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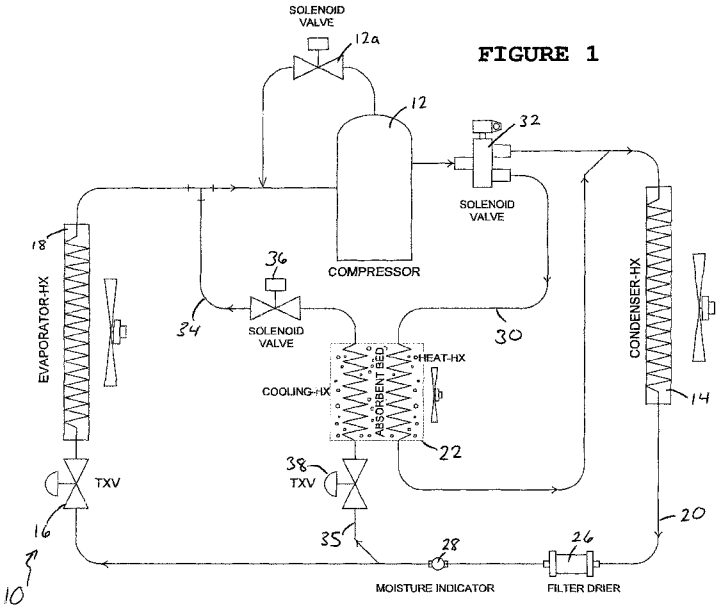
FIGURE 1



(57) Abstract: An air filtering system for an enclosure that additionally heats and/or cools one or more regenerative beds of a regenerative thermal swing absorption (TSA) component of the system includes a closed loop indoor temperature adjusting circuit having a compressor, an outdoor heat exchanger, an indoor heat exchanger, and an expansion valve disposed therealong for conditioning air of the enclosure. At least one diversion line of the temperature adjusting circuit passes through the one or more regenerative beds for at least one of heating or cooling the one or more regenerative beds.

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SYSTEMS AND METHODS OF HEATING, COOLING AND HUMIDITY CONTROL IN AIR FILTRATION ADSORBENT BEDS

[0001] This application claims the benefit of provisional patent application Serial No. 61/046,297, filed April 18, 2008, which is incorporated by reference in its entirety herein.

[0002] The present disclosure relates to filtering systems for removing one or more contaminants from a gas or fluid, and more particularly relates to systems and methods of heating, cooling and/or humidity control in air filtration adsorbent bed systems.

INCORPORATION BY REFERENCE

[0003] The present disclosure relates to filtering systems for removing contaminants from a fluid (gas or liquid). U.S. Patent Publication No. 2002/0005117 discloses a filtering system for removing chemical and biological agents from air and is hereby incorporated by reference as background material for showing the same. U.S. Patent No. 6,319,303 discloses a four bed filtering system for gas and is hereby incorporated by reference as background material for showing the same. U.S. Patent No. 7,115,152 also discloses a four-bed filtering system for gas and is hereby incorporated by reference as background material for showing the same. U.S. Patent Application Serial No. 12/072,569 discloses a filtration heat transfer system and is hereby incorporated by reference as background material for showing the same. U.S. Patent Publication No. 2008/0085672 discloses a vehicle cabin heating and cooling ventilation system and is hereby incorporated by reference as background material for showing the same.

BACKGROUND

[0004] Air handling systems now frequently include filtration systems that can protect an enclosure against noxious airborne vapors released in the vicinity of the enclosure. Such vapors include nuclear, biological or chemical agents (known as NBC), and Toxic Industrial Chemicals (known as TICs). Standard filters are

generally ineffective against the full range of NBC agents, and NBC filters do not effectively remove all TICs.

[0005] Military enclosures in particular may be exposed to both NBC agents and TIC threats. These enclosures can include both dynamic enclosures (e.g., military vehicles) and static enclosures (e.g., buildings or tents). In view of such exposure, these types of military enclosures need to be equipped with life support systems to facilitate operations under such hazardous conditions.

[0006] Contaminating agents are often removed from gases, such as air, by the use of low pressure activated carbon filter bed units, including those that have been impregnated with reactive metal oxides which increase the sorption capacity of the filter for the more volatile agents. These impregnates, however, are known to lose their effectiveness (aging) in systems filtering ambient air continuously to an entire living area (collective protection), as opposed to a filter used for individual protection (which is used only when needed). Therefore, such filtration systems require filter replacement due to limitations in service life, with resultant regimes of replacement at regular intervals needed in order to maintain the required minimum filtration requirements. While replacement of filter canisters for individual masks takes relatively little effort, filter replacements in a vehicle or a stationary structure provide significant logistics problems and cost.

[0007] To reduce the logistical burden and extend the range of chemical vapor protection to include TICs, new advanced filtration systems have been developed, e.g., using thermal swing adsorption (TSA) technology. TSA will permit continuous filtration without filter change-out since the filtration media is continuously regenerated. One known such system is disclosed in U.S. Patent No. 7,115,152, the disclosure of which is incorporated hereinto by reference in its entirety.

[0008] TSA utilizes heat to remove the contaminant from the adsorbent material and allow the adsorbent material to be reused. In particular, such heat typically is used to bring a filter and/or a purge fluid (e.g., purge air) to a desired temperature at which the purge fluid is most effective. There are many industries which utilize thermal or temperature swing adsorption processes. Such applications include

solvent recovery, air drying and removing contaminants, such as CO_2 and H_2O from air prior to cryogenic separation.

[0009] Typically, in most regenerable adsorption-based air purification systems, there are two major steps to a cycle, namely: (1) feed and (2) regeneration. A great deal of design attention is normally focused on the feed step to prevent the target contaminant chemical(s) from penetrating into the product. The complexity and importance of the regeneration step is often given less attention. For regenerable systems, it is the efficiency of the regeneration step that typically determines whether the system can provide the desired level of chemical protection within acceptable power consumption, size and weight constraints. This is true for both the Pressure Swing Adsorption (PSA) and Thermal Swing Adsorption (TSA) technologies.

[0010] The rest of this discussion will focus on TSA system design. The regeneration step in a TSA system can be divided into two parts, namely: (1) heating and (2) cooling. After a bed has reached the end of a feed step, the bed must be heated to a desired regeneration temperature and, while at temperature, clean product air must be introduced to sweep the adsorbed contaminant(s) out of the bed. But before this "cleaned" bed can be used to filter air again, it must be cooled to an acceptable temperature; determined by the adsorption fundamentals of the design-limiting vapor. Typically, in TSA systems, both heating and cooling are accomplished using a fraction of the product air. The major problem with this approach is that temperature and concentration waves move slowly through the bed and temperature waves formed in the bed become very disperse because of heat transfer resistances as well as axial dispersion. Therefore, it takes a lot of purge gas (product) to cool the bed sufficiently to allow the next feed step to begin. For air purification systems that remove relatively weakly adsorbed contaminant gases (e.g., chloroethane), if the bed is not cooled completely (or within several degrees Kelvin) to the desired feed temperature, the contaminant gas in the feed will penetrate much further in the filter bed than desired when the feed step is resumed. Eventually after several cycles, the contaminant gas will penetrate into the vehicle crew compartment or stationary structure imperiling the personnel therein.

[0011] In view of the foregoing, the bed must be both sufficiently heated and cooled to prevent the contaminant vapor(s) from eventually penetrating into the crew compartment of a vehicle or stationary structure. A typical approach in adsorption systems is to increase the bed size. This will not work for regenerable systems. While increasing the bed size will obviously allow the bed to stay in feed mode longer, the increased adsorbent inventory must still be heated and cooled. Everything else being equal, it will take proportionally the same amount of time to complete the regeneration step so nothing is gained by making the beds larger. The normal countermeasure is to increase the purge gas flow rate. But, this obviously increases the feed flow rate (a constant product flow rate must be maintained) as well as the energy requirements. Therefore, the efficiency of the regeneration step corresponds directly to optimizing system design for TSA. In particular, the goal is to add and remove heat from the adsorbent as quickly as possible using as little purge (product) gas as possible.

[0012] Previous works have shown that the efficiency of the regeneration step can be improved by heating the adsorbent directly with little or no gas purge (product) gas flow. These approaches include: (1) electrically resistive heating elements, (2) electrical potential across the adsorbent material itself and (3) microwave heating. All of these approaches can improve the regeneration step efficiency by adding heat quickly and directly to the adsorbent. But after heating, the cooling step is still accomplished by passing purge gas through the bed. This is very inefficient and adds to the overall cycle time as well as the total purge gas requirement.

[0013] U.S. Patent Application Serial No. 12/072,569, which is incorporated hereinto by reference in its entirety, discloses the heating and cooling of the adsorbent directly for purposes of greatly increasing the regeneration step efficiency. Combining the ability to cool with the ability to heat allows one to design and build smaller, less energy intensive TSA systems for air purification applications. In particular, one exemplary adsorbent bed taught by the '569 application includes elements that allow heat transfer fluid to be passed therethrough and contact the adsorbent media itself. The heat transfer fluid can be either hot or cold, depending

upon whether the bed is in the heating mode or the cooling mode. The number of heat transfer elements and their configurations can vary but one objective of the '569 application is to provide as much heat transfer surface as possible, while allowing for enough adsorbent to provide the required contaminant retention capacity. As a result, the regeneration step capacity is increased by adding and removing heat quickly, thus reducing cycle time and overall purge gas requirements.

[0014] To pass the heat transfer fluid through the adsorbent bed or beds for heating and cooling in a regeneration system, a heating and cooling system is of course needed. When such regeneration systems are employed in existing enclosures (e.g., military vehicles or tents), there may already be provided a heating and cooling system for conditioning the air within these enclosures for the personnel housed therein. Rather than add a second, separate system for the regenerative bed system used in an enclosure, efficiencies can be gained by providing combined heating and cooling systems and methods for heating and/or cooling the enclosure itself, as well as heating and/or cooling one or more adsorbent beds of the regeneration system.

BRIEF SUMMARY

[0015] According to one embodiment of the disclosure, an air conditioning system for an enclosure (e.g., a static structure, such as a building or tent, or a dynamic structure, such as a tactical or military vehicle) is used to provide heating and cooling to one or more adsorbent beds in a regenerative TSA system.

[0016] According to another embodiment of the disclosure, a heat pump system is provided for heating and/or cooling of an enclosure (e.g., a static structure, such as a building or tent, or a dynamic structure, such as a tactical or military vehicle). The heat pump system further provides heating and cooling for adsorbent beds in a regenerative TSA system.

[0017] According to still another embodiment of the disclosure, a heat pump system is provided for heating and/or cooling of an enclosure (e.g., a static structure, such as a building or tent, or a dynamic structure, such as a tactical or military

vehicle), and further provided for heating and/or cooling of adsorbent beds in a regenerative TSA system.

[0018] Optionally, one or more of these systems can include humidity control and/or preheating for the enclosure and/or the regenerative bed system.

[0019] According to a further embodiment of the disclosure, an air filtering system is provided for an enclosure that additionally heats and/or cools one or more regenerative beds of a regenerative thermal swing absorption (TSA) component of the system. More particularly, the system includes a closed loop indoor temperature adjusting circuit having a compressor, an outdoor heat exchanger, an indoor heat exchanger, and an expansion valve disposed therealong for conditioning air of the enclosure. At least one diversion line of the temperature adjusting circuit passes through the one or more regenerative beds for at least one of heating or cooling the one or more regenerative beds.

[0020] According to still a further embodiment of the in disclosure, an air filtering system an indoor heat exchanger arranged to exchange heat with air inside an enclosure, an outdoor heat exchanger fluidly connected to the indoor heat exchanger and arranged to exchange heat with air outside the enclosure, a compressor for pressurizing a heat transfer fluid carried between the indoor and outdoor heat exchangers, at least one expansion valve for depressurizing the heat transfer fluid carried between the indoor and outdoor heat exchangers, and at least one diversion line diverting a portion of the heat transfer fluid carried between the indoor and outdoor heat exchangers through at least one regenerative bed for controlling a temperature thereof.

[0021] According to another embodiment of the disclosure, a method of heating and/or cooling a regenerative bed through an air filtering system is provided for an enclosure. More particularly, a closed loop circuit is provided, the circuit having a compressor, an outdoor heat exchanger, an indoor heat exchanger, and an expansion valve disposed therealong for conditioning air of the enclosure. A portion of a heat transfer fluid carried by the circuit is diverted to the regenerative bed to selectively heat or cool the regenerative bed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIGURE 1 is a schematic view of an air conditioning system for an enclosure and for heating and cooling of one or more regenerative beds.

[0023] FIGURE 2 is a schematic view of a heat pump system for heating and cooling an enclosure and for heating and cooling of one or more regenerative beds, the heat pump system shown in a cooling mode.

[0024] FIGURE 3 is another schematic view of the heat pump system of FIGURE 2, but shown in a heating mode.

[0025] FIGURE 4 is a schematic view of a heat pump system for heating and cooling of an enclosure and for heating and cooling one or more regenerative beds, the system including humidity control and preheating; the system is shown in a heat pump heating mode; with both dehumidification and preheat being on.

[0026] FIGURE 5 is a schematic view of the heat pump system of FIGURE 4 in a heating mode of the heat pump but with dehumidification on and preheat off.

[0027] FIGURE 6 is a schematic view of the heat pump system of FIGURE 4 with the heat pump in a cooling mode and dehumidification on and preheat on.

[0028] FIGURE 7 is a schematic view of the heat pump system of FIGURE 4 with the heat pump being in a cooling mode and dehumidification being on, but preheat being off.

[0029] FIGURE 8 is a schematic view of an air conditioner system integrated with four or more regenerable TSA adsorbent filter beds with a feed-air dehumidification heat exchanger, regen heating and cooling heat exchangers, purge-air heat exchangers and a re-heat heat exchanger.

DETAILED DESCRIPTION

[0030] Referring now to the drawings, wherein the showings are only for purposes of illustrating one or more exemplary embodiments of the present disclosure, FIGURE 1 shows an air conditioning system and method for heating and cooling adsorbent beds disposed in an air filtration system. More particularly, an air conditioning system 10 includes a compressor 12, a condenser 14, a thermal expansion valve (TXV) 16 and an evaporator 18. As is known and appreciated by

those skilled in the art, these elements 12-18 are employed in an air conditioning circuit 20 using a heat transfer fluid or medium (e.g., a coolant) for providing cooling. In one exemplary embodiment, the system 10 can be used for cooling a static or dynamic enclosure (e.g., a building or tent or a vehicle), wherein the evaporator 18 removes heat from a space to be cooled. As will be described in more detail below, the system 10 further provides heating and cooling for one or more adsorbent beds, such as schematically illustrated adsorbent bed 22.

[0031] As shown, a solenoid valve 12a can be provided in conjunction with the compressor 12 as is known and understood by those of skill in the art. Additionally, a filter drier 26 and a moisture indicator 28 can be provided in the circuit 20.

[0032] As described in the background section above, heating and cooling of the adsorbent bed 22 is desirable. In particular, it is desirable to rapidly heat the adsorbent bed 22 and/or a purging fluid immediately prior to passing the purging fluid through the bed for removing contaminants, such contaminants being adsorbed by the bed when in the feed mode. It is also desirable to rapidly cool the adsorbent bed 22 after such purging to return the bed to an operating temperature so that it can again effectively remove contaminants from a fluid passing through the bed 22.

[0033] Heating for the adsorbent bed 22 is provided by diverting a portion of the cooling fluid of circuit 20 through a diversion line 30, which is controlled by a solenoid valve 32 downstream of the compressor 12. In the refrigeration cycle of circuit 20, after the cooling fluid absorbs heat at the evaporator 18, the heated cooling fluid is selectively passed through the diverting line 30 via the solenoid valve 32. In the diverting line 30, the superheated coolant from the evaporator 18 returns to compressor 12. Next, superheated coolant discharges from compressor 12 to solenoid valve 32, where it is diverted through line 30 entering adsorbent bed 22 heating heat exchanger, Superheated coolant heats the adsorbent bed 22 to a desired temperature before being re-circulated through the condenser 14 and circuit 20.

[0034] For cooling of the adsorbent bed 22, a cooling diversion line 34 is disposed in the cooling circuit 20. In particular, a branch portion 35 of the line 34 passes through the adsorbent bed 22. A solenoid valve 36 disposed downstream of

the adsorbent bed 22 can be used to selectively direct fluid through diversion line 34 and thereby through the adsorbent bed 22 (i.e., when the solenoid valve 36 is in a closed position, cooling fluid is not directed through line 34). In addition, a thermal expansion valve 38 can be disposed upstream of the adsorbent bed 22 along line 34 for acting on the heat transfer fluid passing thereby and preparing the same for cooling of the adsorbent bed 22.

[0035] With reference to FIGURE 2, a heat pump system 50 is shown for providing conditioned air (i.e., heated and cooled) within an enclosure (e.g., a static enclosure, such as a tent or building, or a dynamic structure, such as a vehicle cabin). In addition, the system 50 provides selective cooling and selective heating to one or more adsorbent beds. More particularly, the system 50 includes a compressor 52 having an associated solenoid valve 53 operatively connected thereto. The system 50 further includes an outdoor heat exchanger 54 and an indoor heat exchanger 56. As is known and understood by those of skill in the art, the outdoor heat exchanger 54 and the indoor heat exchanger 56 can be operated so as to remove heat from an indoor enclosure in which the indoor heat exchanger 56 is disposed, or to provide heating to the indoor enclosure in which the indoor heat exchanger 56 is disposed, depending on the mode of operation of the heat pump system 50 (in FIGURE 2, the system 50 is illustrated in a cooling mode). The outdoor heat exchanger 54 and the indoor heat exchanger 56, as well as the compressor 52, are fluidly connected to one another in a heat pump circuit 58.

[0036] As shown, the circuit 58 includes a thermal expansion valve with a check valve function 60 adjacent the outdoor heat exchanger 54 and a thermal expansion valve with a check valve function 62 adjacent the indoor heat exchanger 56. When operating in the cooling mode of FIGURE 2, the valve 60 is disposed downstream of the outdoor heat exchanger 54 and the valve 62 is disposed upstream of the indoor heat exchanger 56. The system 50 further includes a reversing valve 64, which allows the circuit 58 to be operated in reverse (i.e., to supply heat to an indoor enclosure via the indoor heat exchanger 56). In FIGURE 2, the reversing valve 64 is schematically illustrated in a first position wherein a cooling fluid of the circuit 58 is directed from the compressor 52 to the outdoor heat exchanger 54 and then to the

indoor heat exchanger 56. Like the circuit 10 of FIGURE 1, the circuit 58 can additionally include a filter drier 66 and a moisture indicator 68.

[0037] For heating of an adsorbent bed 70 when the circuit 58 is operated in the cooling mode illustrated in FIGURE 2, a portion of the cooling fluid of the circuit 58 can be directed through the adsorbent bed 70 via diversion line 72. A solenoid valve 78 is operated to control the diversion of fluid through the diversion line 72. A second solenoid valve 80 is operated in coordination with the solenoid valve 78 to direct the diverted cooling fluid back upstream of the outdoor heat exchanger 54 when the system 50 is operated in the cooling mode. As illustrated, a check valve 82 can be disposed downstream of the solenoid valve 80 along line 84 which directs fluid exiting the adsorbent bed 70 upstream of the outdoor heat exchanger 54.

[0038] For cooling of the adsorbent bed 70, a diversion line 90 directs a portion of the fluid from the circuit 58 through the adsorbent bed 70. A solenoid valve 92 specifically controls the diverted fluid from the circuit 58 along the diversion line 90. A Thermal Expansion Valve (TXV) can be disposed between the solenoid valve 92 and the adsorbent bed 70 as illustrated. Accordingly, through operation of the solenoid valves 78 and 92 (and solenoid valve 80), the system 50 can be used to provide cooling to an enclosure in which the indoor heat exchanger 56 is located while simultaneously providing heating and cooling to an adsorbent bed 70 of a regenerative system.

[0039] With reference to FIGURE 3, the system 50 of FIGURE 2 is shown in a heating mode wherein the circuit 58 is run in reverse, with heat being drawn into the circuit via the outdoor heat exchanger 54 and provided to an enclosure via the indoor heat exchanger 56. To effect such heating by the indoor heat exchanger 56, the circuit 58 is run in reverse such that the compressor 52 directs the cooling fluid of the circuit 58 to the indoor heat exchanger 56 and subsequently to the outdoor heat exchanger 54. Such reversing of the circuit 58 is done by the reversing valve 64, which is schematically shown in a second position in FIGURE 3. Diversion line 72 is still used for heating of the adsorbent bed 70 and fluid into the diversion line 72 is still controlled by the solenoid valve 78. However, when the system 50 is in the heating mode of FIGURE 3, the solenoid 80 is moved to a second position wherein

the fluid of the diverting line 72 exiting the adsorbent bed 70 is directed to an alternate line 96 and through a check valve 98. Cooling of the adsorbent bed 70 during the heating mode of FIGURE 3 continues to occur through the diversion line 90 as discussed above.

[0040] With reference to FIGURE 4, a heat pump system 100 is shown for providing conditioned air (i.e., heated and cooled) within an enclosure (e.g., a static enclosure, such as a tent or building, or a dynamic structure, such as a vehicle cabin). In addition, like the system 50, the system 100 provides selective cooling and selective heating to one or more adsorbent beds. Unlike the system 50, the system 100 further provides humidity control and preheating to the one or more temperature controlled adsorbent beds and can employ a single heat exchange coil or path through each adsorbent bed for both heating and cooling of the bed. In contrast, the system 10 of FIGURE 1 and the system 50 of FIGURES 2 and 3 use a pair of coils for heating and cooling of each adsorbent bed, one coil for heating the bed and the other coil for cooling of the bed.

[0041] Like the system 50, the system 100 includes a compressor 102, such as a scroll compressor, which has a solenoid valve 103 operatively connected thereto as illustrated, for modulating same. The system 100 further includes an outdoor heat exchanger 104 and an indoor heat exchanger 106. As is known and understood by those of skill in the art, the outdoor heat exchanger 104 and the indoor heat exchanger 106 can be operated so as to remove heat from an indoor enclosure in which the indoor heat exchanger is disposed (or at least thermally connected), or to provide heating to the indoor enclosure in which the indoor heat exchanger 106 is disposed (or at least thermally connected), depending on the mode of operation of the heat pump system 100 (in FIGURE 4, the system 100 is illustrated in a heating mode). The system is also shown with de-humidification being on and preheat being on and the filter material in the bed being heated. As shown, the outdoor heat exchanger 104 and the indoor heat exchanger 106, as well as the compressor 102, are fluidly connected to one another in a heat pump circuit 108.

[0042] As shown, the circuit 108 includes a thermal expansion valve with a check valve function 110 adjacent the outdoor heat exchanger 104 and a thermal

expansion valve with a check valve function 112 adjacent the indoor heat exchanger 106. When operating in the heating mode of FIGURE 4, the valve 112 is disposed downstream of the indoor heat exchanger 106 and the valve 110 is disposed upstream of the outdoor heat exchanger 104. Like the system 50, the system 100 includes a reversing valve 114 that allows the circuit 108 to be operated in reverse (i.e., to remove heat from an indoor enclosure via the indoor heat exchanger 106). In FIGURE 4, the reversing valve 114 is schematically illustrated in a first position wherein a cooling fluid of the circuit 108 is directed from the compressor 102 to the indoor heat exchanger 106, via a filtration system of the enclosure, and then to the outdoor heat exchanger 104. Like the circuits 10 and 58, the circuit 108 can additionally include a filter drier 116 and a moisture indicator (not shown).

[0043] For heating and cooling of one or more adsorbent beds (only a single bed 120 shown in FIGURE 4) of a regenerative system, the system 100 includes a single coil, heat exchanger or fluid path 122 passing through each bed that operates in conjunction with a plurality of diversion lines and solenoid valves. More particularly, when the circuit 108 is operated in the heating mode of FIGURE 4 and heating of the filter material in the bed 120 is desired (the operation schematically depicted in FIGURE 4), the heated fluid flows through a solenoid valve 124 and into a line 126. A portion of the heat transfer fluid exiting the compressor 102 can be selectively diverted by a solenoid valve 128 and directed along branch or divert line 127. That fluid is then directed through the bed 120 for heating thereof. Further solenoid valves 129 and 130 are operated to direct the heat transfer fluid exiting the bed 120 to an outlet line 132, which directs the diverted heat transfer fluid back to the circuit 108 upstream of the indoor heat exchanger 106. As shown, a check valve 134 can be disposed along the line 133. By this arrangement, a portion of the heating capacity of the heat transfer fluid is used to heat the bed 120 prior to heating the enclosure via the indoor heat exchanger 106.

[0044] The remainder of the heated fluid from the compressor flows via line 126 to line 136 where it serves to preheat air flowing to the adsorbent bed 120 via a heat exchanger 138. The fluid then flows through solenoid valve 140 into the circuit 108. Fluid entering the indoor heat exchanger flows through circuit 108 and, in the

embodiment illustrated in FIGURE 4, can flow directly to the outdoor heat exchanger 104. However, a portion of it can be tapped off via solenoid valve 150 and through thermostatic valve 152 into a further heat exchanger 154 for cooling and dehumidification of the air flowing to the filter bed 120. That fluid can then flow via a line 156 through a suction manifold 158 and back to an inlet of the compressor 102. The remainder of the fluid, as mentioned, flows through the outdoor heat exchanger 104, the reversing valve 114 and back to the compressor 102. In the circuit illustrated in FIGURE 4, a portion of the heat from the heated thermal fluid is tapped off and used for regenerating the adsorbent bed 120. Moreover, another portion of the heated fluid is used to preheat the air flowing to the adsorbent bed. As can be seen, a fan 160 can be provided in order to draw air towards the adsorbent bed 120. Moreover, in the circuit embodiment of FIGURE 4, a portion of the exhausted heat exchange fluid from the indoor heat exchanger can be tapped off and used in a dehumidifier 154 before the fluid is directed to the compressor 102.

[0045] With reference now to FIGURE 5, the circuit of FIGURE 4 is illustrated in another configuration. In this configuration, heat transfer fluid from the compressor flows through solenoid valve 124 and reversing valve 114 directly to the indoor heat exchanger via a line 170. In this embodiment, dehumidification is still on for cooling the air and, therefore, dehumidifying it, but preheat is off. The filter material in the bed 120 is now in a cooling mode instead of the heating mode illustrated in FIGURE 4. Therefore, the fluid flow circuit is different. A portion of the fluid exhausted from the indoor heat exchanger 106 which flows via circuit 108 is tapped off at line 172 and is directed via solenoid valves 130 and 129 and via a thermostatic valve and check valve 174 to the filter bed 120. It flows through heat exchanger 122 in the filter bed in order to cool the filter bed. The fluid then flows through solenoid valve 128 and via suction manifold 158 to the inlet of the compressor 102. The remainder of the thermal exchange fluid from the indoor heat exchanger flows via filter dryer 116 to the outdoor heat exchanger 104 via thermal expansion valve with check valve 110. It is noted that both the indoor and outdoor heat exchangers can be provided with suitable fans 180 and 182. A further portion of the exhausted fluid from the indoor heat exchanger can flow through line 190 and via solenoid valve 150 and

thermostatic valve 152 into the heat exchanger 154 for cooling and, hence, dehumidifying the air flowing towards the filter bed 120. The exhausted fluid then flows through line 156 to the suction manifold 158.

[0046] With reference now to FIGURE 6, a still further circuit is there illustrated. In this embodiment of the system, the heat pump is in a cooling mode and dehumidification of the air, i.e., cooling thereof, is on and preheat of the air flow is also on. In this embodiment of the circuit, heat transfer fluid leaving the compressor 102 flows via solenoid valve 124 through line 126 and enters line 136. A portion of the fluid can then flow via solenoid valve 128 through the regen bed HX 122 in the filter bed 120, whereas another portion can flow via heat exchanger 138 that provides a preheat for the air flow flowing towards the filter. The portion of the heat transfer fluid flowing through the filter bed then flows via thermostatic valve 174 and solenoid valve 129 via a line 190 to a check valve 192 of the circuit 108 and to the outdoor heat exchanger 104. The heat transfer fluid then flows directly in circuit 108 via thermostatic valve and check valve 112 to the indoor heat exchanger 106. After exiting the indoor heat exchanger 106, the heat transfer fluid flows via reversing valve 114 to the compressor 102, as is evident from FIGURE 6.

[0047] With reference now to FIGURE 7, still another mode of the circuit is there illustrated. In this mode, heat transfer fluid exiting the compressor 102 flows via a solenoid valve 124 and reversing valve 114 into circuit 108 and to the outdoor heat exchanger 104. The heat transfer fluid then flows through filter dryer 116 and towards the indoor heat exchanger 106. A portion of the heat transfer fluid is tapped off and flows via solenoid valve 150 and thermostatic valve 152 to heat exchanger 154 and, via line 156 and suction manifold 158 back towards the compressor 102. Another portion of the heat transfer fluid is tapped off via solenoid valves 129 and 130, as well as thermostatic valve 174 (which also has a check valve) and flows through the adsorbent bed 120 via heat exchange path 122. The fluid then flows through solenoid valve 128 and into the suction manifold 158 and, hence, the compressor 102. The remainder of the heat transfer fluid flows through circuit 108 to the indoor heat exchanger 106. Fluid exiting the heat exchanger then flows through reversing valve 114 and again towards the compressor 102.

[0048] Figure 8 is a depiction of a representative integrated, air conditioning – TSA, regenerable air purification system that one might consider for a collective protection application. The proposed schematic system is a natural extension of the individual concepts discussed in Figures 1 through 7. The discussion will be divided into two major parts, namely; (1) the air conditioner components and (2) ambient air flow and purification elements (TSA system components).

[0049] With reference to Figure 8, an air conditioning system 200 is shown for providing conditioned air (i.e., heated and/or cooled) within an enclosure (e.g., static enclosure, such as a tent or building, or dynamic structure, such as a vehicle cabin). In addition, the system 200 provides cooling and selective heating to four or more regenerable TSA adsorbent filter beds. More particularly, the system 200 includes a compressor 210 having an associated solenoid valve 210a operatively connected thereto. The system 200 further includes condenser heat exchanger 214, a check valve 222, a receiver 224, a sub-cooling heat exchanger 226, a thermal expansion valve (TXV) 211, and a recirculation (evaporator) heat exchanger 218. As is known and appreciated by those skilled in the art, these elements 210, 210a, 214, 222, 224, 226, 211 and 218 are fluidly connected to one another and employed in a air conditioning circuit 208 using a heat transfer fluid or medium (e.g., primary coolant) for providing cooling.

[0050] More particularly, a recirculation blower 209 provides airflow over the recirculation (evaporator) heat exchanger 218 where heat can be absorbed into the primary coolant of the system 200, cooling the supply-air entering the enclosure 219. Heat absorbed into primary coolant is returned to the compressor 210 and circuit 208. Superheated primary coolant is discharged through conduit 213 into the regen heating heat exchanger 212 where a secondary coolant de-superheats the primary coolant. The primary coolant routes via conduit 215 to a solenoid valve 260. When the solenoid valve 260 is in position A, the primary coolant is diverted to conduit 217 into the condenser heat exchanger 214, receiver 224 and sub-cooler 226 where the balance of the heat absorbed from the evaporators is rejected outside the enclosure. It is noted that condenser heat exchanger 214 and sub-cooling heat exchangers can

be provided with a suitable fan 203 to exhaust the heat rejected from heat exchangers 214, 226 and circuit 208 to outside ambient air.

[0051] Additionally, as shown, a filter drier 228 and moisture indicator 230 can be provided in circuit 208.

[0052] System 200 can additionally include a re-heat heat exchanger 216 that can provide heating within the enclosure where the hot discharge coolant from the compressor 210 is circulated via conduit 213, through regen heating heat exchanger 212, into conduit 215, entering the solenoid valve 260 in position B and diverting into conduit 261 and entering the re-heat heat exchanger exiting into conduit 263 then inserted into circuit 208. A recirculation blower 209 provides the airflow over the re-heat heat exchanger 216 where the heat from system 200 is rejected into the air stream entering the enclosure, heating the enclosure.

[0053] For heating and cooling of the regenerable TSA adsorbent filter beds 290, 292, 294 and 296, the system 200 provides a single heat exchanger embedded in each of the four or more adsorbent beds. A secondary fluid or medium (e.g., secondary coolant) is heated by the regen heating heat exchanger 212 or cooled by the regen cooling heat exchanger 220 then circulated through the TSA adsorbent filter bed heat exchangers 290, 292, 294 and 296.

[0054] For heating and regeneration of the TSA adsorbent beds during the purge air cycle, a secondary coolant is heated by the regen heating heat exchanger 212 as described previously. Where the heated secondary coolant is circulated from the regen heating heat exchanger 212 via conduit 221, then circuited through solenoid valves 244 and 252 positioned in position-A diverting hot secondary coolant through conduits 223 and 225 into the TSA adsorbent bed heat exchangers 292 and 296, respectively. Flow control valves 282 and 286 are provided to regulate the hot secondary coolant flow rate upstream of a second set of solenoid valves 246 and 254 in position A, diverting hot coolant back though conduit 227, to the hot secondary coolant pump 272, discharging and returning the hot secondary coolant via conduit 229 to the regen heating heat exchanger 212 completing the hot secondary coolant circulation cycle.

[0055] Solenoid valves 244, 246, 252, 254 are sequenced simultaneously to position A during the regeneration heating cycle then to position B for circulation of cold coolant during regeneration and feed-air cycles.

[0056] Heating of the purge-air during the regeneration cycle is provided by the secondary fluid (coolant) from the regen heating heat exchanger 212. Heated secondary coolant is circulated via conduit 221 then diverted through solenoid valve 256 position-A diverting hot coolant via conduit 231 into the purge-air heat exchanger 298. A flow control valve 288 is provided to regulate the hot secondary coolant flow rate upstream of solenoid valve 258 in position-A diverting the hot secondary coolant back through conduit 227, hot secondary coolant pump 272, discharging hot secondary coolant via conduit 229, returning the hot secondary coolant to the regen heating heat exchanger 212.

[0057] Solenoid valves 256 and 258 are sequenced simultaneously to position A during the regeneration heating cycle then to position B for circulation of cold coolant during regeneration and feed-air cycles.

[0058] Cooling of the TSA adsorbent bed is provided through the regen cooling heat exchanger 220. Primary coolant is diverted off circuit 208 via a diverter conduit 265 to thermal expansion valve 266 supplying the primary coolant to regen cooling heat exchanger 220. The primary coolant adsorbs heat from the secondary coolant exiting regen cooling heat exchanger 220 through conduit 267 returning the primary coolant to circuit 208 and the compressor 210. As known and appreciated by those skilled in the art, these elements 265, 266, 220, 267 and 210 are fluidly connected to one another and employed in air conditioning circuit 208 using a heat transfer fluid or medium (e.g., primary coolant) for providing cooling to the TSA adsorbent bed heat exchangers 290, 292, 294, 296 and purge air heat exchanger 298. Secondary coolant is circulated from the regen cooling heat exchanger 220 via conduit 269 then circuited through solenoid valves 240 and 248 positioned in position-B diverting cold coolant into the TSA adsorbent bed heat exchangers 290 and 294, respectively. Flow control valves 280 and 284 are provided to regulate the cold secondary coolant flow rate upstream of a second set of solenoid valves 242 and 250 in position B, diverting cold coolant back though conduit 311, to the cold secondary coolant pump

270, discharging and returning the cold coolant via conduit 313 to the regen cooling heat exchanger 220 completing the cold secondary coolant circulation cycle.

[0059] Solenoid valves 240, 242, 248, 250 are sequenced simultaneously to position B during the regeneration and feed-air cycles then to position A for circulation of hot secondary coolant during regeneration cycle.

[0060] Cooling of the purge-air during the regeneration and feed-air cycles can be provided by the secondary fluid (coolant) from the regen cooling heat exchanger 220. Cold secondary coolant is circulated via conduit 269 to solenoid valve 256 in position-B diverting cold coolant via conduit 231 into the purge-air heat exchanger 298. A flow control valve 288 is provided to regulate the cold secondary coolant flow rate upstream of solenoid valve 258 in position-B diverting the hot coolant back through conduit 311, cold secondary coolant pump 270, conduit 313, returning the cold secondary coolant to the regen cooling heat exchanger 220.

[0061] For dehumidification of the feed-air. The system 200 provides a de-humidification heat exchanger 264. More particularly a feed-air blower 207 circulates air over the dehumidification heat exchanger 264 where heat can be absorbed into the primary coolant of the system 200, cooled dehumidified air is diverted from the dehumidification heat exchanger 264 through the feed-air conduits. Diverting air valves 301, 303, 305 or others direct feed-airflow over a pair or more of "regenerated" TSA adsorbent beds 290, 292, 294, 296, breathable feed-air can be diverted into the air conditioning re-heat heat exchanger 216 or recirculation heat exchanger 218 then diverted into the protected space 219 (i.e., the enclosure). System 200's primary coolant is diverted from circuit 208 via conduit 315 into a thermal expansion valve 262 upstream of dehumidifying (evaporator) heat exchanger 264 exiting via conduit 317 back into compressor 210 and circuit 208. As known and appreciated by those skilled in the art, these elements 315, 262, 264, 317 and 210 are fluidly connected to one another and employed in a air conditioning circuit 208 using a heat transfer fluid or medium (e.g., primary coolant) for providing cooling and dehumidification to the feed air circulating through the TSA adsorbent bed heat exchangers 290, 292, 294, 296 and purge air heat exchanger 298 or others.

[0062] The ambient air contaminated with chemical is introduced into the TSA system at the desired flow rate using the feed airflow blower 207. The air first passes through the dehumidification heat exchanger 264 where it is cooled and dehumidified. As stated in the previous patent (U.S. Patent No. 6,319,303), the air must be cooled and dehumidified to provide the required adsorption capacity for the most weakly adsorbed threat vapors. Next, the air enters the heavy gas bed selector valve 301 which directs air the contaminated air to either bed HA 290 or bed HB 292. In the diagram, bed HA 290 is selected. For reference, the heavy gas beds are designed to remove the most strongly adsorbed vapors so cycle times for bed HA and HB may be relatively long, e.g., valve 301 may change every 2 hours or so. After exiting bed HA, air then enters the light gas bed selector valve 303 which is used to select either bed LA 294 or bed LB 296. In the diagram Bed LA is selected. Valve 303 is changed much more frequently than valve 301, e.g., every 10 minutes. Both Beds HA 290 and LA 294 are being cooled by heat exchange with the fluid from the regen cooling heat exchanger 220. After exiting Bed LA 294, air with all of the TIC and NBC threat vapors removed, passes through the purge bed selector valve 305 and into the protected air space.

[0063] While Beds HA 290 and LA 294 are providing breathable and cool air to the protected space, beds HB 292 and LB 296 are beginning to be regenerated. To accomplish this, air is drawn from the protected space at the desired flow rate using the purge air blower 209. Air exits the blower and passes through the purge air heat exchanger 298 to raise the purge air temperature to the desired level. Hot purge air then enters bed LB 296 which is also being heated using fluid from the regen heat exchanger 212. Purge air exiting bed LB 296 enters the light gas bed selector valve 303 and into bed HB 292 which is also being heated using fluid from the regen heat exchanger 212. Air exits bed HB 292 and enters the heavy gas bed selector valve 301 where it directed to vent.

[0064] It should noted here again that the system design allows for beds HA 290 and HB 292 to operate using different cycle times than beds LA 294 and LB 296. Another possible extension may be to vent the purge effluent from the light gas bed (in this case LB) for selected periods of time.

[0065] In some environments, the system 100 may not work efficiently. For example, the heating mode of the system 100 may not be effective for heating an enclosure when the outdoor heat exchanger 104 operates in low temperature environments (e.g., below 17 degrees Fahrenheit). To overcome this problem, the system 100 can include a preheater as discussed. One such preheater is taught in commonly owned U.S. Patent Publication No. 2008/0085672, the contents of which are expressly incorporated herein by reference in their entirety.

[0066] While the embodiments described herein are illustrated with a particular number of filter beds (e.g., one bed, four beds, etc.), it is to be appreciated by those of skill in the art that the systems are suitable for use with any number of filter beds. In particular, regenerative systems typically require at least a pair of filter beds so that at least one filter bed can remain operation for filtering contaminants while at least a second bed is regenerated. Also, while no particular control system has been illustrated or described, it is to be appreciated that the systems described herein can be operated by a suitable control system (e.g., a control system for operating the reversing valve, the solenoid valves, etc.).

[0067] It will be appreciated that various of the above-disclosed and other features and functions, or alternatives thereof, may be desirably combined into many other different systems or applications. Also it is to be appreciated that various presently unforeseen or unanticipated alternatives, modifications, variations or improvements therein may be subsequently made by those skilled in the art which are also intended to be encompassed by the present disclosure.

CLAIMS:

1. An air filtering system for an enclosure that additionally heats and/or cools one or more regenerative beds of a regenerative thermal swing absorption (TSA) component of the system, the system comprising:

a closed loop indoor temperature adjusting circuit having a compressor, an outdoor heat exchanger, an indoor heat exchanger, and an expansion valve disposed therealong for conditioning air of the enclosure; and

at least one diversion line of the temperature adjusting circuit passing through the one or more regenerative beds for at least one of heating or cooling the one or more regenerative beds.

2. The system of claim 1 wherein said at least one diversion line comprises a first diversion line passing through the one or more regenerative beds to heat the one or more regenerative beds and a second diversion line passing through the one or more regenerative beds to cool the one or more regenerative beds.

3. The system of claim 2 wherein said first diversion line has a first end disposed downstream from said compressor and upstream from said outdoor heat exchanger and a second end disposed farther downstream from said compressor than said first end and upstream from said outdoor heat exchanger, and wherein said second diversion line has a first end disposed downstream from said outdoor heat exchanger and upstream from said expansion valve and a second end disposed downstream from said indoor heat exchanger and upstream from said compressor.

4. The system of claim 3 wherein said second diversion line includes a diversion line expansion valve upstream of the one or more regenerative beds.

5. The system of claim 2 wherein said temperature adjusting circuit further includes solenoid valves for controlling fluid flow through said first and second diversion lines.

6. The system of claim 1 wherein said temperature adjusting circuit further includes:

a reversing valve configured to reverse fluid flow through said circuit for selectively operating said circuit in one of a cooling mode or a heating mode; and

a second expansion valve disposed upstream of one of the indoor and outdoor heat exchangers when said circuit is operated in said cooling mode, said expansion valve disposed upstream of the other of the indoor and outdoor heat exchangers when said circuit is operated in said heating mode.

7. The system of claim 1 wherein said at least one diversion line includes a preheater diversion line having a preheater disposed therealong for preheating airflow passing through the one or more regenerative beds.

8. The system of claim 1 wherein said at least one diversion line includes a dehumidify diversion line having a dehumidifier disposed therealong for dehumidifying airflow passing through the one or more regenerative beds.

9. The system of claim 1 wherein said at least one diversion line includes a single line passing through the one or more regenerative beds that selectively heats the one or more regenerative beds when a heat transfer fluid of said circuit flows in a first direction and cools the one or more regenerative beds when said heat transfer fluid flows in a second direction.

10. An air filtering system, comprising:

an indoor heat exchanger arranged to exchange heat with air inside an enclosure;

an outdoor heat exchanger fluidly connected to said indoor heat exchanger and arranged to exchange heat with air outside said enclosure;

a compressor for pressurizing a heat transfer fluid carried between said indoor and outdoor heat exchangers;

at least one expansion valve for depressurizing said heat transfer fluid carried between said indoor and outdoor heat exchangers; and

at least one diversion line diverting a portion of said heat transfer fluid carried between said indoor and outdoor heat exchangers through at least one regenerative bed for controlling a temperature thereof.

11. The air filtering system of claim 10 wherein said enclosure is a static structure or a moveable structure.

12. The air filtering system of claim 11 wherein said enclosure comprises a tent, a building, or a trailer.

13. The air filtering system of claim 11 wherein said enclosure comprises a vehicle.

14. The air filtering system of claim 10 further including:

a reversing valve configured to reverse a fluid flow direction of said heat transfer fluid between said indoor and outdoor heat exchangers, fluid flow in a first direction corresponding to a heating mode wherein heat from said indoor heat exchanger heats said air inside said enclosure and fluid flow in a second, opposite, direction corresponding to a cooling mode wherein heat from said air inside said enclosure is removed by said indoor heat exchanger.

15. The air filtering system of claim 14 wherein said at least one diversion line comprises a plurality of diversion lines configured to pass said heat transfer fluid through said at least one regenerative bed in a first direction for heating thereof and

to pass said heat transfer fluid through said at least one regenerative bed in a second direction for cooling thereof.

16. The air filtering system of claim 15 wherein said plurality of diversion lines include a common line through said at least one regenerative bed through which said heat transfer fluid flows in said first direction when heating and in said second direction when cooling.

17. The air filtering system of claim 15 wherein said plurality of diversion lines includes a preheater diversion line that selectively preheats air flow passing over a preheater exchanger prior to said air flow passing over said at least one regenerative bed.

18. The air filtering system of claim 15 wherein said plurality of diversion lines includes a dehumidify diversion line that selectively dehumidifies air flow passing over a dehumidify exchanger prior to said air flow passing over said at least one regenerative bed.

19. A method of heating and/or cooling a regenerative bed through an air filtering system for an enclosure, comprising:

providing a closed loop circuit having a compressor, an outdoor heat exchanger, an indoor heat exchanger, and an expansion valve disposed therealong for conditioning air of the enclosure; and

diverting a portion of a heat transfer fluid carried by said circuit to the regenerative bed to selectively heat or cool the regenerative bed.

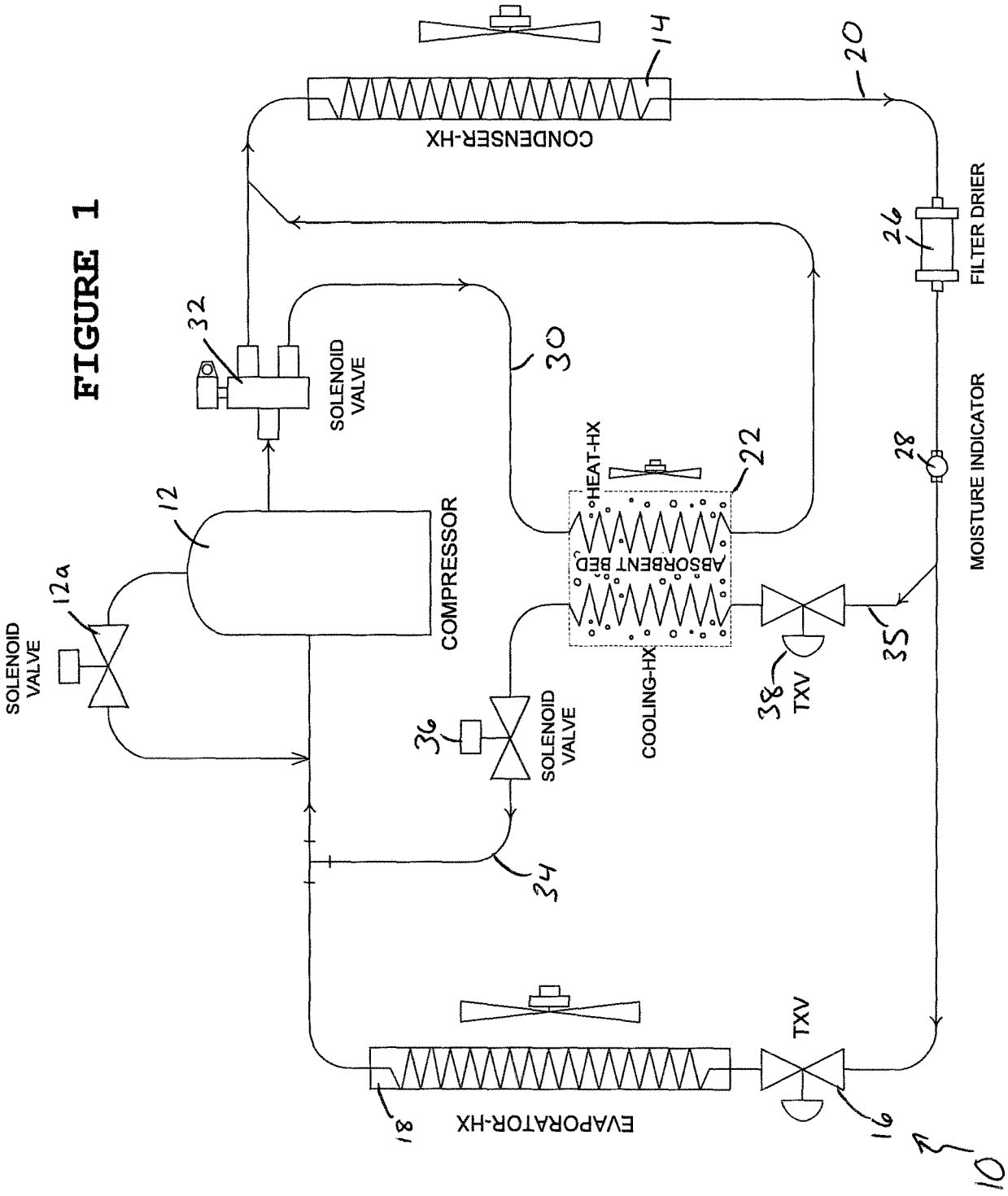
20. The method of claim 19 further including:

preheating an air flow with said portion of said heat transfer fluid prior to said air flow passing over the regenerative bed.

21. The method of claim 20 further including:

dehumidifying said air flow with said portion of said heat transfer fluid prior to said air flow passing over the regenerative bed.

FIGURE 1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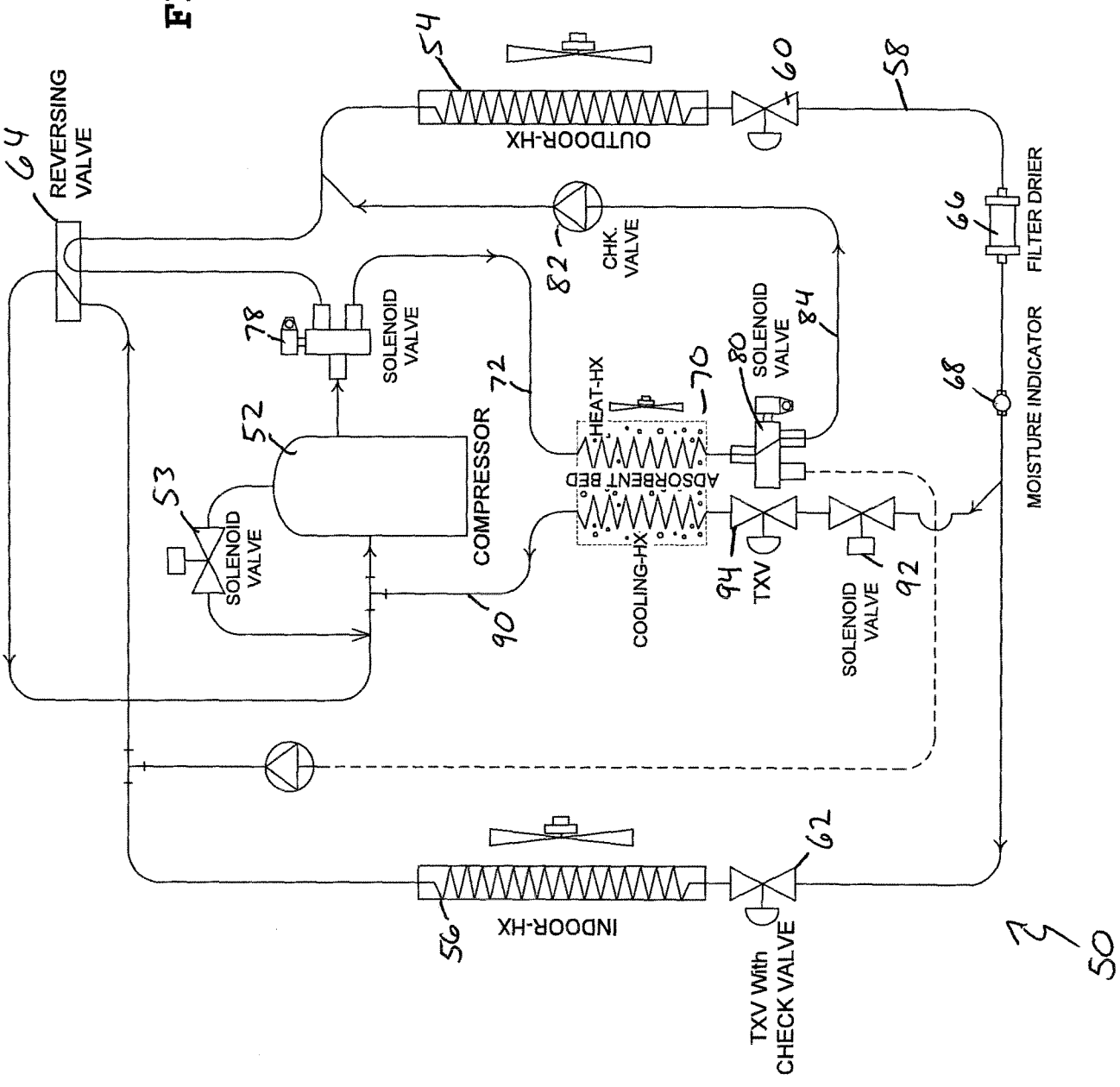
14
20
FILTER DRIER
26
MOISTURE INDICATOR
28
SOLENOID VALVE
32
30
HEAT-HX
22
ABSORBENT BED
COOLING-HX
12
COMPRESSOR
SOLENOID VALVE
12a
SOLENOID VALVE
36
34
38
TXV
35
TXV
EVAPORATOR-HX
18
16
10

FIGURE 2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REVERSING VALVE
54
OUTDOOR-HX
60
58
82
CHK. VALVE
66
FILTER DRIER
78
SOLENOID VALVE
84
80
SOLENOID VALVE
72
HEAT-HX
70
68
MOISTURE INDICATOR
52
ADSORBENT BED
53
SOLENOID VALVE
COMPRESSOR
COOLING-HX
94
TXV
SOLENOID VALVE
92
90
INDOOR-HX
56
62
TXV With CHECK VALVE
50

FIGURE 3

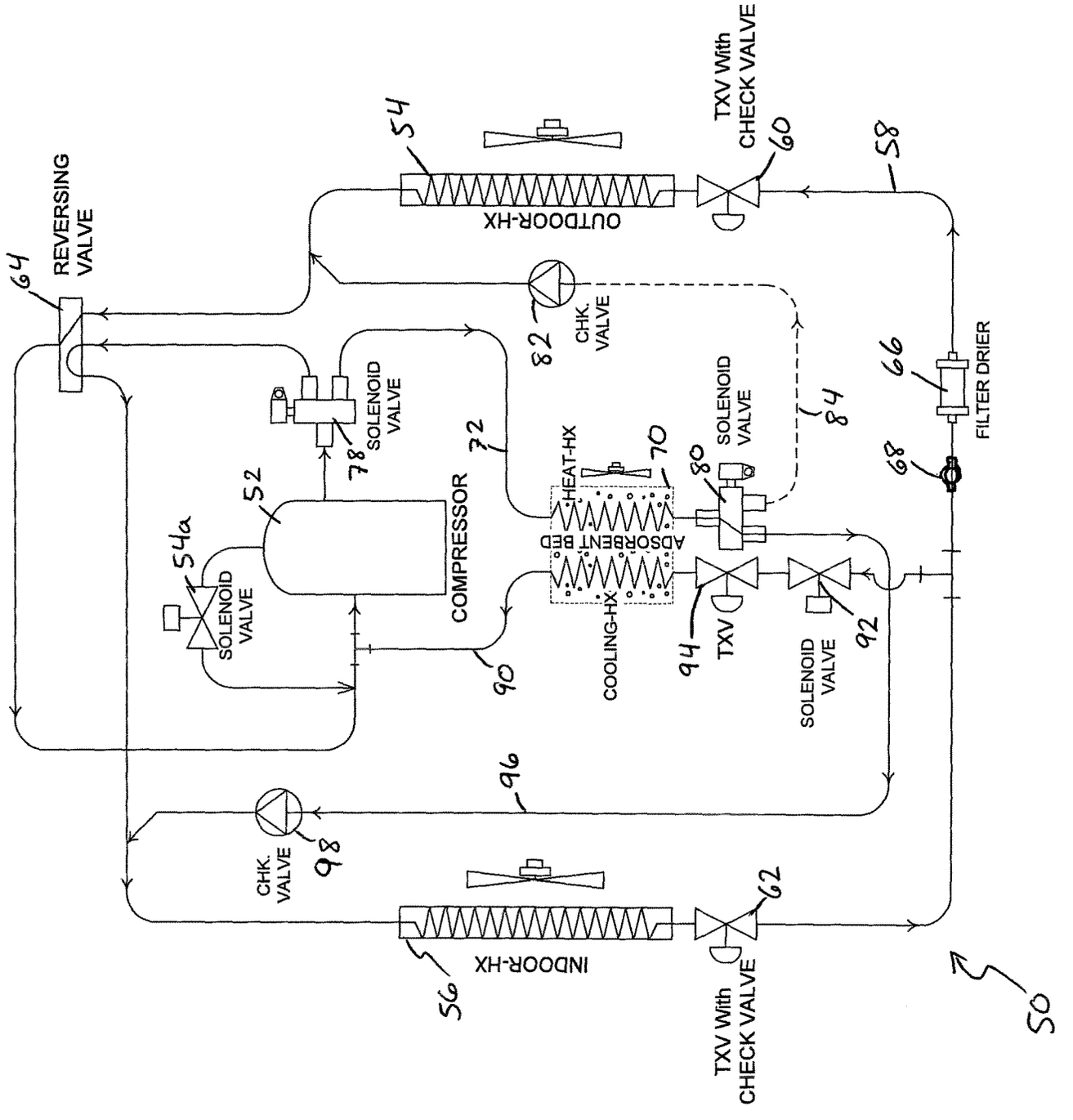
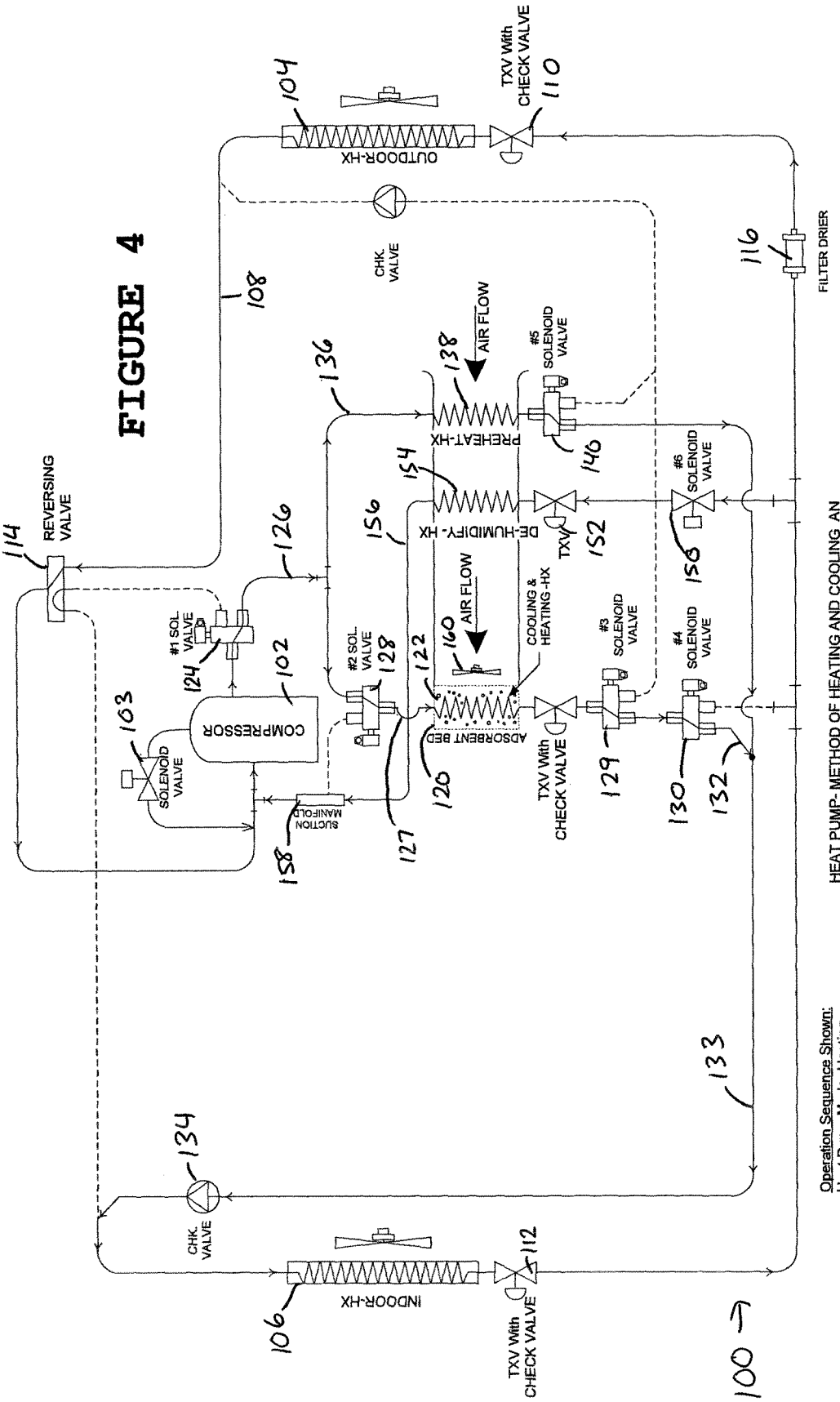

REVERSING VALVE
64
OUTDOOR-HX
54
TXV With CHECK VALVE
60
58
CHK. VALVE
82
SOLENOID VALVE
78
SOLENOID VALVE
80
84
66
FILTER DRIER
68
72
HEAT-HX
70
52
COMPRESSOR
ADSORBENT BED
COOLING-HX
54a
SOLENOID VALVE
90
94
TXV
SOLENOID VALVE
92
96
CHK. VALVE
98
INDOOR-HX
56
TXV With CHECK VALVE
62
50

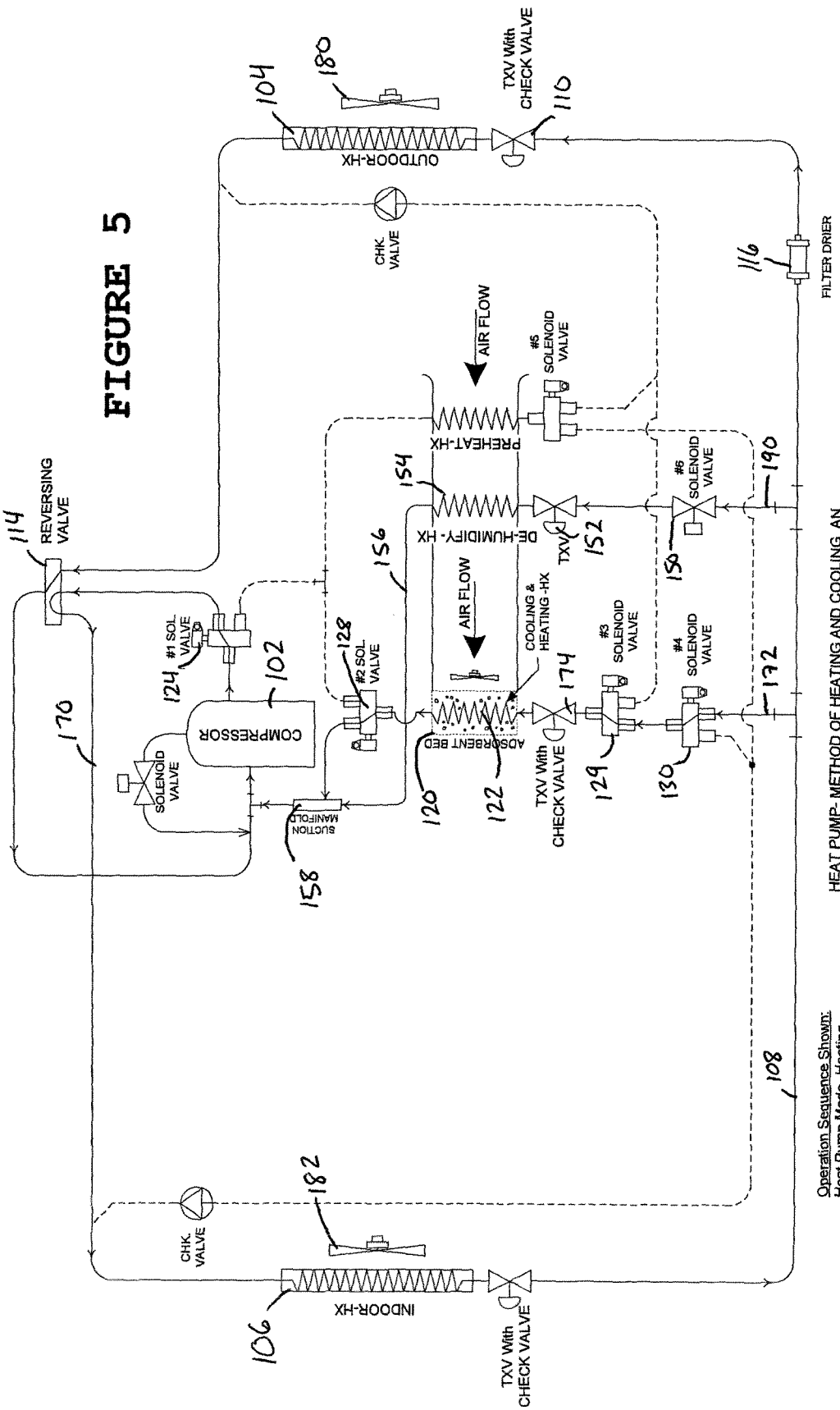
FIGURE 4



HEAT PUMP- METHOD OF HEATING AND COOLING AN ADSORBENT BED IN AIR FILTRATION SYSTEMS WITH DE-HUMIDIFICATION AND PRE-HEAT HEAT EXCHANGERS
(SHOWN IN THE HEATING MODE)

Operation Sequence Shown:
Heat Pump Mode- Heating
Dehumidification HX- ON (Cooling)
Preheat HX- ON (Heating)
Absorbent Bed HX- Heat Mode

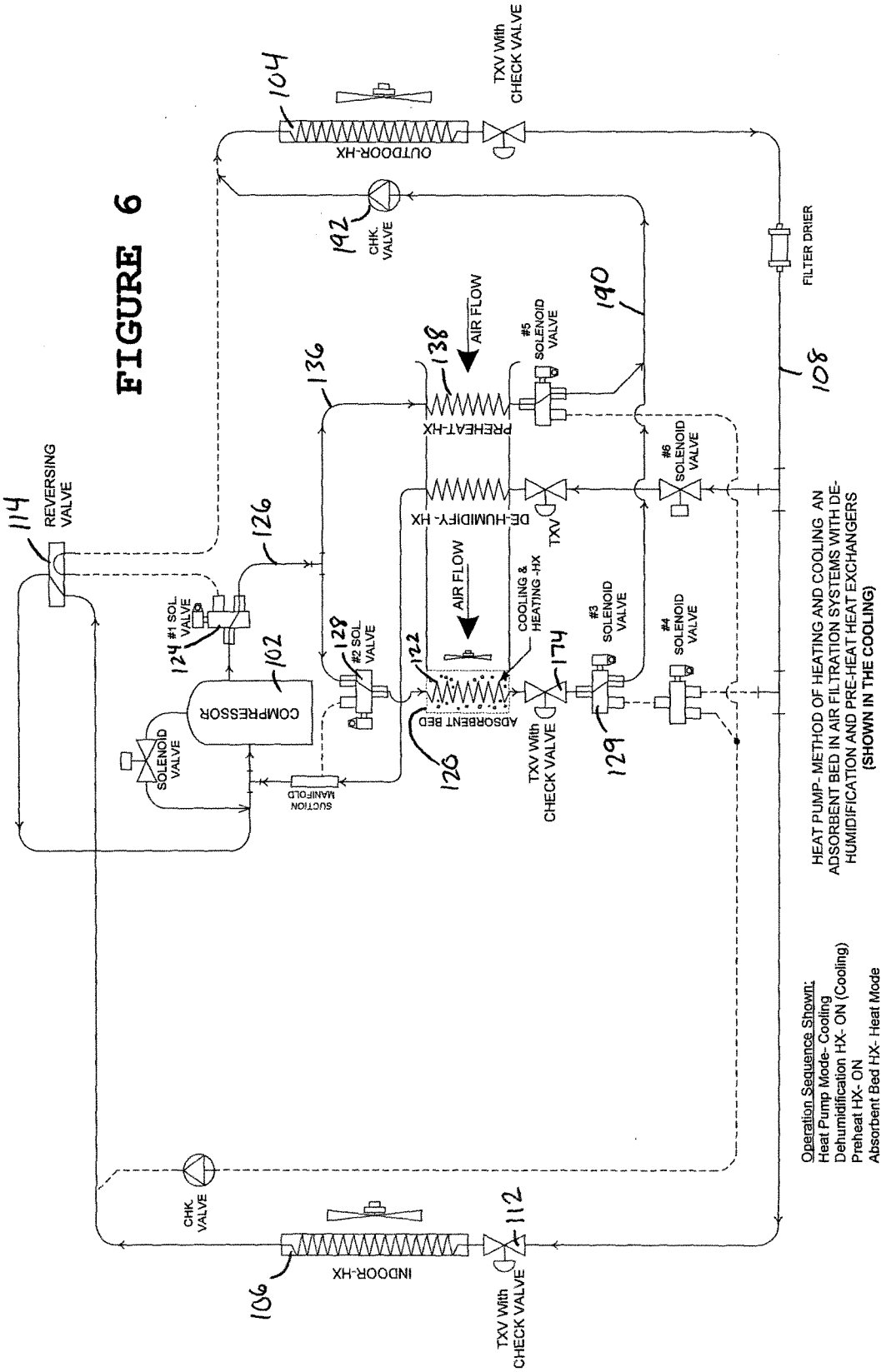
FIGURE 5



HEAT PUMP- METHOD OF HEATING AND COOLING AN ADSORBENT BED IN AIR FILTRATION SYSTEMS WITH DE-HUMIDIFICATION AND PRE-HEAT HEAT EXCHANGERS
(SHOWN IN THE HEATING MODE)

Operation Sequence Shown:
Heat Pump Mode- Heating
Dehumidification HX- ON (Cooling)
Preheat HX- OFF
Absorbent Bed HX- Cool Mode

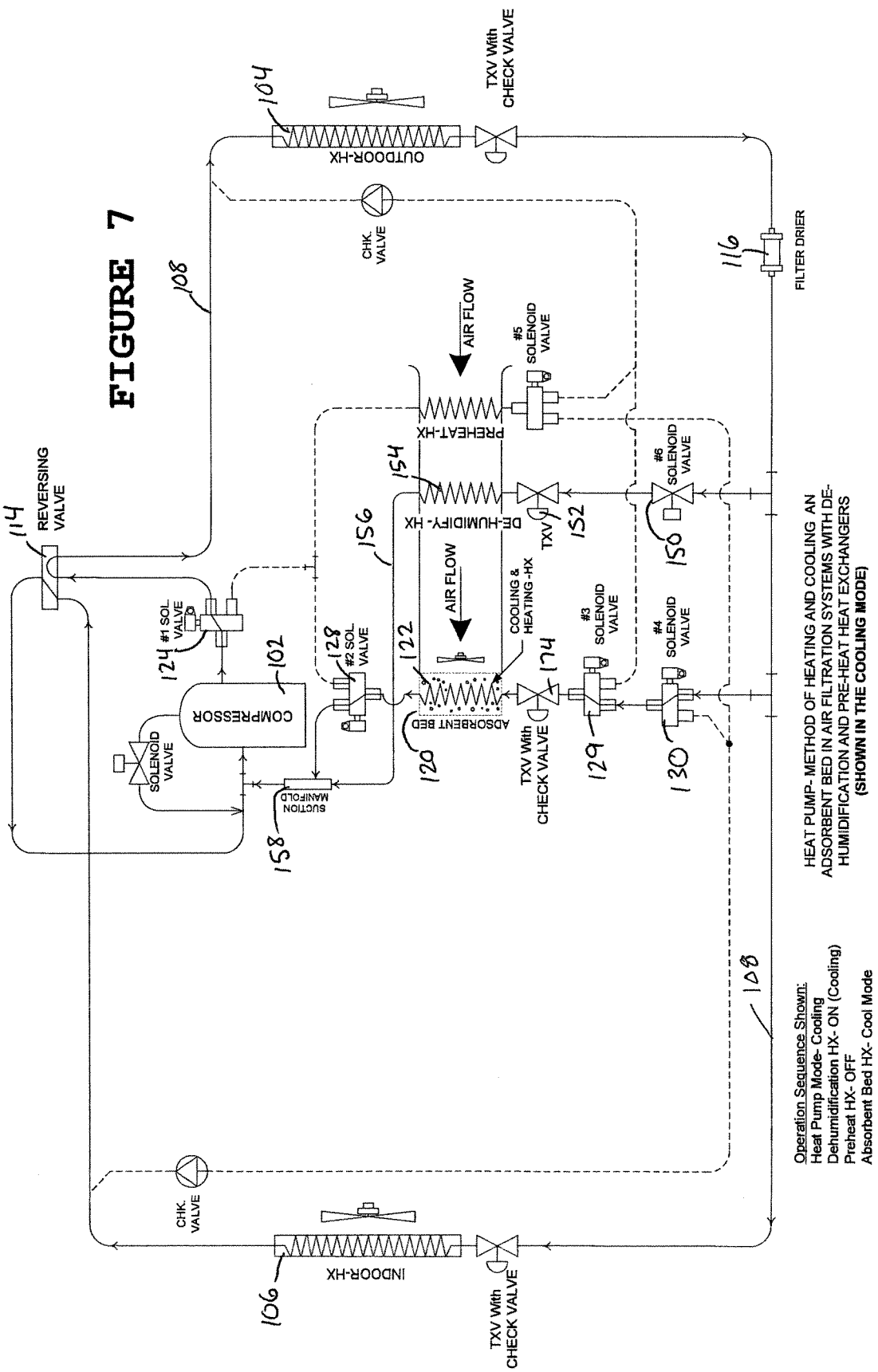
FIGURE 6

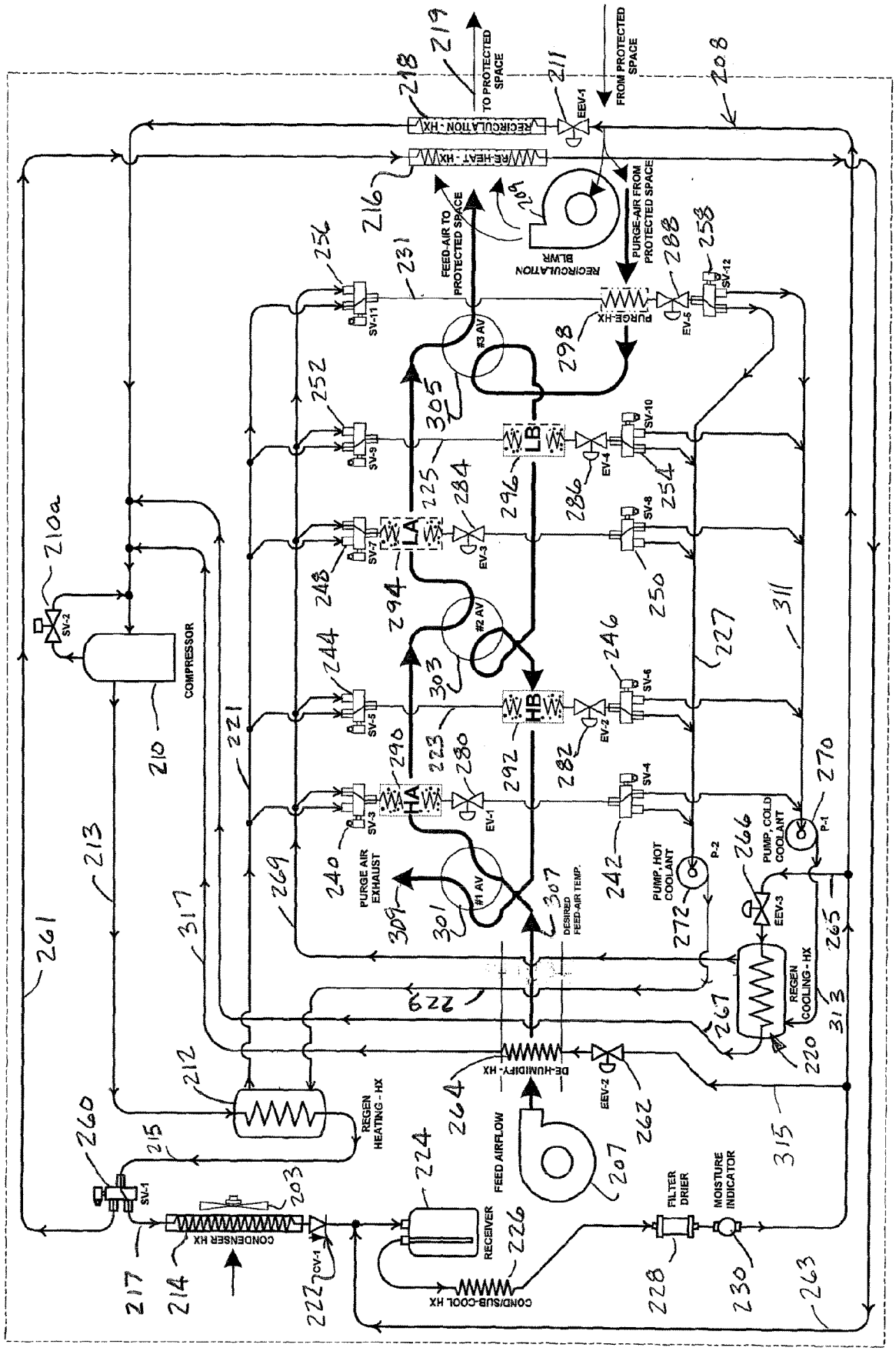


HEAT PUMP- METHOD OF HEATING AND COOLING AN ADSORBENT BED IN AIR FILTRATION SYSTEMS WITH DE-HUMIDIFICATION AND PRE-HEAT HEAT EXCHANGERS (SHOWN IN THE COOLING)

Operation Sequence Shown:
Heat Pump Mode- Cooling
Dehumidification HX- ON (Cooling)
Preheat HX- ON
Absorbent Bed HX- Heat Mode

FIGURE 7


OUTDOOR-HX
TXV With CHECK VALVE
CHK. VALVE
FILTER DRIER
AIR FLOW
#5 SOLENOID VALVE
PREHEAT-HX
DE-HUMIDIFY- HX
#6 SOLENOID VALVE
REVERSING VALVE
TXV
#1 SOL VALVE
#2 SOL VALVE
COOLING & HEATING -HX
#3 SOLENOID VALVE
#4 SOLENOID VALVE
COMPRESSOR
ADSORBENT BED
SOLENOID VALVE
SUCTION MANIFOLD
TXV With CHECK VALVE
INDOOR-HX
TXV With CHECK VALVE
104
108
114
154
156
152
150
124
102
128
122
174
120
129
130
158
106
116
Operation Sequence Shown:
Heat Pump Mode- Cooling
Dehumidification HX- ON (Cooling)
Preheat HX- OFF
Absorbent Bed HX- Cool Mode
HEAT PUMP- METHOD OF HEATING AND COOLING AN ADSORBENT BED IN AIR FILTRATION SYSTEMS WITH DE-HUMIDIFICATION AND PRE-HEAT HEAT EXCHANGERS
(SHOWN IN THE COOLING MODE)



REGEN DIAGRAM
BY: S.G. SKINNER
REV. M
DATE: 4-14-09

FIGURE 8

VAPOR CYCLE AIR CONDITIONING INTEGRATED WITH FOUR REGENERABLE TSA ADSORBENT FILTER BEDS