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(54) **LIQUID DESICCANT AIR-CONDITIONING SYSTEMS AND METHODS FOR GREENHOUSES AND GROWTH CELLS**

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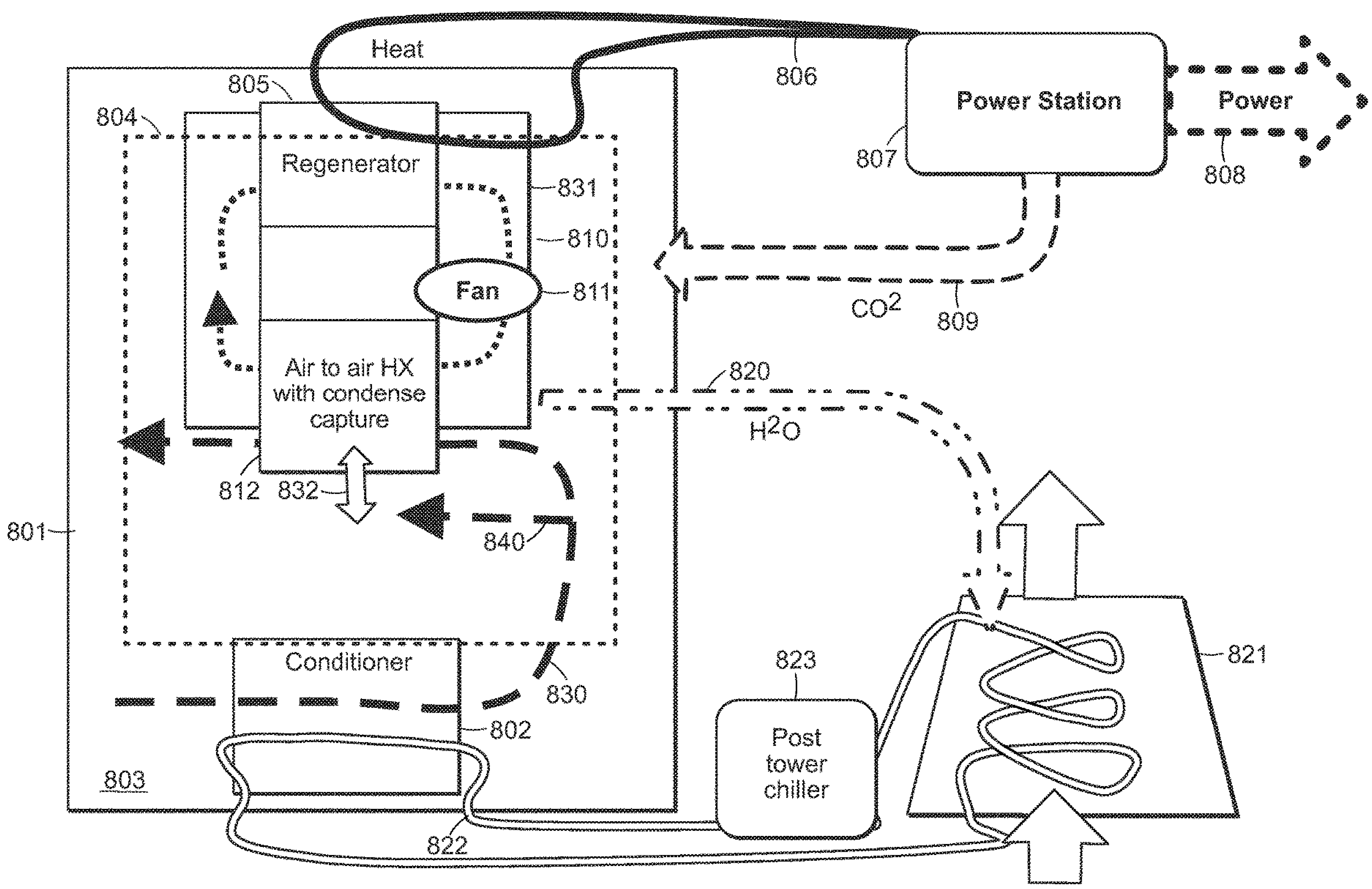
CPC *F24F 3/1417* (2013.01); *F24F 3/06* (2013.01)

(57) **ABSTRACT**

This application relates generally to liquid desiccant air conditioning (LDAC) systems and, more specifically, to liquid desiccant air-conditioning systems for use in greenhouses and growth cells.



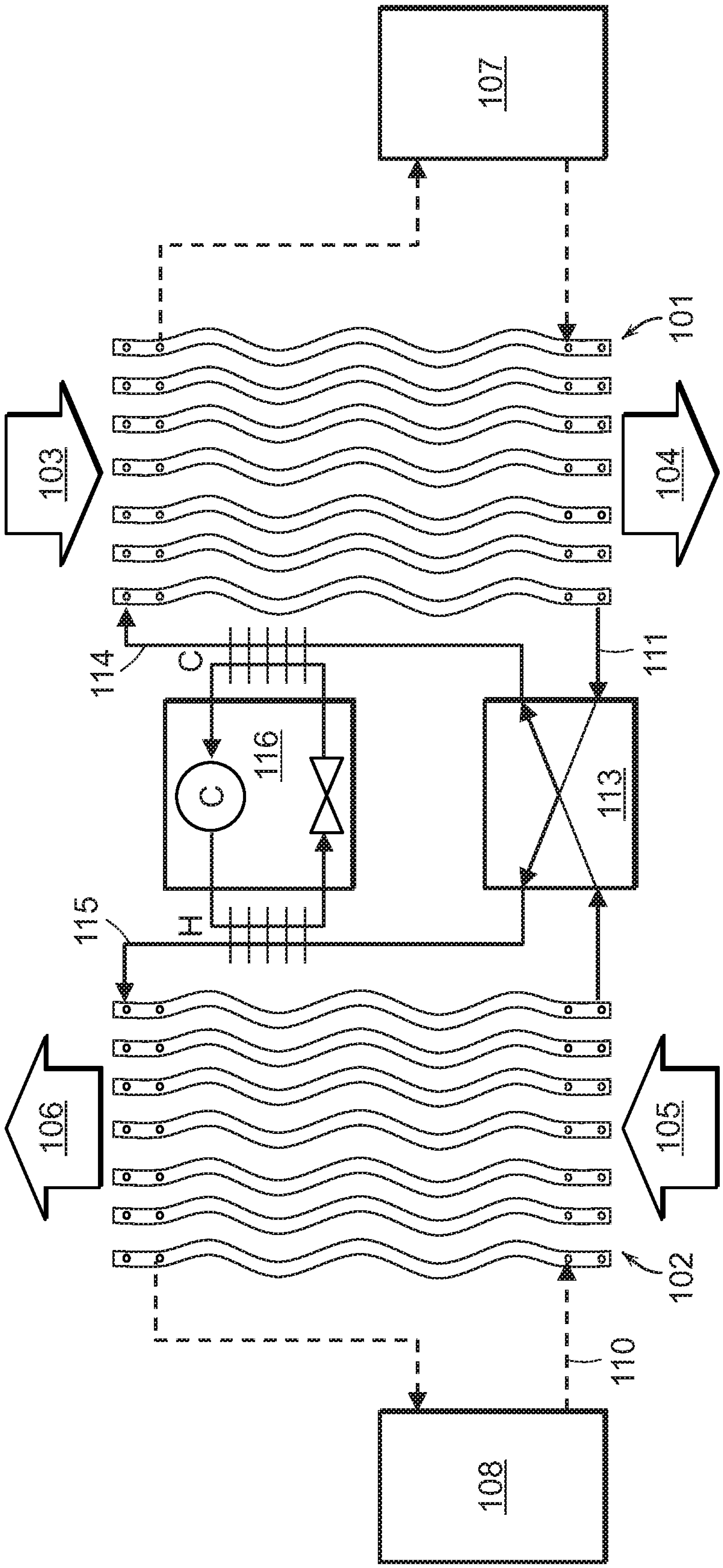


FIG. 1

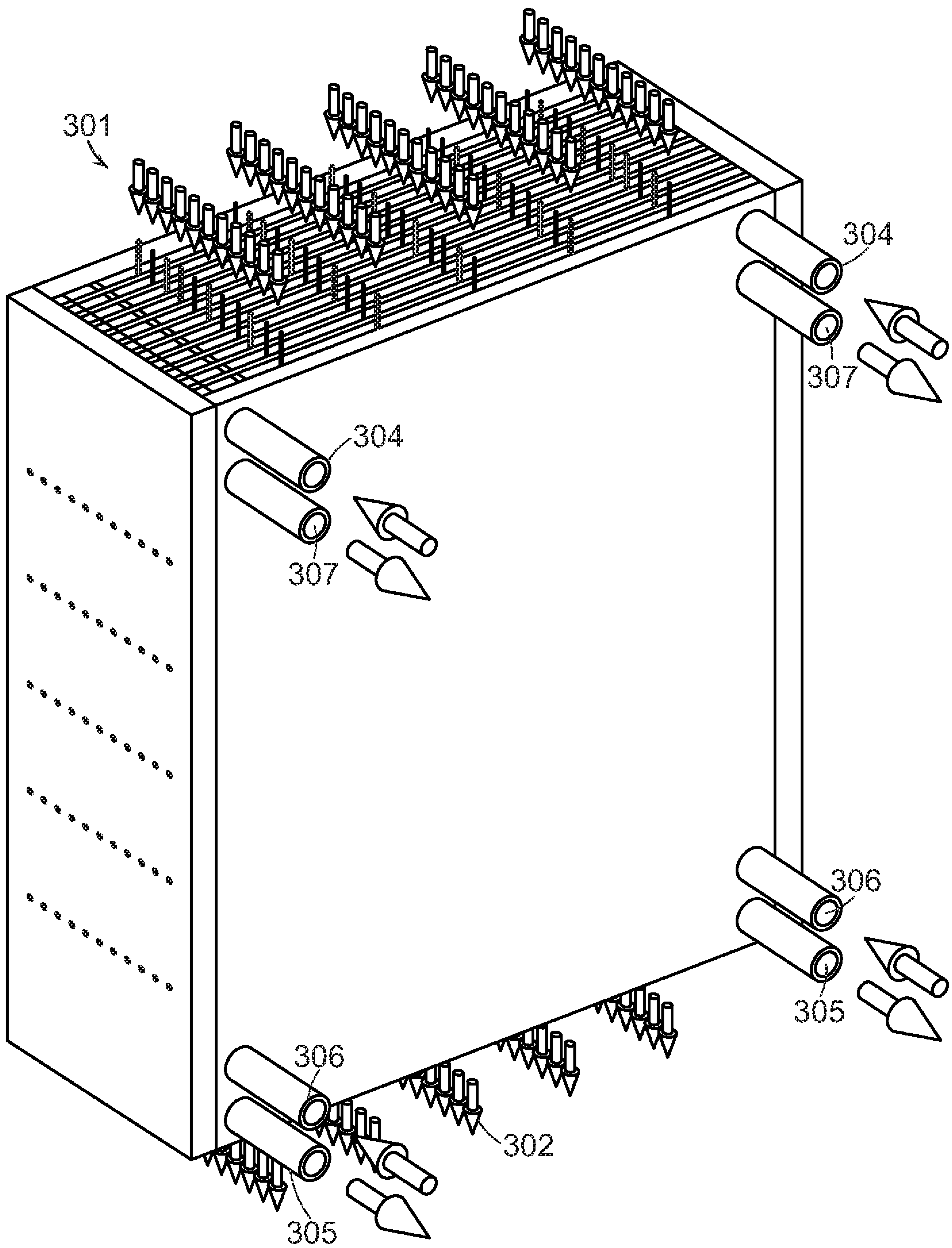


FIG. 2

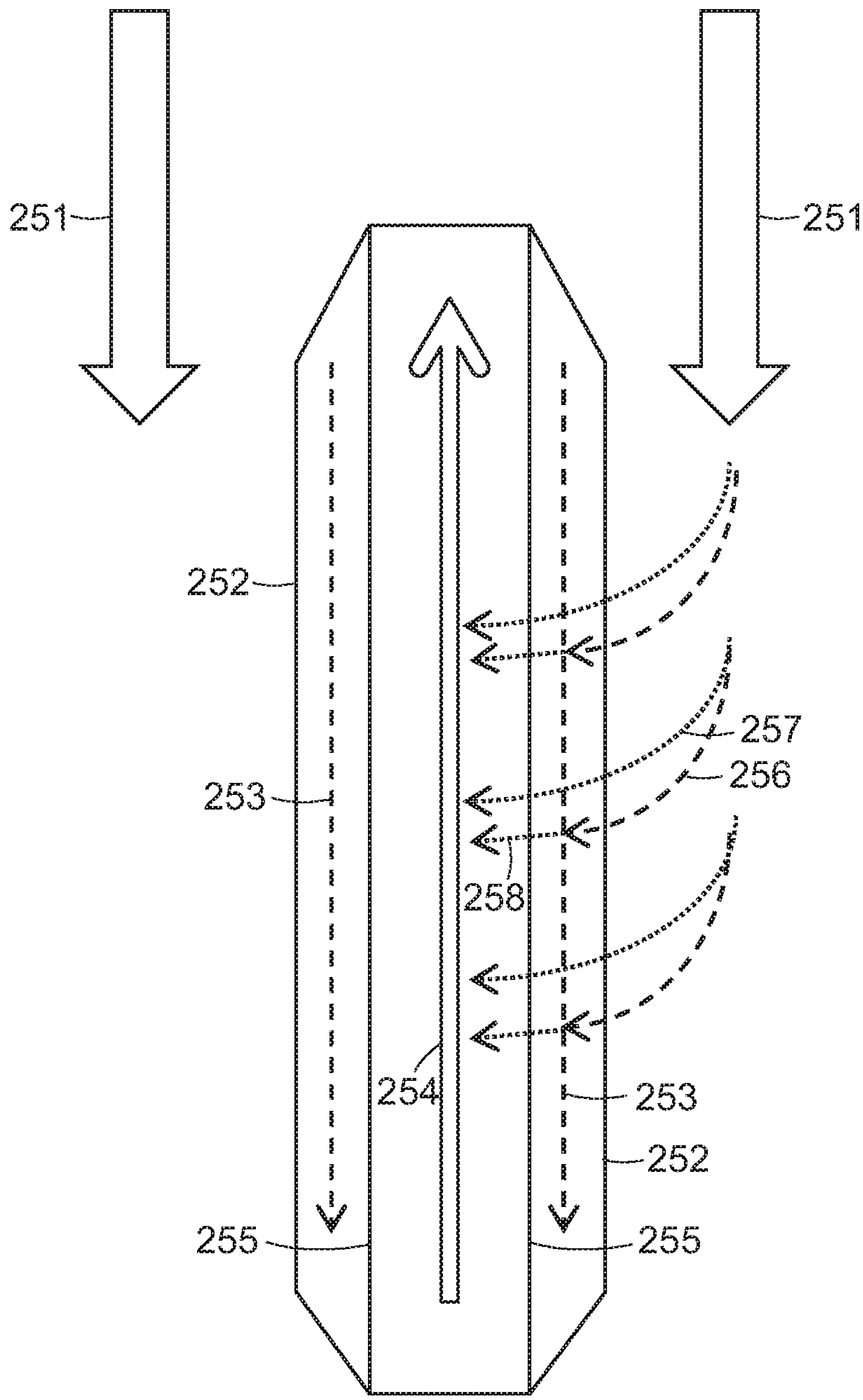
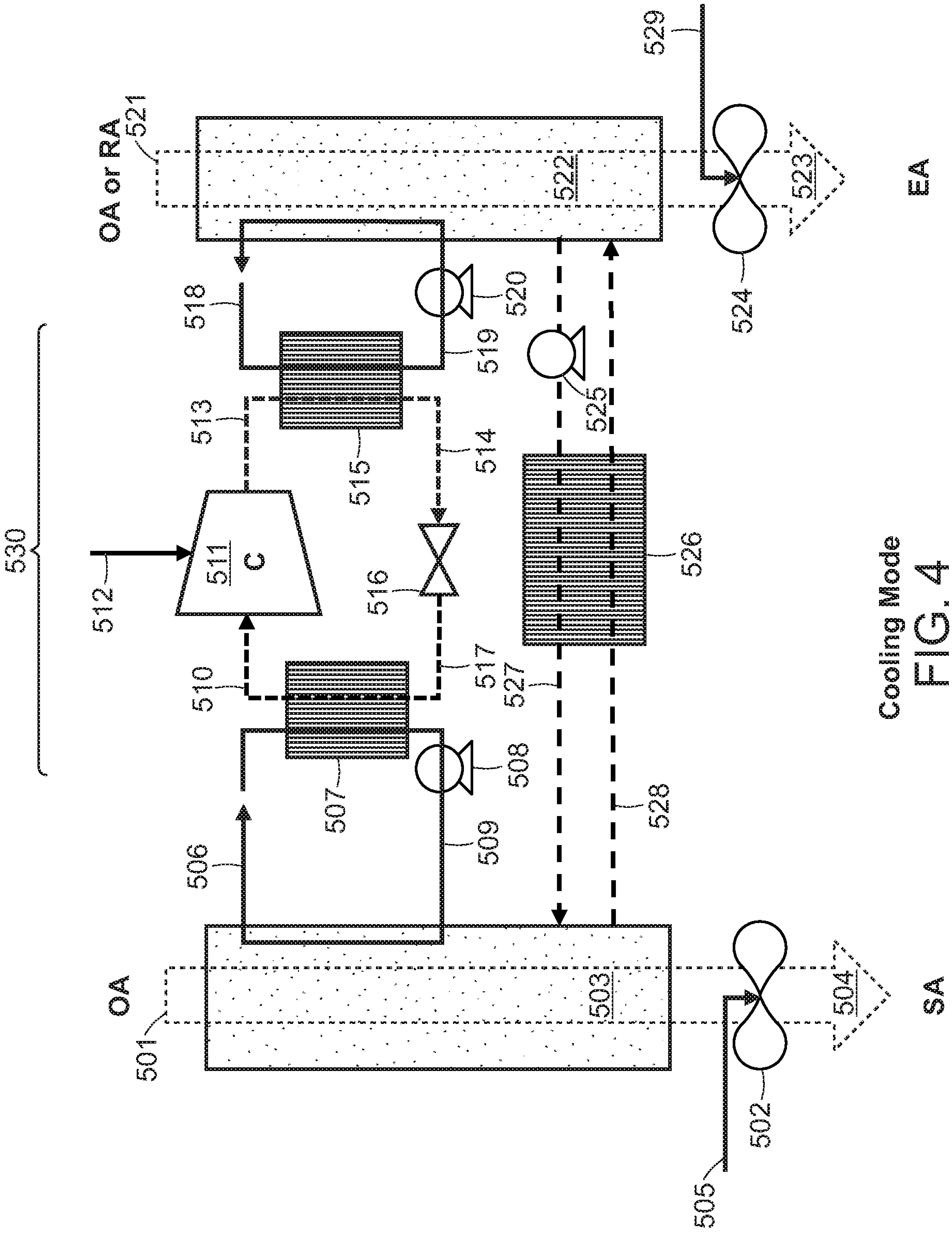


FIG. 3



Cooling Mode
FIG. 4

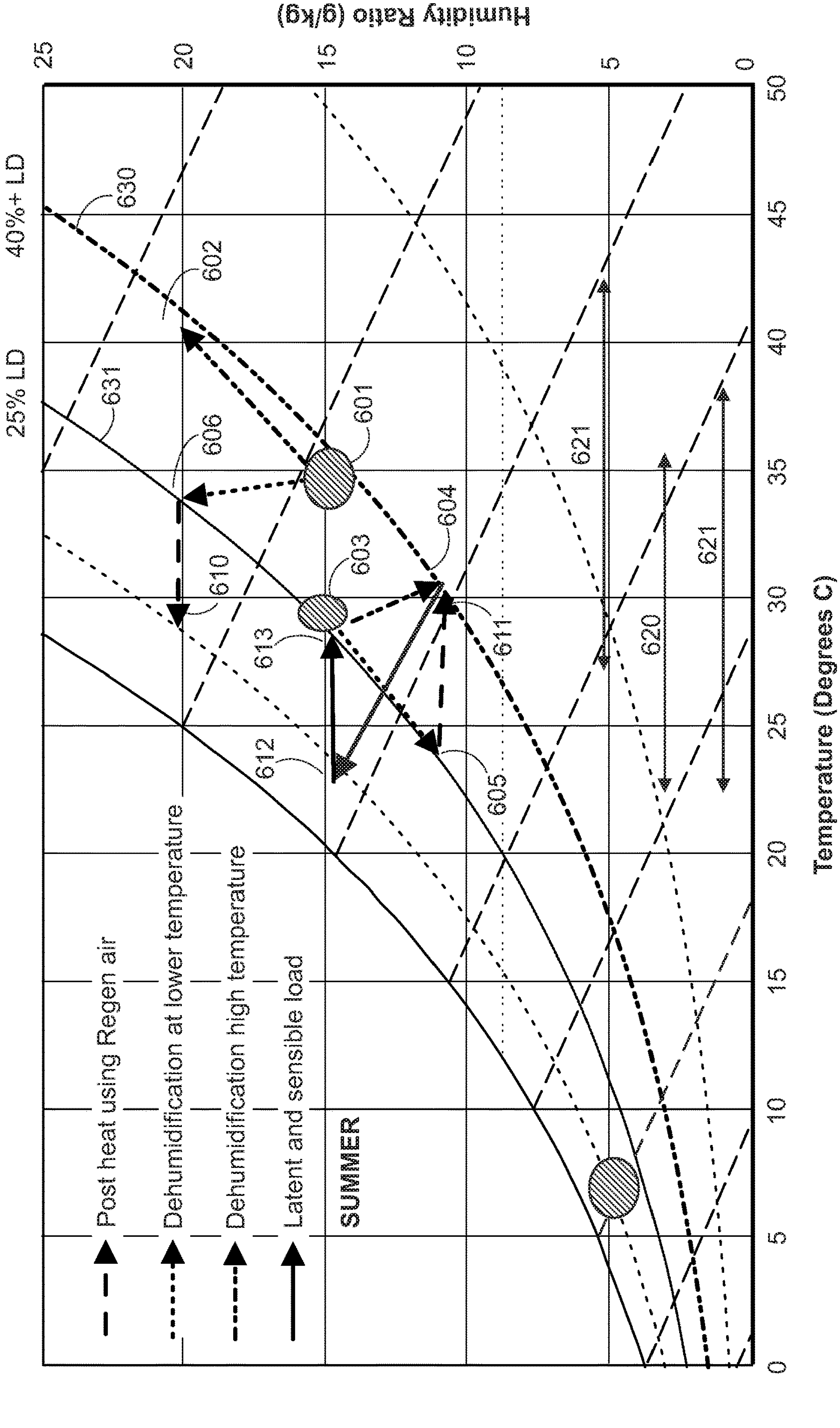

Humidity Ratio (g/kg)
Temperature (Degrees C)
25% LD
40%+ LD
Post heat using Regen air
Dehumidification at lower temperature
Dehumidification high temperature
Latent and sensible load
SUMMER
601
602
603
604
605
606
610
611
612
613
620
621
630
631

FIG. 5

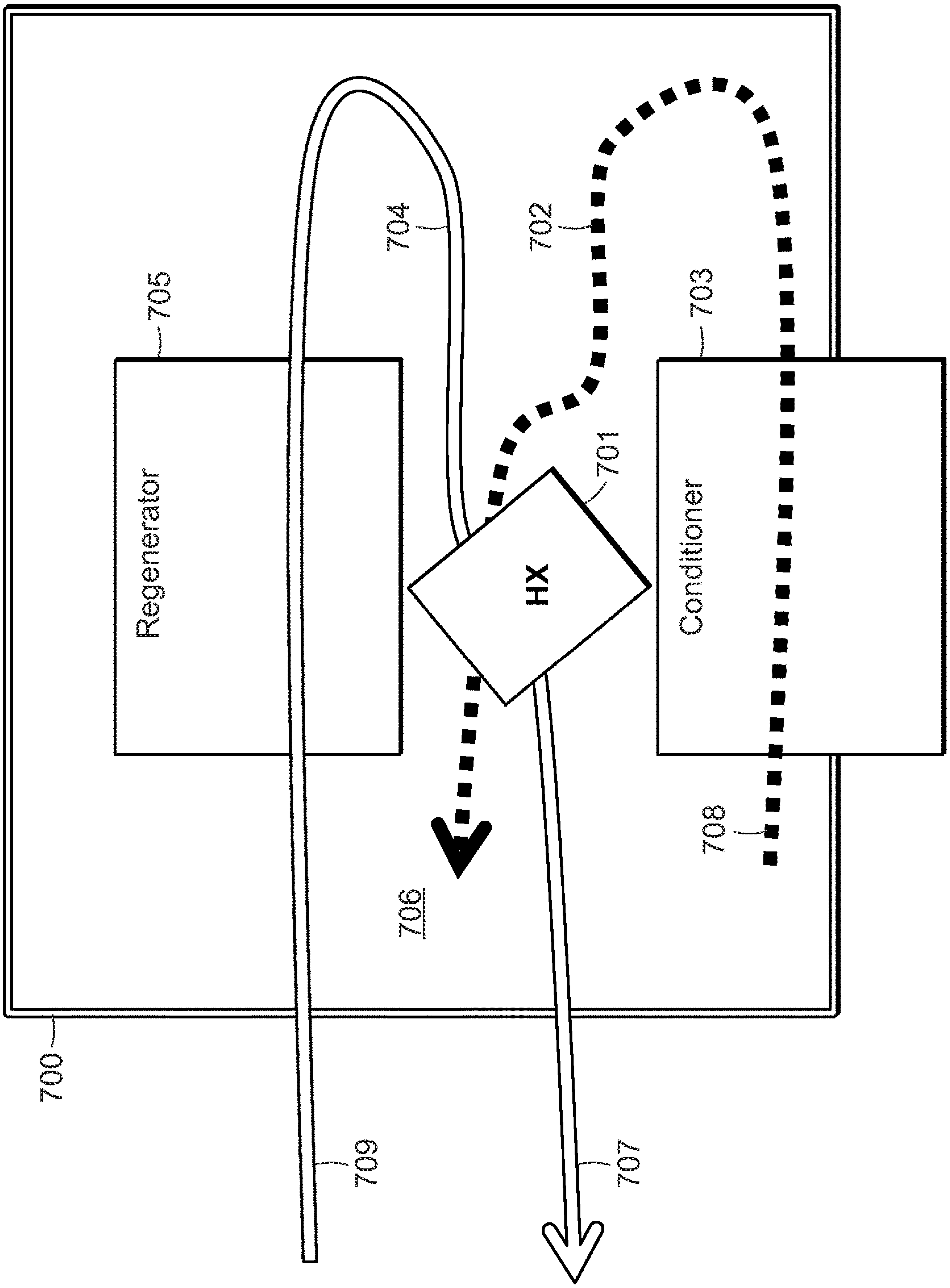
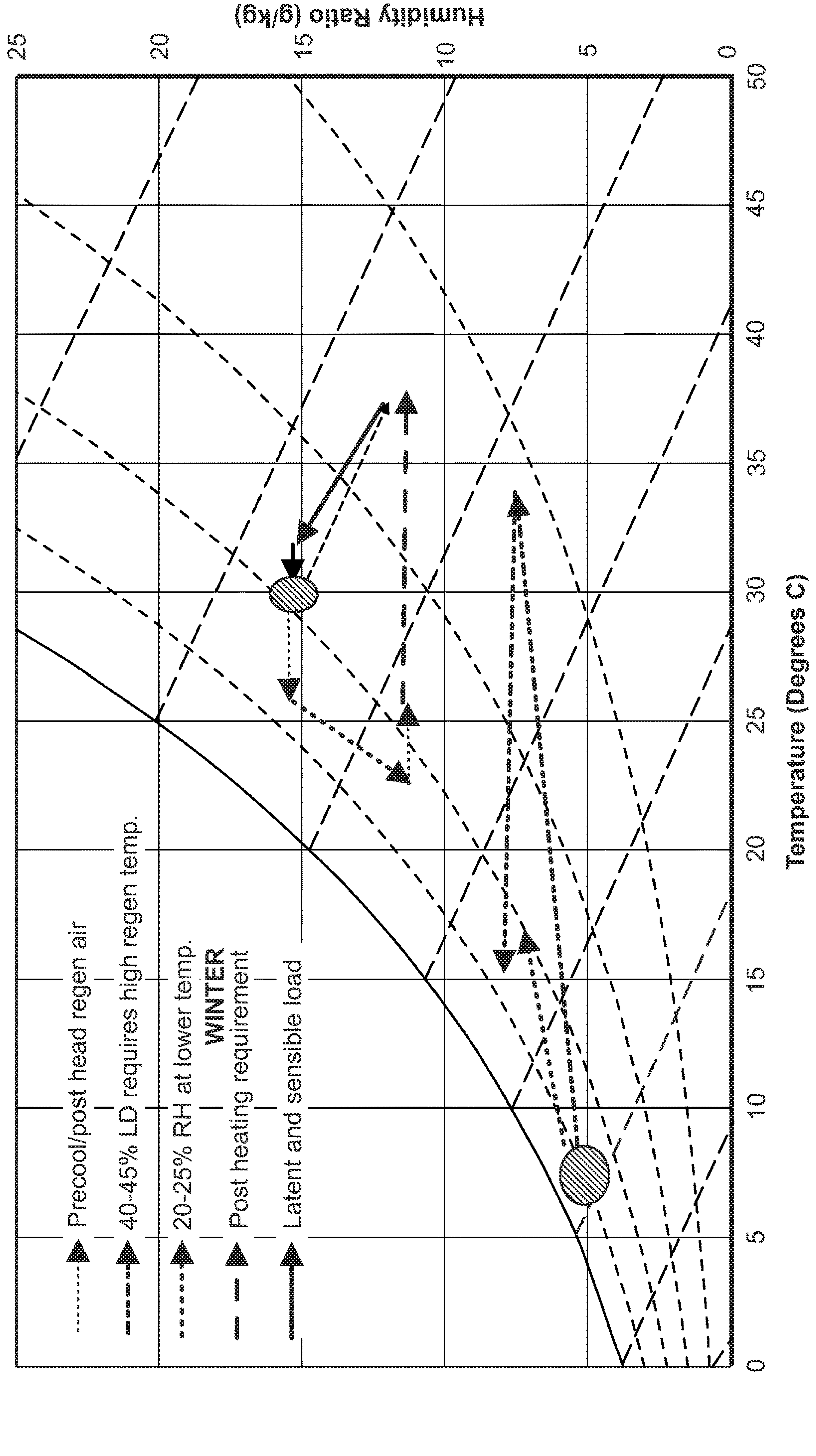

Regenerator
Conditioner
HX
700
701
702
703
704
705
706
707
708
709

FIG. 6



Humidity Ratio (g/kg)
25
20
15
10
5
0
Temperature (Degrees C)
0
5
10
15
20
25
30
35
40
45
50
Precool/post head regen air
40-45% LD requires high regen temp.
20-25% RH at lower temp.
WINTER
Post heating requirement
Latent and sensible load

FIG. 7

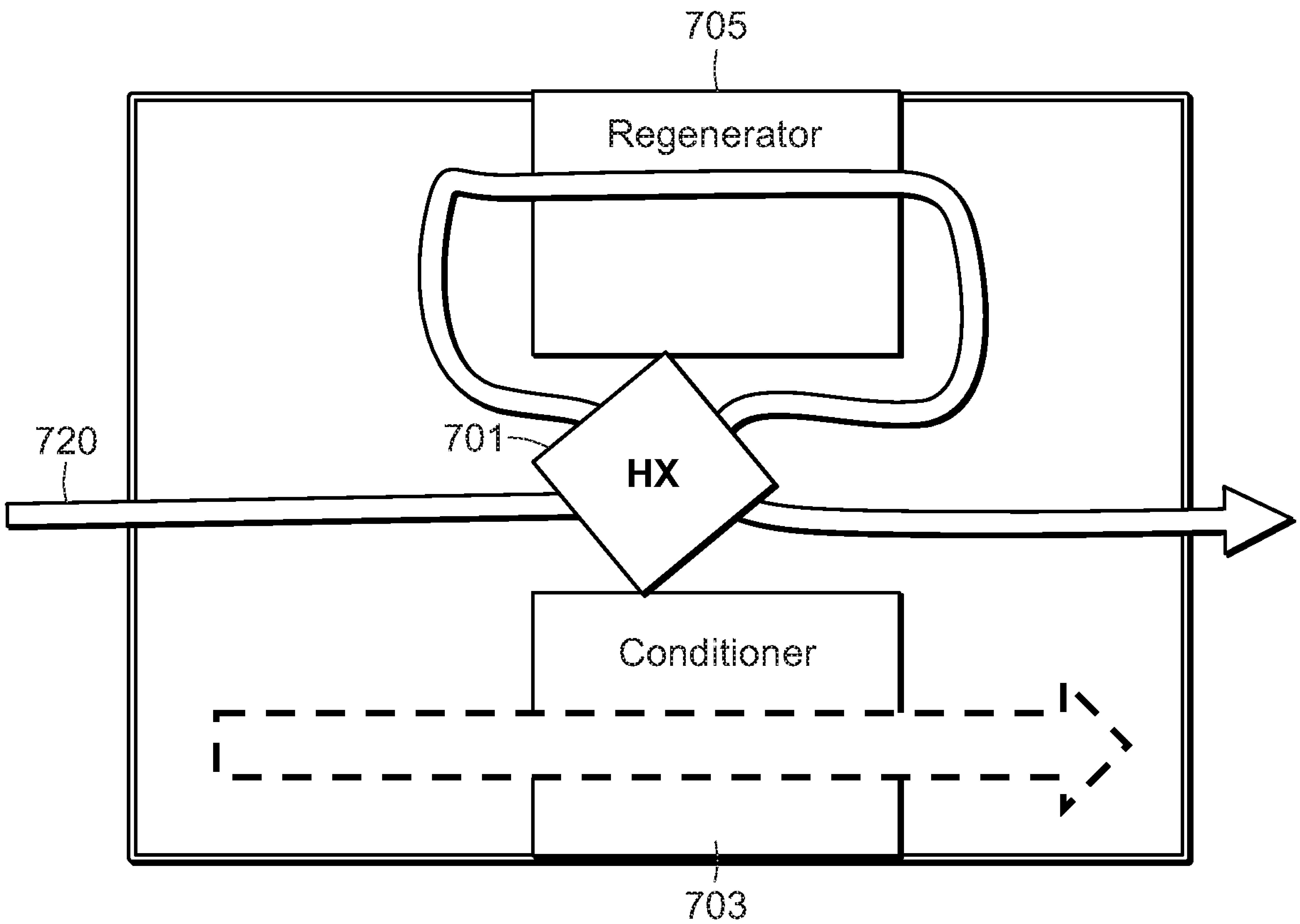


FIG. 8A

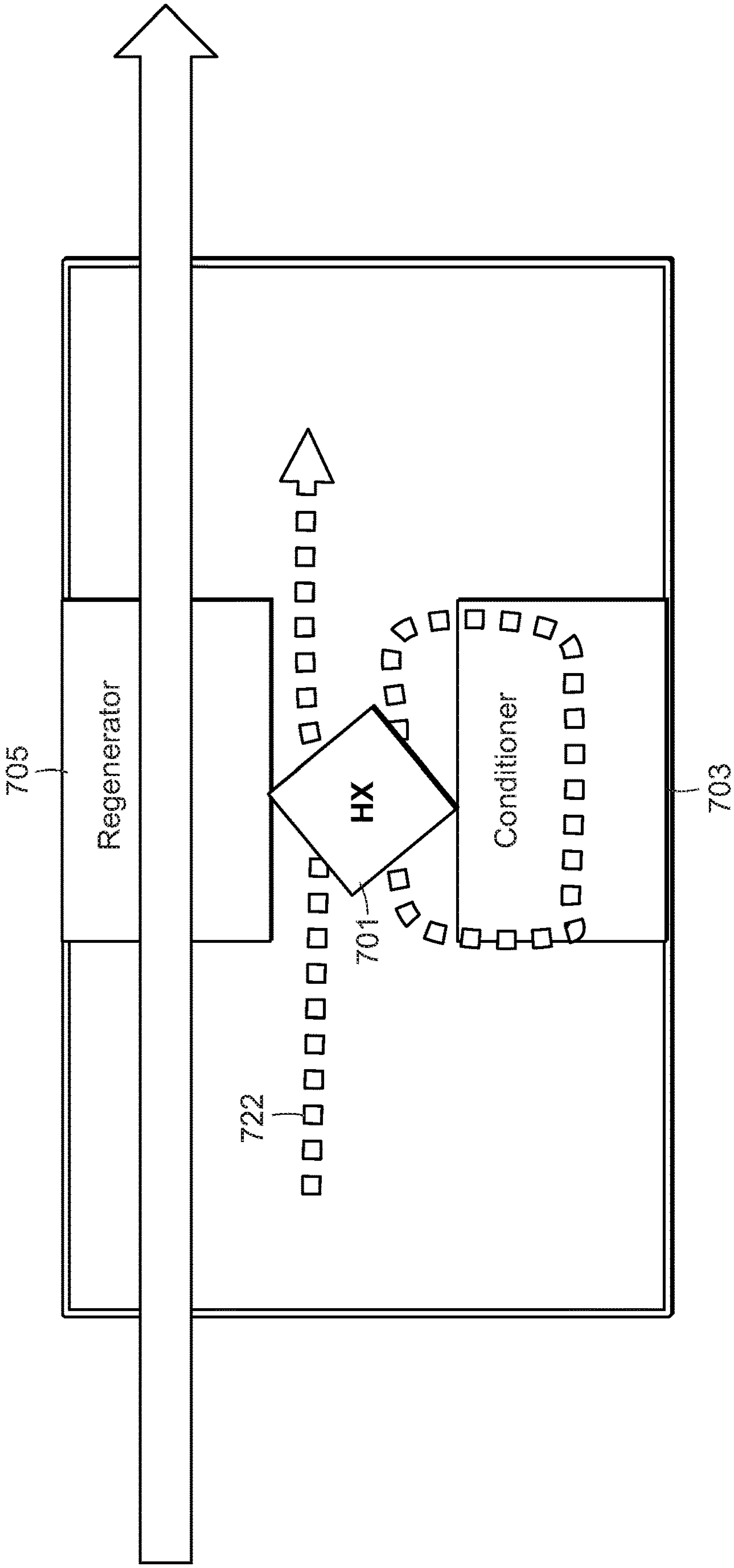


FIG. 8B

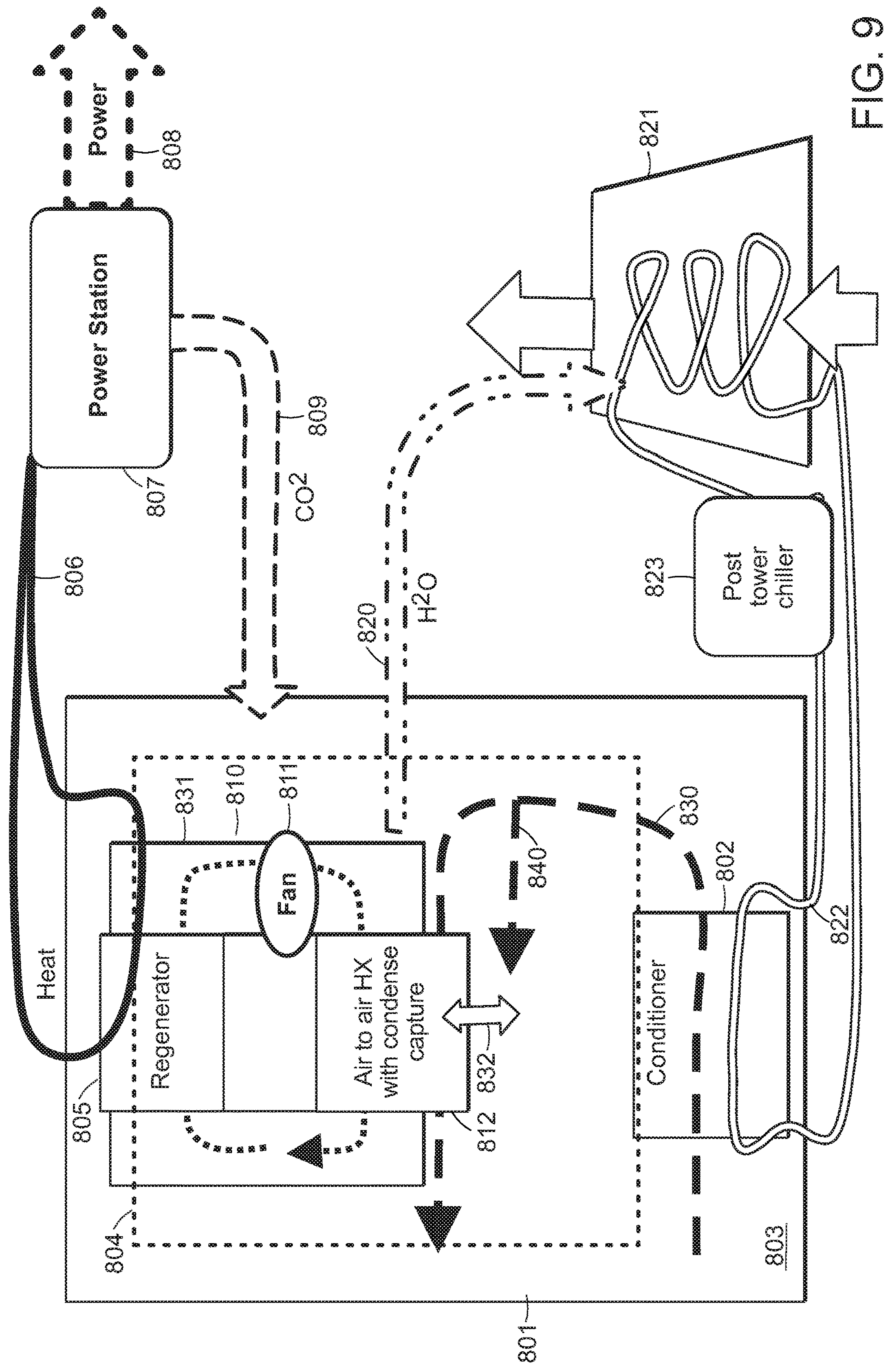

Power
808
Power Station
807
809
CO_2
806
820
H_2O
821
823
Post tower chiller
831
810
811
Fan
830
840
802
822
Heat
Regenerator
Air to air HX with condense capture
832
805
812
Conditioner
804
803
801

FIG. 9

LIQUID DESICCANT AIR-CONDITIONING SYSTEMS AND METHODS FOR GREENHOUSES AND GROWTH CELLS

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims priority from U.S. Provisional Patent Application No. 62/776210 filed on Dec. 6, 2018 entitled LIQUID DESICCANT AIR-CONDITIONING SYSTEMS AND METHODS FOR GREENHOUSES, which is hereby incorporated by reference.

BACKGROUND

[0002] The present application relates generally to liquid desiccant air conditioning (LDAC) systems and, more specifically, to liquid desiccant air-conditioning systems for greenhouses and closed building growth cells (also known as grow rooms).

[0003] High value added agricultural production is increasingly done in completely controlled production environment in closed greenhouses and growth cells.

[0004] Greenhouses have direct access to sunlight, and have large sensible and latent loads during the summer, while heating and dehumidification is required in the winter. In winter, lights are an additional heat source to maintain 12-16 hour growth periods.

[0005] Growth cells are within closed buildings with limited or no ventilation. Lighting is artificial. Large volumes of water are added to the plants, which use it for growth and evaporation. This will also significantly cool the space. Heating sources are lights and production of carbon dioxide (CO_2) supplied to the space. The lights can be low efficiency sodium and natrium lights or high efficiency LEDs. CO_2 can be provided from burning gas or from bottled gas.

[0006] While most greenhouses and growth cells require significant cooling, growth cells with LEDs and bottled CO_2 have much lower or even negative cooling or heating requirements year round.

[0007] Greenhouse and growth-cell production conditions differ not only by crop but also by crop maturity. For example, many products maximize production at high relatively humidity (60-80%), but humidity levels above 80% can lead to significant damage to crops due to growth of pathogens. Some crops require much lower humidities, e.g., 50% RH for some marijuana products.

[0008] Various embodiments disclosed herein relate to combining superior dehumidification of liquid desiccants with appropriate energy management to maintain the required conditions at minimum temperature requirements.

BRIEF SUMMARY

[0009] A liquid desiccant air-conditioning system in accordance with one or more embodiments is provided for managing temperature and humidity conditions in a greenhouse or a growth cell. The system includes a liquid desiccant conditioner utilizing a liquid desiccant to dehumidify a first air stream flowing therethrough. The first air stream enters the liquid desiccant conditioner from a space within the greenhouse or growth cell and exits the liquid desiccant conditioner as supply air to the greenhouse or growth cell. The system also includes a liquid desiccant regenerator receiving the liquid desiccant used in the liquid desiccant conditioner, and humidifying a second air stream flowing therethrough to concentrate the liquid desiccant and then returning the liquid desiccant to the conditioner. An air-to-air heat exchanger is thermally coupled to the air stream exiting the liquid desiccant conditioner or an air stream drawn from the space within the greenhouse or growth cell and the second air stream exiting the liquid desiccant regenerator for cooling the second air stream and producing water therefrom. The second air stream circulates between the liquid desiccant regenerator and the air-to-air heat exchanger within a closed enclosure.

[0010] In accordance with one or more embodiments, a method is provided for managing temperature and humidity conditions in a greenhouse or a growth cell using a liquid desiccant air conditioning system. The method incudes the steps of: dehumidifying a first air stream flowing through a liquid desiccant conditioner utilizing a liquid desiccant, the first air stream being drawn into the liquid desiccant conditioner from a space within the greenhouse or growth cell and exiting the liquid desiccant conditioner as supply air to the greenhouse or growth cell; receiving, in a liquid desiccant regenerator, the liquid desiccant used in the liquid desiccant conditioner, and humidifying a second air stream flowing through the liquid desiccant regenerator to concentrate the liquid desiccant and then returning the liquid desiccant to the conditioner; and cooling the second air stream humidified by the liquid desiccant regenerator and producing water therefrom using an air-to-air heat exchanger thermally coupled to the air stream exiting the liquid desiccant conditioner or an air stream drawn from the space within the greenhouse or growth cell; and circulating the second air stream between the liquid desiccant regenerator and the air-to-air heat exchanger within a closed enclosure.

[0011] A liquid desiccant air-conditioning system in accordance with one or more embodiments is disclosed for managing temperature and humidity conditions in a greenhouse or a growth cell. The system includes a liquid desiccant conditioner utilizing a liquid desiccant to dehumidify a first air stream flowing therethrough to be provided as supply air to the greenhouse or growth cell, the first air stream entering the liquid desiccant conditioner from a space within the greenhouse or growth cell. The system also includes a liquid desiccant regenerator receiving the liquid desiccant used in the liquid desiccant conditioner, and utilizing a second air stream flowing therethrough to concentrate the liquid desiccant, and then returning the liquid desiccant to the conditioner. The liquid desiccant regenerator heats and humidifies the second air stream. The second air stream enters the liquid desiccant regenerator from outside the greenhouse or growth cell and exits the liquid desiccant regenerator to be exhausted outside the greenhouse or growth cell. The system further includes an air-to-air heat exchanger thermally coupled to the first air stream exiting the liquid desiccant conditioner and the second air stream exiting the liquid desiccant regenerator for heating the first air stream before the first air stream is provided as the supply air to the greenhouse or growth cell and the second air stream is exhausted from the greenhouse or growth cell.

[0012] A liquid desiccant air-conditioning system in accordance with one or more embodiments is provided for managing temperature and humidity conditions in a greenhouse or a growth cell. The system includes a liquid desiccant conditioner utilizing a liquid desiccant to dehumidify a first air stream flowing therethrough to be provided as supply air to the greenhouse or growth cell. The first air stream enters the liquid desiccant conditioner from a space within the greenhouse or growth cell. A liquid desiccant regenerator receives the liquid desiccant used in the liquid desiccant conditioner, and utilizes a second air stream flowing therethrough to concentrate the liquid desiccant, and then returns the liquid desiccant to the conditioner, wherein the liquid desiccant regenerator heats and humidifies the second air stream, the second air stream provided to the liquid desiccant regenerator from outside the greenhouse or growth cell and exiting the liquid desiccant regenerator to be exhausted outside the greenhouse or growth cell. An air-to-air heat exchanger is thermally coupled to the second air stream prior to entering the liquid desiccant regenerator and the second air stream exiting the liquid desiccant regenerator for preheating the second air stream entering the liquid desiccant regenerator and post cooling the second air stream exiting the liquid desiccant regenerator.

[0013] A liquid desiccant air-conditioning system in accordance with one or more embodiments is provided for managing temperature and humidity conditions in a greenhouse or a growth cell. The system includes a liquid desiccant conditioner utilizing a liquid desiccant to dehumidify a first air stream flowing therethrough to be provided as supply air to the greenhouse or growth cell. The first air stream enters the liquid desiccant conditioner from a space within the greenhouse or growth cell. A liquid desiccant regenerator receives the liquid desiccant used in the liquid desiccant conditioner, and utilizes a second air stream flowing therethrough to concentrate the liquid desiccant, and then returns the liquid desiccant to the conditioner, wherein the liquid desiccant regenerator heats and humidifies the second air stream, the second air stream provided to the liquid desiccant regenerator from outside the greenhouse or growth cell and exits the liquid desiccant regenerator to be exhausted outside the greenhouse or growth cell. An air-to-air heat exchanger is thermally coupled to the first air stream prior to entering the liquid desiccant conditioner and the first air stream exiting the liquid desiccant conditioner for precooling the first air stream entering the liquid desiccant conditioner and post heating the first air stream exiting the liquid desiccant conditioner.

BRIEF DESCRIPTION OF THE FIGURES

[0014] FIG. **1** is a simplified diagram illustrating a prior art liquid desiccant air-conditioning system.

[0015] FIG. **2** illustrates a prior art three-way heat exchanger block of a liquid desiccant air conditioning system.

[0016] FIG. **3** is a simplified diagram illustrating a prior art three-way heat exchanger panel assembly in the heat exchanger block.

[0017] FIG. **4** is a simplified diagram illustrating another prior art liquid desiccant air conditioning system.

[0018] FIG. **5** is a Psychrometric charts showing air properties in summer operation.

[0019] FIG. **6** is a simplified block diagram illustrating a liquid desiccant air-conditioning system in accordance with one or more embodiments.

[0020] FIG. **7** is a Psychrometric chart showing air properties in a winter operation.

[0021] FIGS. **8**A and **8**B are simplified block diagrams illustrating liquid desiccant air-conditioning systems with energy recovery for improved efficiency.

[0022] FIG. **9** is a simplified block diagram illustrating another liquid desiccant air-conditioning system in accordance with one or more embodiments.

DETAILED DESCRIPTION

[0023] FIG. **1** illustrates an exemplary prior art liquid desiccant air conditioning system as disclosed in U.S. Patent Application Publication No. 20120125020 and U.S. Pat. Nos. 9,243,810 and 9,631,848 used in a cooling and dehumidifying mode of operation. (Liquid desiccant air conditioning systems can also operate in various other modes including cooling, heating, cooling and humidification, heating and dehumidification, and heating and humidification modes.) A conditioner **101** comprises a set of 3-way heat exchange plate structures that are internally hollow. A cold heat transfer fluid is generated in a cold source **107** and introduced into the plates. A liquid desiccant solution at **114** is flowed onto the outer surface of the plates. The liquid desiccant runs over the outer surface of each of the plates behind a thin membrane, which is located between the air flow and the surface of the plates. Return air, outside air **103**, or mixture thereof is blown between the set of conditioner plates. The liquid desiccant on the surface of the plates attracts the water vapor in the air flow and the cooling water (heat transfer fluid) inside the plates helps to inhibit the air temperature from rising. The treated air **104** is introduced into a building space.

[0024] The liquid desiccant is collected at the other end of the conditioner plates at **111** and is transported through a heat exchanger **113** to the liquid desiccant entry point **115** of the regenerator **102** where the liquid desiccant is distributed across similar plates in the regenerator. Return air, outside air **105**, or a mixture thereof is blown across the regenerator plates and water vapor is transported from the liquid desiccant into the leaving air stream **106**. An optional heat source **108** provides the driving force for the regeneration. A hot heat transfer fluid **110** from a heat source can be flowed inside the plates of the regenerator similar to the cold heat transfer fluid in the conditioner. Again, the re-concentrated liquid desiccant is collected at one end of the plates and returned via the heat exchanger to the conditioner. Since there is no need for either a collection pan or bath, the desiccant flow through the regenerator can be horizontal or vertical. Air and water is preferably in counterflow to each other. They can also be a horizontal or vertical flow. A variety of configurations are possible from all flows being vertical, to a combination of horizontal and vertical flows in crossflow, to all flows being horizontal in flat plate structures.

[0025] An optional heat pump **116** can be used to provide cooling and heating of the liquid desiccant. It is also possible to connect a heat pump between the cold source **107** and the hot source **108**, which is thus pumping heat from the cooling fluids rather than the liquid desiccant. Cold sources could comprise an indirect evaporative cooler, a cooling tower, geothermal storage, cold water networks, black roof panel that cools down water during the night, and cold storage options like an ice box. Heat sources could include waste heat from power generation, solar heat, geothermal heat, heat storage, and hot water networks. Those skilled in the art will understand that a wide variety of other sources for heating and cooling are possible including, e.g., heat from refrigeration in stores to heat from compressors in industrial applications.

[0026] FIG. **2** illustrates an exemplary prior art 3-way heat exchanger comprising a set of plate structures stacked in a block as disclosed in U.S. Pat. No. 9,308,490. A liquid desiccant enters the structure through ports **304** and is directed behind a series of membranes as described in FIG. **1**. The liquid desiccant is collected and removed through ports **305**. A cooling or heating fluid is provided through ports **306** and runs counter to the air stream **301** inside the hollow plate structures, again as described in FIG. **1** and in greater detail in FIG. **3**. The cooling or heating fluids exit through ports **307**. The treated air **302** is directed to a space in a building or is exhausted as the case may be. The figure illustrates a 3-way heat exchanger in which the air and heat transfer fluid are in a primarily vertical orientation.

[0027] FIG. **3** schematically illustrates operation of an exemplary prior art membrane plate assembly or structure as disclosed in U.S. Pat. No. 9,631,848. The air stream **251** flows counter to a cooling fluid stream **254**. Membranes **252** contain a liquid desiccant **253** that is falling along the wall **255** that contains the heat transfer fluid **254**. Water vapor **256** entrained in the air stream is able to transfer through the membrane **252** and is absorbed into the liquid desiccant **253**. The heat of condensation of water **258** that is released during the absorption is conducted through the wall **255** into the heat transfer fluid **254**. Sensible heat **257** from the air stream is also conducted through the membrane **252**, liquid desiccant **253** and wall **255** into the heat transfer fluid **254**.

[0028] FIG. **4** illustrates a schematic representation of another prior art liquid desiccant air conditioner system operating in a cooling mode, as disclosed in U.S. Pat. No. 10,323,867. Similar liquid air conditioning systems are disclosed in U.S. Patent Application Publication No. 20120125020 and U.S. Pat. Nos. 9,243,810 and 9,631,848. A three-way heat and mass exchanger conditioner **503** (which is similar to the conditioner **101** of FIG. **1**) receives an air stream **501** from the outside ("OA"). Fan **502** pulls the air **501** through the conditioner **503** wherein the air is cooled and dehumidified. The resulting cool, dry air **504** ("SA") is supplied to a space for occupant comfort. The three-way conditioner **503** receives a concentrated desiccant **527** in the manner explained under FIGS. **1-3**. It is preferable to use a membrane on the three-way conditioner **503** to contain the desiccant and inhibit it from being distributed into the air stream **504**. The diluted desiccant **528**, which contains the captured water vapor is transported to a heat and mass exchanger regenerator **522**. Furthermore, chilled water **509** is provided by pump **508**, which enters the conditioner module **503** where it picks up heat from the air as well as latent heat released by the capture of water vapor in the desiccant **527**. The warmer water **506** is brought to the heat exchanger **507** on the chiller system **530**. The liquid desiccant **528** leaves the conditioner **503** and is moved through the optional heat exchanger **526** to the regenerator **522** by pump **525**. The chiller system **530** comprises a water to refrigerant evaporator heat exchanger **507**, which cools the circulating cooling fluid **506**. The liquid, cold refrigerant **517** evaporates in the heat exchanger **507** thereby absorbing the thermal energy from the cooling fluid **506**. The gaseous refrigerant **510** is now re-compressed by compressor **511**. The compressor **511** ejects hot refrigerant gas **513**, which is liquefied in the condenser heat exchanger **515**. The liquid refrigerant exiting the condenser **514** then enters expansion valve **516**, where it rapidly cools and exits at a lower pressure. The condenser heat exchanger **515** now releases heat to another cooling fluid loop **519** which brings hot heat transfer fluid **518** to the regenerator **522**. Circulating pump **520** brings the heat transfer fluid back to the condenser **515**. The three-way regenerator **522** thus receives a dilute liquid desiccant **528** and hot heat transfer fluid **518**. A fan **524** brings outside air **521** ("OA") through the regenerator **522**. The outside air picks up heat and moisture from the heat transfer fluid **518** and desiccant **528** which results in hot humid exhaust air ("EA") **523**. The compressor **511** receives electrical power **512**. The fans **502** and **524** receive electrical power **505** and **529**, respectively. Pumps **508**, **520**, and **525** have relatively low power consumption.

[0029] Various embodiments disclosed herein relate to use of liquid desiccant air-conditioning systems in greenhouses and growth cells.

[0030] Greenhouses process recirculated air to maintain warm and humid conditions (e.g., 30 C/80% RH). Liquid desiccant air conditioning systems have the ability to manage heat and humidity independently and can significantly improve greenhouse control over growth cycles with sharply increasing humidification loads as plants mature. Greenhouses tend to have a large sensible load from lights.

[0031] Liquid desiccant air conditioning systems work most efficiently at moderate concentrations of liquid desiccant (e.g., 15-25%), which fits well with the target RH (relative humidity) of about 70-80% in greenhouses, including the latent and sensible loads.

[0032] Using regenerator air to maintain warm temperatures in the greenhouse can further improve efficiency. A heat exchanger can be used to preheat/postcool regenerator air during cold periods. One heat exchanger can be used to do both using a set of dampers.

[0033] Greenhouses and growth cells operate at high temperatures and high humidities, typically 30 C and an RH of 80%. Cooling loads in greenhouses include significant solar heat, but in growth cells, the heat supply is nearly completely from artificial lights. The plants humidify and cool air. Air is refreshed to allow people to operate inside. Greenhouses have high sensible loads from sunlight and heating through low insulated walls. In the winter, the solar loads are reduced and partially replaced with artificial lighting, while heat losses through the walls require significant added heat. In-building growth cells rely 100% on artificial light, but they do have rest periods, which can be during the day while low cost night rates are used for powering the lights. Using heat pipes and plate heat exchangers for precooling and then reheating return air reduces the temperature at which dehumidification takes place and thus the liquid desiccant concentration required for effective dehumidification. This allows the regenerator to maintain the concentration at a much lower temperature. Thus, the chiller can operate at lower temperatures with lower lift.

[0034] Urban agriculture uses closed growth cells with only LED lighting to grow a variety of crops. Humidity loads differ over the growth cycle, but optimal conditions tend to be stable at about 30 C and 80% RH. The ability of liquid desiccant air conditioning systems to efficiently manage these different loads effectively while maintaining a constant supply is significantly enhanced by adding the ability to post cool or post heat conditioned air with regenerator or unconditioned air.

[0035] With a damper, a single heat exchanger can support the liquid desiccant air conditioning system during dehumidification and either sensible cooling or sensible heating.

Referring to FIG. **5**, during the hot and humid outside air conditions **601** for the regenerator, regeneration requires higher temperature at **602**. At the RH of **602**, conditioning can be done from the return air condition **603** to condition **604**, which is warm and dry. Supply air **604** is humidified **612** and heated **613** because of the typical conditions in a greenhouse/growth cell humidification results when plants desorb large amounts of water to pump nutrients from the roots to the plant and heating results from radiation in a greenhouse or lights in a growth cell.

[0036] Typically, liquid desiccant at 30% or higher requires air with an RH of less than 40% to regenerate **630**. While liquid desiccant at 20% can be regenerated at an RH of about 60% at **631**.

[0037] However, typically compressor performance benefits from dehumidifying and cooling air at the lower concentration **605**. The main driver for that is that the regenerator can fully reconcentrate the liquid desiccant at **606**. The disadvantage is that the greenhouse air is dry and cool, while plants tend to prefer dry and warm conditions for optimal growth. The heat exchanger **610**/**611** can be used to heat up the cool air from the conditioner with the hot air from the regenerator.

[0038] As a result total lift of the system is only **620** rather than **621** with the higher concentration.

[0039] FIG. **6** shows a liquid desiccant air conditioning system for a greenhouse (or growth cell) **700** that includes a heat exchanger **701**, which takes the supply air **702** from the conditioner **703** and warms the supply air **702** up with the regeneration air **704** from regenerator **705** before returning it to the space **706** in the greenhouse **700** to be air conditioned. Regenerator exhaust air is expelled from the greenhouse at **707**. Return air **708** from the space **706** is provided to the conditioner **703**, and the outside air **709** is used by the regenerator **705** to concentrate the liquid desiccant. The water (i.e., heat transfer fluid) and desiccant circuits in and between conditioner **703** and regenerator **705** are not shown. These can be as described in prior art, e.g., in FIG. **4**.

[0040] As depicted in FIG. **7**, one advantage of the liquid desiccant air conditioning systems is that they can dehumidify at low concentrations of liquid desiccant while maintaining high temperatures and controlling RH levels. By managing the flow of regenerator air through the heat exchanger with the processed conditioner air, temperature and RH can be managed in a narrow bandwidth.

[0041] In winter conditions, outside air can be cold with a High RH, the high humidity loads will need to be removed, while significant heat needs to be added.

[0042] There are two possible approaches. One is to use highly concentrated liquid desiccant that dehumidifies and warms the air. This requires significant additional heat to regenerate the liquid desiccant with the cold outside air. Part of that can be recovered through an extra heat exchanger for the regenerator.

[0043] Alternatively, the heat exchanger can be used to precool and then reheat the process air. Using a heat pump, the air can be further cooled to reach the target DP at 80% RH and a cooler temperature. This allows the regenerator to regenerate with just the condenser heat of the heatpump. However, additional waste heat or gas heat is then needed to post heat the process air. Determining which is the lower cost solution depends not only on starting conditions and loads in the greenhouse/growth cell and the outside air conditions esp. HR, but also on the availability and quality of waste heat, the cost of components, and the effectiveness of the liquid desiccant heat exchanger.

[0044] Detailed thermodynamic models can be used to evaluate alternative strategies and optimize control conditions.

[0045] FIGS. **8**A and **8**B are simplified block diagrams illustrating liquid desiccant air-conditioning systems with energy recovery for improved efficiency. In FIG. **8**A, the air stream **720** in the regenerator **705** is preheated and post cooled. Outside air flows into a heat exchanger **701**, which preheats the air stream **720** with the air stream exiting the regenerator **705** before it is exhausted. In FIG. **8**B, the air stream **722** in the conditioner **703** is precooled and post heated during the winter season. The air stream **722** flows through a heat exchanger **701**, which precools the air stream with the airstream exiting the conditioner **703**. The water (i.e., heat transfer fluid) and desiccant circuits in and between conditioner **703** and regenerator **705** are not shown. These can be as described in prior art, e.g., in FIG. **4**.

[0046] FIG. **9** illustrates a liquid desiccant air conditioning system in accordance with one or more embodiments used in a greenhouse (or growth cell) **801**. The greenhouse **801** has a conditioner **802** that take air from a space **803** in the greenhouse **801** and returns it to the greenhouse space after dehumidifying it to a DP of 45-60 F. The optimal humidity level is crop dependent, with some crops preferring higher absolute humidity levels and others requiring dryer conditions. For example, tomatoes grow best at RH levels as high as 70% and temperatures above 75 F. For other crops, the RH level should not exceed 50-60% for optimal quality. RH levels are a combination of DB temperature and absolute humidity levels. Optimal temperatures even differ by time of day, with temperature during dark periods being lower than when light is present to allow the plant to grow.

[0047] Maintaining the concentration of the liquid desiccant **804** used in the conditioner **802** is needed to maintain the RH of the air stream **830** coming out of the conditioner **802**. The liquid desiccant **804** is diluted in the conditioner **802** as humidity as absorbed in the liquid desiccant **804**. The regenerator **805** is used to reconcentrate the liquid desiccant **804** before returning it to the conditioner **802**. Waste heat **806** is used to heat up the air flowing through the regenerator **805** to a temperature of 40 to 60 C (110-150 F). The waste heat **806** can come from various sources such as, e.g., solar power or a power generator **807**, which results in CO2 production **809**. Cooling the generator **807** increases power production **808**.

[0048] The air stream **831** flowing through regenerator **805** is enclosed in a space **810** and circulated by fan **811** to an air-to-air heat exchanger **812** that uses greenhouse air to cool the air to a DP equal to the DB condition in the greenhouse **801**. This produces water **820**, which can either be used to water soil in the greenhouse **801** or to drive a cooling tower **821** that provide cooling water **822** to the conditioner **802**. A small chiller **823** can be used to accurately control cooling water conditions and thus DP depending on plant conditions and the quality and the amount of waste heat availability at any point during the day or year.

[0049] As noted above, the air-to-air heat exchanger **812** that uses greenhouse air to cool the air in the regenerator space **810**. The greenhouse air can be provided to the air-to-air heat exchanger **812** in different ways. In one embodiment, the air stream **830** coming out of the conditioner **802** is flowed through the heat exchanger **812** and then returned to the greenhouse space **803**. In another embodiment, the air stream **830** coming out of the conditioner **802** flows directly to the greenhouse space **803** as indicated at **840**. Air from the greenhouse space **803** is directly provided to the heat exchanger **812** as indicated at **832**. In yet another embodiment, some of the air stream **830** coming out of the conditioner **802** is provided to the air space **803** and some of the air stream **830** coming out of the conditioner **802** is flowed through the heat exchanger **812**.

[0050] This results in a closed system that does not require extra heat from either the sun or lamps to compensate for the cooling linked to the evaporation by the plants. It also minimizes water usage for use by the plant and the cooling tower. It uses the heat needed to drive the lights through cogeneration and/or to produce the CO_2 that combined with water is used by the plant to build carbohydrate molecules. This minimizes energy and water usage by greenhouses, which has become a major concern during the growth of high intensity and highly productive enclosed in-building agriculture. One advantage of enclosed agro systems is a smaller physical foot print as production per m^2 can increase 10 to 100 fold. Use of liquid desiccant systems in accordance with various embodiments can significantly reduce the energy foot print. Keeping the greenhouse closed also reduces risk of contamination of the crop as well as environmental concerns like odor from the growing process.

[0051] Having thus described several illustrative embodiments, it is to be appreciated that various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to form a part of this disclosure, and are intended to be within the spirit and scope of this disclosure. While some examples presented herein involve specific combinations of functions or structural elements, it should be understood that those functions and elements may be combined in other ways according to the present disclosure to accomplish the same or different objectives. In particular, acts, elements, and features discussed in connection with one embodiment are not intended to be excluded from similar or other roles in other embodiments. Additionally, elements and components described herein may be further divided into additional components or joined together to form fewer components for performing the same functions. Accordingly, the foregoing description and attached drawings are by way of example only and are not intended to be limiting.

1. A liquid desiccant air-conditioning system for managing temperature and humidity conditions in a greenhouse or a growth cell, comprising:

a liquid desiccant conditioner utilizing a liquid desiccant to dehumidify a first air stream flowing therethrough, said first air stream entering the liquid desiccant conditioner from a space within the greenhouse or growth cell and exiting the liquid desiccant conditioner as supply air to the greenhouse or growth cell;

a liquid desiccant regenerator receiving the liquid desiccant used in the liquid desiccant conditioner, and humidifying a second air stream flowing therethrough to concentrate the liquid desiccant and then returning the liquid desiccant to the conditioner; and

an air-to-air heat exchanger thermally coupled to the air stream exiting the liquid desiccant conditioner or an air stream drawn from the space within the greenhouse or growth cell and the second air stream exiting the liquid desiccant regenerator for cooling the second air stream and producing water therefrom;

wherein the second air stream circulates between the liquid desiccant regenerator and the air-to-air heat exchanger within a closed enclosure.

2. The system of claim **1**, further comprising a heat source for heating the liquid desiccant regenerator and a cold source for cooling the liquid desiccant conditioner.

3. The system of claim **2**, wherein the heat source comprises a power generator.

4. The system of claim **3**, wherein the power generator supplies carbon dioxide to the greenhouse or growth cell.

5. The system of claim **1**, further comprising a chiller system for heating the liquid desiccant regenerator and cooling the liquid desiccant conditioner.

6. The system of claim **1**, wherein the water is used to water soil in the greenhouse or growth cell.

7. The system of claim **1**, wherein the water drives a cooling tower that provides cooling water to the liquid desiccant conditioner.

8. The system of claim **7**, further comprising a chiller for controlling temperature of the cooling water provided to the liquid desiccant conditioner.

9. A method of managing temperature and humidity conditions in a greenhouse or a growth cell using a liquid desiccant air conditioning system, comprising:

dehumidifying a first air stream flowing through a liquid desiccant conditioner utilizing a liquid desiccant, said first air stream being drawn into the liquid desiccant conditioner from a space within the greenhouse or growth cell and exiting the liquid desiccant conditioner as supply air to the greenhouse or growth cell;

receiving, in a liquid desiccant regenerator, the liquid desiccant used in the liquid desiccant conditioner, and humidifying a second air stream flowing through the liquid desiccant regenerator to concentrate the liquid desiccant and then returning the liquid desiccant to the conditioner; and

cooling the second air stream humidified by the liquid desiccant regenerator and producing water therefrom using an air-to-air heat exchanger thermally coupled to the air stream exiting the liquid desiccant conditioner or an air stream drawn from the space within the greenhouse or growth cell; and

circulating the second air stream between the liquid desiccant regenerator and the air-to-air heat exchanger within a closed enclosure.

10. The method of claim **9**, further comprising heating the liquid desiccant regenerator and cooling the liquid desiccant conditioner.

11. The method of claim **10**, wherein heating is performed utilizing heat from a power generator.

12. The method of claim **11**, wherein the power generator supplies carbon dioxide to the greenhouse or growth cell.

13. The method of claim **9**, further comprising using the water to water soil in the greenhouse or growth cell.

14. The method of claim **9**, further comprising providing the water to a cooling tower that provides cooling water to the liquid desiccant conditioner.

15. The method of claim **14**, further comprising controlling temperature of the cooling water provided to the liquid desiccant conditioner using a chiller.

16. A method of managing temperature and humidity conditions in a greenhouse or a growth cell using a liquid desiccant air conditioning system, comprising:
(a) dehumidifying, using a liquid desiccant, a first air stream drawn from a space within the greenhouse or growth cell to be provided as supply air to the greenhouse or growth cell;
(b) concentrating the liquid desiccant used in (a) by humidifying a second air stream;
(c) cooling the second air stream to produce water therefrom using the first air stream or an air stream received from the space within the greenhouse or growth cell; and
(d) circulating the second air stream in a closed enclosure for repeating (b) and (c).

17. A liquid desiccant air-conditioning system for managing temperature and humidity conditions in a greenhouse or a growth cell, comprising:
a liquid desiccant conditioner utilizing a liquid desiccant to dehumidify a first air stream flowing therethrough to be provided as supply air to the greenhouse or growth cell, said first air stream entering the liquid desiccant conditioner from a space within the greenhouse or growth cell;
a liquid desiccant regenerator receiving the liquid desiccant used in the liquid desiccant conditioner, and utilizing a second air stream flowing therethrough to concentrate the liquid desiccant, and then returning the liquid desiccant to the conditioner, wherein the liquid desiccant regenerator heats and humidifies the second air stream, said second air stream entering the liquid desiccant regenerator from outside the greenhouse or growth cell and exiting the liquid desiccant regenerator to be exhausted outside the greenhouse or growth cell;
an air-to-air heat exchanger thermally coupled to the first air stream exiting the liquid desiccant conditioner and the second air stream exiting the liquid desiccant regenerator for heating the first air stream before the first air stream is provided as the supply air to the greenhouse or growth cell and the second air stream is exhausted from the greenhouse or growth cell.

18. The system of claim 17, further comprising a heat source for heating the liquid desiccant regenerator and a cold source for cooling the liquid desiccant conditioner.

19. The system of claim 18, wherein the heat source comprises a power generator.

20. The system of claim 19, wherein the power generator supplies carbon dioxide to the greenhouse or growth cell.

21. The system of claim 17, further comprising a chiller system for heating the liquid desiccant regenerator and cooling the liquid desiccant conditioner.

22. A liquid desiccant air-conditioning system for managing temperature and humidity conditions in a greenhouse or a growth cell, comprising:
a liquid desiccant conditioner utilizing a liquid desiccant to dehumidify a first air stream flowing therethrough to be provided as supply air to the greenhouse or growth cell, said first air stream entering the liquid desiccant conditioner from a space within the greenhouse or growth cell;
a liquid desiccant regenerator receiving the liquid desiccant used in the liquid desiccant conditioner, and utilizing a second air stream flowing therethrough to concentrate the liquid desiccant, and then returning the liquid desiccant to the conditioner, wherein the liquid desiccant regenerator heats and humidifies the second air stream, said second air stream provided to the liquid desiccant regenerator from outside the greenhouse or growth cell and exiting the liquid desiccant regenerator to be exhausted outside the greenhouse or growth cell;
an air-to-air heat exchanger thermally coupled to the second air stream prior to entering the liquid desiccant regenerator and the second air stream exiting the liquid desiccant regenerator for preheating the second air stream entering the liquid desiccant regenerator and post cooling the second air stream exiting the liquid desiccant regenerator.

23. The system of claim 22, further comprising a heat source for heating the liquid desiccant regenerator and a cold source for cooling the liquid desiccant conditioner.

24. The system of claim 23, wherein the heat source comprises a power generator.

25. The system of claim 24, wherein the power generator supplies carbon dioxide to the greenhouse or growth cell.

26. The system of claim 22, further comprising a chiller system for heating the liquid desiccant regenerator and cooling the liquid desiccant conditioner.

27. A liquid desiccant air-conditioning system for managing temperature and humidity conditions in a greenhouse or a growth cell, comprising:
a liquid desiccant conditioner utilizing a liquid desiccant to dehumidify a first air stream flowing therethrough to be provided as supply air to the greenhouse or growth cell, said first air stream entering the liquid desiccant conditioner from a space within the greenhouse or growth cell;
a liquid desiccant regenerator receiving the liquid desiccant used in the liquid desiccant conditioner, and utilizing a second air stream flowing therethrough to concentrate the liquid desiccant, and then returning the liquid desiccant to the conditioner, wherein the liquid desiccant regenerator heats and humidifies the second air stream, said second air stream provided to the liquid desiccant regenerator from outside the greenhouse or growth cell and exiting the liquid desiccant regenerator to be exhausted outside the greenhouse or growth cell;
an air-to-air heat exchanger thermally coupled to the first air stream prior to entering the liquid desiccant conditioner and the first air stream exiting the liquid desiccant conditioner for precooling the first air stream entering the liquid desiccant conditioner and post heating the first air stream exiting the liquid desiccant conditioner.

28. The system of claim 27, further comprising a heat source for heating the liquid desiccant regenerator and a cold source for cooling the liquid desiccant conditioner.

29. The system of claim 28, wherein the heat source comprises a power generator.

30. The system of claim 29, wherein the power generator supplies carbon dioxide to the greenhouse or growth cell.

31. The system of claim 27, further comprising a chiller system for heating the liquid desiccant regenerator and cooling the liquid desiccant conditioner.

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