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(54) **MILD AMBIENT VEHICULAR HEAT PUMP SYSTEM**

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(57) **ABSTRACT**

A vehicular heat pump system for controlling the temperature of a passenger compartment and vehicle battery is provided. The heat pump system may include a cooling mode and a heating mode. The components of each of the respective heating and cooling circuits may include: a compressor, an AC condenser, a heat pump condenser, a cabin evaporator, a heat pump evaporator, a receiver/dryer, a plurality of expansion devices, and a plurality of flow control valves. The use of multiple evaporators and condensers eliminates the need to reverse the direction of refrigerant flow upon a change in operating mode; therefore, the position of the low-pressure side of the system remains constant in all operating modes. The low-pressure side of the system is not cooled with ambient air, minimizing the complexity of the system and eliminating the need to interrupt heating mode in order to de-ice the outside heat exchanger.

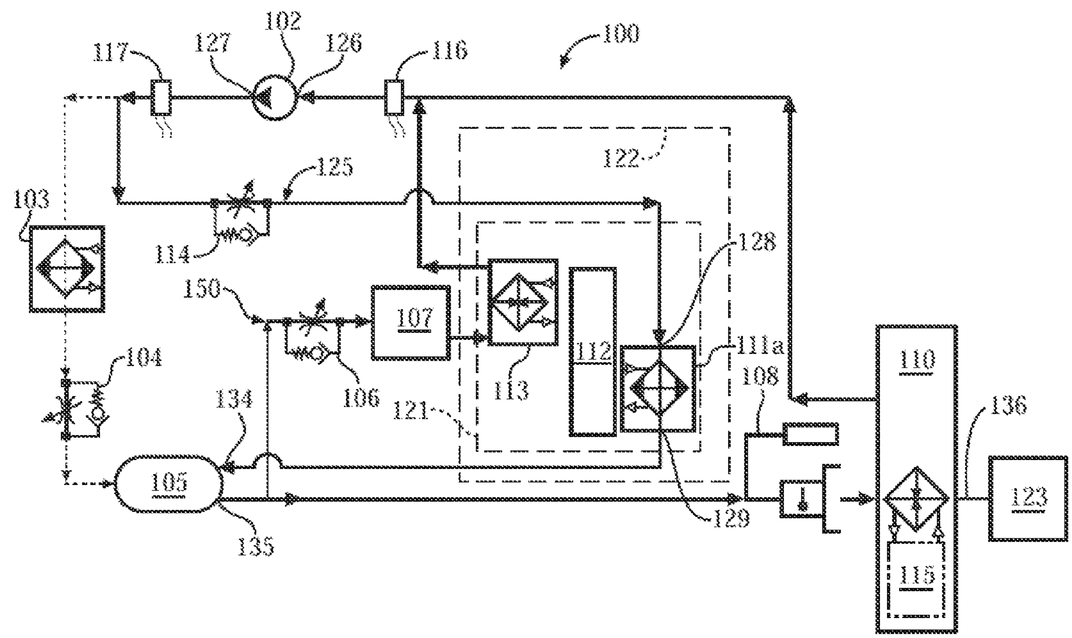

FIG. 1A

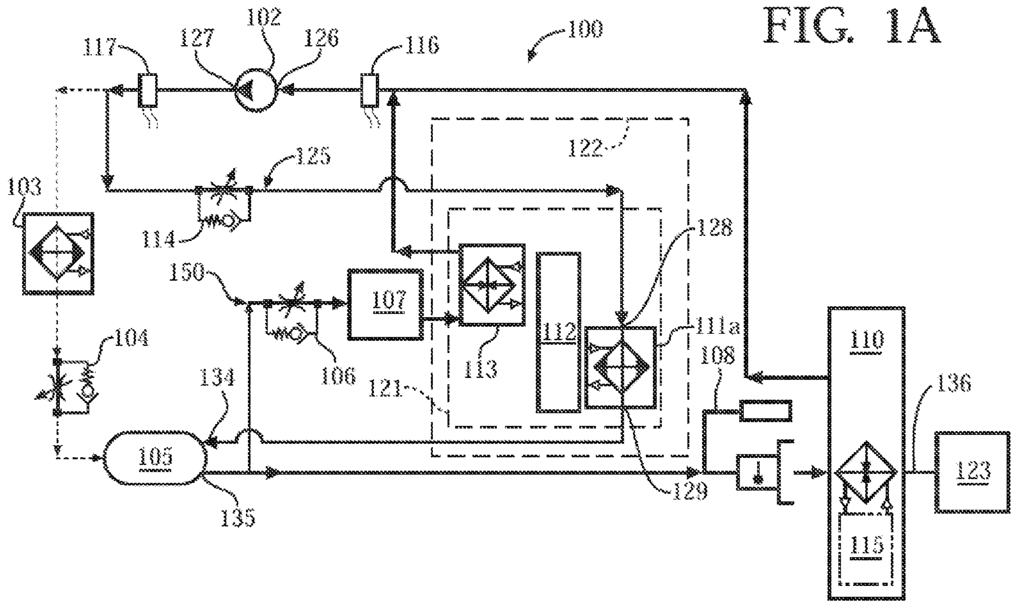
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FIG. 1B

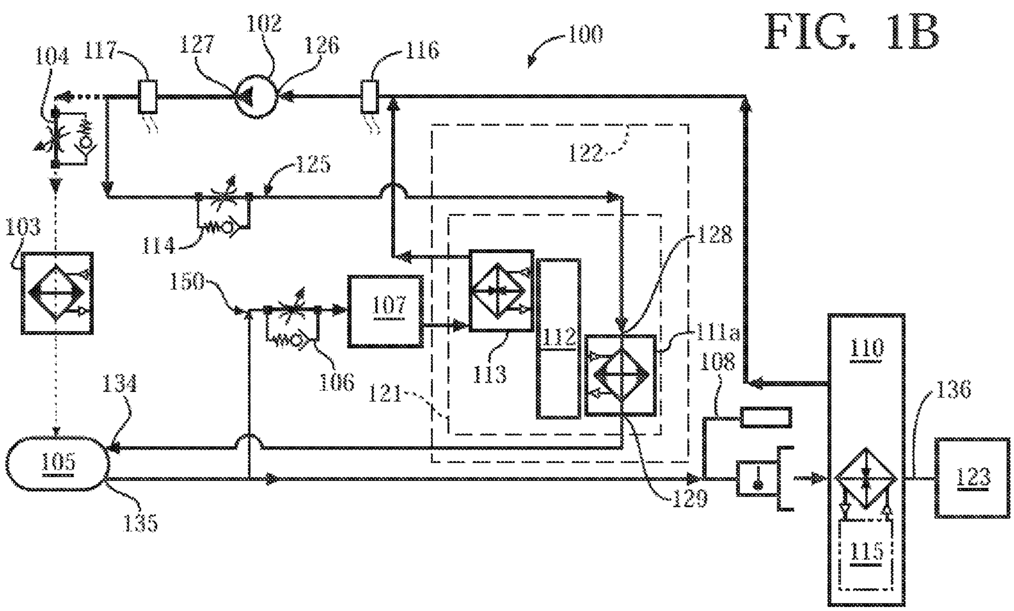
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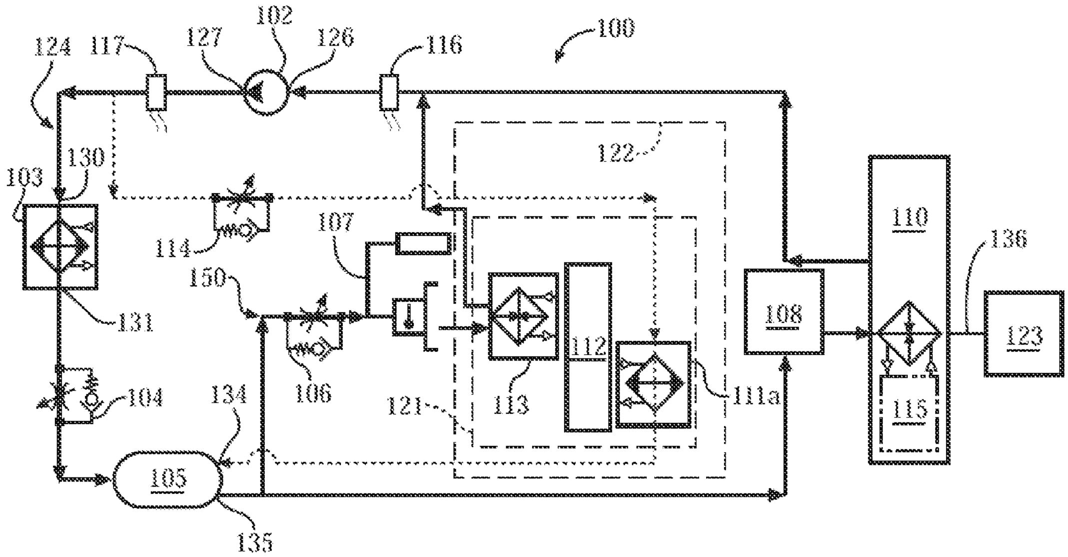
FIG. 2A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113
111a
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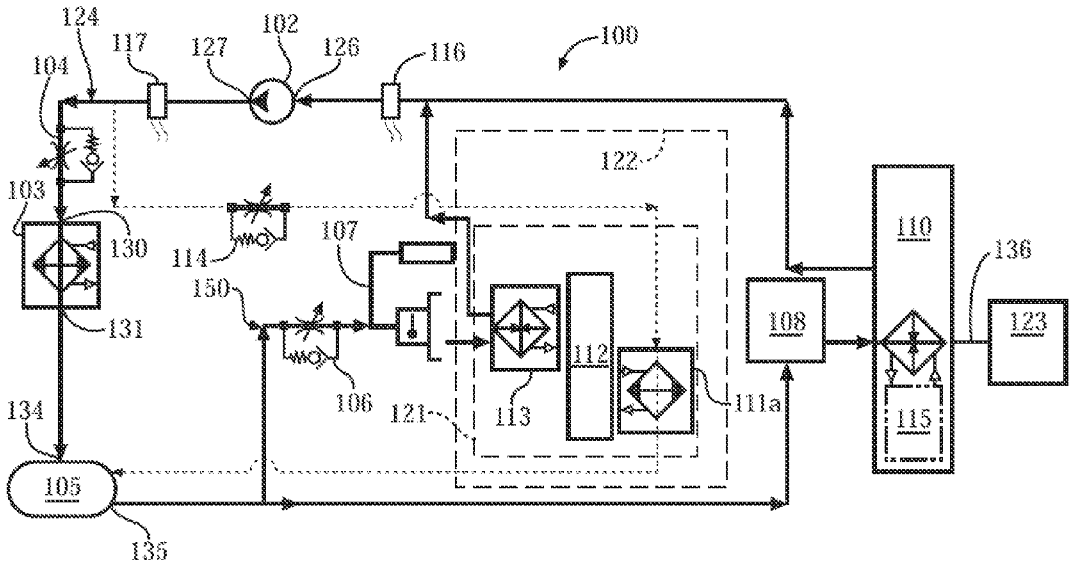
FIG. 2B


124
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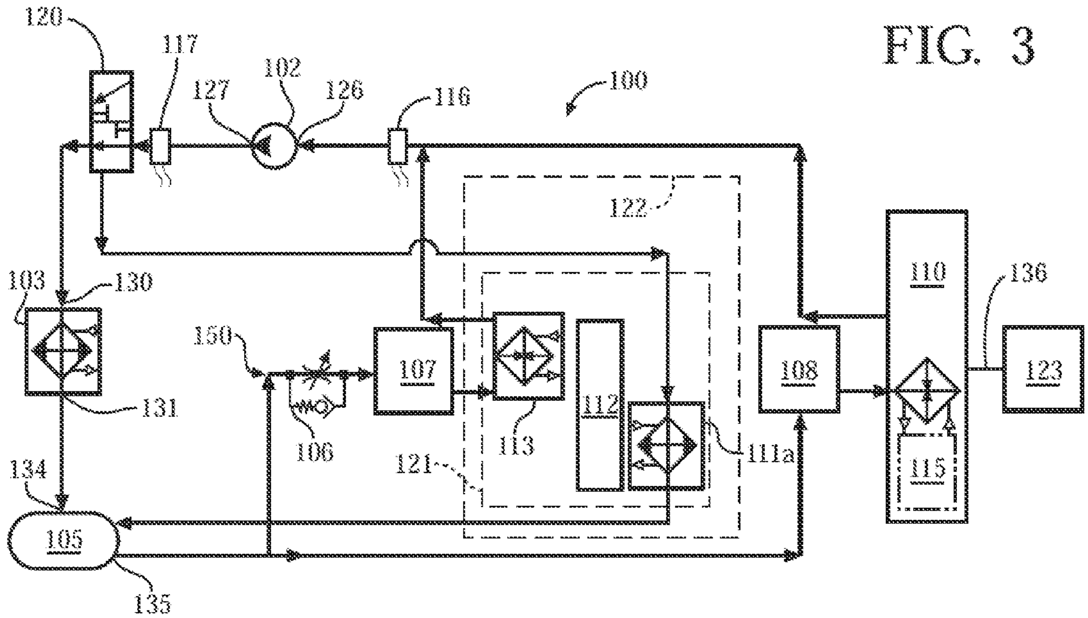
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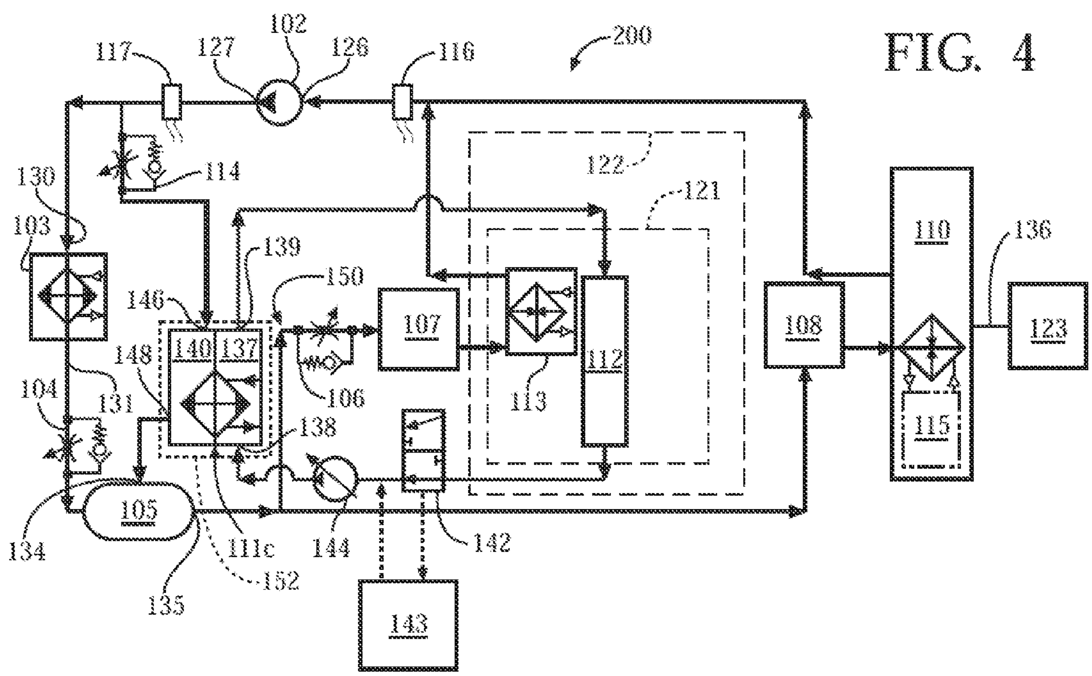
FIG. 3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136
123
148
131
106
104
138
115
105
134
111c
144
142
135
152
143

FIG. 4

MILD AMBIENT VEHICULAR HEAT PUMP SYSTEM

TECHNICAL FIELD

[0001] The disclosure relates to a vehicular heat pump system for use in mild ambient temperatures.

BACKGROUND

[0002] In conventional heating, ventilating, and air conditioning (HVAC) systems, two separate fluid circuits are present: a refrigerant fluid circuit for cooling the cabin and a coolant fluid circuit for heating the cabin. The cooling circuit circulates a refrigerant which may be a compound such as R-134a or the like. The heating circuit circulates a fluid which may generally be a mixture of ethylene glycol and water. Such HVAC systems may include reversible refrigerant heat pump systems, in which the refrigerant flow is controlled by refrigerant valves, thus, permitting the heat pump system to operate in both cabin heating mode and cabin cooling mode, by reversing the function of the two heat exchangers.

[0003] In cabin cooling mode, refrigerant flows from the compressor through an outside heat exchanger acting as a condenser, into an expansion valve, and through an inside heat exchanger acting as an evaporator. Heat is extracted from the air blown across the inside heat exchanger (evaporator), thereby providing cooled air to the passenger compartment.

[0004] In cabin heating mode, the refrigerant heat exchanger located outside the passenger compartment (outside heat exchanger) acts as an evaporator. The refrigerant heat exchanger inside the passenger compartment (inside heat exchanger) acts as a condenser. The refrigerant flows from the compressor through the inside heat exchanger acting as a condenser, into a receiver and orifice tube or other type of expansion device, and through the outside heat exchanger acting as an evaporator. Heat from the refrigerant is absorbed by the air flowing across the inside heat exchanger, which is blown into the passenger compartment to provide heat.

SUMMARY

[0005] A vehicular heat pump system for controlling the temperature of the passenger compartment and vehicle battery, for use in mild ambient temperatures, is provided. The heat pump system may include two operating modes: a cooling mode and a heating mode, which, in operation, may circulate a refrigerant. The refrigerant is generally directed along a heating circuit in heating mode and a cooling circuit in cooling mode. The refrigerant may be directed along one of the respective heating circuit or cooling circuit and through a plurality of components to cool or warm the passenger compartment and to cool the vehicle battery.

[0006] The vehicular heat pump system may include a compressor, an AC condenser, a heat pump condenser, a cabin evaporator, a rechargeable energy storage system (RESS) chiller acting as heat pump evaporator, a receiver dryer, a plurality of expansion devices, and a plurality of flow control valves.

[0007] The vehicular heat pump system may operate in two operating modes, namely heating mode and cooling mode, either independently or simultaneously. During heating mode, the system employs a heat pump condenser, inside the HVAC module or within the vehicle underhood, and the RESS chiller as the heat pump evaporator. Additionally, the heating circuit may include a cabin evaporator, which may be configured to cool and dehumidify air transmitted to the passenger compartment. In cooling mode, the system utilizes an independent AC condenser outside the HVAC module, and a cabin evaporator.

[0008] It is, therefore, not necessary to require the reversal of refrigerant flow when changing operating modes. Absent the requirement to reverse the system, the position of the low-pressure side of the system, defined between one of the plurality of expansion devices and the compressor, remains constant in all operating modes reducing or eliminating the need to de-ice an outside heat exchanger in heating mode, and allowing uninterrupted heating of the passenger compartment.

[0009] The above features and advantages, and other features and advantages, of the present invention are readily apparent from the following detailed description of some of the best modes and other embodiments for carrying out the invention, as defined in the appended claims, when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1**A is a schematic diagram of a first configuration of a first embodiment of the vehicular heat pump system operating in heating mode;

[0011] FIG. **1**B is a schematic diagram of a second configuration of the first embodiment of the vehicular heat pump system operating in heating mode;

[0012] FIG. **2**A is a schematic diagram of a third configuration of the first embodiment of the vehicular heat pump system operating in cooling mode;

[0013] FIG. **2**B is a schematic diagram of a fourth configuration of the first embodiment of the vehicular heat pump system operating in cooling mode;

[0014] FIG. **3** is a schematic diagram of a fifth configuration of the first embodiment of the vehicular heat pump system; and

[0015] FIG. **4** is a schematic diagram of a second embodiment of the vehicular heat pump system wherein the heat pump condenser is a refrigerant-to-coolant heat exchanger located in the vehicle underhood.

DETAILED DESCRIPTION

[0016] The following description and figures refer to example embodiments and are merely illustrative in nature and not intended to limit the invention, its application, or uses. Throughout the figures, some components are illustrated with standardized or basic symbols. These symbols are representative and illustrative only, and are in no way limiting to any specific configuration shown, to combinations between the different configurations shown, or to the claims. All descriptions of componentry are open-ended and any examples of components are non-exhaustive.

[0017] Referring to the figures, wherein like reference numbers correspond to like or similar components throughout the several views, a vehicular heat pump system **100**, **200** for controlling the temperature of a vehicle passenger compartment **122** and vehicle battery **115**, for use in cool and mild ambient temperatures is provided and shown in a variety of configurations and operating modes, in FIGS. **1**A-B, **2**A-B, **3**, and **4**.

[0018] The heat pump system **100**, may operate in two modes: a cooling mode, as shown in FIGS. **2**A-B, **3**, and **4**, and a heating mode, as shown in FIGS. **1**A-B, **3**, and **4**. When operating in each of the respective heating mode and cooling mode, the heat pump system **100** circulates a refrigerant. The refrigerant may be one of R-134a, R-1234yf, R-744, R-152a or the like. In heating mode, the refrigerant may be directed through a plurality of components along the heating circuit **125** to heat and dehumidify a vehicle passenger compartment **122** and/or cool a vehicle battery **115**. In cooling mode the refrigerant may be directed through a plurality of components along the cooling circuit **124** to cool and dehumidify the vehicle passenger compartment **122** and/or cool the vehicle battery **115**.

[0019] The heating circuit **125**, shown generally in FIG. 1A, may include a compressor **102** having a compressor inlet **126** and a compressor outlet **127**; at least one high-side refrigerant pressure sensor **117**; a first flow control valve **114**; a second flow control valve **106**; a third flow control valve **104**; a heat pump condenser **111***a;* a receiver dryer **105**; a first expansion device **108**; a second expansion device **107**; an RESS chiller **110** functioning as a heat pump evaporator; a cabin evaporator **113**; at least one low-side refrigerant pressure sensor **116**; and at least one control module **123**.

[0020] The heating circuit **125** has a distinct high-pressure side and low-pressure side. The high-pressure side, wherein the refrigerant is in a condensed high pressure state, is defined between a compressor outlet **127** and each of the respective expansion devices **107**, **108**. The low-pressure side of the system, wherein the refrigerant in an expanded, low pressure state, is defined between each of the respective expansion devices **107**, **108** and the compressor inlet **126**.

[0021] The compressor **102** may be driven by an electric motor (not shown), which may be of the single or variable speed variety. The compressor **102** may also be a pump driven by a belt connected to the engine crankshaft (not shown). The compressor **102** may include a compressor inlet **126** and a compressor outlet **127**. The compressor **102** may be configured to receive refrigerant gas on the low-pressure side of the system at the compressor inlet **126** and may pressurize the refrigerant gas into a high-pressure state. The compressor **102** may be further configured to expel compressed refrigerant gas to the compressor outlet **127**, exiting on the high-pressure side of the system.

[0022] The at least one low-side refrigerant pressure sensor **116** may be positioned on the low-pressure side of the compressor **102** proximate the compressor inlet **126**. The at least one high-side refrigerant pressure sensor **117** may be positioned on the high-pressure side of the compressor **102** proximate the compressor outlet **127**.

[0023] The heating circuit **125** may additionally include a first flow control valve **114** that may be fully open when the heat pump system **100** is operating in heating mode. The first flow control valve **114** may be fully open in heating mode and may be configured to direct and selectively distribute refrigerant to the heat pump condenser **111***a*. The third flow control valve **104** may be fully closed in heating mode. The second flow control valve **106** may be fully open, in heating mode, if passenger compartment **122** dehumidification is needed; the second flow control valve **106** may be fully closed, in heating mode, if passenger compartment **122** dehumidification is not needed.

[0024] The heat pump condenser may be a refrigerant-to-air heat exchanger **111***a* located within the HVAC module **121**, as shown in FIGS. **1**A-B. Alternatively, the heat pump condenser may be a refrigerant-to-coolant heat exchanger **111***c* located in the vehicle underhood **152**, as shown in FIG. **4**. The heat pump condenser **111***a,* **111***c* may include a condenser inlet **128** and a condenser outlet **129**. The heat pump condenser **111***a,* **111***c* may be configured to receive pressurized refrigerant gas at the condenser inlet **128**, and may extract heat from the pressurized refrigerant gas as it passes through the condenser **111***a,* **111***c*, to the extent that the pressurized refrigerant gas is cooled to a point at which it is reclaimed into a liquid state. The heat extracted from the refrigerant may be exchanged to the air flowing across the heat pump condenser **111***a*. The heated air may be directed to the passenger compartment **122**. The cooled liquid refrigerant may be expelled from the heat pump condenser **111***a,* **111***c* at the heat pump condenser outlet **129**.

[0025] The receiver dryer **105** may include a receiver dryer inlet **134** and a receiver dryer outlet **135**. The receiver dryer **105** may further include a plurality of desiccants (not shown) to attract and remove moisture from the system **100**. The receiver dryer **105** may receive the high-pressure refrigerant liquid at the receiver dryer inlet **134** and expel the high pressure refrigerant liquid from the receiver dryer outlet **135**.

[0026] The first expansion device **108** may allow the high pressure liquid refrigerant to expand, reducing the pressure in the system **100**. The first expansion device **108** may direct and selectively distribute refrigerant to the RESS chiller **110**, at a significantly reduced pressure. The first expansion device **108** may be a thermostatic or thermal expansion valve, and may be configured to hold a constant evaporator superheat state as the refrigerant enters RESS chiller **110**, which acts as a heat pump evaporator. The thermostatic or thermal expansion valve may be a conventional, mechanically driven, thermal expansion valve, with which no electronic devices are associated, as shown in FIGS. **1**A-B, or the thermal expansion valve may be an electronically driven thermal expansion valve, as shown in FIGS. **2**A-B, **3**, and **4**. The first expansion device **108** may be either electronic or mechanical in any of the configurations shown in FIGS. **1**A-B, **2**A-B, **3**, and **4**. The first expansion device **108** may monitor, such as with a sensor or a bulb, the temperature of the refrigerant leaving the RESS chiller **110**, and may improve the performance of the heat exchange by letting additional or less refrigerant into the RESS chiller **110**.

[0027] The RESS chiller **110** may be located outside the HVAC module **121**. The RESS chiller **110** may function as a heat pump evaporator that may include coils (not shown) or the like to dissipate heat from the battery **115** to the cooled refrigerant. The RESS chiller **110** may direct refrigerant over the low-side pressure sensor **116** and back to the compressor **102**.

[0028] If dehumidification of the passenger compartment **122** is needed, the heating circuit **125** may also circulate refrigerant along flow path **150**, as shown in FIG. **1**A. In such a case, the heating circuit **125** may also include a cabin evaporator **113**, a second flow control valve **106**, and a second expansion device **107**. Additionally, the second flow control valve **106** may be fully open, during heating mode, when passenger compartment **122** dehumidification is desired. The second expansion device **107** may be configured to receive refrigerant from the receiver dryer **105** through the second flow control valve **106** and may be further configured to allow the high-pressure refrigerant to expand, reducing the pressure in the system **100**.

[0029] The second expansion device **107** may control and selectively distribute refrigerant to the cabin evaporator **113**, at a significantly reduced pressure. The second expansion device **107** may be a thermostatic or thermal expansion valve, and is configured to hold a constant evaporator superheat state as the refrigerant enters the cabin evaporator **113**. The thermostatic or thermal expansion valve may be a conventional, mechanically driven, thermal expansion valve, with which no electronic devices are associated, as shown in FIGS. **2**A-B, or the thermal expansion valve may be an electronically driven thermal expansion valve, as shown in FIGS. **1**A-B, **3**, and **4**. The second expansion device **107** may be either electronic or mechanical in any of the configurations shown in FIGS. **1**A-B, **2**A-B, **3**, and **4**. The second expansion device **107** may monitor, such as with a sensor or a bulb, the temperature of the refrigerant leaving the cabin evaporator **113**, and may improve the performance of the heat exchange by letting additional or less refrigerant into the cabin evaporator **113**.

[0030] The cabin evaporator **113** may be located within the HVAC module **121**. The cabin evaporator **113** may include coils (not shown). The cabin evaporator **113** may be configured to cool and dehumidify the air flowing across the coils (not shown) and into the passenger compartment **122**. The cabin evaporator **113** may further include a fan (not shown) to direct air over the coils impregnated with refrigerant, and facilitate the direction of the air into the passenger compartment **122**. The cabin evaporator **113** may be further configured to direct refrigerant over the low-side pressure sensor **116** and back to the compressor **102**.

[0031] The cooling circuit **124**, shown generally in FIG. **2**A-B may include a compressor **102** having a compressor inlet **126** and a compressor outlet **127**; at least one high-side refrigerant pressure sensor **117**; an AC condenser **103**; a first flow control valve **114**; a second flow control valve **106**, a third flow control valve **104**; a receiver dryer **105**; a first expansion device **108**; an RESS chiller **110** functioning as a heat pump evaporator; a second expansion device **107**; a cabin evaporator **113**; at least one low-side refrigerant pressure sensor **116**; and at least one control module **123**.

[0032] The cooling circuit **124** has a distinct high pressure side and low pressure side. The high pressure side, wherein the refrigerant is in a condensed high pressure state, is defined between a compressor outlet **127** and each of the respective expansion devices **107**, **108**. The low pressure side of the system, wherein the refrigerant in an expanded low pressure state, is defined between each of the respective expansion devices **107**, **108** and the compressor inlet **126**.

[0033] The compressor **102** may be driven by an electric motor (not shown), which may be of the single or variable speed variety. The compressor **102** may also be a pump driven by a belt connected to the engine crankshaft (not shown). The compressor **102** may include a compressor inlet **126** and a compressor outlet **127**. The compressor **102** may receive refrigerant gas on the low pressure side of the system at the compressor inlet **126** and may pressurize the refrigerant gas into a high pressure state. The compressor **102** may direct compressed refrigerant gas to the compressor outlet **127**, exiting on the high pressure side of the system **100**.

[0034] The at least one low-side refrigerant pressure sensor **116** may be positioned on the low-pressure side of the compressor **102** proximate the compressor inlet **126**. The at least one high-side refrigerant pressure sensor **117** may be positioned on the high-pressure side of the compressor **102** proximate the compressor outlet **127**.

[0035] In cooling mode, the first flow control valve **114** may be fully closed. Each of the respective second flow control valve **106** and third flow control valve **104** may be fully open, in cooling mode and may be further configured to receive and expel refrigerant.

[0036] The AC condenser **103** may be located outside the HVAC module **121**. The AC condenser **103** may include an AC condenser inlet **130** and an AC condenser outlet **131**. The AC condenser **103** may receive pressurized refrigerant gas at the condenser inlet **130**, and may cool and condense the pressurized refrigerant gas as it flows through the AC condenser **103**, to the extent that the pressurized refrigerant gas is cooled and condensed to a point at which it is reclaimed into a liquid state. The AC condenser outlet **131** may be configured to expel cooled liquid refrigerant.

[0037] The receiver dryer **105** may include a receiver dryer inlet **134** and a receiver dryer outlet **135**. The receiver dryer **105** may further include a plurality of desiccants (not shown) to attract and remove moisture from the system **100**. The receiver dryer **105** may receive the high-pressure refrigerant liquid at the receiver dryer inlet **134** and expel the high pressure refrigerant liquid from the receiver dryer outlet **135** to one of the first expansion device **108** and the second expansion device **107**.

[0038] The first and second expansion devices **108**, **107** may allow the high pressure liquid refrigerant to expand, reducing the pressure of the refrigerant as it exits the first and second expansion devices **108**, **107**. The first and second expansion devices **108**, **107** may be further configured to control and selectively distribute refrigerant to each of the respective RESS chiller **110** functioning as a heat pump evaporator and cabin evaporator **113**, at a significantly reduced pressure. The first and second expansion devices **108**, **107** may be thermostatic or thermal expansion valves, and may be configured to hold a constant evaporator superheat state as the refrigerant enters one of the RESS chiller **110**, which acts as a heat pump evaporator and the cabin evaporator **113**. Each of the respective first expansion device **108** and second expansion device **107** may be either electronic or mechanical in any of the configurations shown in FIGS. **1**A-B, **2**A-B, **3**, and **4**. The first and second expansion devices **108**, **107** may monitor, such as with a sensor or a bulb, the temperature of the refrigerant leaving either the RESS chiller **110** or cabin evaporator **113**, and may improve the performance of the heat exchange by letting additional or less refrigerant into the RESS chiller **110** or cabin evaporator **113**.

[0039] The RESS chiller **110** may include coils (not shown) or the like to dissipate heat from the battery **115** to the cooled refrigerant. The RESS chiller **110** may direct refrigerant over the low-side pressure sensor **116** and back to the compressor **102**.

[0040] The cabin evaporator **113** may be located within the HVAC module **121**. The cabin evaporator **113** may include coils (not shown), which may function to allow the refrigerant flow across the coils (not shown). The cabin evaporator **113** may be configured to cool and dehumidify the air flowing across the coils (not shown) and into the passenger compartment **122**. The cabin evaporator **113** may further include a fan (not shown) to direct air over the coils impregnated with refrigerant, and facilitate the direction of the air into the passenger compartment **122**. The cabin evaporator **113** may be configured to direct refrigerant over the low-side pressure sensor **116** and back to the compressor **102**.

[0041] As shown in FIGS. **1**A-B, **2**A-B, **3**, and **4**, each of the respective heating circuit **125** and cooling circuit **124** may include at least one control module **123** that may be electrically connected with at least one electrical connection **136** and may be configured to monitor and control the heat pump system **100** in a variety of operating modes. The at least one control module **123** may be configured to communicate with the motor (not shown) which may drive the compressor **102**. The at least one control module **123** may further be configured to communicate with the first and second expansion devices **108**, **107**; the plurality of flow control valves **104**, **106**, **114**, **120**; the pressure sensors **116**, **117**; and other subsystems through the at least one electrical connection **136**.

[0042] Illustrative examples of the vehicular heat pump system **100**, **200** are shown in FIGS. **1**A-B, **2**A-B, **3**, and **4**. Each of the embodiments depicts a vehicular heat pump system **100**, **200** capable of operating in both heating mode and cooling mode without the need to reverse the system **100**, **200** upon a change in operating mode. Additionally, each embodiment will allow a hybrid or electric vehicle to operate in both hybrid mode and electric vehicle mode (EV mode) in ambient temperatures at least as low as about 4° C.

[0043] FIGS. **1**A-B depict a first configuration and a second configuration of a first embodiment of the heat pump system **100** operating in heating mode. In the first configuration, shown in FIG. **1**A, low-pressure refrigerant gas is directed across a low-side pressure sensor **116** to a compressor **102**. The compressor **102** may be configured to receive the low-pressure refrigerant gas at the compressor inlet **126**. The compressor **102** may compress the refrigerant gas, produce a high-pressure refrigerant gas, and expel the high pressure refrigerant gas at the compressor outlet **127**.

[0044] The high pressure refrigerant gas may be expelled from the compressor outlet **127** and directed across a high-side pressure sensor **117**, to the first flow control valve **114**. The first flow control valve **114** may be fully open in heating mode, and may be configured to direct and selectively distribute the high pressure refrigerant gas to the heat pump condenser **111***a*.

[0045] The heat pump condenser **111***a*, may be a refrigerant-to-air heat exchanger and may be housed within the HVAC module **121**. The heat pump condenser **111***a* may be configured to receive the high-pressure refrigerant gas from the first flow control valve **114** at the heat pump condenser inlet **128**. The heat pump condenser **111***a* may, additionally, be configured to cool and condense the pressurized refrigerant gas as it flows through the heat pump condenser **111***a*, to the extent that the refrigerant reclaims liquid form. The heat extracted from the refrigerant may be exchanged to the air flowing across the heat pump condenser **111***a*. The heated air may be directed to the passenger compartment **122**. The cooled liquid refrigerant may be expelled from the heat pump condenser outlet **129** and directed to the receiver dryer **105**.

[0046] The receiver dryer **105** may be configured to receive the liquid refrigerant at the receiver dryer inlet **134** from the heat pump condenser **111***a*. The receiver dryer **105** may be further configured to remove moisture from the system **100** through the use of a plurality of desiccants (not shown), which may attract and remove additional moisture from the refrigerant being directed to one of the cabin evaporator **113** and the RESS chiller **110** acting as a heat pump evaporator. After the excess moisture is extracted from the system **100**, the refrigerant liquid may be expelled from the receiver dryer outlet **135** and directed to at least one of the first expansion device **108** or second expansion device **107**.

[0047] If cabin dehumidification is not needed, the second flow control valve **106** may be fully closed and all refrigerant expelled from the receiver dryer **105** may be directed to the first expansion device **108**. If cabin dehumidification is needed, the second flow control valve **106** may be fully open and the refrigerant expelled from the receiver dryer **105** may be directed and selectively distributed to one of the first expansion device **108** and the second expansion device **107**.

[0048] High pressure, liquid refrigerant may be directed from the receiver dryer **105** to the first expansion device **108**. The first expansion device **108** may be configured to receive refrigerant and further configured to allow the liquid refrigerant to depressurize and expand. The first expansion device **108** may be further configured to direct and selectively distribute refrigerant to the RESS chiller **110**, which may act as a heat pump evaporator.

[0049] The RESS chiller **110** acting as a heat pump evaporator may be configured to receive the cooled liquid refrigerant from the first expansion device **108**. The RESS chiller **110** may be further configured to dissipate excess heat from the battery **115** to the refrigerant, and expel the refrigerant over the at least one low-side pressure sensor **116** and back to compressor **102**.

[0050] High pressure, liquid refrigerant may also be directed from the receiver dryer **105** to the second expansion device **107**. Refrigerant directed to the second expansion device **107** may flow along flow path **150** and may first pass through the second flow control valve **106**, which may be fully open, when cabin dehumidification is needed. The second flow control valve **106** may be configured to direct and selectively distribute refrigerant to the second expansion device **107**. The second expansion device **107** may be configured to receive the liquid refrigerant and allow the liquid refrigerant to depressurize and expand. The second expansion device **107** may be further configured to direct and selectively distribute refrigerant to the cabin evaporator **113**.

[0051] The cabin evaporator **113** may be configured to receive the cooled liquid refrigerant from the second expansion device **107**. The cabin evaporator **113** may be further configured to cool and dehumidify the air flowing across the cabin evaporator **113** and into the passenger compartment **122**. The cabin evaporator **113** may be further configured to expel the refrigerant over the low-side pressure sensor **116** and back to the compressor **102**.

[0052] In the second configuration, shown in FIG. **1**B, the third flow control valve **104** may be relocated and placed between the compressor **102** and the AC condenser **103**, to combat refrigerant pooling inside the AC condenser **103**.

[0053] FIGS. **2**A-B depict a third configuration and a fourth configuration of the first embodiment of the heat pump system **100** operating in cooling mode. In the third configuration of the first embodiment, shown in FIG. **2**A, the compressor **102** may be configured to receive low pressure refrigerant gas at the compressor inlet **126**, after the low pressure refrigerant gas passes a low-side pressure sensor **116**. The compressor **102** may compress the refrigerant gas, producing a high-pressure refrigerant gas. The compressor **102** may be further configured to expel the high-pressure refrigerant gas at the compressor outlet **127**.

[0054] The high-pressure refrigerant gas may be directed from the compressor outlet **127** across a high-side pressure sensor **117** and directed to an AC condenser **103**. The AC condenser **103** may be configured to receive the high-pressure refrigerant gas at an AC condenser inlet **130**. The AC condenser **103** may additionally be configured to cool and condense the high-pressure refrigerant gas, to the extent that the refrigerant reclaims liquid form. The cooled liquid refrigerant may be expelled from the AC condenser outlet **131** and directed to the third flow control valve **104**. The third flow control valve **104** may be configured to direct and selectively distribute the high-pressure refrigerant gas to the receiver dryer **105**.

[0055] The receiver dryer **105** may be configured to receive the liquid refrigerant at the receiver dryer inlet **134**. The receiver dryer **105** may be further configured to remove moisture from the system through the use of a plurality of desiccants (not shown), which may attract and remove moisture prior to the refrigerant being directed to one of the cabin evaporator **113** and RESS chiller **110**. After the excess moisture is extracted from the system, the refrigerant liquid may be expelled from the receiver dryer outlet **135** and directed and selectively distributed to one of the second flow control valve **106** and the first expansion device **108**. The selective direction by the at least one control module **123** may be based on the necessary balance between the cooling of the passenger compartment **122** and the cooling of the battery **115**.

[0056] If cooling is desired in the passenger compartment **122** only, all refrigerant will be directed to the second flow control valve **106**, which will be fully open, and on to second expansion device **107**. If cooling is desired for the battery **115** only, all refrigerant will be directed to the first expansion device **108**, as the second flow control valve **106** will be fully closed. If both the passenger compartment **122** and the battery **115** require cooling, the refrigerant will be directed and selectively distributed to each of the respective first expansion device **108** and the second expansion device **107**.

[0057] High-pressure, liquid refrigerant directed to the second expansion device **107** may first pass through the second flow control valve **106**, which may be fully open in cooling mode. The second flow control valve **106** may be configured to direct, selectively distribute, and meter refrigerant to the second expansion device **107**. The second expansion device **107** may be configured to receive the liquid refrigerant and allow the liquid refrigerant to depressurize and expand. The second expansion device **107** may direct and selectively distribute refrigerant to the cabin evaporator **113**.

[0058] The cabin evaporator **113** may be configured to receive the cooled liquid refrigerant from the second expansion device **107**. The cabin evaporator **113** may be further configured to cool and dehumidify the air flowing across the cabin evaporator **113** and into the passenger compartment **122**. The cabin evaporator **113** may be further configured to expel and direct the refrigerant over the low-side pressure sensor **116** and back to the compressor **102**.

[0059] If battery **115** cooling is needed in addition to passenger compartment **122** cooling, high-pressure liquid refrigerant may also be directed from the receiver dryer **105** to the first expansion device **108** in cooling mode. The first expansion device **108** may be configured to receive the liquid refrigerant from the receiver dryer **105** and allow the liquid refrigerant to depressurize and expand. The first expansion device **108** may be further configured to direct and selectively distribute refrigerant to the RESS chiller **110**.

[0060] The RESS chiller **110** may act as a heat pump evaporator. The RESS chiller **110** may be configured to receive the cooled liquid refrigerant from the first expansion device **108**. The RESS chiller **110** may be further configured to dissipate excess heat from the battery **115** to the refrigerant, and expel and direct the refrigerant over the low-side pressure sensor **116** and back to the compressor **102**.

[0061] In the fourth configuration of the first embodiment, shown in FIG. 2B, the third flow control valve **104** may be relocated between the compressor **102** and the AC condenser **103**, to combat refrigerant pooling inside the AC condenser **103**. In the fourth configuration, the third flow control valve **104** may be configured to receive high-pressure refrigerant gas from the compressor outlet **127**. The third flow control valve **104** may be fully open and may be further configured to direct, selectively distribute, and meter refrigerant flow to the AC condenser **103**.

[0062] FIG. **3** depicts the fifth configuration of the first example embodiment of the vehicular heat pump system **100**, which is applicable in both heating mode and cooling mode. In fifth configuration, shown in FIG. **3**, the first flow control valve **114** and the third flow control valve **104** may be replaced with a three-way, two-position flow control valve **120**. This three-way, two-position control valve **120** can serve as the flow control valve **114** between the compressor **102** and heat pump condenser **111***a*, which may be fully open in heating mode and the flow control valve **104** between the compressor **102** and AC condenser **103**, which may be fully open in cooling mode.

[0063] FIG. **4** depicts a second embodiment of the vehicular heat pump system **200**, which is applicable in both heating mode and cooling mode. In the second embodiment, the cooling circuit **124** functions in the same manner as the cooling circuits **124** described with respect to the third and fourth configurations of the first embodiment shown in FIGS. **2**A-**2**B and **3**.

[0064] The heating circuit **125** of the second embodiment may contain substantially the same structure as described with respect to the first embodiment described above. However, the heat pump condenser **111***c* may be a refrigerant-to-coolant heat exchanger rather than a refrigerant-to-air heat exchanger **111***a*. Further, in the third example embodiment, the refrigerant-to-coolant heat pump condenser **111***c* may be located in the vehicle underhood **152**, rather than within the HVAC module **121**.

[0065] The refrigerant-to-coolant heat pump condenser **111***c* may include a refrigerant cavity **140** and a coolant cavity **137**. The refrigerant cavity **140** may include a refrigerant inlet **146** and a refrigerant outlet **148**. The coolant cavity **137** may include a coolant inlet **138** and a coolant outlet **139**.

[0066] The refrigerant-to-coolant heat pump condenser **111***c* may be configured to receive pressurized refrigerant gas at the refrigerant inlet **146**, and may extract heat from the pressurized gas as it flows through the refrigerant cavity **140** to the extent that the pressurized refrigerant gas is cooled and condensed to a point at which it is reclaimed into a liquid state. The heat extracted from the refrigerant as it flows through the refrigerant cavity **140** may be transferred to the coolant flowing through the coolant cavity **137**.

[0067] The warmed coolant flowing through the coolant cavity **137** may be expelled from the coolant outlet **139** and directed through a coolant heater core **112**. The coolant heater core **112** may be housed in the HVAC module **121**. Heat may then be transferred from the coolant flowing through the coolant heater core **112** to the air flowing across the coolant heater core **112**. The heated air may be directed across the coolant heater core **112** to the passenger compartment **122**.

[0068] In vehicles that are electric only propulsion vehicles, the vehicular heat pump system **200** may further include: an electric coolant pump **144**. In such systems, coolant may be expelled from the coolant heater core **112** and directed to the electric coolant pump **144**. The electric coolant pump **144** may be configured to receive coolant from the coolant heater core **112** and expel coolant to the coolant cavity **137**. The coolant cavity **137** may be configured to receive coolant from the electric coolant pump **144** at the coolant cavity inlet **138**.

[0069] In advanced propulsion vehicles, the vehicular heat pump system **200** may further include an electric coolant pump **144**; a heating source **143**, such as an internal combustion engine, a fuel cell stack, a fuel operated heater, a thermal storage device or the like; and a coolant valve **142**. In such systems, coolant may be expelled from the coolant heater core **112** and directed to the coolant valve **142**. The coolant valve **142** may be a three-way, two-position valve and may be configured to direct coolant flow from the heater core **112** to the coolant pump **144**, when the heating source **143** is too cold to operate. When the heating source **143** is sufficiently warmed, the coolant valve **142** may be further configured to direct coolant flow from the coolant heater core **112** to the heating source **143**, which may expel coolant to the coolant pump **144**.

[0070] The cooled, liquid refrigerant may be expelled from the heat pump condenser outlet **148** and directed to the receiver dryer **105**. The receiver dryer **105** may be configured to receive the liquid refrigerant at the receiver dryer inlet **134**. The receiver dryer **105** may be further configured to remove moisture from the system through the use of a plurality of desiccants (not shown), which may attract and remove additional moisture from the refrigerant. After the excess moisture is extracted from the system **100**, the refrigerant liquid may be expelled from the receiver dryer outlet **135** and directed to at least one of the respective first expansion device **108** or the second expansion device **107**.

[0071] If cabin dehumidification is not needed, all refrigerant expelled from the receiver dryer **105** may be directed to the first expansion device **108**, as the second flow control valve **106** will be fully closed. If cabin dehumidification is needed, the refrigerant expelled from the receiver dryer **105** may be directed and selectively distributed to one of the first expansion device **108** and the second expansion device **107**, through the fully open second control valve **106**.

[0072] High pressure, liquid refrigerant directed to the second expansion device **107**, may flow along flow path **150** and may first pass through the second flow control valve **106**. The second flow control valve **106**, may be fully open in heating mode if passenger compartment **122** dehumidification is needed. The second flow control valve **106** may be configured to direct and selectively distribute refrigerant to the second expansion device **107**. The second expansion device **107** may be configured to receive the liquid refrigerant and allow the liquid refrigerant to depressurize and expand. The second expansion device **107** may be further configured to direct and selectively distribute refrigerant to the cabin evaporator **113**.

[0073] The cabin evaporator **113** may be configured to receive the cooled, liquid refrigerant from the second expansion device **107**. The cabin evaporator **113** may be further configured to cool and dehumidify the air flowing across the evaporator **113** and into the passenger compartment **122**. The cabin evaporator **113** may be further configured to expel and direct refrigerant over the low-side pressure sensor **116** and back to the compressor **102**.

[0074] Refrigerant may also be directed from the receiver dryer **105** to the first expansion device **108**. The first expansion device **108** may be configured to receive and allow the liquid refrigerant to depressurize and expand. The first expansion device may be further configured to direct and selectively distribute refrigerant to the RESS chiller **110**.

[0075] The RESS chiller **110** may act as a heat pump evaporator and may be configured to receive the cooled, liquid refrigerant from the first expansion device **108**. The RESS chiller **110** may be further configured to dissipate excess heat from the battery **115** to the refrigerant, and expel and direct the refrigerant over the low-side pressure sensor **116** and back to the compressor **102**.

[0076] The mild ambient heat pump system **100** maintains an independent heating circuit **125** and an independent cooling circuit **124**. Therefore, the system **100** does not require a reversing upon a change to the operating mode. Each of the heat exchangers always function as an evaporator **110**, **113** or always functions as a condenser **103**, **111***a*, **111***c*, rather than as conventional heat exchangers, which switch between evaporator function and condenser function upon a change in operating mode. Accordingly, the position of the low-pressure side of the system remains constant in all operating modes. The low-pressure side of the system is always defined between each of the respective expansion devices **107**, **108** and the compressor inlet **126**. Additionally, the low-pressure side of the heat pump system is not directly cooled with ambient air. Such a configuration of the vehicular heat pump system **100**, **200** allows for passenger compartment **122** heating in EV mode in mild and cold ambient temperatures without interruption, as the de-icing of the RESS chiller **110** during heating mode is not necessary. Such a system **100**, **200** also preserves underhood **152** packing space which can be scarce in hybrid or electric vehicle models.

[0077] The detailed description and the drawings or figures are supportive and descriptive of the invention, but the scope of the invention is defined solely by the claims. While some of the best modes and other embodiments for carrying out the claimed invention have been described in detail, various alternative designs and embodiments exist for practicing the invention defined in the appended claims.

1. A heat pump system for use in a vehicle having a battery and a passenger compartment comprising:

a heating circuit, having a low-pressure side and a high-pressure side, the heating circuit configured to circulate refrigerant in a first operating mode, to heat the passenger compartment and cool the battery;

a cooling circuit, having a low pressure side and a high pressure side, the cooling circuit configured to circulate refrigerant in a second operating mode, to cool and dehumidify the passenger compartment and cool the battery;

wherein in the low pressure side of each of the respective heating circuit and cooling circuit remains constant during operation of the heat pump system in each of the respective first operating mode and second operating mode.

2. The heat pump system of claim **1** wherein the heating circuit further includes:

a compressor configured to compress the refrigerant;

at least one low-side pressure sensor configured to monitor the pressure of the refrigerant entering the compressor;

at least one high-side pressure sensor configured to monitor the pressure of the refrigerant exiting the compressor;

a first flow control valve configured to receive refrigerant from the compressor;

a refrigerant-to-air heat pump condenser configured to receive refrigerant from the first flow control valve and further configured to cool and condense the refrigerant; and

wherein the refrigerant-to-air heat pump condenser is configured to exchange heat between the refrigerant flowing through the refrigerant-to-air heat pump condenser and air flowing across the refrigerant-to-air heat pump condenser to heat the passenger compartment.

3. The heat pump system of claim **2** further comprising:

a receiver dryer configured to receive refrigerant from the refrigerant-to-air heat pump condenser and further configured to remove moisture from the refrigerant;

a first expansion device configured to receive refrigerant from the receiver dryer and further configured to allow the refrigerant to cool and expand;

a second flow control valve configured to receive refrigerant from the receiver dryer; and

wherein the receiver dryer is configured to expel refrigerant to one of the first expansion device and second flow control valve.

4. The heat pump system of claim **3** wherein the receiver dryer is configured to expel refrigerant to the first expansion device.

5. The heat pump system of claim **4** further comprising an RESS chiller configured to act as a heat pump evaporator capable of exchanging heat from air surrounding the vehicle battery to the refrigerant, the RESS chiller further configured to receive refrigerant from the first expansion device and expel refrigerant to the compressor.

6. The heat pump system of claim **3** wherein the receiver dryer is configured to expel refrigerant to the second flow control valve.

7. The heat pump system of claim **6** further comprising:

a second expansion device configured to receive refrigerant from the second flow control valve and further configured to allow the refrigerant to cool and expand; and

a cabin evaporator configured to receive refrigerant from the second expansion device and expel refrigerant to the compressor, the cabin evaporator further configured to exchange heat between the refrigerant and air in the passenger compartment to cool and dehumidify the passenger compartment.

8. The heat pump system of claim **1** wherein the cooling circuit further comprises:

a compressor configured to compress the refrigerant;

at least one low-side pressure sensor configured to monitor the pressure of the refrigerant entering the compressor;

at least one high-side pressure sensor configured to monitor the pressure of the refrigerant exiting the compressor; and

an AC condenser configured to receive refrigerant from one of the third flow control valve and the compressor, the AC condenser further configured to cool and condense the refrigerant.

9. The heat pump system of claim **8** wherein the AC condenser is configured to receive refrigerant from the compressor and expel refrigerant to the third flow control valve.

10. The heat pump system of claim **8** further comprising:

a receiver dryer configured to remove moisture from the refrigerant; and

wherein the AC condenser is configured to receive refrigerant from the third flow control valve and expel refrigerant to the receiver dryer.

11. The heat pump system of claim **8** further comprising:

a receiver dryer configured to receive refrigerant from one of the AC condenser and the third flow control valve, the receiver dryer further configured to remove moisture from the refrigerant;

a first thermal expansion device configured to receive refrigerant from the receiver dryer and further configured to allow the refrigerant to cool and expand; and

an RESS chiller configured to act as a heat pump evaporator capable of exchanging heat from air surrounding the battery to the refrigerant, the RESS chiller further configured to receive refrigerant from the first expansion device and expel refrigerant to the compressor.

12. The heat pump system of claim **8** further comprising:

a receiver dryer configured to receive refrigerant from one of the AC condenser and the third flow control valve, the receiver dryer further configured to remove moisture from the refrigerant;

a second flow control valve configured to receive refrigerant from the receiver dryer;

a second expansion device configured to receive refrigerant from the second flow control valve and further configured to allow the refrigerant to cool and expand;

a cabin evaporator configured to receive refrigerant from the second expansion device and expel refrigerant to the compressor, the cabin evaporator further configured to exchange heat between the refrigerant and air in the passenger compartment to cool and dehumidify the passenger compartment.

13. The heat pump system of claim **1** wherein the heating circuit includes:

an compressor configured to compress the refrigerant;

at least one low-side pressure sensor configured to monitor the pressure of the refrigerant entering the compressor;

at least one high-side pressure sensor configured to monitor the pressure of the refrigerant exiting the compressor;

a first flow control valve configured to receive refrigerant from the compressor;

a refrigerant-to-coolant heat pump condenser having a refrigerant cavity and a coolant cavity, the refrigerant-to-coolant heat pump condenser configured to receive refrigerant from the first flow control valve and further configured to exchange heat from refrigerant flowing through the refrigerant cavity to coolant flowing through the coolant cavity;

a coolant heater core configured to receive coolant from the refrigerant-to-coolant heat pump condenser and further configured to exchange heat between the coolant flowing through the coolant heater core and air flowing across the coolant heater core to the passenger compartment;

a receiver dryer configured to receive refrigerant from the refrigerant cavity, the receiver dryer further configured to remove moisture from the refrigerant;

a coolant valve configured to receive coolant from the coolant heater core;

a heating source configured to receive coolant from the coolant valve and further configured to warm the coolant;

an electric coolant pump configured to receive coolant from one of the coolant valve and heating source and further configured to expel coolant to the coolant cavity; and wherein the coolant valve is configured to direct coolant to one of the heating source and the electric coolant pump.

14. The heat pump of claim **13** wherein the heat pump system further includes:

a first thermal expansion device configured to receive refrigerant from the receiver dryer and further configured to allow the refrigerant to cool and expand; and

an RESS chiller configured to act as a heat pump evaporator capable of exchanging heat from air surrounding the vehicle battery to the refrigerant, the RESS chiller further configured to receive refrigerant from the first expansion device and expel refrigerant to the compressor.

15. The heat pump system of claim **13** further comprising:

a second flow control valve configured receive refrigerant from the receiver dryer;

a second expansion device configured to receive refrigerant from the second flow control valve and further configured to allow the refrigerant to cool and expand; and

a cabin evaporator configured to receive refrigerant from the second expansion device and expel refrigerant to the compressor, the cabin evaporator further configured to exchange heat between the refrigerant and air in the passenger compartment to cool and dehumidify the passenger compartment.

16. A vehicle comprising:

a passenger compartment;

a vehicle battery configured to provide a power source for the vehicle;

a heat pump system including:

a heating circuit, having a low-pressure side and a high-pressure side, the heating circuit configured to circulate refrigerant in a first operating mode, to heat the passenger compartment and cool the battery;

a cooling circuit, having a low-pressure side and a high-pressure side, the cooling circuit configured to circulate refrigerant in a second operating mode, to cool and dehumidify the passenger compartment and cool the battery;

a plurality of flow control valves, including at least a first flow control valve, a second flow control valve, and a third flow control valve, each of the respective first, second, and third flow control valves configured to receive and selectively distribute refrigerant through one of the heating circuit and cooling circuit; and

wherein the low-pressure side of each of the respective heating circuit and cooling circuit remains constant during operation of the heat pump system in each of the respective first operating mode and second operating mode.

17. The vehicle of claim **16** wherein the heating circuit includes:

a compressor configured to compress the refrigerant;

at least one low-side pressure sensor configured to monitor the pressure of the refrigerant entering the compressor;

at least one high-side pressure sensor configured to monitor the pressure of the refrigerant exiting the compressor;

the first flow control valve configured to receive refrigerant from the compressor;

a refrigerant-to-air heat pump condenser configured to receive refrigerant from the first flow control valve and further configured to condense and cool the refrigerant, wherein the refrigerant-to-air heat pump condenser is configured to exchange heat between the refrigerant flowing through the refrigerant-to-air heat pump condenser and air flowing across the refrigerant-to-air heat pump condenser to heat the passenger compartment;

a receiver dryer configured to receive refrigerant from the heat pump condenser and further configured to remove moisture from the refrigerant;

a first expansion device configured to receive refrigerant from the receiver dryer and further configured to allow the refrigerant to cool and expand; and

an RESS chiller configured to act as a heat pump evaporator capable of exchanging heat from air surrounding the vehicle battery to the refrigerant, the RESS chiller further configured to receive refrigerant from the first expansion device and expel refrigerant to the compressor.

18. The vehicle of claim **17** wherein the heating circuit further includes:

a compressor configured to compress the refrigerant;

at least one low-side pressure sensor configured to monitor the pressure of the refrigerant entering the compressor;

at least one high-side pressure sensor configured to monitor the pressure of the refrigerant exiting the compressor;

the first flow control valve configured to receive refrigerant from the compressor;

a refrigerant-to-air heat pump condenser configured to receive refrigerant from the first flow control valve and further configured to condense and cool the refrigerant, wherein the refrigerant-to-air heat pump condenser is configured to exchange heat between the refrigerant flowing through the refrigerant-to-air heat pump condenser and air flowing across the refrigerant-to-air heat pump condenser to heat the passenger compartment;

a receiver dryer configured to receive refrigerant from the heat pump condenser and further configured to remove moisture from the refrigerant;

the second flow control valve configured to receive refrigerant from the receiver dryer;

a second expansion device configured to receive refrigerant from the second flow control valve and further configured to allow the refrigerant to cool and expand; and

a cabin evaporator configured to receive refrigerant from the second expansion device and expel refrigerant to the compressor, the cabin evaporator further configured to exchange heat between the refrigerant and air in the passenger compartment to cool and dehumidify the passenger compartment.

19. The vehicle of claim **16** wherein the cooling circuit includes:

an compressor configured to compress the refrigerant;

at least one low-side pressure sensor configured to monitor the pressure of the refrigerant entering the compressor;

at least one high-side pressure sensor configured to monitor the pressure of the refrigerant exiting the compressor;

an AC condenser configured to receive refrigerant from one of the second flow control valve and the compressor, the AC condenser further configured to cool and condense the refrigerant;

the third flow control valve configured to receive refrigerant from one of the compressor and the AC condenser;

a receiver dryer configured to receive refrigerant from one of the AC condenser and the third flow control valve, the receiver dryer further configured to remove moisture from the refrigerant;

a first expansion device configured to receive refrigerant from the receiver dryer and further configured to allow the refrigerant to cool and expand; and

an RESS chiller configured to act as a heat pump evaporator capable of exchanging heat from air surrounding the vehicle battery to the refrigerant, the RESS chiller further configured to receive refrigerant from the first expansion device and expel refrigerant to the compressor.

20. The vehicle of claim **16** wherein the cooling circuit further includes:

a compressor configured to compress the refrigerant;

at least one low-side pressure sensor configured to monitor the pressure of the refrigerant entering the compressor;

at least one high-side pressure sensor configured to monitor the pressure of the refrigerant exiting the compressor;

an AC condenser configured to receive refrigerant from one of the second flow control valve and the compressor, the AC condenser further configured to cool and condense the refrigerant;

the third flow control valve configured to receive refrigerant from one of the compressor and the AC condenser;

a receiver dryer configured to receive refrigerant from one of the AC condenser and the third flow control valve, the receiver dryer further configured to remove moisture from the refrigerant;

the second flow control valve configured to receive refrigerant from the receiver dryer;

a second expansion device configured to receive refrigerant from the second flow control valve and further configured to allow the refrigerant to cool and expand; and

a cabin evaporator configured to receive refrigerant from the second expansion device and expel refrigerant to the compressor, the cabin evaporator further configured to exchange heat between the refrigerant and air in the passenger compartment to cool and dehumidify the passenger compartment.

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