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(54) **LIQUID DESICCANT AIR-CONDITIONING SYSTEMS USING ANTIFREEZE-FREE HEAT TRANSFER FLUIDS**

(71) Applicant: **7AC Technologies, Inc.**, Beverly, MA (US)

(72) Inventors: **Scott N. Rowe**, Dover, NH (US); **Mark A. Allen**, Essex, MA (US); **Peter Luttik**, Beverly, MA (US)

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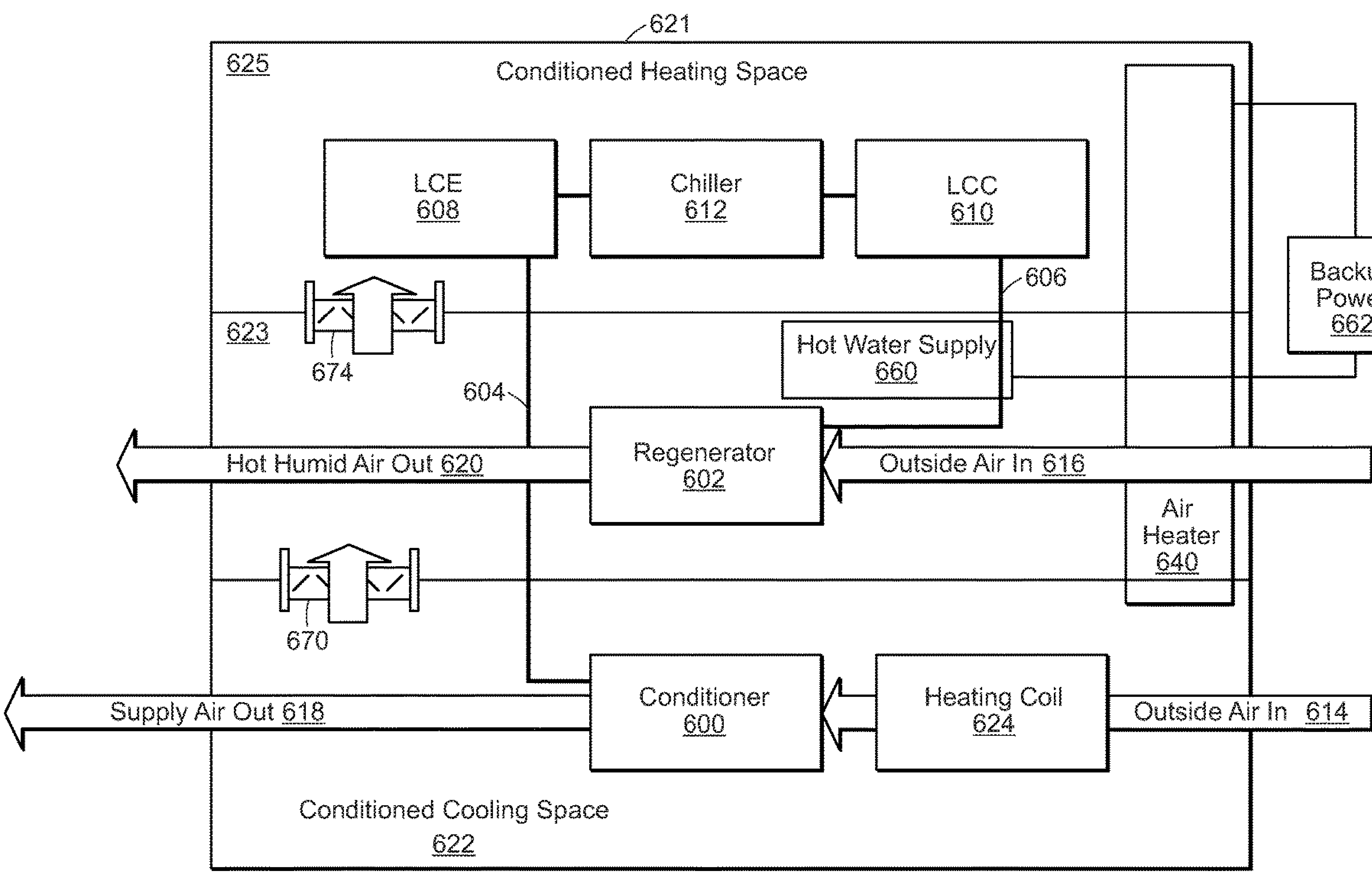
CPC ***F24F 3/1417*** (2013.01); *F24F 2221/52* (2013.01); ***F24F 3/06*** (2013.01)

(57) **ABSTRACT**

This application relates generally to liquid desiccant air conditioning (LDAC) systems and, more specifically, to liquid desiccant air-conditioning systems configured to use antifreeze-free heat transfer fluids.



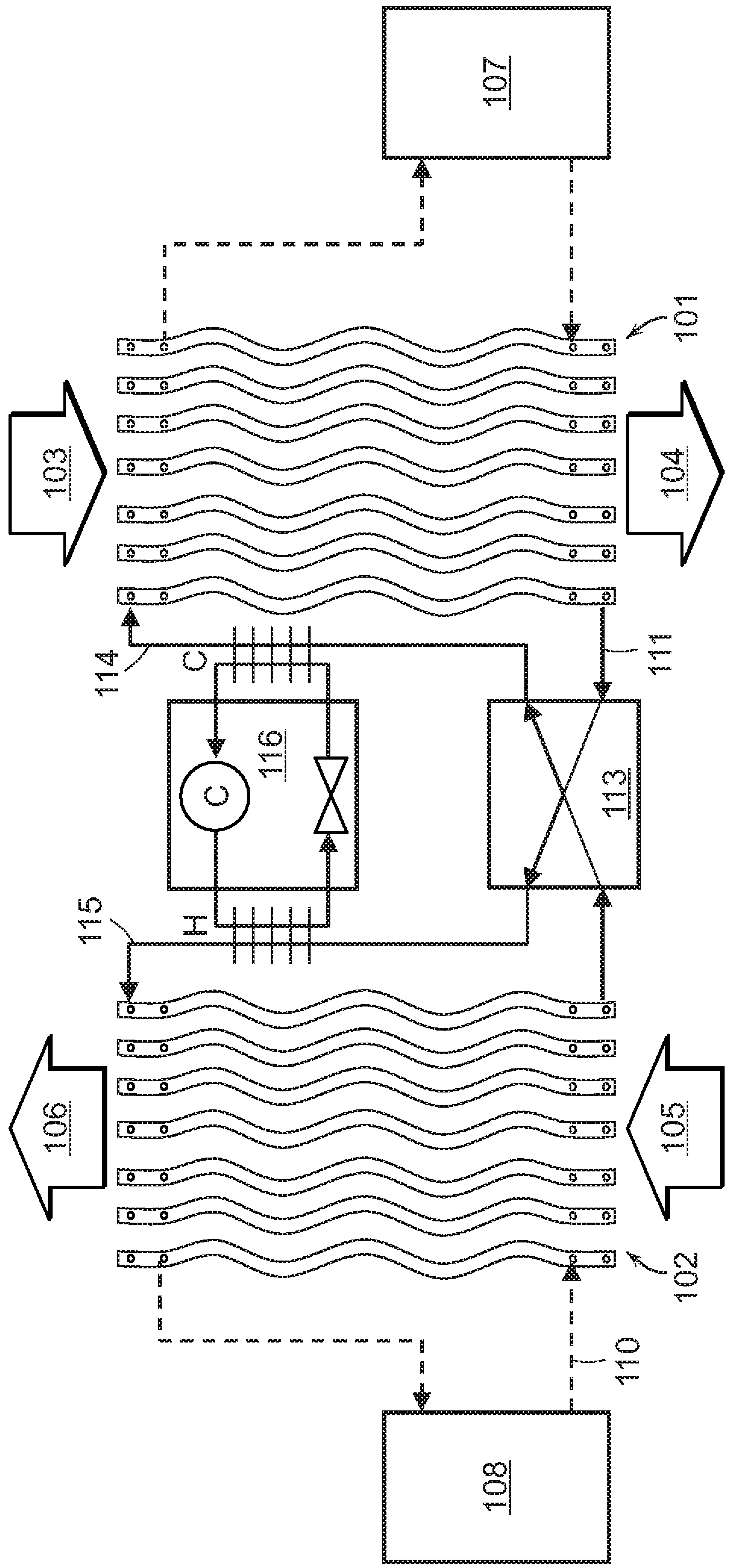


FIG. 1
Prior Art

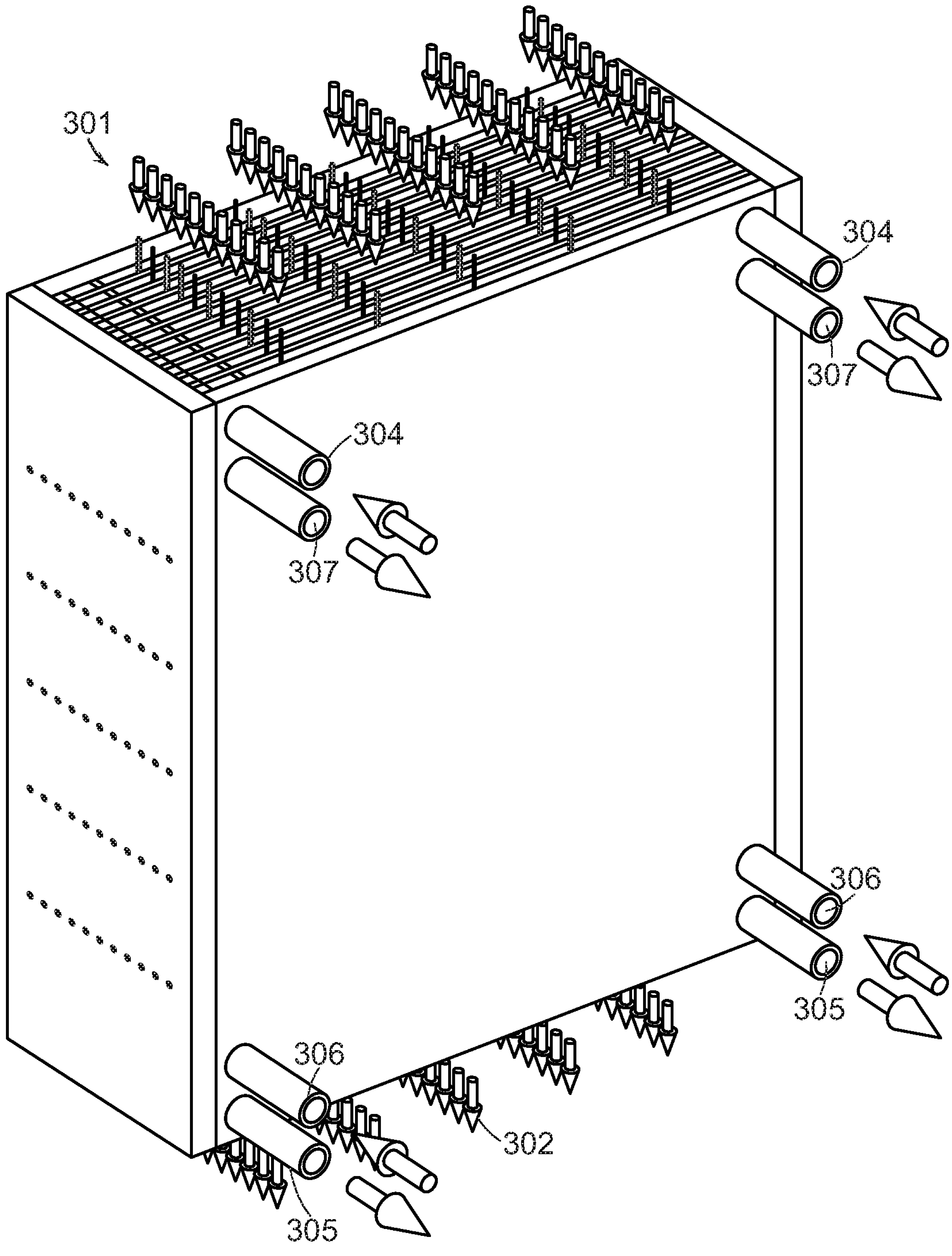


FIG. 2
Prior Art

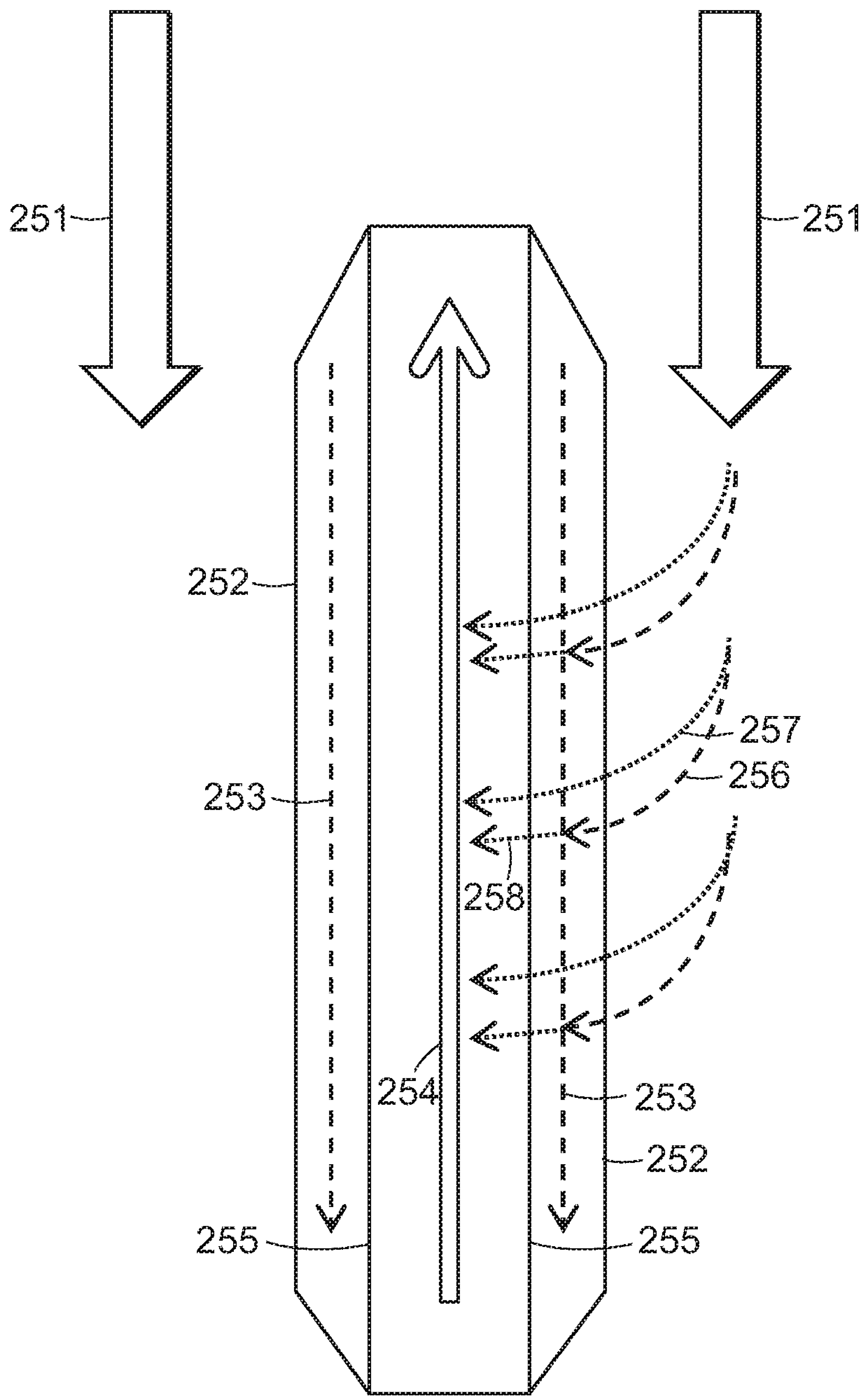
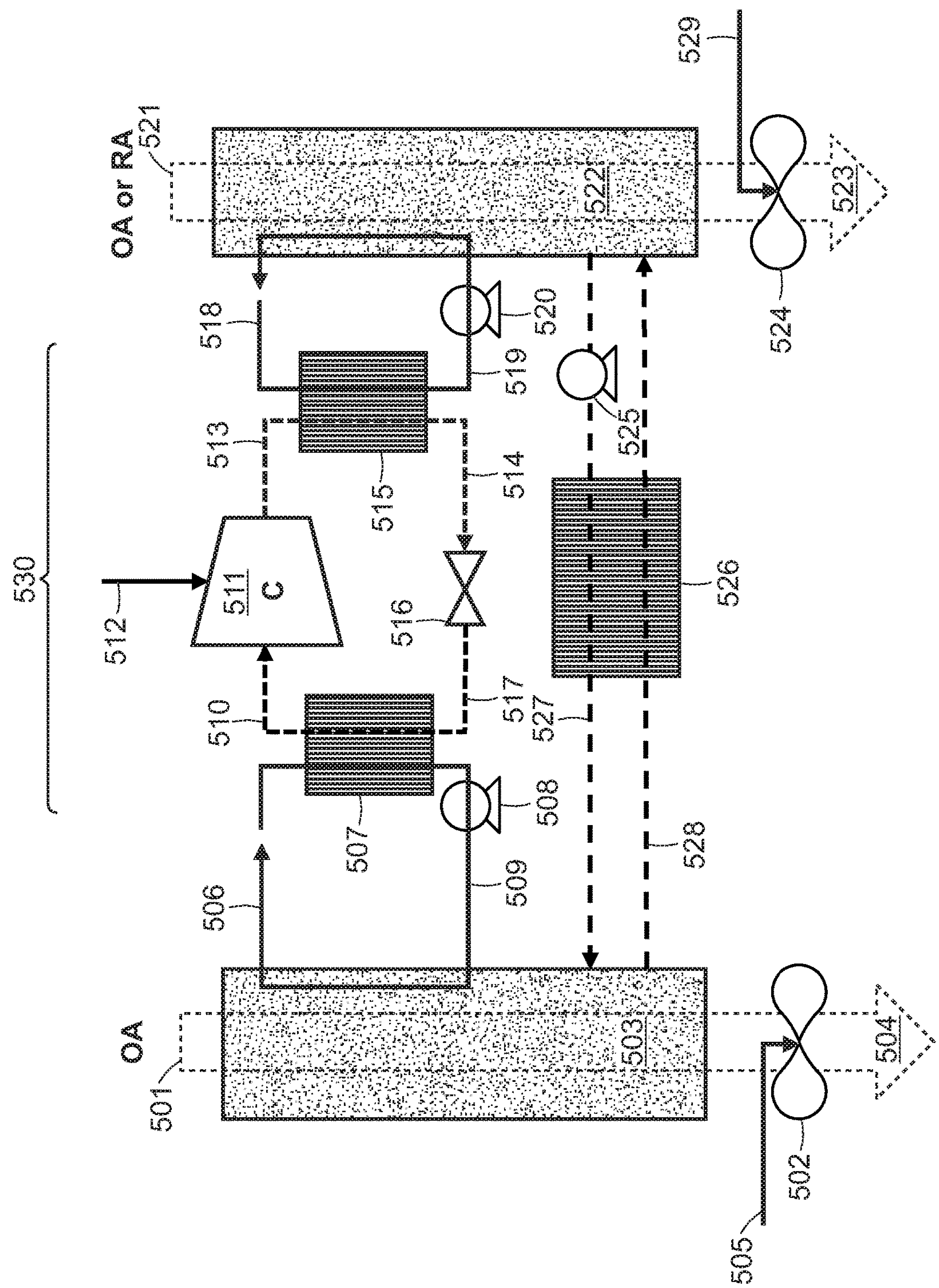


FIG. 3
Prior Art



Cooling Mode
FIG. 4
Prior Art

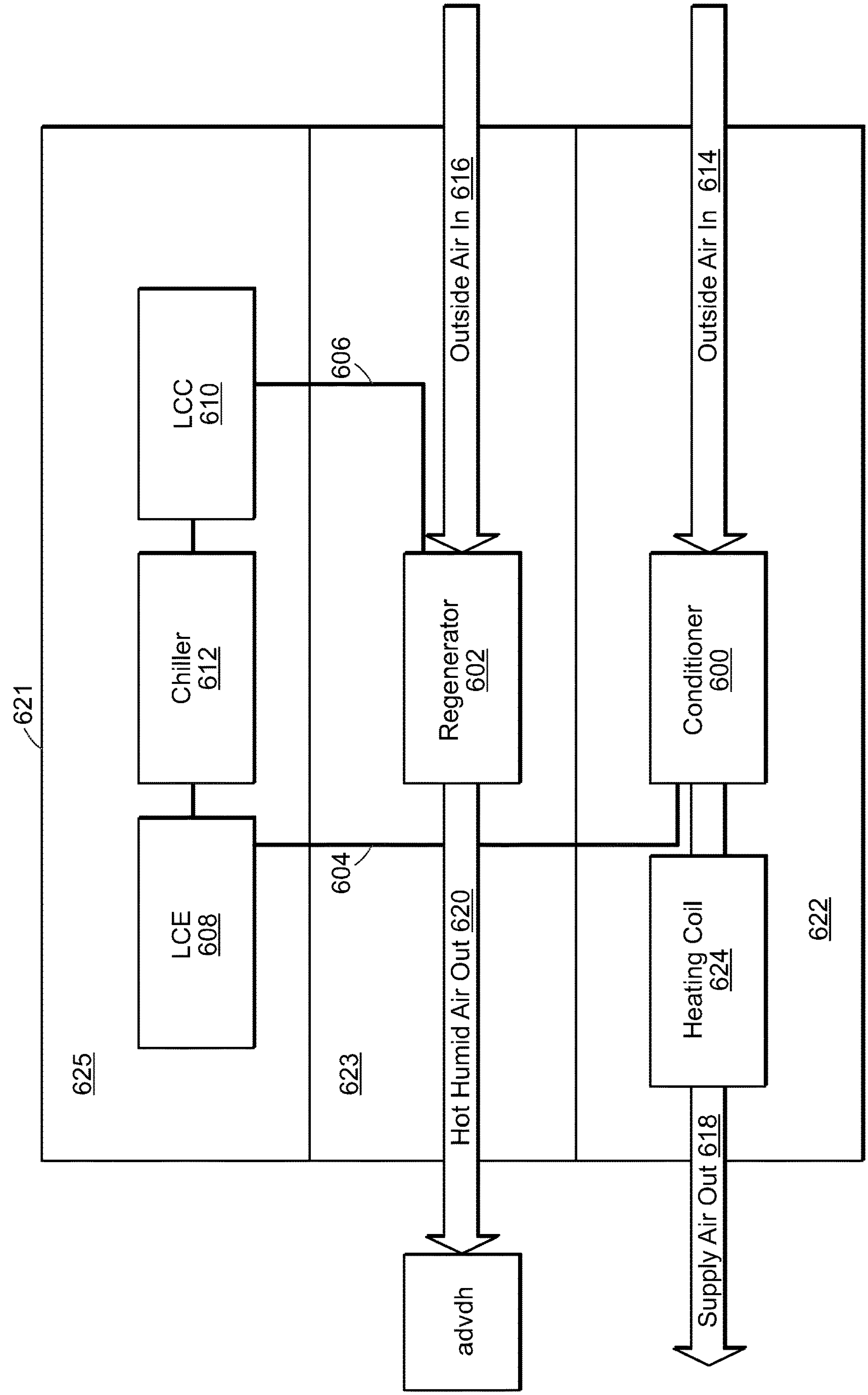

Outside Air In 616
Outside Air In 614
621
LCC
610
606
Chiller
612
Regenerator
602
Conditioner
600
LCE
608
604
Heating Coil
624
622
625
623
Hot Humid Air Out 620
Supply Air Out 618
advdh

FIG. 5

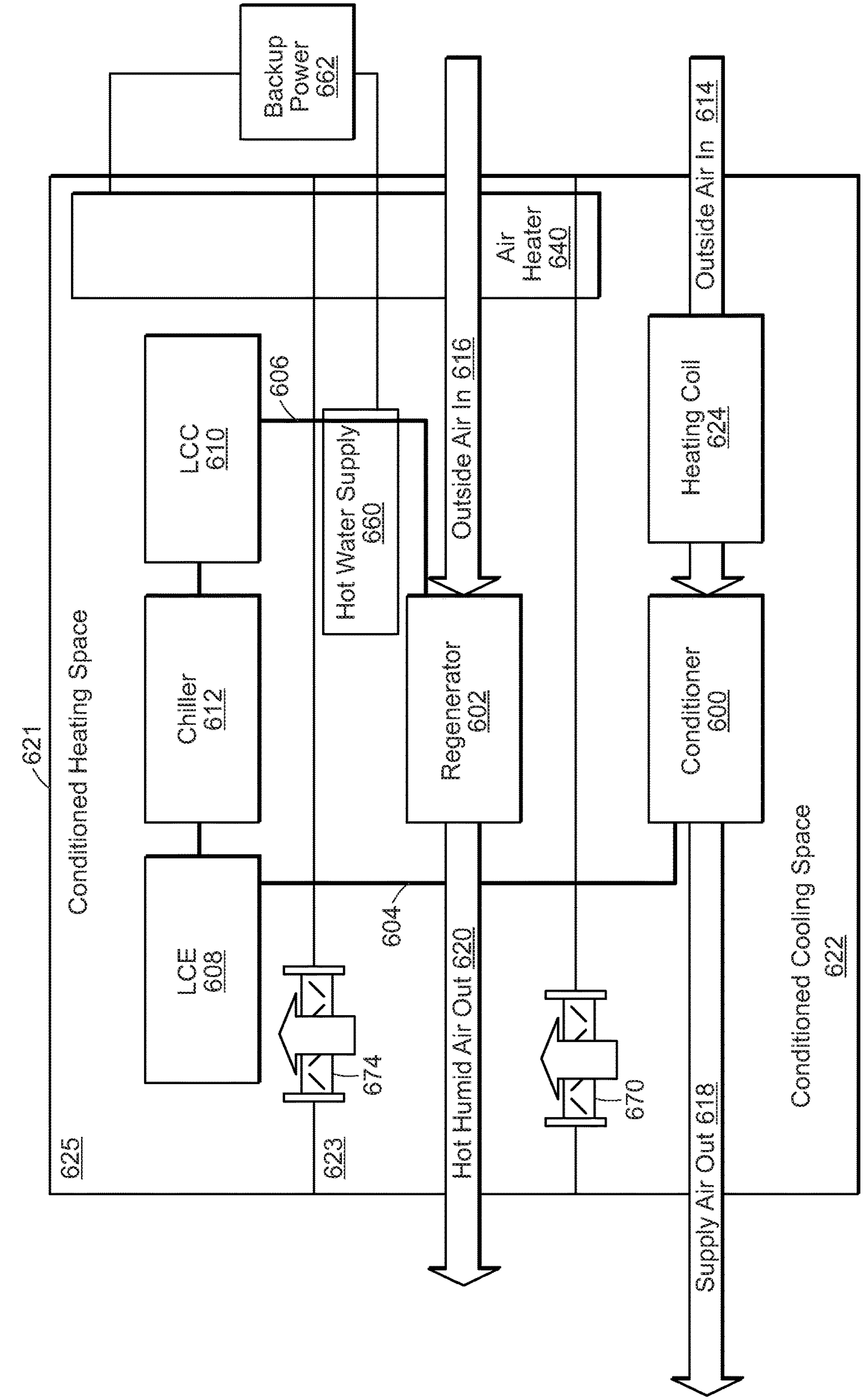

Backup Power 662
Air Heater 640
Outside Air In 614
Outside Air In 616
LCC 610
606
Hot Water Supply 660
Heating Coil 624
Chiller 612
Regenerator 602
Conditioner 600
621
Conditioned Heating Space
LCE 608
604
Hot Humid Air Out 620
674
670
Supply Air Out 618
Conditioned Cooling Space 622
625
623

FIG. 6

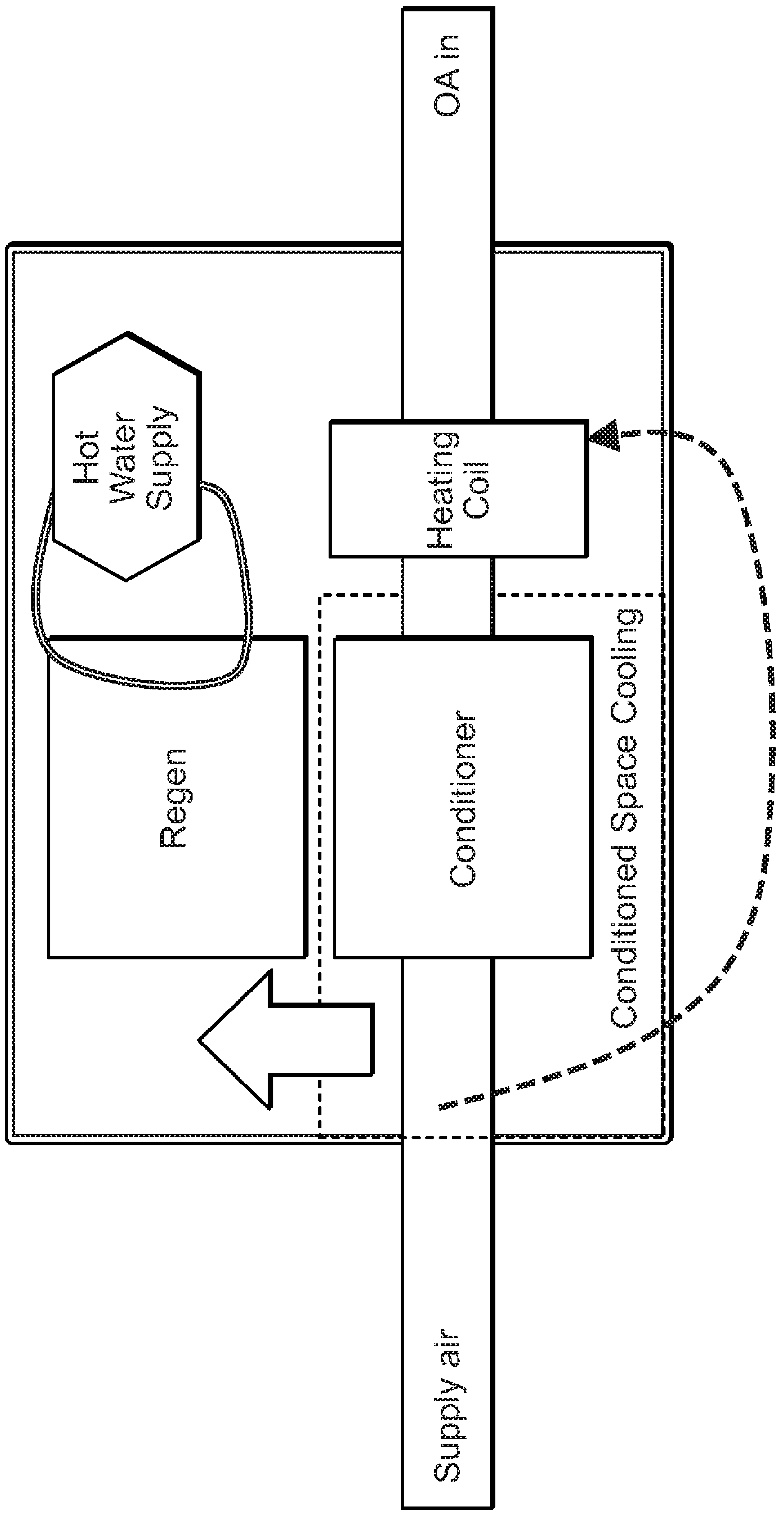

OA in
Hot Water Supply
Heating Coil
Regen
Conditioner
Conditioned Space Cooling
Supply air

FIG. 7

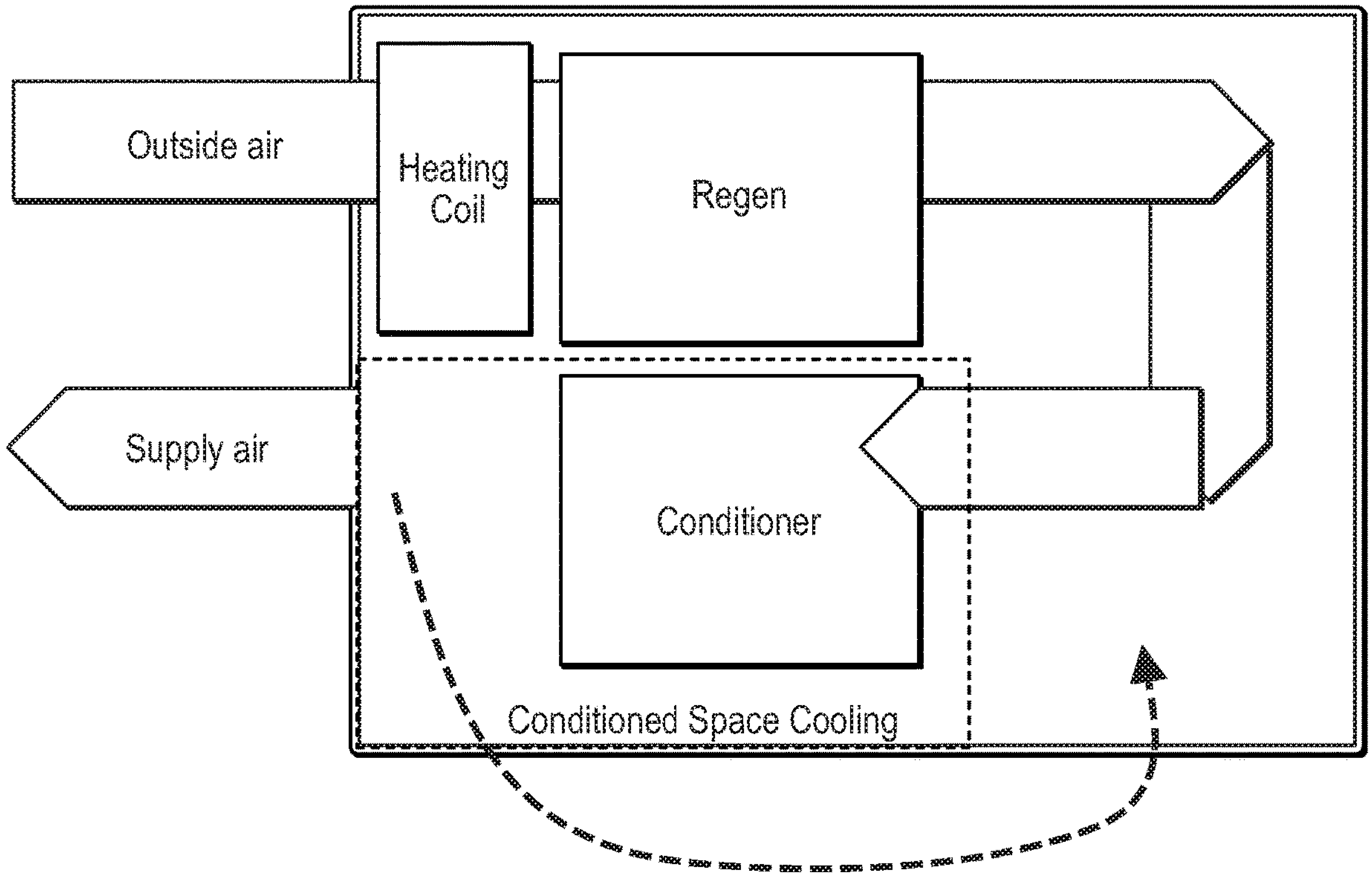

Outside air
Heating Coil
Regen
Supply air
Conditioner
Conditioned Space Cooling

FIG. 8

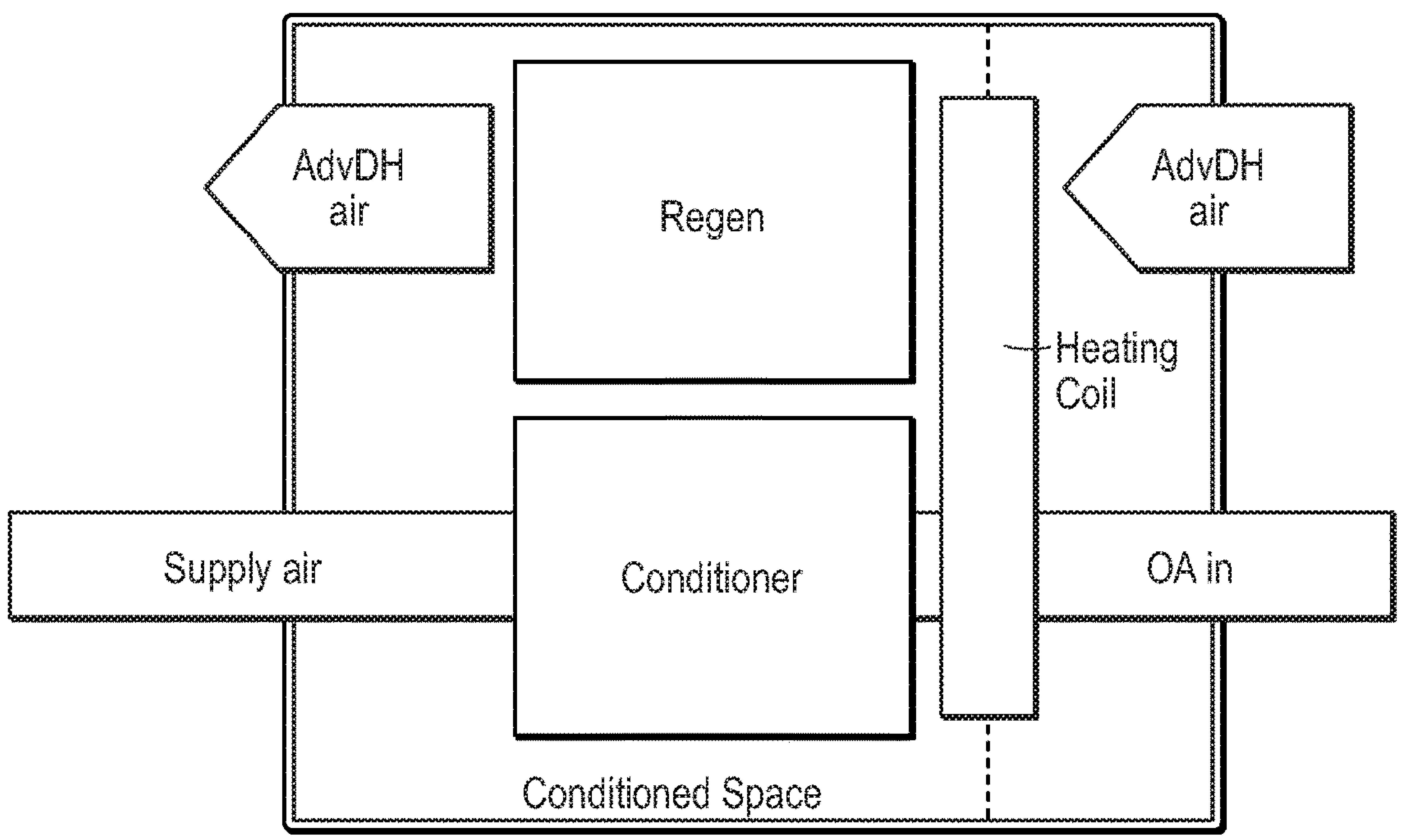

AdvDH air
Regen
AdvDH air
Heating Coil
Supply air
Conditioner
OA in
Conditioned Space

FIG. 9

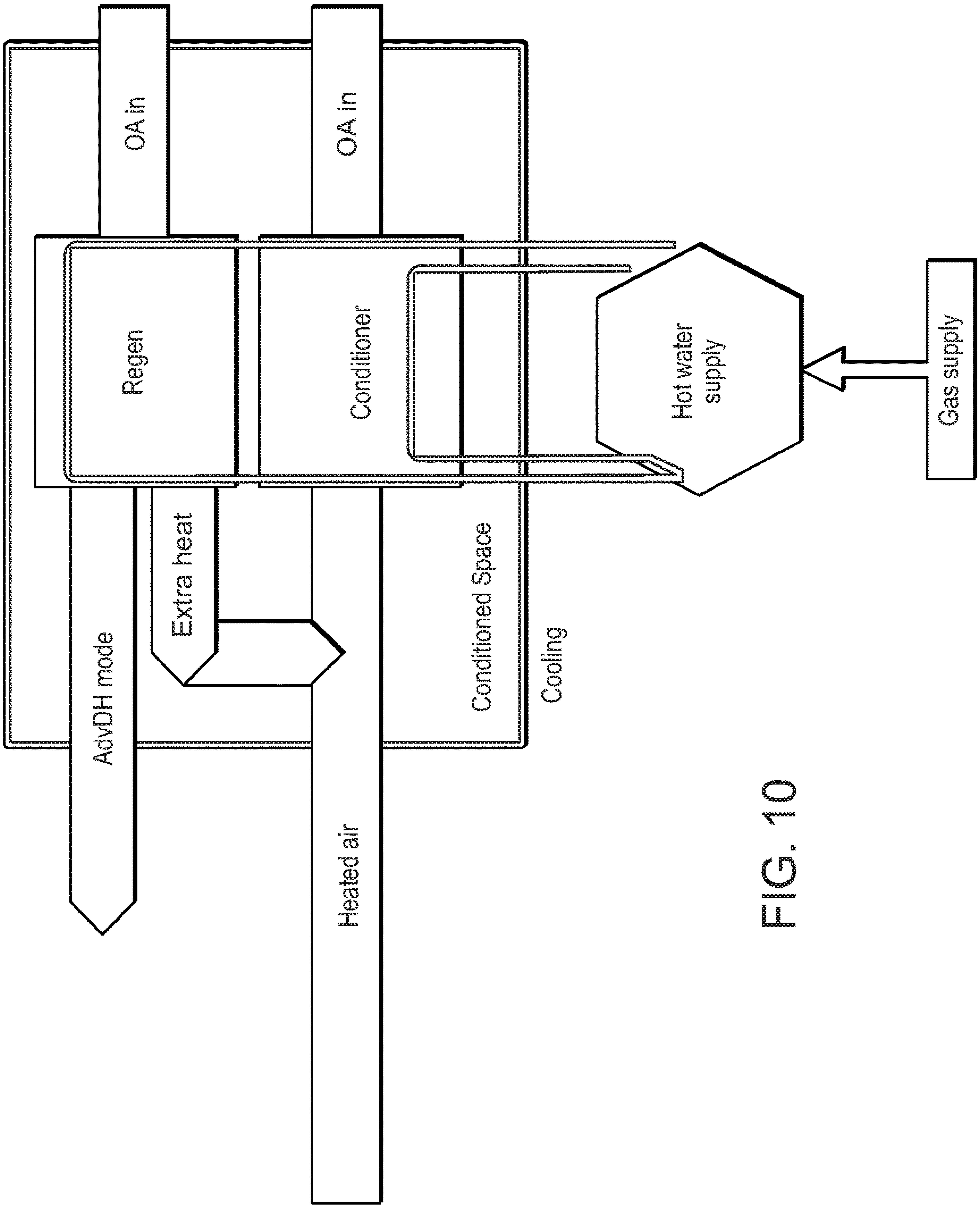

OA in
OA in
Regen
Conditioner
Hot water supply
Gas supply
Extra heat
AdvDH mode
Conditioned Space
Cooling
Heated air

FIG. 10

LIQUID DESICCANT AIR-CONDITIONING SYSTEMS USING ANTIFREEZE-FREE HEAT TRANSFER FLUIDS

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims priority from U.S. Provisional Patent Application No. 62/774,448 filed on Dec. 3, 2018 entitled LIQUID DESICCANT AIR-CONDITIONING SYSTEMS USING ANTIFREEZE-FREE HEAT TRANSFER FLUIDS, 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 using antifreeze-free heat transfer fluids.

BRIEF SUMMARY

[0003] A liquid desiccant air-conditioning system is disclosed for treating an air stream entering a building space. The system includes a compressor-based cooling system through which a refrigerant flows. A liquid desiccant conditioner utilizes a liquid desiccant and a heat transfer fluid to cool, heat, humidify, or dehumidify a first air stream flowing therethrough depending on a mode of operation of the liquid desiccant air conditioning system. The heat transfer fluid used in the conditioner contains substantially no antifreeze additive. A liquid desiccant regenerator receives the liquid desiccant used in the liquid desiccant conditioner, and utilizes a heat transfer fluid and a second air stream flowing therethrough to concentrate or dilute the liquid desiccant depending on the mode of operation of the liquid desiccant air conditioning system, and then return the liquid desiccant to the conditioner. The heat transfer fluid and the liquid desiccant cool, heat, humidify, or dehumidify the second air stream depending on the mode of operation of the liquid desiccant air conditioning system. The heat transfer fluid used in the regenerator contains substantially no antifreeze additive. The system also includes a first heat exchanger thermally coupled to the heat transfer fluid used in the liquid desiccant conditioner and to the refrigerant flowing through the compressor-based cooling system for exchanging heat between the refrigerant and the heat transfer fluid. A second heat exchanger is thermally coupled to the heat transfer fluid used in the liquid desiccant regenerator and to the refrigerant flowing through another portion of the compressor-based cooling system for exchanging heat between the refrigerant and the heat transfer fluid. A first enclosure contains the liquid desiccant conditioner. The first enclosure includes an inlet for receiving the first air stream and an outlet for outputting a supply air stream to the building space comprising the first air stream after treatment by the conditioner. A second enclosure contains the liquid desiccant regenerator. The second enclosure includes an inlet for receiving the second air stream and an outlet for exhausting the second air stream after treatment by the regenerator. A third enclosure contains the compressor-based cooling system, the first heat exchanger, and the second heat exchanger. The system includes one or more dampers between the first enclosure, the second enclosure, and the third enclosure selectively permitting flow of the supply air stream from the first enclosure to the second enclosure and the third enclosure during operation of the liquid desiccant air-conditioning system in a heating operation mode to prevent freezing of the heat transfer fluid. The system also includes a heating system positioned in the first enclosure to heat the first air stream prior to the air stream entering the conditioner.

[0004] A method is disclosed for operating a liquid desiccant air-conditioning system for treating an air stream entering a building space. The liquid desiccant air conditioning system includes a compressor-based cooling system through which a refrigerant flows. A liquid desiccant conditioner utilizes a liquid desiccant and a heat transfer fluid to cool, heat, humidify, or dehumidify a first air stream flowing therethrough depending on the mode of operation of the liquid desiccant air conditioning system. The heat transfer fluid used in the conditioner contains substantially no antifreeze additive. The system also includes a liquid desiccant regenerator receiving the liquid desiccant used in the liquid desiccant conditioner, and utilizing a heat transfer fluid and a second air stream flowing therethrough to concentrate or dilute the liquid desiccant depending on the mode of operation of the liquid desiccant air conditioning system, and then returning the liquid desiccant to the conditioner. The heat transfer fluid and the liquid desiccant cool, heat, humidify, or dehumidify the second air stream depending on the mode of operation of the liquid desiccant air conditioning system, wherein the heat transfer fluid used in the regenerator contains substantially no antifreeze additive. The system includes a first heat exchanger thermally coupled to the heat transfer fluid used in the liquid desiccant conditioner and to the refrigerant flowing through the compressor-based cooling system for exchanging heat between the refrigerant and the heat transfer fluid. A second heat exchanger is thermally coupled to the heat transfer fluid used in the liquid desiccant regenerator and to the refrigerant flowing through another portion of the compressor-based cooling system for exchanging heat between the refrigerant and the heat transfer fluid. The system includes a first enclosure containing the liquid desiccant conditioner, the first enclosure including an inlet for receiving the first air stream and an outlet for outputting a supply air stream to the building space comprising the first air stream after treatment by the conditioner. The system includes a second enclosure containing the liquid desiccant regenerator. The second enclosure includes an inlet for receiving the second air stream and an outlet for exhausting the second air stream after treatment by the regenerator. A third enclosure contains the compressor-based cooling system, the first heat exchanger, and the second heat exchanger. The method comprises heating the first air stream prior to the air stream entering the conditioner and selectively permitting flow of the supply air stream from the first enclosure to the second enclosure and the third enclosure during operation of the liquid desiccant air-conditioning system in a heating operation mode to prevent freezing of the heat transfer fluid.

BRIEF DESCRIPTION OF THE FIGURES

[0005] FIG. **1** is a simplified diagram illustrating a prior art liquid desiccant air-conditioning system.

[0006] FIG. **2** illustrates a prior art three-way heat exchanger block of a liquid desiccant air conditioning system.

[0007] FIG. **3** is a simplified diagram illustrating a prior art three-way heat exchanger panel assembly in the heat exchanger block.

[0008] FIG. **4** is a simplified diagram illustrating another prior art liquid desiccant air conditioning system.

[0009] FIG. **5** is a simplified diagram showing the layout of a liquid desiccant air conditioning system with the conditioner, regenerator, and chiller sections.

[0010] FIG. **6** is a simplified block diagram illustrating an antifreeze-free liquid desiccant air-conditioning system in accordance with one or more embodiments.

[0011] FIGS. **7-10** are simplified block diagrams illustrating alternate layouts of liquid desiccant air-conditioning systems in accordance with one or more embodiments.

DETAILED DESCRIPTION

[0012] 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. A conditioner **101** comprises a set of three-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.

[0013] 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.

[0014] 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.

[0015] FIG. **2** illustrates an exemplary prior art three-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 three-way heat exchanger in which the air and heat transfer fluid are in a primarily vertical orientation, though other orientations (e.g., a substantially horizontal orientation) are also possible.

[0016] 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**.

[0017] 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. patent Ser. 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.

[0018] The liquid desiccant air conditioning systems disclosed herein can operate in various modes including cooling, heating, cooling and dehumidification, cooling and humidification, heating and dehumidification, and heating and humidification modes.

[0019] Many chillers and other compressor-based cooling systems have a separate heating subsystem using gas, steam, or other heat sources. These heating systems are used when outside air temperatures require the air to be heated, and also when latent and sensible loads require additional heating, e.g., in a greenhouse with many plants, a freezer section of a department store, and similar spaces with low Sensible Heat Ratio (SHR) cooling loads. Such heating systems are only used for reheat in ASHRAE Zone 1 (Tropical conditions). In ASHRAE Zone 2, they are used for both reheat and limited heating in winter time. Heat loads are small and may be provided by electric power. Design conditions only require a low concentration of Glycol to fully protect the unit, typically about 10%. For colder zones (ASHRAE Zones 3, 4, 5 USA), heating is often done with oil or gas and can be the main energy load of the unit. Lower minimum design temperatures require higher concentrations of Glycol (30-50%), but these cannot be accommodated without major changes in the sizing of heat exchangers and pumps. The disclosed design configurations for protecting the unit without the use of Glycol are especially important for the colder zones (ASHRAE Zones 2+ USA).

[0020] Both the electric and the oil/gas heating systems can be used for reheating the air directly or alternatively the heat transfer fluid to the regenerator during low SHR cooling and dehumidification in the summer. They can be either the main source of heating in winter time or they can augment the chiller when it is operating in a heatpump mode.

[0021] The heat transfer fluid in liquid desiccant air-conditioning systems described above can be a refrigerant in some configurations, and also water or antifreeze solutions such as a water-based solution containing a Propylene or Polyethylene Glycol. Use of Glycol is particularly important in heating applications where the probability of below freezing temperatures affecting the heat transfer fluid is high. Mini-split systems like those described in U.S. Patent Application Publication No. 20140260399 and U.S. Pat. No. 9,470,426 are a special case. In these systems, the conditioner is inside the building, but the regeneration unit and chiller/compressor components are kept outside the building, so that only these components require protection of the heat transfer fluid from freezing.

[0022] Traditional chillers use Glycol for antifreeze even when the compressor is not used in a heatpump mode. When the chiller components are exposed to outside air, they risk freezing without the Glycol. However, the use of Glycol and other antifreeze additives reduces system performance or requires an increase in the size of key components because of the lower heat capacity compared to pure water.

[0023] Various embodiments disclosed herein relate to liquid desiccant air-conditioning systems using antifreeze-free heat transfer fluids, which comprise heat transfer fluids like water with no antifreeze additive or only minimal amounts of antifreeze additives, e.g., the heat transfer fluid is no more than 10% antifreeze additive. These systems provide freeze protection through system design rather than reliance on Glycol or other antifreeze additives.

[0024] A large part of the United States, e.g., areas south of Virginia, has a very limited number of freezing hours, but still a significant number of heating hours at temperatures >32° F. Systems in accordance with various embodiments are configured to include all water (i.e., heat transfer fluid) systems in fluid communication with the conditioned space during a heating operation mode. Since building owners do not allow conditioned space is to freeze, this prevents freezing without using Glycol, while maintaining high cooling and heating performance.

[0025] Increasing the size of the refrigerant-to-water heat exchangers (liquid cooled evaporator (LCE) coils and liquid cooled condenser (LCC) coils) and the air cooled water coils to handle increased heat transfer flows can maintain heat transfer capacity of the heat transfer fluid, but it involves significant additional cost and weight increases. Changing the unit layout, on the other hand, does not involve additional costs and can even reduce system size by avoiding the need for an air cooled coil for advanced dehumidification.

[0026] To maintain performance, Glycol based systems may require a >50% higher water flow and similarly larger refrigerant-to-heat transfer fluid heat exchangers (LCE/LCC coils) to maintain heat transfer capacity. Without such configuration, Polyethylene Glycol can reduce performance by 25-30% in terms of Integrated Energy Efficiency Ratio (JEER) and Integrated Seasonal Moisture Removal Efficiency (ISMRE). With such a configuration, performance will be affected by higher pump power requirements especially at high concentrations and low temperatures. For liquid desiccant air conditioning systems designed for heating in a heat pump mode, this would at least enable improved heating performance compared to gas or steam. In the current system, the Glycol is only used as freeze protection and reduces performance. Finding alternatives to protect the system during freezing periods therefore becomes more important.

[0027] Various embodiments disclosed herein relate to design alternative approaches to freeze protection that seek to eliminate or reduce the need for Glycol. The systems include a change in design with optional additional components.

[0028] In many instances the LDAC system conditioner is already positioned inside the conditioned space. This improves energy efficiency. Freezing protection can be achieved by positioning all water heat transfer fluid components inside or in fluid communication with the conditioned space. In addition, the water and air in the unit can be heated directly when the unit is closed down and outside temperatures fall below zero degrees C.

[0029] As long as all water components are in spaces that can be closed to the outside air and connected to the inside of the building via a ducting system, above freezing conditions can be maintained. The LDAC water system will need to be treated as part of the building water system, meaning that in extreme emergencies, where freezing temperatures inside the building cannot be avoided, the water system may need to be drained. This can be accomplished using a drainage point at the lowest point of the water system.

[0030] In accordance with one or more embodiments, winter heating coils used for heating an air stream are positioned before rather than after the conditioner (in the direction of the airflow). Currently, the heater is generally positioned behind the cooling coil. This allows the heater to be used for reheat as well as winter heating. In accordance with one or more embodiments, during the use of the unit as a heater, heated air could still mostly bypass the liquid desiccant heat exchanger as long as the liquid desiccant heat exchanger components are in the conditioned space. With the heater on, both the regenerator and compressor sections are closed to the outside but opened to the conditioned space through a set of dampers. Keeping the regenerator in a conditioned space during times the cooling system is not operating can be done by allowing some of the supply air to be provided to the building by the conditioner to heat up the regenerator and the heat exchanger through a damper, while at the same time closing off dampers and louvers used to provide air to the regenerator and any heat dump coil used in cooling mode.

[0031] An alternative solution is to heat regenerator air with an air or water heater that can, be gas, oil or waste heat based. In summer cooling conditions, such a regenerator heater can be a replacement for an AdvDH (advanced dehumidification) coil. By circulating regenerator air in a closed circuit, air entering the regenerator can be kept above freezing and the compressor can be used in a heat pump mode. In this arrangement, the delta T across the heat pump between conditioner and regenerator can be less than 20 C/40 F, which makes the heat pump significantly more effective than when outside air is used. Managing humidity levels in the building can involve water addition, which can take the form of direct evaporative cooling, vaporization or a membrane water addition as disclosed, e.g., in U.S. Patent Application Publication No. 20150338140.

[0032] In a heat pump mode, the air or water heater can maintain conditions above freezing to avoid the use of Glycol. Typically the airflow*delta T*spec. heat air of the conditioner in BTU should be less than the water flow*(T high-32 F)*spec. heat water for the regenerator and the conditioner. The high water temperature T(Whigh) can be between 40-50 C (100-120 F).

[0033] Alternatively, a water heater can be added to the regenerator water circuit or by using a gas heater to preheat regenerator air. During cool and humid periods, the water heater can then be used as an alternative for the advanced dehumidification coil by adding regeneration capacity using gas for heating the water when the supply air is already sufficiently cooled.

[0034] For systems in areas with significant deep freezing conditions, passive protection is to be used for times that the power system or the heating system is down. During power outages, the whole unit can be treated as part of the building water system by ensuring air from the building is used to warm up the unit and by connecting the water system to protective systems for the building water system. When these protective systems also fail, e.g., during prolonged outages, the building water system may need to be drained to avoid freezing of pipes. This will also involve the unit being fully closed while it is not operational. This is different from traditional DX systems where the condenser part of the unit can be exposed to freezing conditions when the unit is not used.

[0035] To avoid the use of Glycol, other alternatives are also possible. For instance, a water heater can be added at the lowest point in the regenerator water circuit to prevent freezing. This heating unit can also be used for the advanced dehumidification process. Another option is to add a space heater to the LDAC housing to maintain temperatures above freezing in the unit.

[0036] In split systems, the conditioner and its water system can be positioned inside the building through a refrigerant link. In that case, the freeze protection alternatives disclosed herein apply to the regenerator/condenser unit.

[0037] Since heating days always outnumber freezing days, efficient heating capacity will be available in all buildings that have freezing risks at least during some hours of the year.

[0038] FIG. **5** illustrates shows a liquid desiccant air conditioning unit comprising a liquid desiccant conditioner **600** and a liquid desiccant regenerator **602**, which are connected through heat transfer fluid lines **604** and **606** with heat transfer fluid-to-refrigerant heat exchangers (LCE coil **608** and LCC coil **610**, respectively) with a chiller **612**.

[0039] The conditioner **600** is in an enclosure in space **622**, the regenerator **602** is in an enclosure in space **623**, and the chiller **612** is in an enclosure in space **625**, all in an insulated housing **621**.

[0040] The air stream **614** supplied to the conditioner **600** can be outside air or return air from the building or a mixture of the two. Similarly, the air supply **616** to the regenerator **602** can be outside air, air from the building or a mixture thereof. The conditioner **600** supplies air **618** to the building space through a duct or directly into the space, and is therefore in open fluid communication with the building. In a cooling and dehumidification mode of operation, the air stream **616** is heated and humidified by the regenerator **602** and is exhausted at **620**.

[0041] The liquid desiccant air conditioning unit can be run in different modes, including: a cooling mode, a heating and dehumidification mode, a cooling and humidification mode, a cooling and dehumidification mode, a heating mode, and a heating and dehumidification mode. The unit depicted in FIG. **5** can be a single rooftop unit. It can also be a split unit, in which the conditioner **600** is inside the building and the regenerator **602** and chiller **612** can be on the roof or otherwise outside of the building or in a technical space.

[0042] The chiller **612** can comprise a heatpump or a simple compressor system.

[0043] The conditioner **600** is positioned in the cooled space **622** in the unit when the unit is performing cooling. A heating coil **624** is positioned after the conditioner **100**.

[0044] The positioning of the heating coil **624** after the conditioner **600** allows it to be used for reheat as well as for winter heating. Traditionally with a heating coil after the conditioner during the winter period, all parts of the unit before the heating coil remain at outside air conditions. By switching the position, the parts containing heat transfer fluid can be protected.

[0045] FIG. **6** shows a Glycol-free liquid desiccant air conditioning unit in accordance with one or more embodiments. The unit of FIG. **6** is similar to FIG. **5** in that in contains many of the same or similar components indicated by the same reference numbers.

[0046] The FIG. **6** unit comprises a liquid desiccant conditioner **600** and regenerator **602**, which are connected through cooling fluid lines **604** and **606** with cooling fluid-to-refrigerant heat exchangers (LCE coil **608** and LCC coil **610**, respectively) with a chiller **612**.

[0047] The heating coil **624** is moved from the position shown in FIG. **5** to the air intake side of the unit such that the supply air to the conditioner **600** is heated. The heated supply air can bypass the conditioner **600** to reduce pressure drop as long as the conditioner **600** remains in the heated space.

[0048] Unlike the FIG. **5** unit, in the FIG. **6** unit, the regenerator space **623** is connected to the conditioner space **622** at duct **670**. The chiller space **625** is connected to the regenerator space **623** by duct **674**. The ducting prevents freezing of the heat transfer fluid when the outside air temperature is low. In emergencies where the heater breaks down, freezing of the heat transfer fluid is prevented through the connection of the conditioned space through the ducting to the inside of the building.

[0049] FIG. **7** shows how moving the heating coil and connecting the conditioner and regenerator spaces can be used to prevent freezing of system components. The hot water supply or a space heater can directly heat the regenerator block and the piping space. Alternatively, the regenerator can be connected to the conditioner space, which is already connected to the building via ducts.

[0050] FIG. **8** shows how a single heating coil can be used for heating/freeze protection in winter, while replacing the advanced dehumidification coil in the cooling season. Bypasses can be used to minimize pressure drop.

[0051] FIG. **9** shows a system in which the heating coil is positioned in the outside air intake without the need for a damper between the regenerator and the conditioner spaces. The capacity to add heat directly to the regenerator can replace the advanced dehumidification coil. Various configurations are possible that allow a single coil or gas supply to serve both the regenerator and the conditioner. Air can bypass the blocks so long as the blocks are in the conditioned space.

[0052] If during an emergency, the building itself cools below freezing then additional measures are needed. These can vary from using a backup power supply **662** in combination with a space heater **640** or a water heater **660**, which can be used to maintain temperatures above freezing.

[0053] FIG. **10** shows how instead of heating the air, water flowing through the regenerator and conditioner can be heated directly to prevent freezing of the water and allow outside air to be heated in winter time and in the advanced dehumidification mode. Sources of heat can include, e.g., condensers, and solar, gas, and waste heat sources.

[0054] A further protection measure during extreme emergencies where all power and backup fails is to drain the system from the low point in the water/heat transfer fluid circuit. Since the unit is connected to the building this can be done at the same time that water pipes in the building are drained to prevent pipes from bursting.

[0055] Use of Glycol might not be avoided in the regenerator when the unit is used in heatpump mode, where the regenerator is cooled and the conditioner is heated. In that case, the additional sizing of the system can be justified by the improved heating performance.

[0056] The capacity to add heat directly to the regenerator can avoid the need for an advanced dehumidification (AdvDH) coil. Various configurations are possible that allow a single coil or gas supply to serve both the regenerator and the conditioner. Air can bypass the units as long as the units are in the conditioned space.

[0057] In one or more alternate embodiments, gas is used to heat water through the regenerator/conditioner rather than heating the air itself. This is similar to indirect heating of the air with gas. With direct gas heating there is an additional humidification benefit during the dry winter conditions.

[0058] 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 treating an air stream entering a building space, comprising:

a compressor-based cooling system through which a refrigerant flows;

a liquid desiccant conditioner utilizing a liquid desiccant and a heat transfer fluid to cool, heat, humidify, or dehumidify a first air stream flowing therethrough depending on a mode of operation of the liquid desiccant air conditioning system, wherein the heat transfer fluid used in the conditioner contains substantially no antifreeze additive;

a liquid desiccant regenerator receiving the liquid desiccant used in the liquid desiccant conditioner, and utilizing a heat transfer fluid and a second air stream flowing therethrough to concentrate or dilute the liquid desiccant depending on the mode of operation of the liquid desiccant air conditioning system, and then returning the liquid desiccant to the conditioner, wherein the heat transfer fluid and the liquid desiccant cool, heat, humidify, or dehumidify the second air stream depending on the mode of operation of the liquid desiccant air conditioning system, wherein the heat transfer fluid used in the regenerator contains substantially no antifreeze additive;

a first heat exchanger thermally coupled to the heat transfer fluid used in the liquid desiccant conditioner and to the refrigerant flowing through the compressor-based cooling system for exchanging heat between the refrigerant and the heat transfer fluid;

a second heat exchanger thermally coupled to the heat transfer fluid used in the liquid desiccant regenerator and to the refrigerant flowing through another portion of the compressor-based cooling system for exchanging heat between the refrigerant and the heat transfer fluid;

a first enclosure containing the liquid desiccant conditioner, the first enclosure including an inlet for receiving the first air stream and an outlet for outputting a supply air stream to the building space comprising the first air stream after treatment by the conditioner;

a second enclosure containing the liquid desiccant regenerator, said second enclosure including an inlet for receiving the second air stream and an outlet for exhausting the second air stream after treatment by the regenerator;

a third enclosure containing the compressor-based cooling system, the first heat exchanger, and the second heat exchanger;

one or more dampers between the first enclosure, the second enclosure, and the third enclosure selectively permitting flow of the supply air stream from the first enclosure to the second enclosure and the third enclosure during operation of the liquid desiccant air-conditioning system in a heating operation mode to prevent freezing of the heat transfer fluid; and

a heating system positioned in the first enclosure to heat the first air stream prior to the air stream entering the conditioner.

2. The system of claim **1**, wherein space in the first enclosure is in fluid communication with the building space.

3. The system of claim **1**, wherein the liquid desiccant conditioner includes a plurality of structures arranged in a substantially parallel orientation, each of the structures has at least one surface across which the liquid desiccant can flow and an internal passage through which the heat transfer fluid can flow, wherein the first air stream flows between the plurality of structures.

4. The system of claim **1**, wherein the liquid desiccant regenerator includes a plurality of structures arranged in a substantially parallel orientation, each of the structures has at least one surface across which the liquid desiccant can flow and an internal passage through which a heat transfer fluid can flow, wherein a second air stream flows between the plurality of structures.

5. The system of claim **1**, further comprising a heating system in the second enclosure to heat the air or heat transfer fluid therein and obviate need for an advanced dehumidification coil.

6. The system of claim **5**, wherein the heating system comprises a water heater to heat the heat transfer fluid or a space heater.

7. The system of claim **1**, wherein one or more of the enclosures include a low point from which the heat transfer fluid can be drained.

8. The system of claim **1**, wherein the compressor-based cooling system comprises a chiller.

9. A method of operating a liquid desiccant air-conditioning system for treating an air stream entering a building space, wherein the liquid desiccant air conditioning system includes:

a compressor-based cooling system through which a refrigerant flows;

a liquid desiccant conditioner utilizing a liquid desiccant and a heat transfer fluid to cool, heat, humidify, or dehumidify a first air stream flowing therethrough depending on the mode of operation of the liquid desiccant air conditioning system, wherein the heat transfer fluid used in the conditioner contains substantially no antifreeze additive;

a liquid desiccant regenerator receiving the liquid desiccant used in the liquid desiccant conditioner, and utilizing a heat transfer fluid and a second air stream flowing therethrough to concentrate or dilute the liquid desiccant depending on the mode of operation of the liquid desiccant air conditioning system, and then returning the liquid desiccant to the conditioner, wherein the heat transfer fluid and the liquid desiccant cool, heat, humidify, or dehumidify the second air stream depending on the mode of operation of the liquid desiccant air conditioning system, wherein the heat transfer fluid used in the regenerator contains substantially no antifreeze additive;

a first heat exchanger thermally coupled to the heat transfer fluid used in the liquid desiccant conditioner and to the refrigerant flowing through the compressor-based cooling system for exchanging heat between the refrigerant and the heat transfer fluid;

a second heat exchanger thermally coupled to the heat transfer fluid used in the liquid desiccant regenerator and to the refrigerant flowing through another portion of the compressor-based cooling system for exchanging heat between the refrigerant and the heat transfer fluid;

a first enclosure containing the liquid desiccant conditioner, the first enclosure including an inlet for receiving the first air stream and an outlet for outputting a supply air stream to the building space comprising the first air stream after treatment by the conditioner;

a second enclosure containing the liquid desiccant regenerator, said second enclosure including an inlet for receiving the second air stream and an outlet for exhausting the second air stream after treatment by the regenerator; and

a third enclosure containing the compressor-based cooling system, the first heat exchanger, and the second heat exchanger;

wherein the method comprises

heating the first air stream prior to the air stream entering the conditioner and selectively permitting flow of the supply air stream from the first enclosure to the second enclosure and the third enclosure during operation of the liquid desiccant air-conditioning system in a heating operation mode to prevent freezing of the heat transfer fluid.

10. The method of claim **9**, wherein space in the first enclosure is in fluid communication with the building space.

11. The method of claim **9**, further comprising heating the heat transfer fluid using a water heater.

12. The method of claim **9**, further comprising heating space in the second enclosure or the third enclosure using one or more space heaters.

13. The method of claim **9**, further comprising draining the heat transfer fluid from a low point in the liquid desiccant air conditioning system in the event of power failure.

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