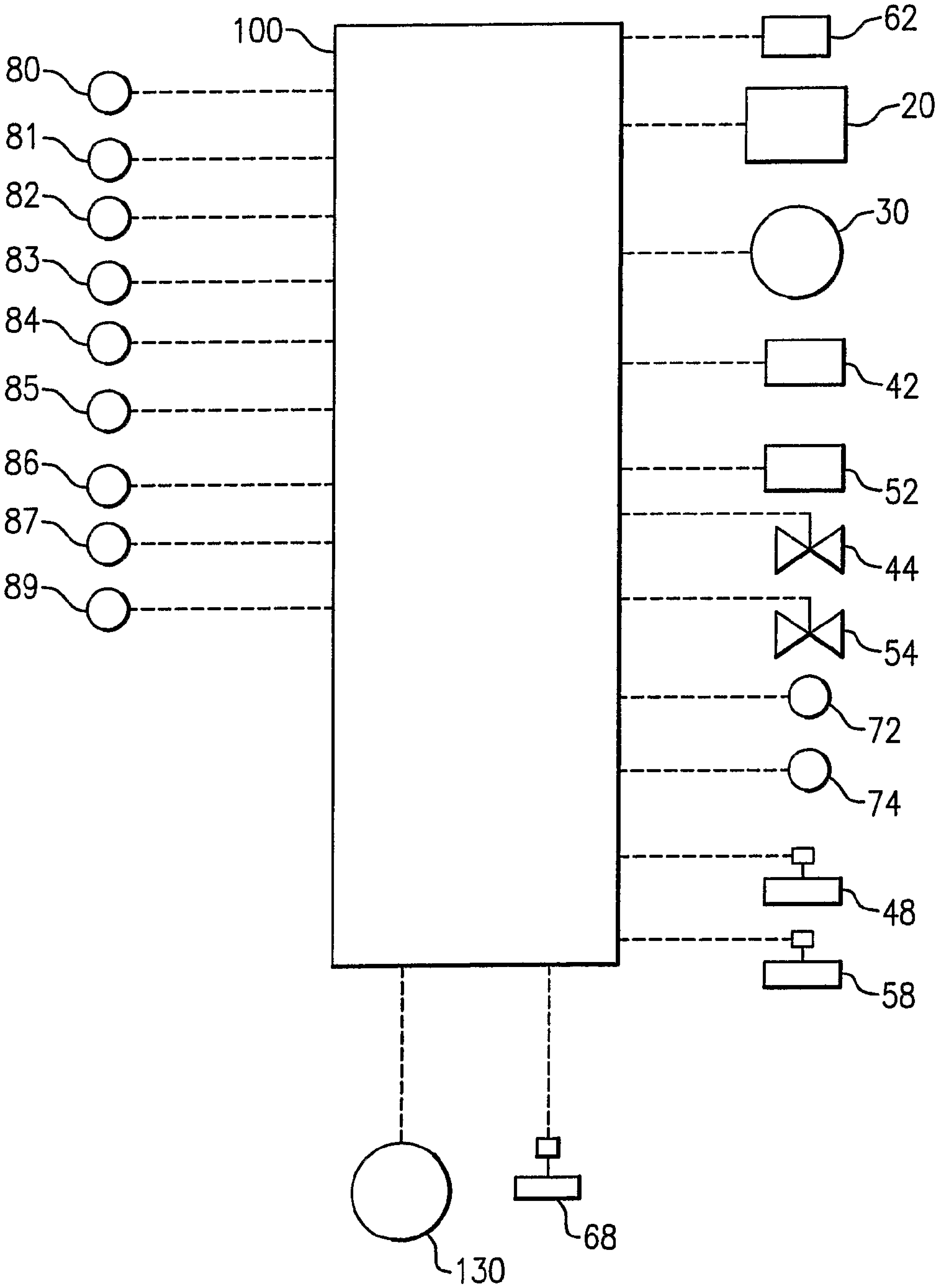

FIG.8

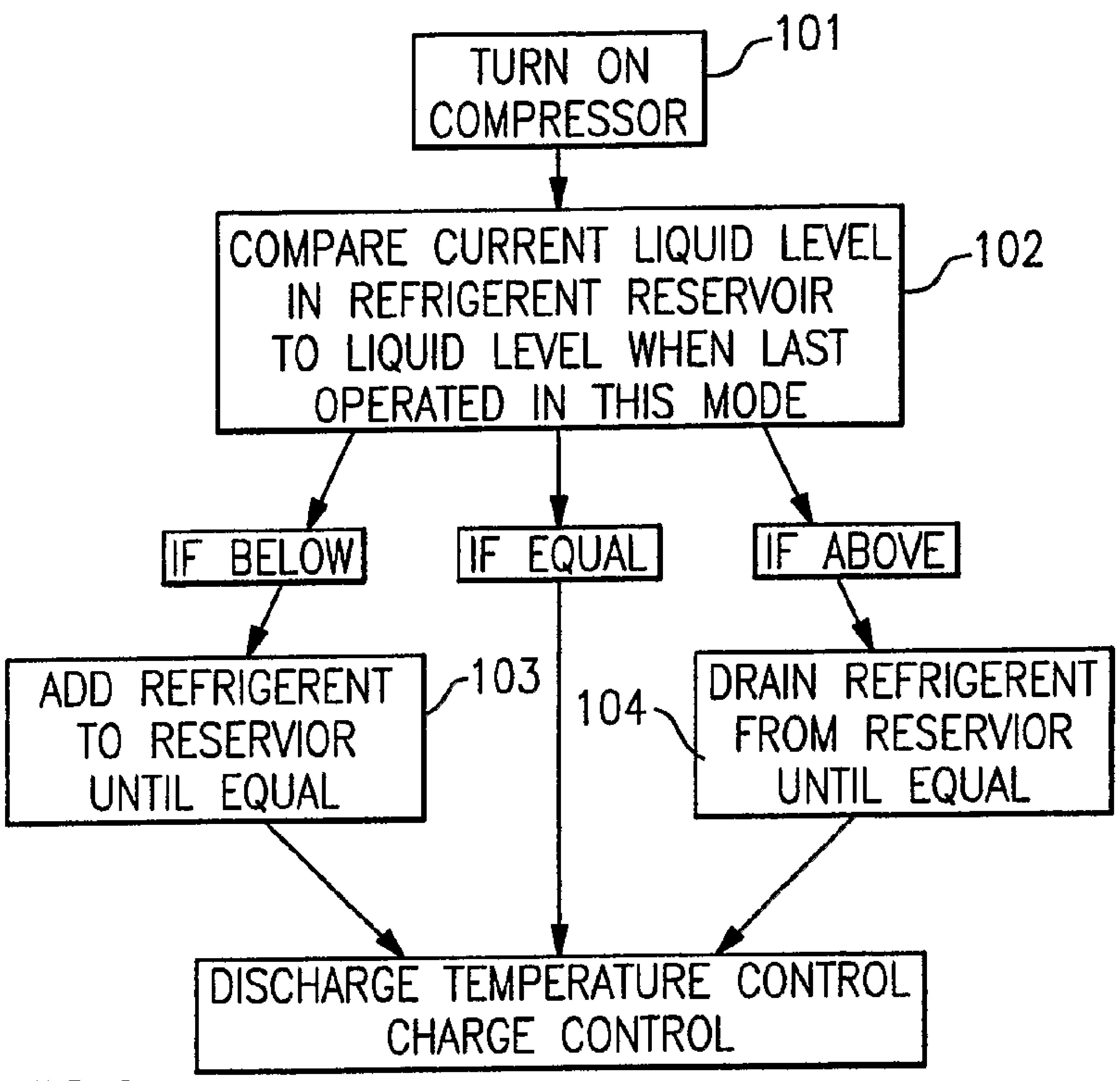
TURN ON COMPRESSOR
101
COMPARE CURRENT LIQUID LEVEL IN REFRIGERENT RESERVOIR TO LIQUID LEVEL WHEN LAST OPERATED IN THIS MODE
102
IF BELOW
IF EQUAL
IF ABOVE
ADD REFRIGERENT TO RESERVIOR UNTIL EQUAL
103
104
DRAIN REFRIGERENT FROM RESERVIOR UNTIL EQUAL
DISCHARGE TEMPERATURE CONTROL CHARGE CONTROL

FIG.9

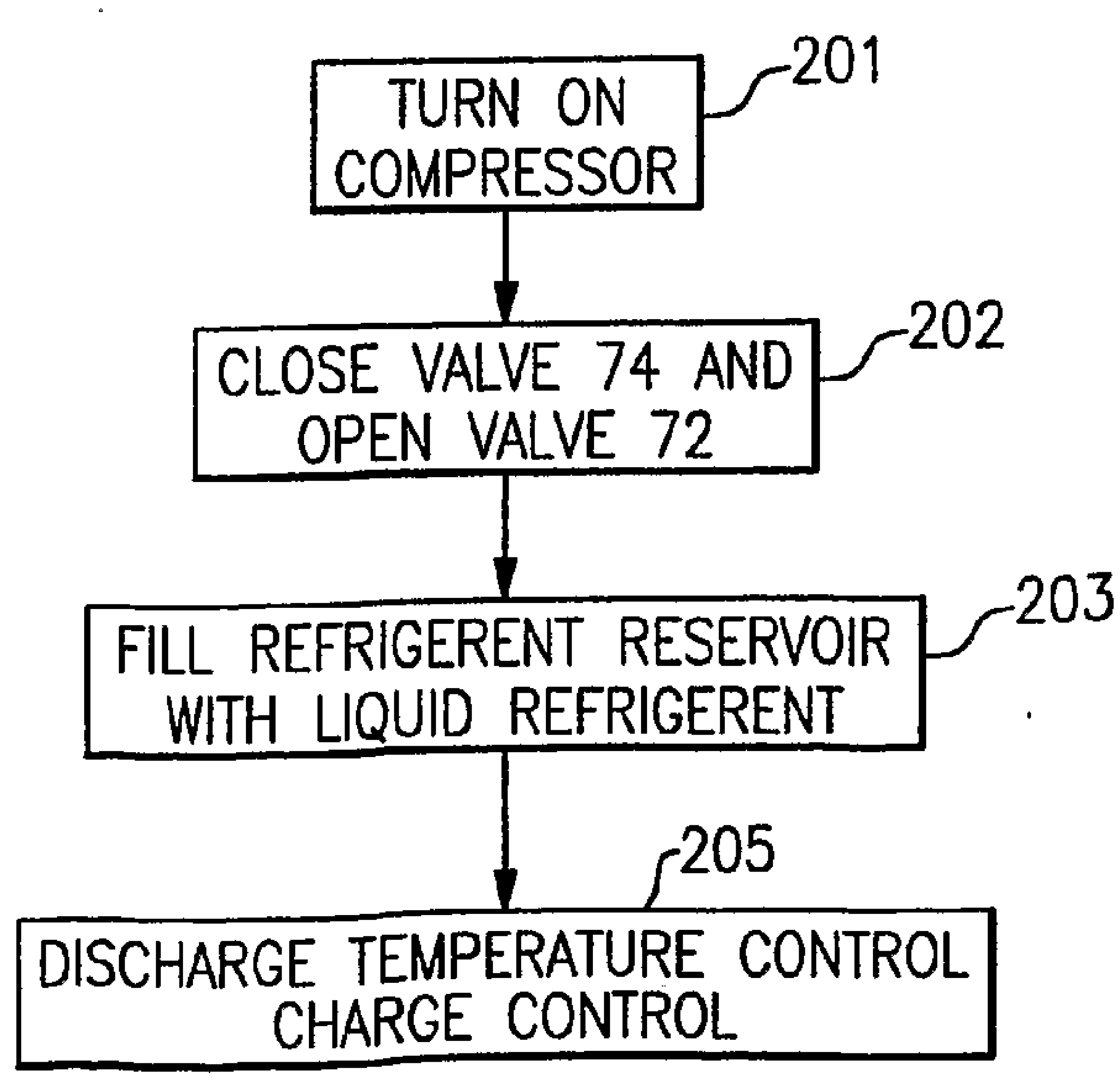
TURN ON COMPRESSOR
201
CLOSE VALVE 74 AND OPEN VALVE 72
202
FILL REFRIGERENT RESERVOIR WITH LIQUID REFRIGERENT
203
205
DISCHARGE TEMPERATURE CONTROL CHARGE CONTROL

FIG.10

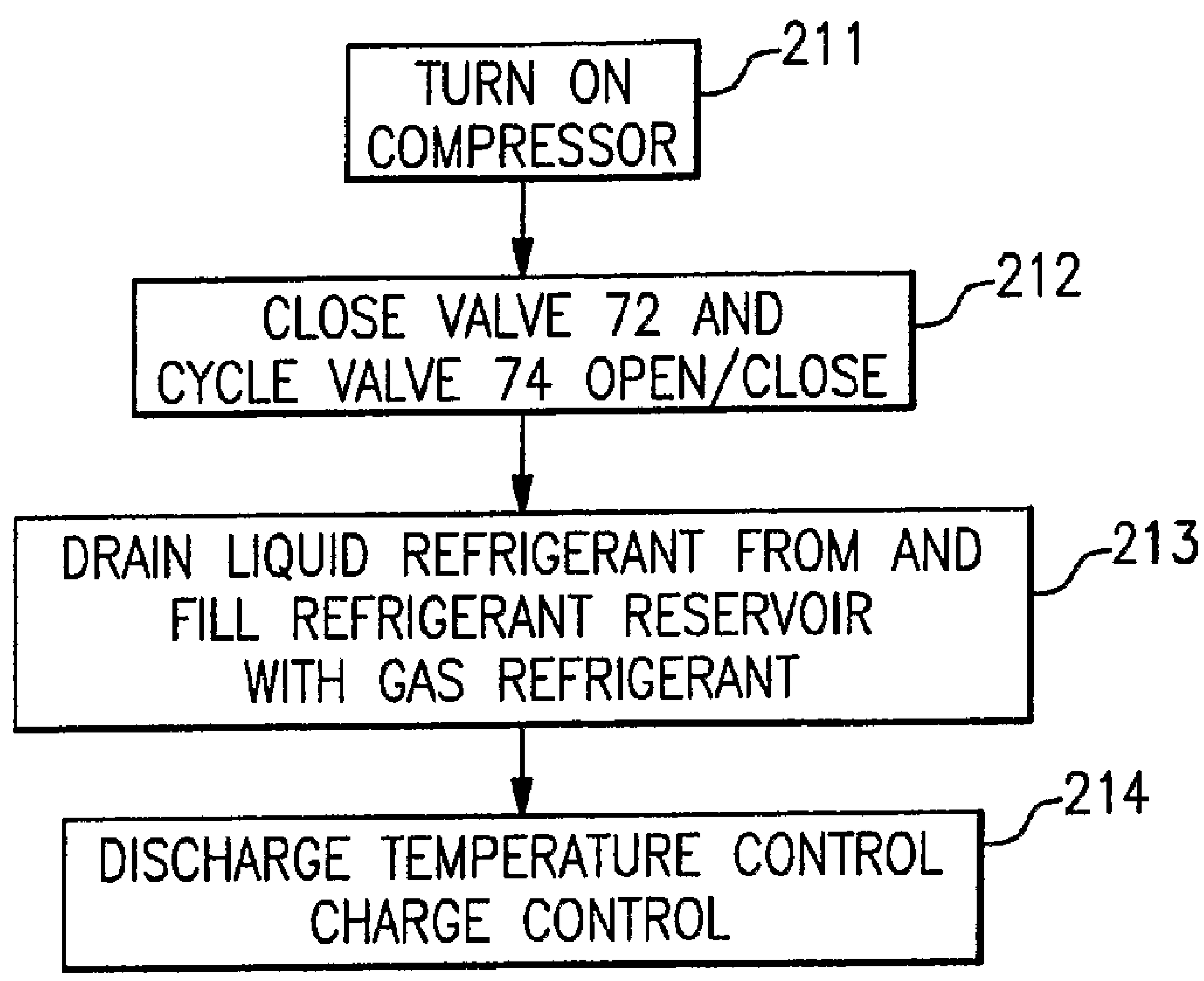
TURN ON COMPRESSOR
211
CLOSE VALVE 72 AND CYCLE VALVE 74 OPEN/CLOSE
212
DRAIN LIQUID REFRIGERANT FROM AND FILL REFRIGERANT RESERVOIR WITH GAS REFRIGERANT
213
DISCHARGE TEMPERATURE CONTROL CHARGE CONTROL
214

FIG.11

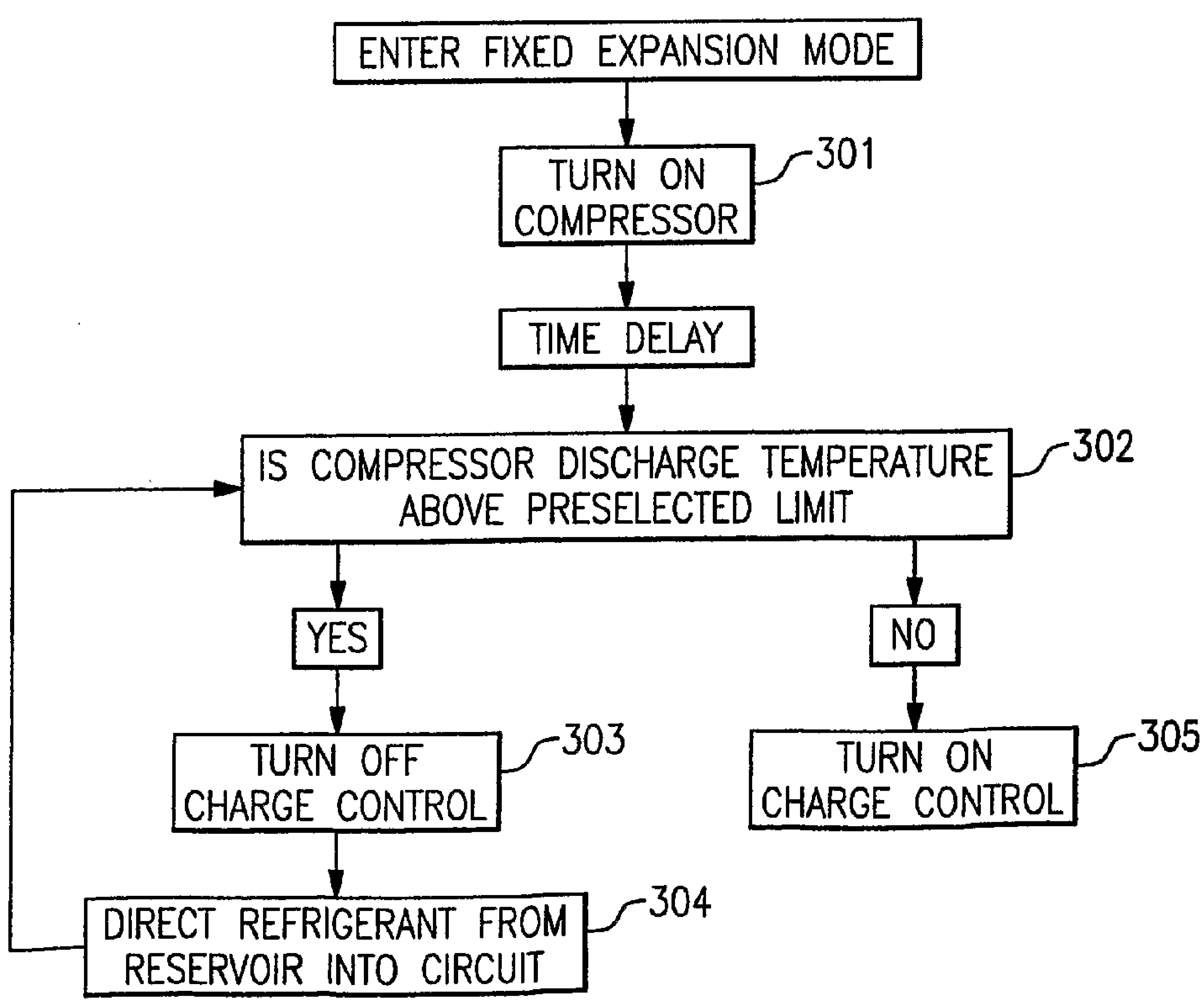
ENTER FIXED EXPANSION MODE
TURN ON COMPRESSOR
301
TIME DELAY
IS COMPRESSOR DISCHARGE TEMPERATURE ABOVE PRESELECTED LIMIT
302
YES
NO
TURN OFF CHARGE CONTROL
303
TURN ON CHARGE CONTROL
305
DIRECT REFRIGERANT FROM RESERVOIR INTO CIRCUIT
304

FIG.12

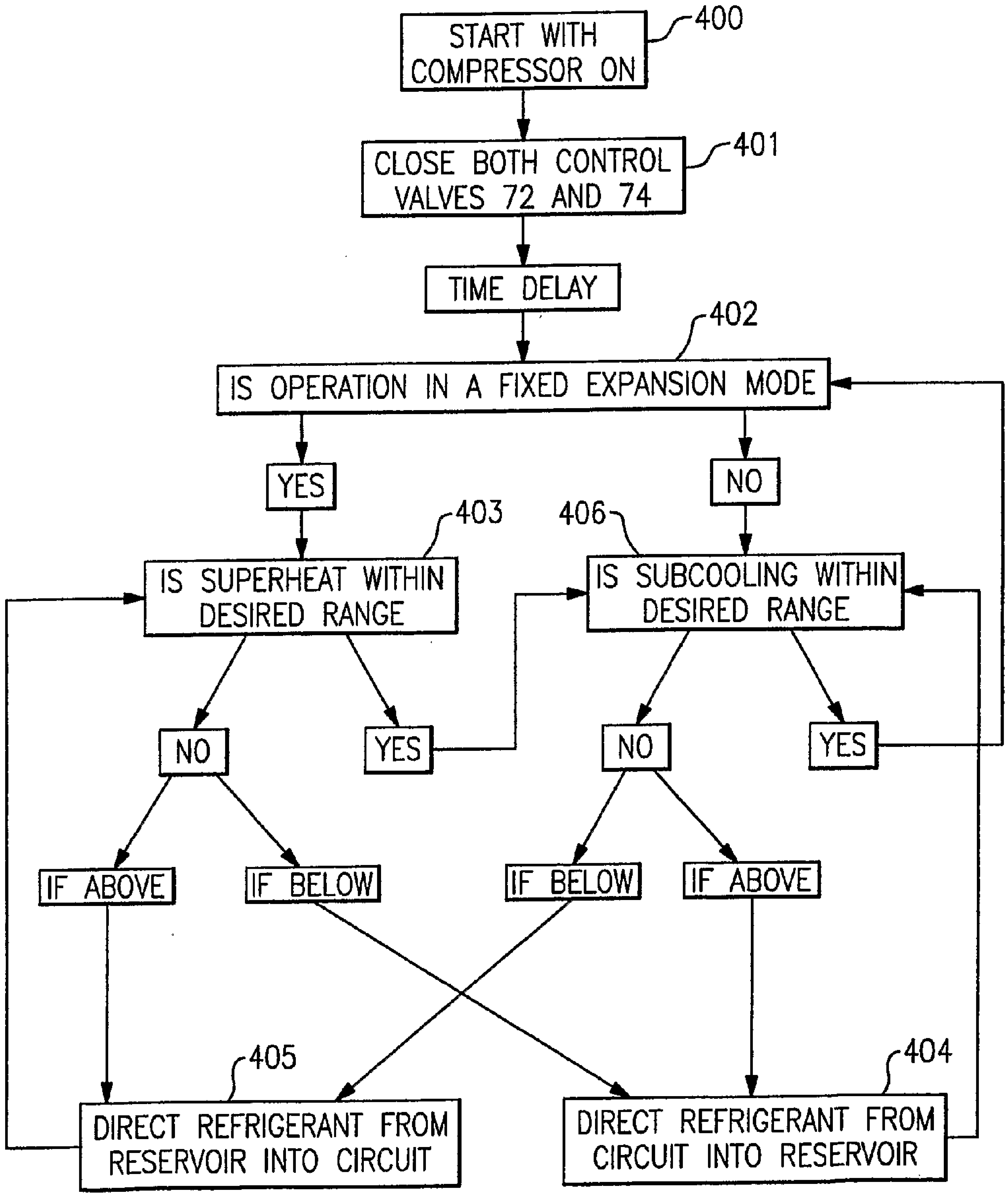
START WITH COMPRESSOR ON
400
CLOSE BOTH CONTROL VALVES 72 AND 74
401
TIME DELAY
402
IS OPERATION IN A FIXED EXPANSION MODE
YES
NO
403
IS SUPERHEAT WITHIN DESIRED RANGE
406
IS SUBCOOLING WITHIN DESIRED RANGE
NO
YES
NO
YES
IF ABOVE
IF BELOW
IF BELOW
IF ABOVE
405
DIRECT REFRIGERANT FROM RESERVOIR INTO CIRCUIT
404
DIRECT REFRIGERANT FROM CIRCUIT INTO RESERVOIR

FIG.13

REFRIGERANT SYSTEM WITH WATER HEATING

TECHNICAL FIELD

[0001] This invention relates generally to refrigerant systems for cooling or cooling/heating indoor air and, more particularly, to such refrigerant systems including auxiliary liquid heating, including for example heating water for swimming pools, household water systems and the like.

BACKGROUND ART

[0002] Refrigerant systems, such as air conditioners and reversible heat pumps are well known in the art and commonly used for cooling and cooling/heating, respectively, a climate controlled comfort zone within a residence or a building. A conventional air conditioner or heat pump refrigerant system includes a compressor, a suction accumulator, an outdoor heat exchanger with an associated fan, an indoor heat exchanger **50** with an associated fan, and an expansion valve operatively associated with the indoor heat exchanger. A heat pump system further includes a reversing valve and an additional expansion valve operatively associated with the outdoor heat exchanger. The aforementioned components are typically arranged in a closed refrigerant circuit employing the well known Carnot vapor compression cycle. When operating in the cooling mode, excess heat absorbed by the refrigerant in passing through the indoor heat exchanger is rejected to the environment as the refrigerant passes through the outdoor heat exchanger.

[0003] It is well known in the art that an additional refrigerant-to-water heat exchanger may be added to a heat pump system to absorb this excess heat for the purpose of heating water, rather than simply rejecting the excess heat to the environment. Further, heat pumps often have non-utilized heating capacity when operating in the heating mode for heating the climate controlled zone. For example, each of U.S. Pat. Nos. 3,188,829; 4,098,092; 4,492,092 and 5,184,472 discloses a heat pump system including an auxiliary hot water heat exchanger. U.S. Pat. No. 5,802,864 discloses an air conditioning system for use in cooling and dehumidifying air for an interior space while rejecting heat to several alternative heat sinks, such as the atmosphere, domestic hot water heating and pool water heating. However, these systems do not include any device for controlling the refrigerant charge within the refrigerant circuit. Therefore, while functional, these systems would not be optimally efficient in all modes of operation.

[0004] In heat pump systems, the outdoor heat exchanger and the indoor heat exchanger each operate as evaporator, condenser or subcooler, depending on the mode and point of operation. As such, condensing may occur in either heat exchangers, and the suction line may be filled with refrigerant in a gaseous or liquid state. As a consequence, the amount of system refrigerant charge required in each mode of operation in order to ensure operation within an acceptable efficiency envelope will be different for each mode.

[0005] U.S. Pat. No. 4,528,822 discloses a heat pump system including an additional refrigerant-to-liquid heat exchanger for heating liquid utilizing the heat that would otherwise be rejected to the environment. The system is operable in four independent modes of operation: space heating, space cooling, liquid heating and simultaneous space cooling with liquid heating. In the liquid heating only mode, the indoor heat exchanger fan is turned off, while in the space cooling and liquid heating mode, the outdoor heat exchanger fan is turned off. A refrigerant charge reservoir is provided into which liquid refrigerant drains by gravity from the refrigerant to liquid heat exchanger during the liquid heating only mode and the simultaneous space cooling and liquid heating mode. However, no control procedure is disclosed for actively controlling refrigerant charge in the refrigerant circuit in all modes of operation. Further, no simultaneous space heating and liquid heating mode is disclosed.

[0006] Accordingly, it is desirable that the system be provide that includes active refrigerant charge control in all modes of operation whereby the heat pump system may operate effectively in an air cooling only mode, an air cooling and liquid heating mode, an air heating only mode, an air heating and liquid heating mode, and a liquid heating only mode.

SUMMARY OF THE INVENTION

[0007] In one aspect, it is an object of the invention to provide an air conditioner/heat pump system having liquid heating capability and improved refrigerant charge control.

[0008] In one aspect, it is a object of the invention to provide an air conditioner/heat pump refrigerant system having liquid heating capability with refrigerant charge control in all operating modes.

[0009] In one embodiment of the invention, the system includes a refrigerant compressor having a suction port and a discharge port; a selectively positionable four-port reversing valve having a first position for coupling the first port and the second port in fluid flow communication and the third port and the fourth port in fluid flow communication, and a second position for coupling the first port and the fourth port in fluid flow communication and the second port and the third port in fluid flow communication; and a refrigerant circuit providing a closed loop refrigerant circulation flow path. The refrigerant circuit has a first refrigerant line establishing a flow path between the discharge port of the compressor and the first port of the reversing valve, a second refrigerant line establishing a flow path between the second port of the reversing valve and the suction port of the compressor. An outdoor heat exchanger is disposed in operative association with the second refrigerant line and is adapted for passing refrigerant passing through the second refrigerant line in heat exchange relationship with ambient air. An indoor heat exchanger is disposed inoperative association with the second refrigerant line and is adapted for passing refrigerant passing through the second refrigerant line in heat exchange relationship with the air from the comfort zone. The indoor heat exchanger is disposed downstream of the outdoor exchanger with respect to refrigerant flow in the air cooling mode. A third refrigerant line establishes a flow path between the fourth port of the reversing valve and the second refrigerant line at a location intermediate the outdoor heat exchanger and the indoor heat exchanger. A refrigerant to liquid heat exchanger is disposed in operative association with the third refrigerant line and is adapted for passing refrigerant passing through the third refrigerant line in heat exchange relationship with a liquid. A refrigerant reservoir may be provided having an inlet coupled in fluid flow communication to the second refrigerant line at a location intermediate the outdoor heat exchanger and the indoor heat exchanger and an outlet coupled in fluid flow communication to the suction inlet of the compressor. A first flow control valve is disposed in the second refrigerant line intermediate the outdoor heat exchanger and the location of the intersection of the third refrigerant line with the second refrigerant line, and a second flow control valve is disposed in the second refrigerant line intermediate the indoor heat exchanger and the location of the intersection of the third refrigerant line with the second refrigerant line. A controller is provided to selectively control the respective positioning of the first and second flow control valves between their respective open and closed positions so as to selectively control refrigerant flow through the second refrigerant line. A flow check valve may be disposed in the third refrigerant line so as to permit refrigerant flow therethrough in a direction from the reversing valve into the second refrigerant line and to block flow from the second refrigerant line to the reversing valve.

[0010] In another embodiment of the invention, a heat pump system includes a refrigerant compressor having a suction port and a discharge port; a first selectively positionable four-port valve having a first position for coupling the first port and the second port in fluid flow communication and the third port and the fourth port in fluid flow communication, and a second position for coupling the first port and the fourth port in fluid flow communication and the second port and the third port in fluid flow communication; and a refrigerant circuit providing a closed loop refrigerant circulation flow path. The refrigerant circuit has a first refrigerant line establishing a flow path between the discharge port of the compressor and the first port of the reversing valve, a second refrigerant line establishing a flow path between the second port of the reversing valve and the suction port of the compressor. An outdoor heat exchanger is disposed in operative association with the second refrigerant line and is adapted for passing refrigerant passing through the second refrigerant line in heat exchange relationship with ambient air. An indoor heat exchanger is disposed inoperative association with the second refrigerant line and is adapted for passing refrigerant passing through the second refrigerant line in heat exchange relationship with the air from the comfort zone. The indoor heat exchanger is disposed downstream of the outdoor exchanger with respect to refrigerant flow in the air cooling mode and upstream of the outdoor heat exchanger with respect to refrigerant flow through the second refrigerant line in the air heating mode.

[0011] In this embodiment, a second selectively positionable four-port valve is provided having a first position for coupling the first port and the second port in fluid flow communication and the third port and the fourth port in fluid flow communication and a second position for coupling the first port and the third port in fluid flow communication and the second port and the fourth port in fluid flow communication. A third refrigerant line establishes a flow path between the fourth port of the first reversing valve and the first port of the second reversing valve. A fourth refrigerant line establishes a flow path between the third port of the second reversing valve and the second refrigerant line at a location intermediate the outdoor heat exchanger and the indoor heat exchanger. A fifth refrigerant line establishes a flow path between the second port of the reversing valve and the second refrigerant line at a location intermediate the indoor heat exchanger and the suction inlet to the compressor. A refrigerant to liquid heat exchanger is disposed in operative association with the fourth refrigerant line and is adapted for passing refrigerant passing through the fourth refrigerant line in heat exchange relationship with a liquid. A first flow control valve is disposed in the second refrigerant line intermediate the outdoor heat exchanger and the location of the intersection of the third refrigerant line with the second refrigerant line. A second flow control valve is disposed in the second refrigerant line intermediate the indoor heat exchanger and the location of the intersection of the third refrigerant line with the second refrigerant line. A third flow control valve is disposed in the second refrigerant line intermediate the location of the intersection of the fifth refrigerant line with the second refrigerant line and the suction inlet to the compressor. A controller is provided to selectively control the respective positioning of the first, second and third flow control valves between their respective open and closed positions so as to selectively control refrigerant flow through the second refrigerant line. A flow check valve may be disposed in the third refrigerant line so as to permit refrigerant flow therethrough in a direction from the reversing valve into the second refrigerant line and to block flow from the second refrigerant line to the reversing valve.

[0012] In the heat pump embodiment, as in the air conditioning embodiment of the system, a refrigerant reservoir may be provided having an inlet coupled in fluid flow communication to the second refrigerant line at a location intermediate the outdoor heat exchanger and the indoor heat exchanger and an outlet coupled in fluid flow communication to the suction inlet of the compressor. Advantageously, a first flow control valve may be provided in operative association with the refrigerant reservoir for controlling the flow of refrigerant from the second refrigerant line to the inlet of the refrigerant reservoir; and a second flow control valve may be provided in operative association with the refrigerant reservoir for controlling the flow refrigerant between the outlet of refrigerant reservoir and the suction inlet of the compressor. The controller selectively controls the respective positioning of these flow control valves between their respective open and closed positions so as to selectively control the refrigerant charge within the refrigerant circuit. These flow control valves may also have at least one partially open position and may comprise pulse width modulated solenoid valves. The controller may be further operative to selectively modulate the respective positioning of these flow control valves between their open, partially open and closed positions.

[0013] In a further embodiment, a liquid level sensor may be provided for sensing the level of liquid refrigerant in the refrigerant reservoir and for providing a signal to the controller indicative of the liquid level within the refrigerant reservoir. In response to the liquid level signal, the controller will selectively control the respective positioning of the first and second flow control valves operatively associated with the refrigerant reservoir so as to selectively control the refrigerant charge within the refrigerant circuit.

[0014] In a further aspect of the invention, in the heat pump embodiment, the system may be used to heat both indoor air and water by cycling between the indoor air heating mode and the water heating mode. To do so, the system controller will switch between the air heating only mode and the water heating only mode every few minutes until the water temperature set point or the air indoor temperature set point has been reached.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] For a further understanding of these and objects of the invention, reference will be made to the following detailed description of the invention which is to be read in connection with the accompanying drawing, where:

[0016] FIG. **1** is a schematic diagram illustrating a first embodiment of the system of the invention illustrating operation in the indoor air cooling only mode;

[0017] FIG. **2** is a schematic diagram illustrating a first embodiment of the system of the invention illustrating operation in the indoor air cooling with water heating mode;

[0018] FIG. **3** is a schematic diagram illustrating a first embodiment of the system of the invention illustrating operation in the water heating only mode;

[0019] FIG. **4** is a schematic diagram illustrating a second embodiment of the heat pump system of the invention illustrating operation in an air cooling only mode;

[0020] FIG. **5** is a schematic diagram illustrating a second embodiment of the system of the invention illustrating operation in the indoor air cooling with water heating mode;

[0021] FIG. **6** is a schematic diagram illustrating a second embodiment of the heat pump system of the invention illustrating operation in an air heating mode;

[0022] FIG. **7** is a schematic diagram illustrating a second embodiment of the heat pump system of the invention illustrating operation in a water heating mode;

[0023] FIG. **8** is a schematic diagram illustrating an embodiment of a control system arrangement for the system of the invention;

[0024] FIG. **9** is block diagram illustrating a first embodiment of a refrigerant charge adjustment procedure at start-up in a new mode of operation;

[0025] FIG. **10** is a block diagram illustrating a second embodiment of a refrigerant charge adjustment procedure at start-up in a new mode of operation;

[0026] FIG. **11** is a block diagram illustrating a third embodiment of a refrigerant charge adjustment procedure at start-up in a new mode of operation;

[0027] FIG. **12** is a block diagram illustrating a discharge temperature limit control procedure for adjusting refrigerant charge post start-up; and

[0028] FIG. **13** is a block diagram illustrating a charge control procedure for adjusting refrigerant charge post start-up.

DETAILED DESCRIPTION OF THE INVENTION

[0029] The refrigerant heat pump system **10**, depicted in a first embodiment in FIGS. **1-3** and a second embodiment in FIGS. **4-7**, provides in the first embodiment cooling of air to a comfort region and in the second embodiment cooling and heating of air to a comfort region, for example an indoor zone located on the inside of a building (not shown), and also auxiliary water heating in each embodiment when desired. The system includes a compressor **20**, a suction accumulator **22**, a reversing valve **30**, an outdoor heat exchanger **40** and associated fan **42** located on the outside of the building in heat transfer relation with the surrounding ambient, an indoor heat exchanger **50** and associated fan **52** situated in the comfort zone, a first expansion valve **44** operatively associated with the outdoor heat exchanger **40** and a second expansion valve **54** operatively associated with the indoor heat exchanger **50**. A refrigerant circuit including refrigerant lines **35**, **45** and **55** provide a closed loop refrigerant flow path coupling these components in a conventional manner for a heat pump system employing the well known Carnot vapor compression cycle. Additionally, the system **10** includes a refrigerant-to-water heat exchanger **60** wherein refrigerant is passed in heat exchange relationship with water to be heated. The water to be heated is pumped by a circulating pump **62** via water circulation line **65** from a water reservoir **64**, for example a hot water storage tank or a swimming pool, through the heat exchanger **60** and back to the reservoir **64**.

[0030] The compressor **20**, which may comprise a rotary compressor, a scroll compressor, a reciprocating compressor, a screw compressor or any other type of compressor, has a suction inlet for receiving refrigerant from the suction accumulator **22** and an outlet for discharging compressed refrigerant. The reversing valve **30** may comprise a selectively positionable, two-position, four-port valve having a first port **30-1**, a second port **30-2**, a third port **30-3** and a fourth port **30-4**. The reversing valve **30** is positionable in a first position for coupling the first port and the second port in fluid flow communication and for simultaneously coupling the third port and the fourth port in fluid flow communication. The reversing valve **30** is positionable in a second position for coupling the first port and the fourth port in fluid flow communication and for simultaneously coupling the second port and the third port in fluid flow communication. Advantageously, the respective port-to-port couplings established in the first and second positions are accomplished internally within the reversing valve **30**. The outlet **28** of the compressor **20** is connected in fluid flow communication via refrigerant line **35** to the first port **30-1** of the reversing valve **30**. The second port **30-2** of the reversing valve **30** is connected in fluid flow communication to refrigerant line **45**A. The third port **30-3** of the reversing valve **30** is connected in fluid flow with refrigerant line **47**. The refrigerant-to-water heat exchanger **60** is operatively associated with the refrigerant line **25** whereby refrigerant flowing through the refrigerant line **25** passes in heat exchange relationship with water passing through water circulation line **65**.

[0031] The outdoor heat exchanger **40** and the indoor heat exchanger **50** are operatively disposed in the refrigerant line **45**. The outdoor heat exchanger **50** is connected in fluid flow communication via section **45**A of the refrigerant line **45** with the second port **30-2** of the reversing valve **30**. The indoor heat exchanger **50** is connected in fluid flow communication to the third port **30-3** of the reversing valve **30** via section **45**C of the refrigerant line **45**. Section **45**B of the refrigerant line **45** couples the outdoor heat exchanger **40** and the indoor heat exchanger **50** in refrigerant flow communication. A suction accumulator **22** may be disposed in refrigerant line **55** on the suction side of the compressor **20**, having its inlet connected in refrigerant flow communication to refrigerant line **45**C via section **45**C of refrigerant line **55** and having its outlet connected in refrigerant flow communication to the suction inlet of the compressor **20** via refrigerant line **55**. Therefore, refrigerant lines **35**, **45** and **55** together couple the compressor **20**, the outdoor heat exchanger **40** and the indoor heat exchanger **50** in refrigerant flow communication, thereby creating a closed loop for refrigerant flow circulation through the heat pump system **10**.

[0032] A first flow control valve **48** and a second flow control valve **58** are disposed in section **45**B of refrigerant line **45** between the outdoor heat exchanger **40** and the indoor heat exchanger **50**. After traversing the refrigerant-to-water heat exchanger **60**, refrigerant line **25** connects in fluid flow communication into refrigerant line **45** at a point intermediate the two flow control valves **48** and **58**. A check valve **26** disposed in refrigerant line **25** permits flow through line **25** into refrigerant line **45**, but closes line **25** to flow in the reverse direction. Advantageously, both of the flow control valves **48**

and **58** are solenoid valves selectively positionable by controller **100** in either the open position or the closed position.

[0033] In the both embodiments, an expansion valve **54** is disposed in section **45**B of the refrigerant line **45** in operative association with the indoor heat exchanger. In the heat pump embodiment, illustrated in FIGS. **4-7**, an expansion valve **44** is also provided in operative association with the outdoor heat exchanger. Each of the expansion valves **44** and **54** is provided with a bypass line equipped with a check valve permitting flow in only one direction. Check valve **46** in bypass line **43** associated with the outdoor heat exchanger expansion valve **44** passes refrigerant flowing from the outdoor heat exchanger **40** to the indoor heat exchanger **50**, thereby bypassing the outdoor heat exchanger expansion valve **44** and passing the refrigerant to the indoor heat exchanger expansion valve **54**. Conversely, check valve **56** in bypass line **53** associated with the indoor heat exchanger expansion valve **54** passes refrigerant flowing from the indoor heat exchanger **50** to the outdoor heat exchanger **40**, thereby bypassing the indoor heat exchanger expansion valve **54** and passing the refrigerant to the outdoor heat exchanger expansion valve **44**.

[0034] In the embodiment of the system depicted in FIGS. **4-7**, the system includes, in addition to the previously mentioned components, a second reversing valve **130** and an additional flow control valve **68**. The second reversing valve **130** may comprise a selectively positionable, two-position, four-port valve having a first port **130-1**, a second port **130-2**, a third port **130-3** and a fourth port **130-4**. The second reversing valve **130** is positionable in a first position for coupling the first port and the second port in fluid flow communication and for simultaneously coupling the third port and the fourth port in fluid flow communication. The reversing valve **130** is positionable in a second position for coupling the first port and the third port in fluid flow communication and for simultaneously coupling the second port and the fourth port in fluid flow communication. Advantageously, the respective port-to-port couplings established in the first and second positions are accomplished internally within the reversing valve **30**. The first port **130-1** of the reversing valve **130** is connected in refrigerant flow communication via refrigerant line **23** to the fourth port **30-1** of the reversing valve **30**. The second port **130-2** of the reversing valve **130** is connected in refrigerant flow communication via refrigerant line **27** into refrigerant line **45**C. The third port **130-3** of the reversing valve **130** is connected in refrigerant flow communication via refrigerant line **25** into refrigerant line **45**B. The fourth port **130-4** of the reversing valve **130** is connected in refrigeration flow communication via refrigerant line **29** into refrigerant line **47**.

[0035] Like the first and second flow control valves **48** and **58**, the third flow control valve **68** may advantageously be a solenoid valve selectively positionable by controller **100** in either the open position or the closed position. When flow control valve **68** is in its open position, refrigerant can flow through refrigerant line **45**C to the suction accumulator through line **45**C. When flow control valve **68** is in its closed position, however, refrigerant can not flow through refrigerant line **45**C back to the suction accumulator through line **45**C.

[0036] In the embodiment of the system of the invention depicted in FIGS. **1-3**, the system functions to cool air to a comfort region, and also to heat water on demand. Therefore, in this embodiment, the system must operate effectively in an air cooling only mode, an air cooling and water heating mode, and a water heating only mode. In the embodiment of the system depicted in FIGS. **4-7**, the system functions to cool and to heat air to a comfort region, and to also heat water on demand except when in the air heating mode. Therefore, in this embodiment, the system must operate effectively in an air cooling only mode, an air cooling and water heating mode, an air heating only mode, and a water heating only mode. As each of the outdoor heat exchanger **40**, the indoor heat exchanger **50** and the refrigerant-to-water heat exchanger **60** will operate one as a condenser, another as an evaporator and another bled of refrigerant depending on the mode, the refrigerant charge required in each mode in order to ensure operation within an acceptable efficiency envelope will be different, the optimal refrigerant charge will also depend on the operation temperatures within each mode and the amount of refrigerant within the working and bleed lines for each mode.

[0037] Accordingly, the system **10** further includes a refrigerant storage reservoir **70**, termed a charge tank, having an inlet connected in fluid flow communication with the refrigerant line **45** via refrigerant line **71** and an outlet connected in fluid flow communication with the refrigerant line **45**C via refrigerant line **73**, a first flow control valve **72** disposed in the refrigerant line **71**, and a second flow control valve **74** disposed in the refrigerant line **73**. Each of the first and second flow control valves **72** and **74** has an open position and a closed position so that flow therethrough may be selectively controlled whereby the refrigerant charge within the refrigerant circuit may be actively controlled. Advantageously, each of the first and second flow control valves **72** and **74** may also have at least one partially open position and may be a pulse width modulated solenoid valve. Additionally, a liquid level meter **80**, such as for example a transducer, may be disposed in the charge tank **70** for monitoring the refrigerant level within the charge tank.

[0038] Referring now to FIG. **8**, a system controller **100**, advantageously a microprocessor, controls the operation of the water pump **62**, the compressor **20**, the reversing valve **30** and other heat pump components, such as the outdoor heat exchanger fan **42** and the indoor heat exchanger fan **52**, in response to the cooling or heating demand of the comfort region in a conventional manner and/or the demand for water heating. In the embodiment depicted in FIGS. **4-7**, the system controller **100** also controls operation of the second reversing valve **130** and the additional flow control valve **68**. In addition, the system controller **100** controls the opening and closing of the flow control valves **72** and **74** to adjust the refrigerant charge to coordinate with system requirements for the various modes of operation. The system controller **100** receives input signals indicative of various system operational parameters from a plurality of sensors, including, without limitation, a suction temperature sensor **81**, a suction pressure sensor **83**, a discharge temperature sensor **85**, a discharge pressure sensor **87**, a water temperature sensor **89**, an outdoor heat exchanger refrigerant temperature sensor **82**, an indoor heat exchanger refrigerant temperature sensor **84**, and a refrigerant temperature sensor **86** disposed in operative association with section **45**B of refrigerant line **45** at a location between the expansion valves **44** and **54**.

[0039] The suction temperature sensor **81** and the suction pressure sensor **83** are disposed in operative association with refrigerant line **55** near the suction inlet to the compressor **20** as in conventional practice for sensing the refrigerant temperature and pressure, respectively, at the compressor suction inlet and for passing respective signals indicative thereof to the system controller **100**. The discharge temperature sensor

85 and the discharge pressure sensor **87** are disposed in operative association with refrigerant line **35** near the discharge outlet to the compressor **20** as in conventional practice for sensing the refrigerant temperature and pressure, respectively, at the compressor discharge outlet and for passing respective signals indicative thereof to the system controller **100**. The water temperature sensor **89** is disposed in operative association with the water reservoir **64** for sensing the temperature of the water therein and for passing a signal indicative of the sensed water temperature to the system controller **100**. The temperature sensor **82** is disposed in operative association with the outdoor heat exchanger **40** at a location appropriate for measuring the refrigerant phase change temperature of refrigerant passing therethrough when the indoor heat exchanger is operating and for sending a signal indicative of that sensed temperature to the system controller **100** for controlling operation of the expansion valve **44**. Similarly, the temperature sensor **84** is disposed in operative association with the indoor heat exchanger **50** at a location for measuring the refrigerant phase change temperature of refrigerant passing therethrough when the outdoor heat exchanger is operating and for sending a signal indicative of that sensed temperature to the system controller **100** for controlling operation of the expansion valve **54**. The system controller **100** determines the degree of superheat from the refrigerant temperature sensed by whichever of sensors **82** and **84** is associated with the heat exchanger that is acting as an evaporator in the current operating mode. The refrigerant temperature sensor **86** operatively associated with refrigerant line **45** senses the temperature of the refrigerant at a location between the expansion valves **44** and **54** and passes a signal indicative of the sensed temperature to the system controller **100**. The system controller determines the degree of subcooling present from the sensed temperature received from temperature sensor **86**.

[0040] Referring now to FIG. **1**, in the indoor air cooling only mode, in response to a demand for cooling, the system controller **100** activates the compressor **20**, the outdoor heat exchanger fan **42** and the indoor heat exchanger fan **52** and opens both of the flow control valves **48** and **58**. High pressure, superheated refrigerant from the compressor **20** passes through refrigerant line **35** to the reversing valve **30** wherein the refrigerant is directed to and through section **45**A of refrigerant line **45** to the outdoor heat exchanger **40**, which in the air cooling mode functions as a condenser. With the outdoor heat exchanger fan **42** operating, ambient air flows through the outdoor heat exchanger **40** in heat exchange relationship with the refrigerant passing therethrough, whereby the high pressure refrigerant is condensed to a liquid and subcooled. With the flow control valves **48** and **58** open, high pressure liquid refrigerant passes from the outdoor heat exchanger **40** through section **45**B of refrigerant line **45** to the indoor heat exchanger **50**, which in the air cooling mode functions as an evaporator. In passing through section **45**B of refrigerant line **45**, the high pressure liquid refrigerant bypass the expansion valve **44** through bypass line **43** and check valve **46** and thence passes through the expansion valve **54** wherein the high pressure liquid refrigerant expands to a lower pressure, thereby further cooling the refrigerant prior to the refrigerant entering the indoor heat exchanger **50**. As the refrigerant traverses the indoor heat exchanger, the refrigerant evaporates. With the indoor heat exchanger fan **52** operating, indoor air passes through the indoor heat exchanger **50** in heat exchange relationship with the refrigerant thereby evaporating the refrigerant and cooling the indoor air. The refrigerant passes from the indoor heat exchanger through section **45**C of refrigerant line **45** to the suction accumulator **22** before returning to the compressor **20** through refrigerant line **55** connecting to the suction inlet of the compressor **20**. In this air cooling only mode, the check **26** in refrigerant line **25** is closed and any refrigerant that may be in line **25**, for example refrigerant remaining in the refrigerant-to-water heat exchanger **60** from a prior water heating mode, is bleed back to the suction accumulator **22** through line **57** to line **45**C.

[0041] Referring now to FIG. **2**, when there is a demand for water heating while the system is in the indoor air cooling mode, the system controller **100** repositions the reversing valve **30**, closes the flow control valve **48**, keeps the flow control valve **58** open, deactivates the outdoor heat exchanger fan **42**, and activates the water pump **60**. With the water pump activated, water is pumped via water line **65** from water reservoir **64** through heat exchanger **60** in heat exchange relationship with the high pressure superheated refrigerant flowing through refrigerant line **25** to heat the water. Having traversed the heat exchanger **60**, the heated water returns to the reservoir **64**. The high pressure superheated refrigerant from the compressor **20** is directed in the reversing valve **30** from port **30-1** to port **30-4** into the refrigerant line **25**. As the refrigerant passes through the heat exchanger **60**, the refrigerant is condensed and subcooled as it gives up heat to heat the water flowing through the heat exchanger **60** in heat exchange relationship with the refrigerant. Having already condensed and subcooled, the refrigerant pass directly into the refrigerant line **45**B through the check valve **26** in line **25**, thereby bypassing the outdoor heat exchanger **40**. With valve **48** closed and valve **58** open, the refrigerant continues on through the expansion valve **54** and traverses the indoor heat exchanger **50** wherein the refrigerant is evaporated as it passes in heat exchange relationship with and cools the indoor air being circulated through the indoor heat exchanger **50** via fan **52**. The refrigerant vapor leaving the indoor heat exchanger thence passes through line **45**C to line **45**C to the suction accumulator **22** and returns to the compressor **20** through line **55**B. With the reversing valve **30** in this position, ports **30-2** and **30-3** are connected in flow communication thereby coupling line **45**A in refrigerant flow communication with refrigerant line **57**, whereby any refrigerant remaining within the outdoor heat exchanger **40** from a prior operating mode will bleed back through lines **45**A and **57** back to the line **45**C to the suction accumulator **22**.

[0042] Referring now to FIG. **3**, when there is a demand for water heating while the system is off, that is not in the indoor air cooling mode, the system controller **100** activates the water pump **60**, the compressor **20**, and the outdoor heat exchanger fan **42**, but not the indoor heat exchanger fan **52**, opens flow control valve **48** and closes flow control valve **58**. With the pump **60** turned on, water is pumped via water line **65** from storage tank **64** through heat exchanger **60** in heat exchange relationship with the high pressure superheated vapor refrigerant flowing through refrigerant line **25**. Having traversed the heat exchanger **60**, the heated water returns to the reservoir **64**. The high pressure superheated refrigerant from the compressor **20** is directed in the reversing valve **30** from port **30-1** to port **30-4** into the refrigerant line **25**. Having already condensed and subcooled, the refrigerant pass directly into the refrigerant **45** through the check valve **26** in line **25**. With valve **48** open and valve **58** closed, the refrigerant continues on through the expansion valve **44** and traverses the outdoor heat exchanger **40** wherein the refrigerant is evaporated as it passes in heat exchange relationship with and cools the ambient air being circulated through the outdoor heat exchanger **40** via fan **42**. With the reversing valve **30** in this position, ports **30-2** and **30-3** are connected in flow communication thereby coupling line **45**A in refrigerant flow communication with refrigerant line **45**D. Therefore, the refrigerant vapor leaving the outdoor heat exchanger passes through line **45**A, thence via the reversing valve **30** to line **57**, thence to line **45**C to the suction accumulator **22** and returns to the compressor **20** through line **55**. With valve **58** closed, any refrigerant remaining within the indoor heat exchanger **50** from a prior operating mode will bleed back through line **45**C back to the suction accumulator **22**.

[0043] As noted previously, the embodiment of the refrigerant system **10** depicted in FIGS. **4-7** provides for not only cooling air to a comfort region, for example an indoor zone located on the inside of a building (not shown), but also for heating air to the comfort zone and also auxiliary water heating when desired. Referring now to FIG. **4**, in the indoor air cooling only mode, in response to a demand for cooling, the system controller **100** activates the compressor **20**, the outdoor heat exchanger fan **42** and the indoor heat exchanger fan **52** and opens both of the flow control valves **48** and **58**. High pressure, superheated refrigerant from the compressor **20** passes through refrigerant line **35** to the reversing valve **30** wherein the refrigerant is directed to and through section **45**A of refrigerant line **45** to the outdoor heat exchanger **40**, which in the air cooling mode functions as a condenser. With the outdoor heat exchanger fan **42** operating, ambient air flows through the outdoor heat exchanger **40** in heat exchange relationship with the refrigerant passing therethrough, whereby the high pressure refrigerant is condensed to a liquid and subcooled. With the flow control valves **48** and **58** open, high pressure liquid refrigerant passes from the outdoor heat exchanger **40** through section **45**B of refrigerant line **45** to the indoor heat exchanger **50**, which in the air cooling mode functions as an evaporator. In passing through section **45**B of refrigerant line **45**, the high pressure liquid refrigerant bypass the expansion valve **44** through bypass line **43** and check valve **46** and thence passes through the expansion valve **54** wherein the high pressure liquid refrigerant expands to a lower pressure, thereby further cooling the refrigerant prior to the refrigerant entering the indoor heat exchanger **50**. As the refrigerant traverses the indoor heat exchanger, the refrigerant evaporates. With the indoor heat exchanger fan **52** operating, indoor air passes through the indoor heat exchanger **50** in heat exchange relationship with the refrigerant thereby evaporating the refrigerant and cooling the indoor air. With the flow control valve **68** open, the refrigerant passes from the indoor heat exchanger through section **45**C of refrigerant line **45** to the suction accumulator **22** before returning to the compressor **20** through refrigerant line **55** connecting to the suction inlet of the compressor **20**. In the air cooling only mode, as the check valve **26** in refrigerant line **25** is closed to flow from line **45**B, any refrigerant that may be in line **25**, for example refrigerant remaining in the refrigerant-to-water heat exchanger **60** from a prior water heating mode, is bleed back through reversing valve **130** and reversing valve **130** to the suction accumulator **22** through line **57** to line **45**C.

[0044] Referring now to FIG. **5**, when there is a demand for water heating while the system is in the indoor air cooling mode, the system controller **100** repositions the reversing valve **30**, closes the flow control valve **48**, keeps the flow control valve **58** open, deactivates the outdoor heat exchanger fan **42**, and activates the water pump **60**. With the water pump activated, water is pumped via water line **65** from water reservoir **64** through heat exchanger **60** in heat exchange relationship with the high pressure superheated refrigerant flowing through refrigerant line **25** to heat the water. Having traversed the heat exchanger **60**, the heated water returns to the reservoir **64**. The high pressure superheated refrigerant from the compressor **20** is directed in the reversing valve **30** from port **30-1** to port **30-4** into the refrigerant line **23** to port **130-1** of the reversing valve **130** and through the reversing valve **130** to line **25** which connects to port **130-3** of the reversing valve **130**. As the refrigerant passes through the heat exchanger **60**, the refrigerant is condensed and subcooled as it gives up heat to heat the water flowing through the heat exchanger **60** in heat exchange relationship with the refrigerant. Having already condensed and subcooled, the refrigerant pass directly into the refrigerant line **45**B through the check valve **26** in line **25**, thereby bypassing the outdoor heat exchanger **40**. With valve **48** closed and valve **58** open, the refrigerant continues on through the expansion valve **54** and traverses the indoor heat exchanger **50** wherein the refrigerant is evaporated as it passes in heat exchange relationship with and cools the indoor air being circulated through the indoor heat exchanger **50** via fan **52**. With flow control valve **68** open, the refrigerant vapor leaving the indoor heat exchanger thence passes through line **45**C to the suction accumulator **22** and returns to the compressor **20** through line **55**. With the reversing valves **30** and **130** in this position, ports **30-2** and **30-3** are connected in flow communication and ports **130-2** and **130-4** are also connected in flow communication thereby coupling line **45**A in refrigerant flow communication with refrigerant line **57**, whereby any refrigerant remaining within the outdoor heat exchanger **40** from a prior operating mode will bleed back through lines **45**A and **57** back to the line **45**C to the suction accumulator **22**.

[0045] Referring now to FIG. **6**, in the indoor air heating only mode, in response to a demand for cooling, the system controller **100** activates the compressor **20**, the outdoor heat exchanger fan **42** and the indoor heat exchanger fan **52**, closes flow control valve **68**, and opens both of the flow control valves **48** and **58**. Further, the system controller **100** positions the reversing valve **30** such that port **30-1** communicates with port **30-4** and port **30-2** communicates with **30-3**, and also positions the reversing valve **130** such that port **130-1** communicates with port **130-2** and port **130-3** communicates with port **130-4**. High pressure, superheated refrigerant from the compressor **20** passes through refrigerant line **35** to port **30-1** of the reversing valve **30** wherein the refrigerant is directed to port **30-4** thereof and through refrigerant line **23** to port **130-1** of the reversing valve **130**. From the reversing valve **130**, the high pressure, superheated refrigerant passes from port **130-2** through refrigerant line **27** and refrigerant line **45**C to the indoor heat exchanger **50**, which in the air heating mode functions as a condenser. With the indoor heat exchanger fan **52** operating, indoor air flows through the indoor heat exchanger **50** in heat exchange relationship with the refrigerant passing therethrough, whereby the high pressure refrigerant is condensed to a liquid and subcooled. With the flow control valves **48** and **58** open, high pressure liquid refrigerant passes from the indoor heat exchanger **50** through section **45**B of refrigerant line **45** to the outdoor heat exchanger **40**, which in the air heating mode functions as an evaporator. In passing through section **45**B of refrigerant line **45**, the high pressure liquid refrigerant bypass the expansion valve **54** through bypass line **53** and check valve **56** and thence passes through the expansion valve **44** wherein the high pressure liquid refrigerant expands to a lower pressure, thereby further cooling the refrigerant prior to the refrigerant entering the outdoor heat exchanger **40**. As the refrigerant traverses the outdoor heat exchanger, the refrigerant evaporates. With the outdoor heat exchanger fan **42** operating, ambient air passes through the outdoor heat exchanger **50** in heat exchange relationship with the refrigerant thereby evaporating the refrigerant and cooling the ambient air. With the flow control valve **68** closed, the refrigerant passes from the outdoor heat exchanger **40** through section **45**A of refrigerant line **45** to port **30-2** of the reversing valve **30**, thence from port **30-3** of the reversing valve **30** through line **57** and refrigerant line **45**C to the suction accumulator **22** before returning to the compressor **20** through refrigerant line **55** connecting to the suction inlet of the compressor **20**. In the air heating only mode, as the check valve **26** in refrigerant line **25** is closed to flow from line **45**B, any refrigerant that may be in line **25**, for example refrigerant remaining in the refrigerant-to-water heat exchanger **60** from a prior water heating mode, is bleed back through reversing valve **130** to the suction accumulator **22** through refrigerant line **29**, refrigerant line **57** and refrigerant line **45**C.

[0046] Referring now to FIG. **7**, when there is a demand for water heating while the system is off, that is not in the indoor air cooling or indoor heating mode, the system controller **100** activates the water pump **60**, the compressor **20**, and the outdoor heat exchanger fan **42**, but not the indoor heat exchanger fan **52**, opens flow control valve **48** and flow control valve **68** and closes flow control valve **58**. With the pump **60** turned on, water is pumped via water line **65** from storage tank **64** through heat exchanger **60** in heat exchange relationship with the high pressure superheated vapor refrigerant flowing through refrigerant line **25**. Having traversed the heat exchanger **60**, the heated water returns to the reservoir **64**. The high pressure superheated refrigerant from the compressor **20** is directed in the reversing valve **30** from port **30-1** to port **30-4**, thence through line **23** to port **130-1** of the reversing valve **130-1** and through port **130-3** into the refrigerant line **25**. Having traversed the refrigerant-to-water heat exchanger **60**, the already condensed and subcooled refrigerant pass directly into refrigerant line **45** through the check valve **26** in line **25**. With valve **48** open and valve **58** closed, the refrigerant continues on through the expansion valve **44** and traverses the outdoor heat exchanger **40** wherein the refrigerant is evaporated as it passes in heat exchange relationship with and cools the ambient air being circulated through the outdoor heat exchanger **40** via fan **42**. With the reversing valve **30** in this position, ports **30-2** and **30-3** are connected in flow communication thereby coupling line **45**A in refrigerant flow communication with refrigerant line **45**D. Therefore, the refrigerant vapor leaving the outdoor heat exchanger passes through line **45**A, thence via the reversing valve **30** to line **57**, thence to line **45**C to the suction accumulator **22** and returns to the compressor **20** through line **55**. With valve **58** closed and valve **68** open, any refrigerant remaining within the indoor heat exchanger **50** from a prior operating mode will bleed back through line **45**C to the suction accumulator **22**.

[0047] As noted hereinbefore, in the embodiment of the system of the invention depicted in FIGS. **1-3**, the system must operate effectively in an air cooling only mode, an air cooling and water heating mode, and a water heating only mode. In the embodiment of the system of the invention depicted in FIGS. **4-7**, the system must additionally operate effectively in an air heating mode. As each of the outdoor heat exchanger **40**, the indoor heat exchanger **50** and the refrigerant-to-water heat exchanger **60** will operate one as a condenser, another as an evaporator and another bled of refrigerant depending on the mode, the refrigerant charge required in each mode in order to ensure operation within an acceptable efficiency envelope will be different, the optimal refrigerant charge will also depend on the operation temperatures within each mode and the amount of refrigerant within the working and bleed lines for each mode. Accordingly, the system controller system **100** controls the amount of refrigerant flowing through the refrigerant circuit at any time, i.e. the refrigerant charge, by monitoring and adjusting the level of refrigerant in the charge tank **70** by selectively opening and closing the first flow control valve **72** disposed in the refrigerant line **71** and a second flow control valve **74** disposed in the refrigerant line **73**.

[0048] In a most advantageous embodiment, the charge tank **70** is provided with a liquid level meter **80** that generates and transmits a signal indicative of the refrigerant level within the charge tank **70** to the system controller **100**. The liquid level meter **80** may be configured to transmit a liquid level signal to the system controller **100** continuously, on a periodic basis at specified intervals, or only when prompted by the controller. Referring now to FIG. **9**, in operation, when the controller switches from one mode of operation to a new mode of operation, the controller **100** turns on the compressor **20** at block **101**, and then, at block **102**, the controller **100** compares the then current liquid level in the charge tank **70** with the liquid level last experienced the last time the system was operated in a mode equivalent to the new mode of operation, the liquid level last experienced having been stored in the controller's memory. If the current level is the same as the last experienced level for this particular mode of operation, the controller at block **105** activates the normal charge control procedure and/or discharge temperature control procedure.

[0049] However, if the current liquid level is not the same as the last experienced level for this particular mode of operation, the controller **100** will selectively modulate the solenoid valves **72** and **74** to open and close as necessary to adjust the current liquid level to equal the last experienced level for this particular mode of operation. If the current level is below the last experienced level, at block **103** the controller **100** will close the solenoid valve **74** and modulate the solenoid valve **72** open to drain refrigerant from the refrigerant circuit into the charge tank **70** until the current reaches the last experience level. Conversely, if the current level is above the last experienced level, the controller **100** at block **104** will close the solenoid valve **72** and modulate the solenoid valve **74** open to drain refrigerant from the charge tank **70** into the refrigerant circuit until the current liquid level reaches the last experienced level. For example, the controller will open the appropriate valve for a short period of time, for example 2 seconds, close the valve, recheck the level and repeat this sequence until the current liquid level equalizes to the last experience level. Once the current level has been equalized to the last experienced level, the controller at block **105** activates the normal charge control procedure and/or discharge temperature control procedure.

[0050] The system controller **100** may also employ the control procedure discussed herein in embodiments of the heat pump system of the invention that do not include a liquid level sensor in association with the charge tank **70**. However, when the heat pump system switches to a new operation mode, the system controller **100** first fills the charge tank either with refrigerant in the liquid state or with refrigerant in the gas state depending upon the volume of refrigerant charge required for efficient operation of the refrigerant to water heat exchanger **60** vis-a-vis the volume of refrigerant charge required for efficient operation of either the outdoor air-to-refrigerant heat exchanger **40** or the indoor heat air-to-refrigerant exchanger **50** depending upon the particular mode of operation being entered.

[0051] If the new mode of operation involves air cooling, whether air cooling only or air cooling with water heating, the system controller will proceed either to fill the refrigerant tank **70** with liquid refrigerant according to the procedure illustrated by the block diagram in FIG. **10** if the volume of refrigerant charge required for efficient operation of the refrigerant to water heat exchanger **60** is significantly greater than the volume of refrigerant charge required for efficient operation of either the outdoor air-to-refrigerant heat exchanger **40**, or to fill the refrigerant tank **70** with gaseous refrigerant according to the procedure illustrated by the block diagram in FIG. **11** if the volume of refrigerant charge required for efficient operation of the refrigerant to water heat exchanger **60** is significantly less than the volume of refrigerant charge required for efficient operation of either the outdoor air-to-refrigerant heat exchanger **40**. If the new mode of operation involves indoor air heating or water heating only, the system controller will proceed either to fill the refrigerant tank **70** with liquid refrigerant according to the procedure illustrated by the block diagram in FIG. **10** if the volume of refrigerant charge required for efficient operation of the refrigerant to water heat exchanger **60** is significantly greater than the volume of refrigerant charge required for efficient operation of either the indoor air-to-refrigerant heat exchanger **50**, or to fill the refrigerant tank **70** with gaseous refrigerant according to the procedure illustrated by the block diagram in FIG. **11** if the volume of refrigerant charge required for efficient operation of the refrigerant to water heat exchanger **60** is significantly less than the volume of refrigerant charge required for efficient operation of either the indoor air-to-refrigerant heat exchanger **50**. However, in any air cooling operating mode, if the volume of refrigerant charge required for efficient operation of the refrigerant to water heat exchanger **60** is relatively equal to the volume of refrigerant charge required for efficient operation of the outdoor air-to-refrigerant heat exchanger **40**, then the system controller **100** will enter the new mode of operation without adjusting the refrigerant level in the refrigerant charge tank **70**. Similarly, in the air heating or water heating modes of operation, if the volume of refrigerant charge required for efficient operation of the refrigerant to water heat exchanger **60** is relatively equal to the volume of refrigerant charge required for efficient operation of the indoor air-to-refrigerant heat exchanger **50**, then the system controller **100** will enter the new mode of operation without adjusting the refrigerant level in the refrigerant charge tank **70**.

[0052] Referring now to FIG. **10**, to fill the refrigerant charge tank **70** with liquid refrigerant, after turning the compressor **20** on at block **201**, the system controller at block **202** closes solenoid valve **74** and opens solenoid valve **72** to allow liquid refrigerant to pass from line **71** into the charge tank **70**. After a programmed time delay at block **203** sufficient to allow the charge tank **70** to fill with liquid refrigerant, for example about 3 minutes, the system controller at block **205** proceeds to adjust the refrigerant circuit charge as need by the discharge temperature control procedure and/or the charge control procedure as desired. The solenoid valve **72** may be positioned either open or closed at this point.

[0053] Referring now to FIG. **11**, to fill the refrigerant charge tank **70** with gaseous refrigerant, after turning the compressor **20** on at block **211**, the system controller at block **212** closes solenoid valve **72** and modulates solenoid valve **74** on/off for a period of time, for example open 3 seconds, closed 17 seconds repeatedly for two minutes, to allow refrigerant in the gas state to pass from line **73** into the charge tank **70**. After a programmed time delay at block **213** sufficient to allow the charge tank **70** to fill with gaseous refrigerant, for example about 3 minutes, the system controller at block **214** proceeds to adjust the refrigerant circuit charge as need by the discharge temperature control procedure and/or the charge control procedure as desired. The solenoid valve **74** may be positioned either open or closed at this point. In any water heating mode, the controller **100** will shut the pump **62** off when temperature sensor **89** detects that the water temperature in water reservoir **64** has reached a desired limit value, for example 60 degrees C.

[0054] In accord with the discharge temperature limit control procedure, illustrated by the block diagram of FIG. **12**, after a brief time delay, for example about 30 seconds, following turning on the compressor at block **301**, the system controller compares at block **302** the current discharge temperature, TDC, i.e. the temperature of the refrigerant discharging from the compressor **20**, received from temperature sensor **150** to a discharge temperature limit, TDL, preprogrammed into the controller **100**. A typical compressor discharge limit might be a desired number of degrees, for example about 7 degrees C., below the manufacturer's application guide specification. A typical compressor discharge temperature limit would be about 128 degrees C. If the current discharge temperature, TDC, exceeds the discharge temperature limit, the system controller **100** at block **303** deactivates the charge control procedure if it is currently active, and then at block **304** closes the solenoid valve **72** and modulates the solenoid valve **74** open to drain refrigerant from the charge tank **70** into the refrigerant circuit through the refrigerant line **73**. If the current discharge temperature received from temperature sensor **150** is equal to or below the discharge temperature limit, the system controller **100** at block **305** activates the charge control procedure if it is not currently active and proceeds to follow the charge control procedure to adjust the refrigerant charge in the refrigerant circuit as necessary.

[0055] In the charge control procedure, illustrated in FIG. **13**, with the refrigerant charge initially set, the system controller **100** at block **401** closes both solenoid valves **72** and **74**. After a brief time delay, for example about one minute, depending upon the particular mode of current operation, the system controller will at block **402** compare either or both of the degree of superheat or the degree of subcooling currently present in the system to a permissible range of superheat preprogrammed into the controller **100**. For example, in the air cooling only and the air cooling with water heating modes, the permissible range of superheat may be from 0.5 to 20 degrees C. and the permissible range of subcooling may be from 2 to 15 degrees C. In the air heating only, the air heating with water heating and the water heating only modes, the permissible range of superheat may be from 0.5 to 11 degrees C. and the permissible range of subcooling may be from 0.5 to 10 degrees C., for example.

[0056] If operating in a mode with fixed expansion, the system controller, at block **403**, compares the current degree of superheat against the permissible range of superheat preprogrammed into the controller **100**. If the current degree of superheat is below the permissible range, at block **404**, the system controller **100** will modulate the solenoid valve **72** open to drain refrigerant from the refrigerant circuit into the charge tank **70**. If the current degree of superheat is above the permissible range, at block **405**, the system controller **100** will modulate the solenoid valve **74** open to drain refrigerant from the charge tank **70** into the refrigerant circuit. If the degree of superheat falls within the permissible range of superheat, the system controller proceeds to block **406**.

[0057] If operating in a mode without fixed expansion, the system controller, at block **406**, compares the current degree of subcooling against a permissible range of subcooling programmed into the controller. If the current degree of subcooling is above the permissible range, at block **404**, the system controller **100** will modulate the solenoid valve **72** open to drain refrigerant from the refrigerant circuit into the charge tank **70**. If the current degree of subcooling is below the permissible range, at block **405**, the system controller **100** will modulate the solenoid valve **74** open to drain refrigerant from the charge tank **70** into the refrigerant circuit. If the degree of subcooling falls within the permissible range of subcooling, the system controller proceeds to control refrigerant charge through the charge control procedure and the discharge temperature limit control procedure as described.

[0058] The various control parameters presented as examples hereinbefore, such as compressor discharge temperature limit, the various time delays, the desired superheat ranges, the desired subcooling ranges, are for a typical 5 ton capacity, split-system heat pump system having a brazed plate water to refrigerant heat exchanger **60**, a refrigerant reservoir (charge tank) **70** having a liquid refrigerant storage capacity of 4 kilograms, a system refrigerant charge of 8 kilograms, and overall refrigerant lines of 7 meters. These parameters are presented for purposes of illustration and those skilled in the art will understand that these parameters may vary from the examples presented for different heat pump configurations and capacities. Those having ordinary skill in the art will select precise parameters to be used in implementing the invention to best suit operation of any particular heat pump system.

[0059] In the embodiment of the heat pump system of the invention depicted in FIGS. **4-7**, the heat pump system may be used to heat both indoor air and water by cycling between the indoor air heating mode and the water heating mode. To do so, the system controller **100** will simply operate the system in the indoor air heating mode for a desired period, such as a few minutes, then switch to water heating mode for a desired period, such as a few minutes, and the switch back to the air heating mode. The system controller will continue switching from one mode to the other every few minutes until the water temperature set point or the air indoor temperature set point has been reached. Importantly, the system controller **100** can effectuate this cycling mode of operation without shutting the compressor **20** down. To switch from the indoor air heating mode to the water heating mode, the system controller **100** will reposition the reversing valve **130** to its second position, activate the water pump **62**, close flow control valve **58** and open flow control valve **68**. To return to the indoor air heating mode from the water heating mode, the system controller **100** will reposition the reversing valve **130** to its first position, turn off the water pump **62**, close flow control valve **68** and open flow control valve **58**.

[0060] While the present invention has been particularly shown and described with reference to the preferred mode as illustrated in the drawing, it will be understood by one skilled in the art that various changes in detail may be effected therein without departing from the spirit and scope of the invention as defined by the claims.

1. A refrigerant system operable in at least an air cooling mode and having liquid heating capability comprising:
 - a refrigerant compressor having a suction port and a discharge port;
 - a selectively positionable reversing valve having a first port, a second port, a third port and a fourth port, said reversing valve being positionable in a first position for coupling the first port and the second port in fluid flow communication and the third port and the fourth port in fluid flow communication, said reversing valve being positionable in a second position for coupling the first port and the fourth port in fluid flow communication and the second port and the third port in fluid flow communication;
 - a refrigerant circuit providing a closed loop refrigerant circulation flow path, said refrigerant circuit having a first refrigerant line establishing a flow path between the discharge port of said compressor and the first port of said reversing valve and a second refrigerant line establishing a flow path between the second port of said reversing valve and the suction port of said compressor;
 - an outdoor heat exchanger operatively associated with the second refrigerant line and adapted for passing refrigerant passing through the second refrigerant line in heat exchange relationship with ambient air;
 - an indoor heat exchanger operatively associated with the second refrigerant line and adapted for passing refrigerant passing through the second refrigerant line in heat exchange relationship with the air from the comfort zone, said indoor heat exchanger disposed downstream of said outdoor exchanger with respect to refrigerant flow in the air cooling mode;
 - a third refrigerant line establishing a flow path between the fourth port of said reversing valve and the second refrigerant line at a location intermediate said outdoor heat exchanger and said indoor heat exchanger;
 - a refrigerant to liquid heat exchanger operatively associated with the third refrigerant line and adapted for passing refrigerant passing through the third refrigerant line in heat exchange relationship with a liquid;
 - a first flow control valve disposed in the second refrigerant line intermediate said outdoor heat exchanger and the location of the intersection of the third refrigerant line with the second refrigerant line, said first control valve having an open position and a closed position;
 - a second flow control valve disposed in the second refrigerant line intermediate said indoor heat exchanger and the location the intersection of the third refrigerant line with said second refrigerant line, said second control valve having an open position and a closed position;
 - a controller operatively associated with said first and second flow control valves, said controller operative to selectively control the respective positioning of said first

and second flow control valves between their respective open and closed positions so as to selectively control refrigerant flow through the second refrigerant line; and

a refrigerant reservoir having an inlet coupled in fluid flow communication to said second refrigerant line at a location intermediate said outdoor heat exchanger and said indoor heat exchanger and an outlet coupled in fluid flow communication to the second refrigerant line at a location intermediate the indoor heat exchanger and the suction port of said compressor.

2. A system as recited in claim **1** further comprising a flow check valve disposed in the third refrigerant line so as to permit refrigerant flow therethrough in a direction from said reversing valve into the second refrigerant line and to block flow from the second refrigerant line to said reversing valve.

3. A system as recited in claim **2** further comprising a fourth refrigerant line establishing a flow path between a refrigerant flow path between the third port of said reversing valve and the suction port of said compressor.

4. A system as recited in claim **1** further comprising:

a first flow control valve operatively associated with said refrigerant reservoir for controlling the flow refrigerant from the second refrigerant line to the inlet of said refrigerant reservoir, said first control valve having an open position and a closed position;

a second flow control valve operatively associated with said refrigerant reservoir for controlling the flow refrigerant between the outlet of said refrigerant reservoir and the second refrigerant line at a location intermediate the indoor heat exchanger and the suction port of said compressor, said second control valve having an open position and a closed position; and

a controller operatively associated with said first and second flow control valves, said controller operative to selectively control the respective positioning of said first and second flow control valves between their respective open and closed positions so as to selectively control the refrigerant charge within the refrigerant circuit.

5. A system as recited in claim **4** wherein said first and second flow control valves operatively associated with said refrigerant reservoir comprise valves having at least one partially open position between their respective open and closed positions; and

said controller is further operative to selectively modulate the respective positioning of said first and second flow control valves operatively associated with said refrigerant reservoir between their open, at one partially open and closed positions.

6. A system as recited in claim **5** wherein said first and second flow control valves operatively associated with said refrigerant reservoir comprise pulse width modulated solenoid valves.

7. A system as recited in claim **4** further comprising a liquid level sensor operatively associated with said refrigerant reservoir, said liquid level sensor operative to sense the level of liquid refrigerant in said refrigerant reservoir and provide a signal indicative of the liquid level within said refrigerant reservoir to said controller.

8. A system as recited in claim **7** wherein said controller is operative to selectively control the respective positioning of said first and second flow control valves operatively associated with said refrigerant reservoir between their respective open and closed positions so as to selectively control the refrigerant charge within the refrigerant circuit in response to the liquid level signal received from said liquid level sensor.

9. A refrigerant circuit heat pump system operable in at least an air cooling mode and an air heating air mode and having liquid heating capability comprising:

a refrigerant compressor having a suction port and a discharge port;

a first selectively positionable reversing valve having a first port, a second port, a third port and a fourth port, said reversing valve being positionable in a first position for coupling the first port and the second port in fluid flow communication and the third port and the fourth port in fluid flow communication, said reversing valve being positionable in a second position for coupling the first port and the fourth port in fluid flow communication and the second port and the third port in fluid flow communication;

a refrigerant circuit providing a closed loop refrigerant circulation flow path, said refrigerant circuit having a first refrigerant line establishing a flow path between the discharge port of said compressor and the first port of said first reversing valve and a second refrigerant line establishing a flow path between the second port of said first reversing valve and the suction port of said compressor;

an outdoor heat exchanger operatively associated with the second refrigerant line and adapted for passing refrigerant passing through the second refrigerant line in heat exchange relationship with ambient air;

an indoor heat exchanger operatively associated with the second refrigerant line and adapted for passing refrigerant passing through the second refrigerant line in heat exchange relationship with the air from the comfort zone, said indoor heat exchanger disposed downstream of said outdoor exchanger with respect to refrigerant flow in the air cooling mode;

a second selectively positionable valve having a first port, a second port, a third port and a fourth port, said second selectively positionable valve being positionable in a first position for coupling the first port and the second port in fluid flow communication and the third port and the fourth port in fluid flow communication, said second selectively positionable valve being positionable in a second position for coupling the first port and the third port in fluid flow communication and the second port and the fourth port in fluid flow communication;

a third refrigerant line establishing a flow path between the fourth port of said first reversing valve and the first port of said second reversing valve;

a fourth refrigerant line establishing a flow path between the third port of said second reversing valve and the second refrigerant line at a location intermediate said outdoor heat exchanger and said indoor heat exchanger;

a fifth refrigerant line establishing a flow path between the second port of said reversing valve and the second refrigerant line at a location intermediate said indoor heat exchanger and the suction inlet to said compressor;

a refrigerant to liquid heat exchanger operatively associated with the fourth refrigerant line and adapted for passing refrigerant passing through the fourth refrigerant line in heat exchange relationship with a liquid;

a first flow control valve disposed in the second refrigerant line intermediate said outdoor heat exchanger and the location the intersection of the third refrigerant line with the second refrigerant line, said first flow control valve having an open position and a closed position;

a second flow control valve disposed in the second refrigerant line intermediate said indoor heat exchanger and the location the intersection of the third refrigerant line with said second refrigerant line, said second flow control valve having an open position and a closed position;

a third flow control valve disposed in the second refrigerant line intermediate the location of the intersection of the fifth refrigerant line with the second refrigerant line and the suction inlet to said compressor, said third flow control valve having an open position and a closed position; and

a controller operatively associated with said first, second and third flow control valves, said controller operative to selectively control the respective positioning of said first, second and third flow control valves between their respective open and closed positions so as to selectively control refrigerant flow through the second refrigerant line.

10. A heat pump system as recited in claim **9** further comprising a flow check valve disposed in the fourth refrigerant line so as to permit refrigerant flow therethrough in a direction from said second reversing valve into the second refrigerant line and to block flow from the second refrigerant line to said second reversing valve.

11. A heat pump system as recited in claim **9** further comprising:

a sixth refrigerant line establishing a refrigerant flow path between the third port of said first reversing valve and the suction port of said compressor; and

a seventh refrigerant line establishing a refrigerant flow path between the fourth port of said second reversing valve and the suction port of said compressor.

12. A heat pump system as recited in claim **9** further comprising a refrigerant reservoir having an inlet coupled in fluid flow communication to the second refrigerant line at a location intermediate said outdoor heat exchanger and said indoor heat exchanger and an outlet coupled in fluid flow communication to the second refrigerant line at a location intermediate the indoor heat exchanger and the suction port of said compressor.

13. A heat pump system as recited in claim **12** further comprising:

a first flow control valve operatively associated with said refrigerant reservoir for controlling the flow refrigerant from the second refrigerant line to the inlet of said refrigerant reservoir, said first control valve having an open position and a closed position;

a second flow control valve operatively associated with said refrigerant reservoir for controlling the flow refrigerant between the outlet of said refrigerant reservoir and the second refrigerant line at a location intermediate the third flow control valve associated with the second refrigerant line and the suction port of said compressor, said second flow control valve having an open position and a closed position; and

a controller operatively associated with said first and second flow control valves operatively associated with said refrigerant reservoir, said controller operative to selectively control the respective positioning of said first and second flow control valves operatively associated with said refrigerant reservoir between their respective open and closed positions so as to selectively control the refrigerant charge within the refrigerant circuit.

14. A heat pump system as recited in claim **12** further comprising a liquid level sensor operatively associated with said refrigerant reservoir, said liquid level sensor operative to sense the level of liquid refrigerant in said refrigerant reservoir and provide a signal indicative of the liquid level within said refrigerant reservoir to said controller.

15. A heat pump system as recited in claim **14** wherein said controller is operative to selectively control the respective positioning of said first and second flow control valves operatively associated with said refrigerant reservoir between their respective open and closed positions so as to selectively control the refrigerant charge within the refrigerant circuit in response to the liquid level signal received from said liquid level sensor.

16. A heat pump system as recited in claim **9** wherein said controller is operative to cycle between the indoor air heating mode and the water heating mode whereby the system may effectively heat water while also heating air.

17. A heat pump system as recited in claim **9** further comprising:

a first expansion valve disposed in the second refrigerant line intermediate said outdoor heat exchanger and the first flow control valve in the first refrigerant line; and

a second expansion valve disposed in the second refrigerant line intermediate said indoor heat exchanger and the second flow control valve in the second refrigerant line;

said first expansion valve being operative associated with said outdoor heat exchanger and said second expansion valve being operatively associated with said indoor heat exchanger.

18. A heat pump system as recited in claim **17** further comprising:

a first expansion valve bypass line operatively associated with the second refrigerant line for bypassing refrigerant passing through the second refrigerant line in a direction from said outdoor heat exchanger to said indoor heat exchanger around said first expansion valve and through said second expansion valve.

19. A heat pump system as recited in claim **17** further comprising:

a second expansion valve bypass line operatively associated with the second refrigerant line for bypassing refrigerant passing through the second refrigerant line in a direction from said indoor heat exchanger to said outdoor heat exchanger around said second expansion valve and through said first expansion valve.

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