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(54) **TWO STAGE TRANSCRITICAL REFRIGERATION SYSTEM**

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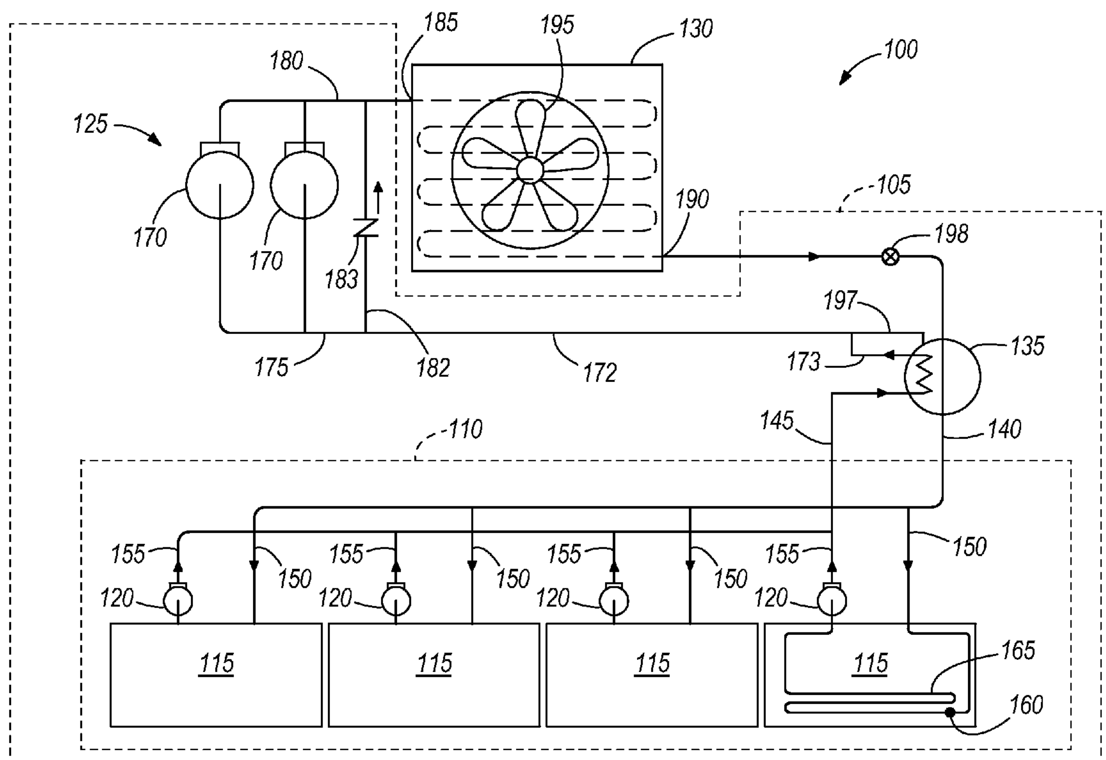
(57) **ABSTRACT**

The invention provides a refrigeration system including a plurality of refrigerated display cases. Each display case has a dedicated evaporator assembly that cools return air by evaporating a refrigerant, and a first stage compressor assembly that is in fluid communication with the respective evaporator assembly to compress the refrigerant to a first pressure corresponding to a first temperature of the refrigerant prior to discharge of the compressed refrigerant. The refrigeration system also includes a second stage compressor assembly that is in fluid communication with the first stage compressor assemblies to compress the refrigerant to a second pressure that is higher than the first pressure, and that corresponds to a second temperature of the refrigerant. The refrigeration system further includes a heat exchanger that is in fluid communication with the second stage compressor assembly to receive the refrigerant from the second stage compressor assembly to reject heat from the refrigerant.



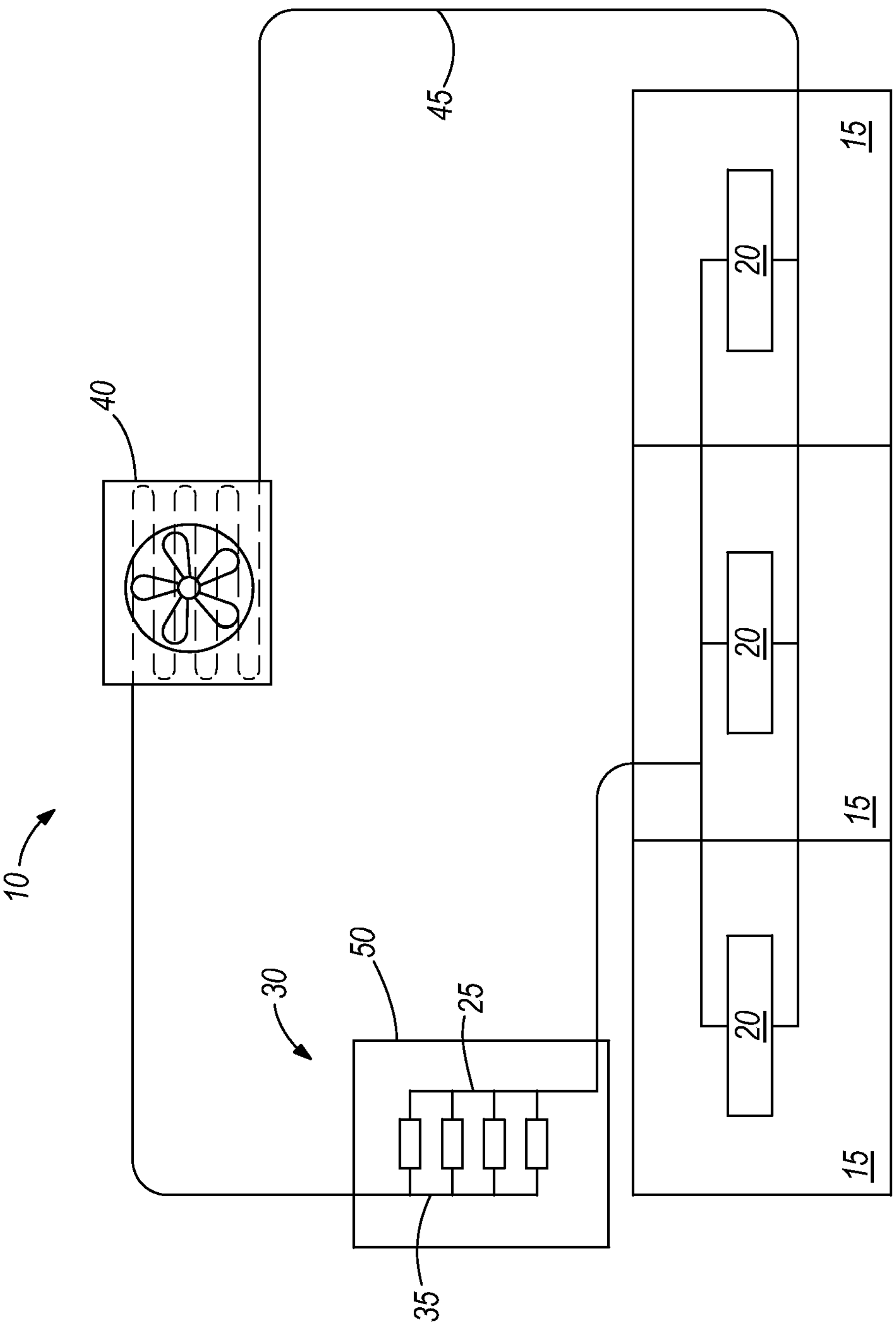
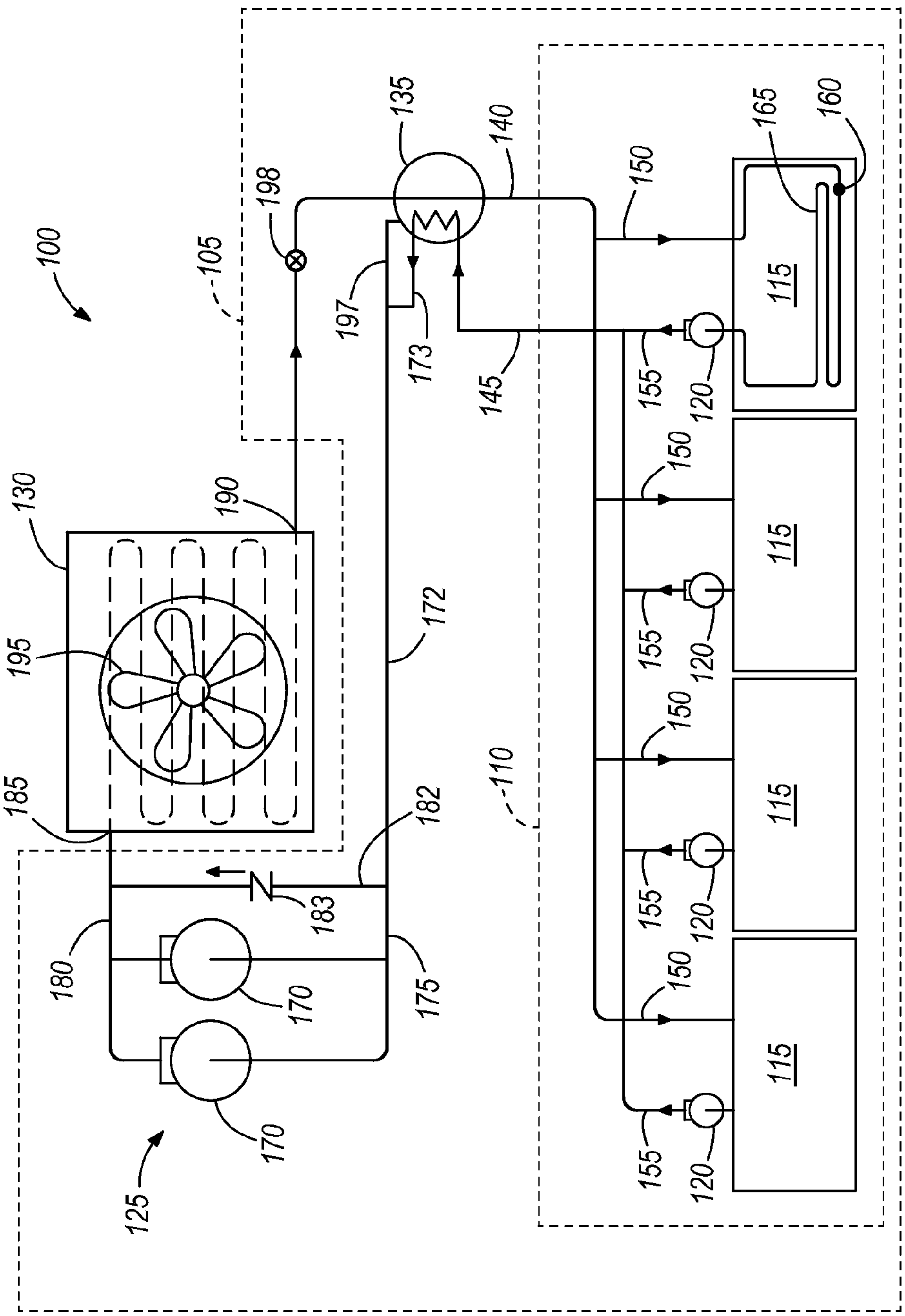


FIG. 1
PRIOR ART


100
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150
155
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172
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183
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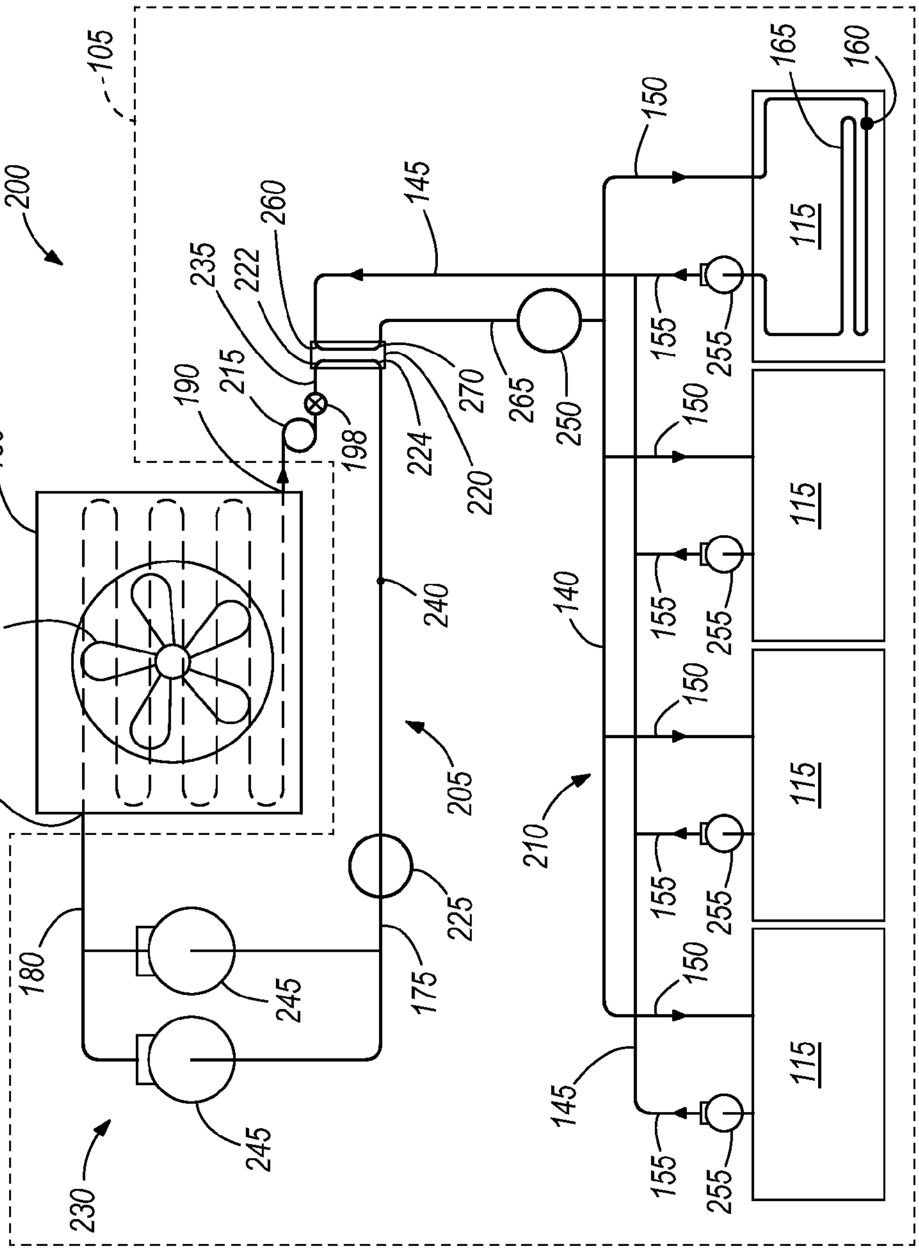
FIG. 2A


200
105
130
195
185
190
215
198
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222
260
145
150
165
160
115
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115
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220
270
265
250
155
255
240
205
210
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150
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175
180
245
245
230
145
155
255

FIG. 2B

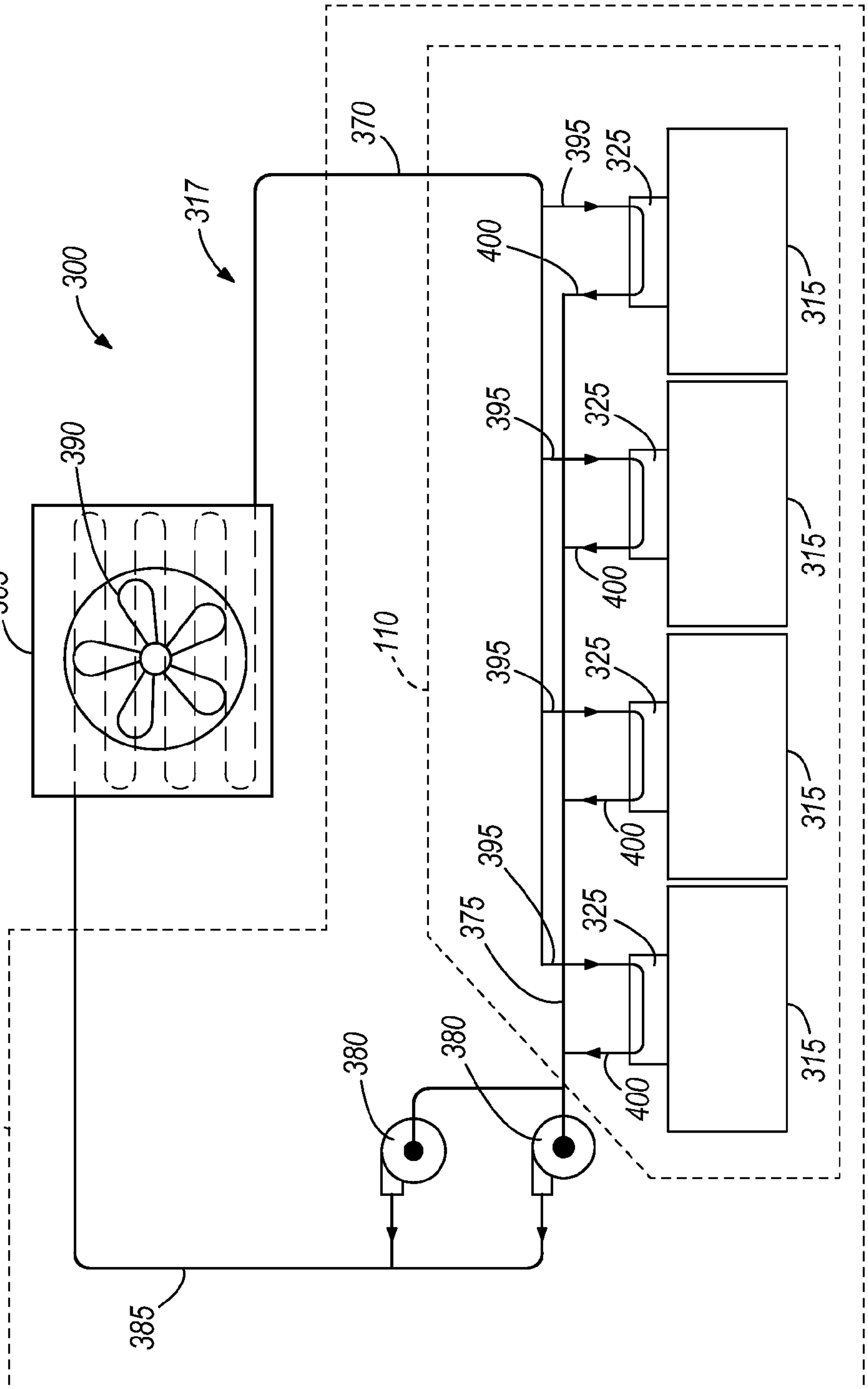

FIG. 3

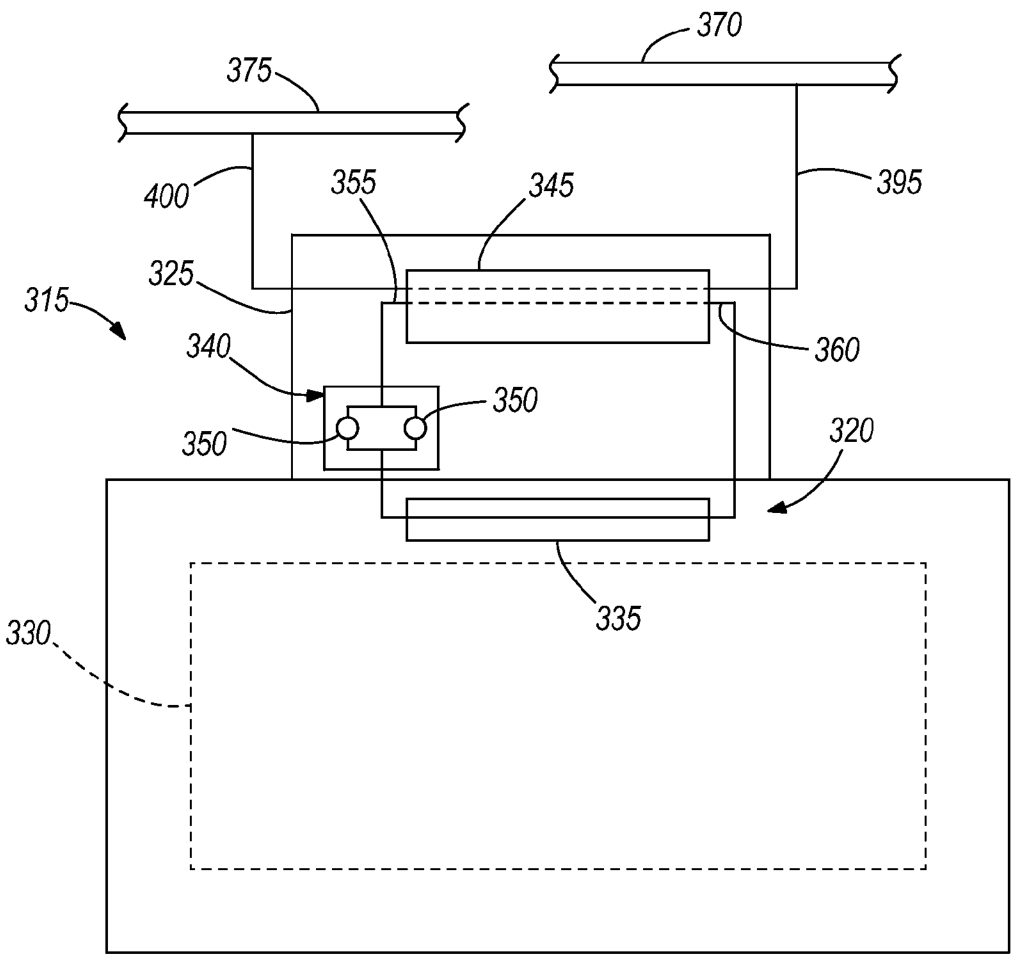

FIG. 4

TWO STAGE TRANSCRITICAL REFRIGERATION SYSTEM

RELATED APPLICATIONS

[0001] This patent application claims priority to U.S. Patent Application Ser. No. 60/858,624, filed Nov. 13, 2006, the entire contents of which are hereby incorporated by reference.

BACKGROUND

[0002] The present invention relates to a refrigeration system, and more specifically, to a transcritical refrigeration system for refrigerating food product displayed in refrigerated display cases in a commercial application.

[0003] A retail store, such as a supermarket, typically contains many refrigerated display cases for displaying and cooling food and/or beverage items for sale. Many types of refrigerated display cases are known in the art, and are in extensive use in retail locations. Such refrigerated display cases require a refrigeration system to maintain a temperature within the display case that is lower than ambient temperature inside the store.

[0004] Refrigeration systems generally include an evaporator, a compressor, and a condenser. A refrigerant fluid flows from one component to the next, exchanging heat so as to absorb heat from a refrigerated area and reject heat at the condenser, typically experiencing a phase change during the cycle.

[0005] One example of a prior art refrigeration system **10** is shown in FIG. **1**. Each refrigerated display case **15** includes an evaporator **20** for removing heat from each refrigerated display case **15**. Evaporated refrigerant is routed from the evaporators **20** via a suction header **25** to a local bank of compressors **30** and then through a discharge header **35** to a remotely located condenser **40** to be condensed. Condensed refrigerant is routed from the condenser **40** via a liquid header **45** to the evaporators **20**. The local bank of compressors **30** is located either at the end of a group or directly atop a group of refrigerated display cases **15** and contains several compressors connected in parallel within a sound-attenuated casing **50**. The suction header **25** and the discharge header **35** are partially located within the sound-attenuated casing **50**. The discharge header **35** establishes fluid communication between the local bank of compressors **30** and the condenser **40** and is not necessarily positioned adjacent each refrigerated display case **15**. Similarly, the liquid header **45** establishes fluid communication between the evaporators **20** and the condenser **40**, and is not necessarily positioned adjacent each refrigerated display case **15**. The local bank of compressors **30** serves to compress heated refrigerant from several evaporators **20**. The remotely located condenser **40** receives heated refrigerant from the single local bank of compressors **30**.

SUMMARY

[0006] In one embodiment, the invention provides a refrigeration system for use in a retail store application that includes a plurality of refrigerated display cases. Each of the plurality of refrigerated display cases has a dedicated evaporator assembly that is adapted to cool return air from the respective refrigerated display case by at least partially evaporating a refrigerant. Each refrigerated display case also has a dedicated first stage compressor assembly that is in fluid communication with the dedicated evaporator assembly to compress the refrigerant from the dedicated evaporator assembly to a first pressure that corresponds to a first temperature of the refrigerant, and to discharge the compressed refrigerant into a discharge main.

[0007] The refrigeration system also includes a second stage compressor assembly and a heat exchanger. The second stage compressor assembly is in fluid communication with the dedicated first stage compressor assembly of each of the plurality of refrigerated display cases to receive the refrigerant and to compress the refrigerant to a second pressure that is higher than the first pressure, and that corresponds to a second temperature of the refrigerant. The heat exchanger is located remotely from the plurality of refrigerated display cases, and is in communication with the refrigerated display cases via a fluid main. The heat exchanger includes an inlet that is in fluid communication with the second stage compressor assembly to receive the refrigerant from the second stage compressor assembly to reject heat from the refrigerant to an environment. The heat exchanger also includes an outlet that is in fluid communication with the dedicated evaporator assembly in each of the plurality of refrigerated display cases via the fluid main.

[0008] In another embodiment, the invention provides a refrigeration system that includes a low temperature refrigeration circuit circulates a first refrigerant, and a high temperature refrigeration circuit circulates a second refrigerant. The low temperature refrigeration circuit includes a plurality of refrigerated display cases, each having a dedicated evaporator assembly that is adapted to cool return air from the respective refrigerated display case by at least partially evaporating the first refrigerant. Each display case also includes a dedicated first stage compressor assembly that is in fluid communication with the dedicated evaporator assembly to compress the first refrigerant from the dedicated evaporator assembly to a first pressure that corresponds to a first temperature of the first refrigerant.

[0009] The high temperature refrigeration circuit includes a second compressor assembly that is operable to compress the second refrigerant to a second pressure that corresponds to a second temperature of the second refrigerant. The high temperature refrigeration system also includes a heat exchanger that cools the second refrigerant. The refrigeration system also includes a heat exchanger that is in communication with the low temperature refrigeration circuit and the high temperature refrigeration circuit to transfer heat from the first refrigerant to the second refrigerant to cool the first refrigerant without mixing the first refrigerant and the second refrigerant.

[0010] In yet another embodiment, the invention provides a refrigeration system that includes a plurality of refrigerated display cases, each having a dedicated evaporator assembly adapted to cool return air from the respective refrigerated display case by at least partially evaporating a refrigerant. The refrigeration system also includes at least one first stage compressor assembly, a second stage compressor assembly, and a heat exchanger. The first stage compressor assembly is in fluid communication with the dedicated evaporator assembly to compress the refrigerant from the dedicated evaporator assembly to a first pressure that corresponds to a first temperature of the refrigerant.

[0011] The second stage compressor assembly is in fluid communication with the at least one first stage compressor assembly to receive the compressed refrigerant and to com-

press the refrigerant to a second pressure that is higher than the first pressure, and that corresponds to a second temperature of the refrigerant. The heat exchanger is located remotely from the plurality of refrigerated display cases, and includes an inlet that is in fluid communication with the second stage compressor assembly to receive the refrigerant from the second stage compressor assembly and to reject heat from the refrigerant to an environment. The refrigeration system also includes a vessel that is positioned between and in fluid communication with the dedicated evaporator assemblies and the heat exchanger to separate liquid and gaseous phases of the refrigerant. The refrigeration system further includes a liquid main and a gas main. The liquid main is fluidly coupled to the dedicated evaporator assemblies and to the vessel, and supplies liquid refrigerant to each dedicated evaporator assembly. The gas main is fluidly coupled to the second stage compressor assembly and to the vessel, and directs gaseous carbon dioxide refrigerant from the vessel to the second stage compressor assembly without passing through the dedicated evaporator assemblies.

[0012] In yet another embodiment, the invention provides a refrigeration system that includes a closed coolant loop that circulates a coolant fluid, and that includes a supply main, a distribution main, and a discharge main. The coolant loop also includes a heat exchanger that is fluidly connected to the discharge main and the supply main and in communication with an environment to reject heat from the coolant fluid into the environment, and at least one coolant pump fluidly connected to the distribution main and the discharge main to pump the coolant fluid to the heat exchanger and through the coolant loop. The refrigeration system also includes a plurality of refrigerated display cases that are coupled to the coolant loop. Each of the plurality of refrigerated display cases includes a dedicated evaporator assembly that cools return air from the respective refrigerated display case by at least partially evaporating a refrigerant, and a dedicated refrigeration unit that is coupled to the evaporator assembly.

[0013] The evaporator assembly and the refrigeration unit are in fluid communication with each other, and define a closed transcritical refrigeration circuit. The refrigeration unit includes a compressor assembly that is in fluid communication with the evaporator assembly to compress the refrigerant from the evaporator assembly, and a heat exchanger in fluid communication with the compressor assembly and with the evaporator assembly. The heat exchanger is in heat exchange relationship with the coolant loop to reject heat from the refrigerant to the coolant fluid.

[0014] Other aspects of the invention will become apparent by consideration of the detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. **1** is a schematic view of a prior art refrigeration system for refrigerating display cases.

[0016] FIG. **2**A is a schematic view of a transcritical refrigeration system for refrigerating display cases.

[0017] FIG. **2**B is a schematic view of another embodiment of a transcritical refrigeration system that includes a cascade refrigeration circuit for refrigerating display cases.

[0018] FIG. **3** is a schematic view of another embodiment of a transcritical refrigeration system that includes a closed coolant loop and a transcritical refrigeration unit for refrigerating display cases.

[0019] FIG. **4** is a schematic view of one refrigerated display case of FIG. **3** that includes a transcritical refrigeration unit of FIG. **3**.

DETAILED DESCRIPTION

[0020] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having" and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms "mounted," "connected," "supported," and "coupled" and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings. Further, "connected" and "coupled" are not restricted to physical or mechanical connections or couplings.

[0021] FIG. **2**A shows a refrigeration system **100** for use with a building **105** that includes a shopping area **110**. As used herein, the term "shopping area **110**" refers to the commonly accessible area of a supermarket where customers may browse items for sale, and generally does not include any areas designated as equipment, storage, or maintenance areas.

[0022] The refrigeration system **100** is a transcritical refrigeration system that circulates carbon dioxide refrigerant ("CO_2 refrigerant") as a cooling fluid. The refrigeration system **100** includes refrigerated display cases **115**, a first stage compressor assembly **120** attached to each of the display cases **115**, a second stage compressor assembly **125**, a gas cooler or heat exchanger **130**, a vessel **135**, a fluid main **140**, and a discharge main **145**. The refrigerated display cases **115** are positioned throughout the shopping area **110** of the building **105** for housing and displaying food product.

[0023] Each refrigerated display case **115** is fluidly connected to the fluid main **140** via a liquid branch line **150**. Each liquid branch line **150** is fluidly connected to the fluid main **140** in parallel with each of the remaining liquid branch lines **150**. The refrigerated display cases **115** are further fluidly coupled to the discharge main **145** via discharge branch lines **155**. Each discharge branch line **155** is fluidly coupled to the discharge main **145** in parallel with each of the remaining discharge branch lines **155**.

[0024] Each of the refrigerated display cases **115** includes an expansion device or valve **160**, and an evaporator assembly **165** coupled to the related first stage compressor assembly **120**. For illustrative purposes, only the expansion device **160** and the evaporator assembly **165** of one of the display cases **115** are shown. The expansion device **160** is located between the fluid main **140** and the evaporator assembly **165** to regulate a pressure of refrigerant flowing from the fluid main **140** to the evaporator assembly **165**.

[0025] The illustrated evaporator assembly **165** of each display case **115** includes a single dedicated evaporator coupled to the related first stage compressor assembly **120**. In other embodiments, the evaporator assembly **165** may employ more than one evaporator, with each of the evaporators connected in parallel or series between the liquid branch line **150** and the first stage compressor assembly **120**.

[0026] As used herein, the phrase "evaporator assembly **165**" does not imply the use of any particular refrigerant (i.e., a two-phase refrigerant or a single-phase refrigerant). Rather, the terms should be generally construed to describe a heat exchanger assembly/coil functioning to transfer heat from an airflow passing through/over the heat exchanger assembly/coil to a refrigerant flowing through the heat exchanger assembly/coil.

[0027] Each first stage compressor assembly **120** is coupled to the discharge branch line **155** between one of the display cases **115** and the discharge main **145**. The illustrated first stage compressor assembly **120** includes a single dedicated compressor to compress refrigerant received from the evaporator assembly **165** of the related display case **115**. Other embodiments of the first stage compressor assembly **120** may include multiple dedicated compressors for a single display case **115**. Still other embodiments may include one or more compressors for a small group of display cases **115**.

[0028] The second stage compressor assembly **125** is located downstream of the first stage compressor assembly **120**. The illustrated embodiment of the second stage compressor assembly **125** shows the second stage compressor assembly **120** including two compressors **170**. In other embodiments, the second stage compressor assembly **120** may include one compressor **170**, or more than two compressors **170**. In some embodiments, the compressors **170** can be one or more variable capacity compressors. In these embodiments, the capacity of the compressors can be varied to accommodate pressure fluctuations that may be present within the refrigeration system **100**.

[0029] The second stage compressor assembly **125** is in fluid communication with the first stage compressor assembly **120** via a fluid line **172**. The fluid line **172** includes an inlet **173** coupled to an upper portion of the vessel **135**, and extends between the inlet **173** and an inlet line **175** of the second stage compressor assembly **125**. The second stage compressor assembly **125** further includes an outlet line **180** that extends between an outlet of the compressor assembly **125** and the heat exchanger **130**.

[0030] A bypass line **182** is coupled between the fluid line **172** and the outlet line **180** to circulate gaseous CO_2 refrigerant from the fluid line **172** to the heat exchanger **130** without passing through the second stage compressor assembly **125**. A check valve **183** is positioned in the bypass line **182** to allow refrigerant flow toward the heat exchanger **130** and to limit refrigerant flow from the outlet line **180** backward to the fluid line **172**.

[0031] The heat exchanger **130** is located remotely from the shopping area **110**, and further outside the building **105** to cool the CO_2 refrigerant. In some embodiments, the heat exchanger **130** may be located inside the building **105** but remote from the shopping area **110**. The heat exchanger **130** includes an inlet **185**, an outlet **190**, and at least one fan **195** to cool the CO_2 refrigerant. The inlet **185** is in fluid communication with the second stage compressor assembly **125** via the gas main **175**, and the outlet **190** is in fluid communication with the vessel **135**.

[0032] The vessel **135** is in fluid communication with the fluid main **140** to separate liquid CO_2 refrigerant from gaseous CO_2 refrigerant, and can be located anywhere along the fluid main **140** between the heat exchanger **130** and the refrigerated display cases **115** (i.e., either inside the building **105** or outside the building **105**), without departing from the scope of the invention. A bypass main **197** is coupled between the vessel **135** and the fluid line **172** to circulate CO_2 refrigerant from the vessel **135** to the second stage compressor assembly **125** without passing through the fluid main **140** to the display cases **115**. An expansion device **198** is disposed along the fluid main **140** downstream of the heat exchanger **130** and upstream of the vessel **135** to regulate the pressure of the CO_2 refrigerant exiting the heat exchanger **130**.

[0033] In the illustrated embodiment, the fluid main **140** and the discharge main **145** are routed throughout the building **105**, such that at least a portion of the fluid main **140** and at least a portion of the discharge main **145** are positioned adjacent each refrigerated display case **115** of the refrigeration system **100**. A downstream end of the discharge main **145** is in heat exchange relationship with the vessel **135**, and in fluid communication with the inlet **173**. The heat exchange between the superheated refrigerant in the discharge main **145** and the refrigerant in the vessel **135** adequately cools the superheated refrigerant prior to entry into the second stage compressor assembly **125**. In other embodiments, the downstream end of the discharge main **145** may be in fluid communication with the vessel **135**. In those embodiments, the refrigerant from the discharge main **145** can be mixed with the refrigerant prior to being directed to the second stage compressor assembly **125**.

[0034] Positioning at least a portion of both the fluid main **140** and the discharge main **145** adjacent each refrigerated display case **115** allows the refrigerated display cases **115** to be installed at a variety of locations in the shopping area **110** by tapping into the fluid main **140** and the discharge main **145** with the pair of respective liquid and discharge branch lines **150**,**155**. In some embodiments, the fluid and discharge mains **140**,**145** may be outside the shopping area **110** adjacent a display case that is near an edge (e.g., a wall) of the shopping area **110**. In other embodiments, the fluid and discharge mains **140**, **145** may extend out into the shopping area **110** adjacent each of a group of more centrally located display cases **115**.

[0035] In still other embodiments, the store may be divided into "sub-loop" areas with a fluid and discharge main **140**, **145** and an air-cooled heat exchanger **130** for each sub-area of the store. For example one set of fluid and discharge mains **140**, **145** with the air-cooled heat exchanger **130** may be positioned on a left side of the store, and a separate set of fluid and discharge mains **140**, **145** and a separate air-cooled heat exchanger **130** may be positioned on a right side of the store. A further embodiment may use such separate sub-loops for different types of refrigerated display cases **115**. For example, one set of fluid and discharge mains **140**, **145** for the meat area, one set for the produce area, etc. Thus, the fluid main **140** and the discharge main **145** allow the refrigerated display cases **115** to be positioned throughout the shopping area **110** of the building **105** in a variety of configurations, without requiring extensive routing of lengthy individual liquid and discharge branch lines **150**, **155** and thereby minimizing the length of the liquid and discharge branch lines **150**, **155**.

[0036] The arrangement of the fluid main **140** and discharge main **145** throughout the building **105** may simplify the installation procedure of refrigerated display cases **115** or allow for the refrigerated display cases **115** to be easily moved from one location to another within the building **105**. The fluid and discharge mains **140**, **145** may be plumbed into the building **105** (e.g., under the floor or behind walls of the shopping area **110**) before any refrigerated display cases **115**

are installed. When refrigerated display cases **115** are ready to be installed, they can be added to the refrigeration system **100** by tapping into the fluid and discharge mains **140**, **145** at a location very near the desired location for the refrigerated display case **115**. This eliminates the need for routing lengthy liquid or discharge branch lines **150**, **155** between each of the refrigerated display cases **115** and a centralized location, remote from the shopping area **110**. This also improves the modularity of the shopping area **110**, in that the refrigerated display cases **115** can be reconfigured and moved throughout the shopping area **110** without requiring the cumbersome activity of re-routing lengthy liquid and discharge branch lines **150**, **155**.

[0037] The transcritical CO_2 refrigeration cycle of the refrigeration system **100** operates in a similar fashion to the reverse-Rankine refrigeration cycle, except the vapor CO_2 refrigerant is compressed to a temperature above the thermodynamic critical point of the CO_2 refrigerant (i.e., approximately 87.7 degrees Fahrenheit). As described in detail below, the CO_2 refrigerant is compressed to a high, transcritical pressure of about 1600 psig corresponding to a temperature above the critical point by the second stage compressor assembly **125** prior to cooling of the refrigerant in the heat exchanger **130**. Consequently, when heat is rejected from the CO_2 refrigerant in the heat exchanger **130**, the vapor CO_2 refrigerant is cooled to a cooled vapor rather than changing phases to a liquid. In the closed circuit travel of the CO_2 refrigerant, the heat exchanger **130** cools the high-pressure CO_2 vapor to a lower temperature as a result of the forced airflow generated by the fan **195**. In the illustrated embodiment, the heat exchanger **130** cools the CO_2 refrigerant from about 250 degrees Fahrenheit to about 100 degrees Fahrenheit. In other embodiments, the temperature of the CO_2 refrigerant may be cooled by the heat exchanger **130** from temperatures above or below 250 degrees Fahrenheit to temperatures above or below 100 degrees Fahrenheit.

[0038] The cooled, high-pressure vapor CO_2 refrigerant is then throttled through the expansion device **198** to an intermediate, subcritical pressure fluid of about 600 psig where, similar to the reverse-Rankine refrigeration cycle, the intermediate-pressure CO_2 refrigerant changes phase to a liquid-vapor mixture prior to entering the vessel **135**. In the illustrated embodiment, the difference between the high pressure of the refrigerant and the intermediate pressure of the refrigerant is approximately 1000 psig. In other embodiments, the difference between the high pressure of the refrigerant and the intermediate pressure of the refrigerant can be above or below 1000 psig.

[0039] The liquid-vapor mixture then enters the vessel **135** where the liquid CO_2 refrigerant is separated from gaseous CO_2 refrigerant. The gaseous CO_2 refrigerant can flow through the bypass main **197** to the inlet **175** of the second stage compressor assembly **125**, while the liquid CO_2 refrigerant can flow through the remaining portion of the fluid main **140** to the refrigerated display cases **115** via the liquid branch lines **150**.

[0040] The intermediate pressure CO_2 refrigerant is throttled by the expansion device **160** of each display case **115** to a low-pressure refrigerant prior to entry into the evaporator assembly **165**. The low-pressure refrigerant boils to a vapor in the evaporator assembly **165**. In other words, the low-pressure CO_2 refrigerant passing through the evaporator assembly **165** absorbs the heat from the airflow as it is passed through the evaporator assembly **165**, thereby cooling the airflow.

[0041] The gaseous CO_2 refrigerant flows from the evaporator assembly **165** to the first stage compressor assembly **120** where the refrigerant is compressed to the intermediate, subcritical pressure that corresponds to a temperature generally below the critical point. While the intermediate pressure of the refrigerant in the illustrated embodiment is at about 600 psig, other pressures of the refrigerant higher and lower than 600 psig are possible.

[0042] The intermediate pressure refrigerant flows from the first stage compressor assembly **120** through the discharge branch lines **155**, and accumulates in the discharge main **145**. The refrigerant flows through the discharge main **145** to the vessel **135**, where the refrigerant can be de-superheated. The refrigerant is de-superheated prior to entering the second stage compressor assembly **125** by heat exchange with the refrigerant in the vessel **135**. The de-superheated refrigerant flows from the discharge main **145** into the fluid line **172** toward the inlet **175**. The second stage compressor assembly **125** receives the intermediate pressure refrigerant from one or both of the discharge main **145** and the bypass main **197** through the inlet **175**. The refrigerant flowing from the bypass main **197** from the vessel **135** is at about the same intermediate pressure as the refrigerant flowing from the fluid line **172**.

[0043] The second stage compressor assembly compresses the CO_2 refrigerant from the intermediate pressure to the high pressure. While the high pressure refrigerant in the illustrated embodiment is at about 1600 psig, other pressures of the refrigerant higher and lower than 1600 psig are capable using the second stage compressor assembly **125**, and are within the scope of the invention. The high pressure refrigerant flows from the second stage compressor assembly **125** through the outlet line **180**, and is cooled in the heat exchanger **130** as described above.

[0044] To obtain desirable refrigeration characteristics from the CO_2 refrigerant, the transcritical CO_2 refrigeration cycle requires higher operating pressures compared to a reverse-Rankine refrigeration cycle using R134a, for example. In some applications, the pressure experienced in the heat exchanger **130** in the transcritical CO_2 refrigeration system **100** can exceed the pressure experienced in a condenser of a reverse-Rankine refrigeration cycle using R134a by as much as eight-fold. Also, the low pressure experienced in the evaporator assembly **165** in the transcritical CO_2 refrigeration cycle can exceed the pressure experienced in an evaporator assembly in a reverse-Rankine refrigeration cycle using R134a by as much as fifteen-fold. As a result, the heat exchanger **130** and evaporator assembly **165** employ a heavy-duty construction to withstand the increased pressure of the transcritical CO_2 refrigeration cycle. Such heavy-duty construction may comprise an increased thickness of the walls of the tubing in the evaporator assembly **165** and heat exchanger **130**. In addition, the thickness of the walls of the fluid main **140**, the discharge main **145**, the liquid branch line **150**, the discharge branch line **155**, and other conduit (not shown) utilized in the refrigeration system **100** to fluidly connect the refrigeration components may also be increased to accommodate the increased pressure of the transcritical CO_2 refrigeration cycle.

[0045] The critical temperature of CO_2 refrigerant is approximately 88 degrees Fahrenheit. In some embodiments of the refrigeration system **100**, the ambient temperature surrounding the heat exchanger **130** may drop below the critical temperature of the refrigerant. In those embodiments, the heat exchanger **130** may function similarly to a condenser, cooling the high pressure CO_2 refrigerant to a liquid-vapor or a liquid-only refrigerant. More specifically, variations in the pressure of the refrigerant within the refrigeration system **100** are controlled by changing the state of the second stage compressor assembly **125**. For example, when the refrigerant pressure in the discharge main **145** drops below a predetermined pressure that corresponds to a temperature at or below the critical point of the refrigerant, the second stage compressor assembly **125** can be shutdown such that the refrigerant can be cycled through the system **100** using only the first stage compressor assembly **120**. When the second stage compressor assembly **125** is shutdown, the refrigerant bypasses the second stage compressor assembly **125** through the bypass line **182**, and flows into the heat exchanger **130**. When the refrigerant pressure in the discharge main **145** increases above the predetermined pressure, the second stage compressor assembly can be re-activated to accommodate the increased pressure within the refrigeration system **100**.

[0046] The second stage compressor assembly **125** capacity can be reduced or eliminated as the ambient temperature decreases below the critical temperature to accommodate a decrease in refrigerant pressure within the refrigeration system **100**. In embodiments where the ambient temperature is significantly below the critical temperature of the refrigerant, the second stage compressor assembly **125** may be shutdown due to a low refrigerant pressure in the discharge main **145** that corresponds to the temperature below the critical temperature. In these embodiments, the first stage compressor assembly **120** of each display case **115** can operate the entire system **100**, entirely bypassing the second stage compressor assembly **125** through the bypass line **182**. The check valve **183** prevents backward flow of refrigerant from the outlet line **180** to the fluid line **172** when the second stage compressor assembly **125** is running.

[0047] The use of the first and second stage compressor assemblies **120**, **125** allows smaller compressors to be positioned adjacent the display cases **115**, which limits parasitic losses that may otherwise occur when the compressor assembly **120** is located remotely from the display case **115**. The losses are limited because the position of the first stage compressor assemblies **120** adjacent to the display cases **115** allows the first stage compressor assemblies **120** to operate at a desired suction pressure, which maintains an efficient refrigeration system **100**. In addition, the close position of the first stage compressor assemblies **120** relative to the display cases **115** allows modulation of the capacity and/or the evaporator temperature of each display case **115** and improves the efficiency of the refrigeration system **100**.

[0048] FIG. 2B shows another embodiment of a refrigeration system **200** for use with the building **105**. Except as described below, the refrigeration system **200** is the same as the refrigeration system **100**, and common elements have been given the same reference numerals. The refrigeration system **200** is a split-stage transcritical refrigeration system that includes a high temperature refrigeration circuit **205** and a low temperature refrigeration circuit **210**.

[0049] The high temperature refrigeration circuit **205** includes the heat exchanger **130**, a high temperature receiver **215**, a cascade cooler or heat exchanger **220**, an accumulator **225**, and a compressor assembly **230**. The receiver **215** is fluidly connected to the heat exchanger **130** to receive cooled refrigerant. When the high temperature refrigeration circuit **205** is operating above the critical point for the refrigerant, only gaseous refrigerant is stored in the receiver **215**. When the high temperature refrigeration circuit **205** is operating at or below the critical point for the refrigerant, some liquid refrigerant may be present in the receiver **215**. The expansion device **198** is positioned downstream of the receiver **215** to control the refrigerant discharge pressure. Refrigerant passing through the expansion device **198** flows to the cascade cooler **220** via a fluid line **235**.

[0050] The high temperature refrigeration circuit **205** is in heat exchange relationship with the low temperature refrigeration circuit **210** via the cascade cooler **220**. The cascade cooler **220** includes a first inlet **222** that is fluidly connected to the fluid line **235** to receive cooled refrigerant from the heat exchanger **130**. The cascade cooler **220** further includes a first outlet **224** that is fluidly connected to the accumulator **225** via a fluid main **240** to deliver heated refrigerant to the accumulator **225**.

[0051] The refrigerant entering the cascade cooler **220** from the refrigeration circuit **205** is cooler than the refrigerant entering the cascade cooler **220** from the refrigeration circuit **210**. As such, the cascade cooler **220** functions similar to an evaporator for the refrigeration circuit **205**, and functions similar to a condenser for the refrigeration circuit **210**. In other words, heat from the refrigerant in the refrigeration circuit **210** is absorbed by the refrigerant in the refrigeration circuit **205**, thereby cooling the refrigerant in the refrigeration circuit **210** and heating the refrigerant in the refrigeration circuit **205**.

[0052] The compressor assembly **230** is located downstream of the accumulator **225**, and is dedicated to the refrigeration circuit **205**. The illustrated embodiment shows the second stage compressor assembly **230** including two compressors **245**. In other embodiments, the first compressor assembly **230** may include one compressor **245**, or more than two compressors **245**. The inlet line **175** fluidly connects the accumulator **225** to the compressor assembly **230**.

[0053] The low temperature refrigeration circuit **210** operates at a refrigerant temperature that is at or below the critical point for the refrigerant. The refrigeration circuit **210** includes the refrigerated display cases **115**, a receiver **250**, and compressor assemblies **255**. As discussed above with regard to FIG. 2A, each display case **115** is fluidly connected to the fluid main **140** via the liquid branch line **150**. The fluid main **140** is coupled to the receiver **250** to distribute cooled refrigerant to the display cases **115**.

[0054] The refrigerated display cases **115** are further fluidly connected to the discharge main **145** via the discharge branch lines **155**. The discharge main **145** is fluidly connected to a second inlet **260** of the cascade cooler **220** to deliver heated refrigerant from the compressor assemblies **255** to the cascade cooler **220**.

[0055] The receiver **250** is fluidly connected to the cascade cooler **220** via a distribution line **265**. The distribution line **265** is coupled to a second outlet **270** of the cascade cooler **220** to direct cooled refrigerant into the receiver **250**. The receiver **250** is further in fluid communication with the fluid main **140** to separate liquid refrigerant from gaseous refrigerant, and can be located anywhere along the fluid main **140** upstream of the display cases **115**.

[0056] Each compressor assembly **255** is dedicated to the refrigeration circuit **205**, and is attached to one of the cases

115. Each compressor assembly **255** is further coupled to the discharge branch line **155** between one of the display cases **115** and the discharge main **145**. In some embodiments, each compressor assembly **255** may be located remotely from each of the display case **115**, with adequate capacity to compress refrigerant from each display case **115**. The illustrated compressor assembly **255** includes a single dedicated compressor to compress refrigerant received from the evaporator assembly **165** of the related display case **115**. Other embodiments of the compressor assembly **255** may include multiple dedicated compressors for a single display case **115**. Still other embodiments may include one or more compressors for a small group of display cases **115**.

[0057] The transcritical CO_2 refrigeration cycle of the refrigeration system **200** provides cooling to the display cases **115** without mixing refrigerant between the high temperature refrigeration circuit **205** and the low temperature refrigeration circuit **210**. Refrigerant entering the cascade cooler **220** through the first inlet **222** is heated by heat exchange with refrigerant flowing through the low temperature refrigeration circuit **210**. The heated refrigerant exits the cascade cooler **220** through the first outlet **224** and flows through the fluid main **240** to the accumulator **225**. When the refrigeration circuit **205** is operating at or below the critical point for the refrigerant, some liquid refrigerant exists in the accumulator **225**. Gaseous refrigerant is separated from the liquid refrigerant in the accumulator **225**, and the gaseous refrigerant is then directed to the compressor assembly **230**. The gaseous, heated refrigerant is then compressed by the compressor assembly **230** prior to being cooled in the heat exchanger **130**. The cooled refrigerant flows from the heat exchanger **130** to the vessel **135**, where the high temperature refrigeration circuit **205** begins anew.

[0058] The heat exchange relationship between the high temperature refrigeration circuit **205** and the low temperature refrigeration circuit **210** in the cascade cooler **220** cools previously heated refrigerant in the refrigeration circuit **210**, and heats previously cooled refrigerant in the high temperature refrigeration circuit **205**. The cooled refrigerant in the low temperature refrigeration circuit **210** flows from the second outlet **270** of the cascade cooler **220** and into the receiver **250** via the distribution line **265**. The cooled refrigerant flows to each of the display cases **115**, where the refrigerant is heated as it passes through the evaporators **165**. The heated refrigerant from each display case **115** is compressed by the respective compressor assembly **255** prior to reaching the discharge main **145**. The heated refrigerant flows from the compressor assembly **255** to the cascade cooler **220** through the second inlet **260**, where the low temperature refrigeration circuit **210** begins anew.

[0059] FIG. **3** shows yet another refrigeration system **300** for use with the building **105**. The refrigeration system **300** includes a plurality of refrigerated display cases **315** that are coupled to a coolant loop **317**. Each refrigerated display case **315** includes an evaporator assembly **320** and a refrigeration unit **325** that is coupled to the evaporator assembly **320** (FIG. **4**). The evaporator assembly **320** is located such that air passing through the evaporator assembly **320** is discharged to a refrigerated area **330** of the refrigerated display case **315**. The evaporator assembly **320** and the refrigeration unit **325** are each dedicated to operate with only one of the refrigerated display cases **315**. As shown in FIG. **3**, the evaporator assembly **320** includes one evaporator **335** to provide cooling to the refrigerated area **330**. However, the quantity of evaporators **335** depends on the cooling requirements of each refrigerated display case **315**, and additional evaporators **335** may be included in the evaporator assembly **320** without deviating from the scope of the invention.

[0060] FIG. **4** illustrates the refrigeration unit **325** of one refrigerated display case **315**. Each refrigeration unit **325** defines a transcritical refrigeration cycle that circulates CO_2 refrigerant to cool the refrigerated area **330**. The refrigeration unit **325** includes a compressor assembly **340** and a gas cooler or heat exchanger **345**. In some embodiments, each refrigeration unit **325** may further include a receiver (not shown) coupled to the compressor assembly **340**.

[0061] The compressor assembly **340** is coupled to the evaporator assembly **320** to compress CO2 refrigerant received from the evaporator assembly **320**. The illustrated compressor assembly **340** includes two dedicated compressors **350** that are placed within the transcritical refrigeration cycle in parallel with each other. Other embodiments of the compressor assembly **340** may include one compressor, or more than two compressors **350** in parallel or in series with each other.

[0062] The heat exchanger **345** includes an inlet **355** that is coupled to the compressor assembly **340**, and an outlet **360** that is coupled to the evaporator assembly **320**. As shown in FIG. **3**, the heat exchanger **345** is in heat-exchange relationship with the coolant loop **317** to reject heat from the compressed CO_2 refrigerant to a coolant fluid in the coolant loop **317**. In some embodiments, an expansion device (not shown) can be located adjacent the outlet **360** to expand the CO_2 refrigerant prior to reaching the evaporator assembly **320**.

[0063] The CO_2 refrigerant in the heat exchanger **345** is cooled by heat exchange with the coolant fluid that is circulated in the coolant loop **317**. In one embodiment, the coolant fluid is a water/glycol mixture. As shown in FIG. **3**, the coolant loop **317** is a closed circulation coolant loop, and includes an air-cooled heat exchanger **365**, a supply main **370**, a distribution main **375**, coolant pumps **380**, and a discharge main **385**. The heat exchanger **365** is located remotely from the shopping area **110**, and is in communication with an environment surrounding the building **105** to cool the coolant fluid. The heat exchanger **365** includes a fan **390** to draw air across the heat exchanger **365** to cool the coolant fluid. In some embodiments, the heat exchanger **365** is located outside the building **105**. In other embodiments, the heat exchanger **365** is located within the building **105** and remote from the shopping area **110**.

[0064] The supply main **370** is coupled to the heat exchanger **365** to distribute coolant fluid from the heat exchanger **365** to an inlet branch line **395** that couples the supply main **370** to the refrigeration unit **325**. The inlet branch line **395** is coupled to and in communication with the heat exchanger **345**. An outlet branch line **400** couples the heat exchanger **345** to the distribution main **375** to deliver heated coolant fluid to the distribution main **375**.

[0065] The distribution main **375** is coupled to the pumps **380** to distribute heated coolant fluid from the outlet branch lines **400** to the pumps **380**. The illustrated pumps **380** are coupled to the distribution main **375** and the discharge main **385** in parallel with each other to pump coolant fluid from the distribution main **375** into the discharge main **385**. In other embodiments, the pumps **380** can be connected in series with each other.

[0066] In operation, CO_2 refrigerant in the refrigeration unit **325** employing a transcritical refrigeration cycle is heated in the evaporator assembly **320** as it removes heat from the refrigerated area **330** of each refrigerated display case **315**. The compressor assembly **340** compresses the heated refrigerant and forces it to flow to the fluid-cooled heat exchanger **345**. The fluid-cooled heat exchanger **345** transfers heat from the CO_2 refrigerant fluid to the coolant fluid that flows through the heat exchanger **345** from the inlet branch line **395** to the outlet branch line **400**. As a result of the heat transfer, the CO_2 refrigerant cools to a lower temperature and returns to the evaporator assembly **320** to be heated and cooled in a cyclical manner. In embodiments of the refrigeration unit **325** that includes the expansion device, the CO_2 refrigerant can be expanded to a lower pressure fluid prior to entering the evaporator assembly **320**.

[0067] Coolant fluid in the coolant loop **317** flows from the inlet branch line **395** to the outlet branch line **400** in heat exchange relationship with the CO_2 refrigerant in the heat exchanger **345**. The heat transfer between the heat exchanger **345** and the coolant loop **317** increases the temperature of the coolant fluid flowing through the coolant loop **317**. The heated coolant fluid flows through the outlet branch lines **400** and collects in the distribution main **375**. The pumps **380** pump the heated coolant fluid from the distribution main **375** to the discharge main **385**. The pumps **380** generally drive coolant fluid flow throughout the closed coolant loop **317**. The heat exchanger **365** receives the heated coolant fluid and discharges heat from the fluid to the environment. The cooled coolant fluid returns to the heat exchanger **345** via the supply main **370** and the inlet branch lines **395** to cool the refrigeration units **325** in a cyclical manner.

[0068] Various features and advantages of the invention are set forth in the following claims.

1. A refrigeration system comprising:

a plurality of refrigerated display cases, each of the plurality of refrigerated display cases including

a dedicated evaporator assembly adapted to cool return air from the respective refrigerated display case by at least partially evaporating a refrigerant, and

a dedicated first stage compressor assembly in fluid communication with the dedicated evaporator assembly to compress the refrigerant from the dedicated evaporator assembly to a first pressure corresponding to a first temperature of the refrigerant, and to discharge the compressed refrigerant into a discharge main;

a second stage compressor assembly in fluid communication with the dedicated first stage compressor assembly of each of the plurality of refrigerated display cases to receive the refrigerant and to compress the refrigerant to a second pressure that is higher than the first pressure, the second pressure corresponding to a second temperature of the refrigerant;

a heat exchanger located remotely from the plurality of refrigerated display cases and in communication with the refrigerated display cases via a fluid main, the heat exchanger including an inlet in fluid communication with the second stage compressor assembly to receive the refrigerant from the second stage compressor assembly to reject heat from the refrigerant to an environment, the heat exchanger further including an outlet in fluid communication with the dedicated evaporator assembly in each of the plurality of refrigerated display cases via the fluid main.

2. The refrigeration system of claim **1**, wherein the refrigerant includes a carbon dioxide refrigerant.

3. The refrigeration system of claim **1**, further comprising a vessel positioned in fluid communication with the fluid main between the refrigerated display cases and the heat exchanger to separate liquid and gaseous phases of the refrigerant and to supply liquid refrigerant to each dedicated evaporator assembly.

4. The refrigeration system of claim **3**, wherein the discharge main is in heat exchange relationship with the refrigerant in the vessel, and wherein the refrigerant in the discharge main is configured to be de-superheated by heat exchange with the refrigerant in the vessel.

5. The refrigerated system of claim **4**, further comprising a fluid line in fluid communication with the discharge main between the second stage compressor assembly and the vessel to direct the de-superheated refrigerant from the discharge main toward the second stage compressor assembly.

6. The refrigerated system of claim **5**, further comprising a bypass main coupled between the vessel and the fluid line to circulate gaseous refrigerant from the vessel toward the second stage compressor assembly without passing through the fluid main to the refrigerated display cases.

7. The refrigerated system of claim **5**, further comprising an outlet line extending between the second stage compressor assembly and the heat exchanger, and a bypass line coupled between the fluid line and the outlet line to circulate gaseous refrigerant from the fluid line to the heat exchanger without passing through the second stage compressor assembly when a temperature of the refrigerant in the discharge main is below a predetermined temperature.

8. The refrigerated system of claim **7**, further comprising a check valve positioned in the bypass line and configured to inhibit flow of the refrigerant from the outlet line backward to the fluid line.

9. The refrigerated system of claim **1**, wherein the refrigerant includes a critical temperature, and wherein the first temperature is a subcritical temperature and the second temperature includes a transcritical temperature.

10. The refrigeration system of claim **1**, wherein the dedicated evaporator assemblies are connected to the liquid main in parallel, and wherein the dedicated compressor assemblies are connected to the discharge main in parallel.

11. A refrigeration system comprising:

a low temperature refrigeration circuit configured to circulate a first refrigerant, the low temperature refrigeration circuit including a plurality of refrigerated display cases, each of the plurality of refrigerated display cases having a dedicated evaporator assembly adapted to cool return air from the respective refrigerated display case by at least partially evaporating the first refrigerant, and a dedicated first stage compressor assembly in fluid communication with the dedicated evaporator assembly to compress the first refrigerant from the dedicated evaporator assembly to a first pressure corresponding to a first temperature of the first refrigerant;

a high temperature refrigeration circuit configured to circulate a second refrigerant, the high temperature refrigeration circuit including a second compressor assembly operable to compress the second refrigerant to a second pressure corresponding to a second temperature of the second refrigerant, and a heat exchanger configured to cool the second refrigerant; and a heat exchanger in communication with the low temperature refrigeration circuit and the high temperature refrigeration circuit to transfer heat from the first refrigerant to the second refrigerant to cool the first refrigerant without mixing the first refrigerant and the second refrigerant.

12. The refrigeration system of claim **11**, wherein the first refrigerant and the second refrigerant include carbon dioxide refrigerant.

13. The refrigeration system of claim **11**, wherein the first refrigerant is circulated in a subcritical refrigeration cycle.

14. The refrigeration system of claim **11**, wherein the low temperature refrigeration circuit further includes a low temperature receiver disposed between and in fluid communication with each dedicated evaporator assembly and the heat exchanger to separate liquid and gaseous phases of the first refrigerant and to supply liquid refrigerant to each dedicated evaporator assembly.

15. The refrigeration system of claim **11**, wherein high temperature refrigeration circuit further includes a high temperature receiver disposed between and in fluid communication with the heat exchanger and the heat exchanger to receive the cooled second refrigerant and to direct the cooled second refrigerant to the heat exchanger.

16. The refrigeration system of claim **11**, wherein the high temperature refrigeration circuit further includes an accumulator disposed between and in fluid communication with the second compressor assembly and the heat exchanger to separate liquid and gaseous phases of the second refrigerant and to supply gaseous phase second refrigerant to the second compressor assembly.

17. The refrigeration system of claim **11**, wherein the heat exchanger is operable as a condenser for the first refrigerant, and wherein the heat exchanger is operable as an evaporator for the second refrigerant.

18. The refrigeration system of claim **11**, wherein the second refrigerant is circulated in a transcritical refrigeration cycle.

19. A refrigeration system comprising:

a plurality of refrigerated display cases, each of the plurality of refrigerated display cases including a dedicated evaporator assembly adapted to cool return air from the respective refrigerated display case by at least partially evaporating a refrigerant;

at least one first stage compressor assembly in fluid communication with the dedicated evaporator assemblies to compress the refrigerant from the dedicated evaporator assemblies to a first pressure corresponding to a first temperature of the refrigerant;

a second stage compressor assembly in fluid communication with the at least one first stage compressor assembly to receive the compressed refrigerant and to compress the refrigerant to a second pressure that is higher than the first pressure, the second pressure corresponding to a second temperature of the refrigerant;

a heat exchanger located remotely from the plurality of refrigerated display cases, the heat exchanger including an inlet in fluid communication with the second stage compressor assembly to receive the refrigerant from the second stage compressor assembly and to reject heat from the refrigerant to an environment;

a vessel positioned between and in fluid communication with the dedicated evaporator assemblies and the heat exchanger to separate liquid and gaseous phases of the refrigerant;

a liquid main fluidly coupled to the dedicated evaporator assemblies and to the vessel, the liquid main configured to supply liquid refrigerant to each dedicated evaporator assembly; and

a gas main fluidly coupled to the second stage compressor assembly and to the vessel, the gas main configured to direct gaseous refrigerant from the vessel to the second stage compressor assembly without passing through the dedicated evaporator assemblies.

20. The refrigeration system of claim **19**, wherein the refrigerant includes a carbon dioxide refrigerant.

21. The refrigerated system of claim **19**, wherein the refrigerant includes a critical temperature, and wherein the first temperature is a subcritical temperature and the second temperature includes a transcritical temperature.

22. A refrigeration system comprising:

a closed coolant loop configured to circulate a coolant fluid, the coolant loop including a supply main, a distribution main, a discharge main, a heat exchanger fluidly connected to the discharge main and the supply main and in communication with an environment to reject heat from the coolant fluid into the environment, and at least one coolant pump fluidly connected to the distribution main and the discharge main to pump the coolant fluid to the heat exchanger and through the coolant loop; and

a plurality of refrigerated display cases coupled to the coolant loop, each of the plurality of refrigerated display cases including

a dedicated evaporator assembly adapted to cool return air from the respective refrigerated display case by at least partially evaporating a refrigerant, and

a dedicated refrigeration unit coupled to the evaporator assembly, the evaporator assembly and the refrigeration unit in fluid communication with each other and defining a closed transcritical refrigeration circuit, the refrigeration unit including a compressor assembly in fluid communication with the evaporator assembly to compress the refrigerant from the evaporator assembly, and a heat exchanger in fluid communication with the compressor assembly and with the evaporator assembly, the heat exchanger in heat exchange relationship with the coolant loop to reject heat from the refrigerant to the coolant fluid.

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