

WATER RECOVERY IN DESICCANT ENHANCED EVAPORATIVE COOLING SYSTEMS

BACKGROUND

[0001] There are many applications for which controlling the environmental conditions within an enclosed space is important - for example, cooling data centers. A data center usually consists of computers and associated components operating 24 hours a day, 7 days a week. The electrical components in data centers produce a lot of heat, which needs to be removed from the space. Air-conditioning systems in data centers can consume as much as 40% of the total energy

[0002] Comfort cooling of residential, commercial and institutional buildings is predominantly done using vapor-compression cooling equipment. Many process applications, such as data centers, also use mechanical cooling for primary or supplemental cooling. In most of these applications, the required cooling temperature is moderate (for example, 50°F - 85°F; 10°C - 30°C). Mechanical cooling equipment can produce high cooling capacities, operate reliably and can have acceptable cost due to mass production of compressors, exchangers and other components. However, these systems require significant amounts of high grade electrical energy to operate. For example, about 15% of the total annual US domestic electricity production is consumed by air conditioning units. Moreover, about one-third of the peak demand in hot summer months is driven by air conditioning units, leading to issues with power grid loading and stability. The production of electricity remains carbon intensive, so electricity driven cooling systems can contribute significantly to emissions and global warming.

[0003] Thermoelectric power production requires vast amounts of water for cooling, and the US average water consumption (evaporated water) for combined thermoelectric and hydroelectric power production is about 2 gallons/kWh. The water consumed to produce the electricity required by an EER 11 air conditioner is about equivalent to the water consumed by an evaporative cooling system producing an equivalent amount of cooling. However, evaporative cooling systems consume far less electricity. Vapor-compression also typically requires synthetic refrigerants operating at high pressures. The deployment of large quantities of refrigerants in air conditioning and refrigeration systems has resulted in safety, health and environmental concerns. Modern high efficiency refrigerants, such as HFCs, can have high global warming potential and are being phased out. There is currently no direct replacement refrigerant option that has all the desired properties in terms of efficiency, stability, flammability, toxicity, and environmental impact.

[0004] Evaporative cooling systems are used successfully in many applications, especially in dry climates. Direct evaporative coolers (DEC) can be simple in design and efficient,

compared to, for example, vapor compression systems. However, conventional DEC systems can have some drawbacks. The supply air temperature coming out of the cooler may be challenging to control and is dependent on the outdoor air temperature and humidity level. The supply air may be excessively humid. These systems need careful maintenance to ensure that bacteria, algae, fungi and other contaminants do not proliferate in the water system and transfer into the supply air stream. Since these systems utilize direct contact between the evaporating liquid water and supply air, carryover of contaminants into the air stream can occur, which can, in turn, lead to reduced indoor air quality, odors and "sick building syndrome." Also, buildup of mineral deposits in the unit and on the evaporative pads can reduce performance and require maintenance.

[0005] Indirect evaporative coolers address the humidity problem but typically operate at lower wet bulb efficiencies. State-of-the-art dew-point evaporative coolers can deliver lower cooling temperatures than conventional direct or indirect evaporative systems and can maintain cooling power to higher outdoor wet bulb temperatures. However, all evaporative cooling technologies lose cooling performance as the working air humidity rises and cannot be used in humid climates without supplemental (usually vapor compression) cooling equipment. The water usage efficiency of evaporative cooling systems also varies widely depending on the system design and control characteristics. The water usage of evaporative coolers can be a problem, or at least a perceived problem. For example, large scale data centers may consume large quantities of potable water. Moreover, for those locations in which evaporative cooling works best (dry climates), the water demand may not be sustainable.

[0006] There remains a need for alternative cooling technologies for comfort conditioning applications, which can largely replace mechanical cooling. The growing awareness of environmental impacts, including water consumption, are pressing challenges for current HVAC cooling equipment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] In the drawings, which are not necessarily drawn to scale, like numerals may describe similar components in different views. Like numerals having different letter suffixes may represent different instances of similar components, sub-components of a larger logical or physical system, or the like. The drawings illustrate generally, by way of example, but not by way of limitation, various examples described in the present disclosure.

[0008] FIG. 1 schematically depicts an example regeneration system for use in a conditioning system with a desiccant dryer LAMEE and an evaporative cooler.

[0009] FIG. 2 schematically depicts another example conditioning system including a regeneration system having a heat recovery exchanger (HRE).

[0010] FIG. 3 schematically depicts a portion of the regeneration system of FIG. 2.

[0011] FIG. 4 schematically depicts another example conditioning system including a regeneration system.

[0012] FIG. 5 schematically depicts another example conditioning system including a centralized regeneration system.

[0013] FIG. 6 schematically depicts another example regeneration system for use in a conditioning system.

[0014] FIG. 7 is a flowchart depicting a method of operating a conditioning system in accordance with this disclosure.

OVERVIEW

[0015] The inventor(s) recognize, among other things, an opportunity for improved performance in providing cooling to an enclosed space through design of a conditioning system using a first Liquid-to-Air Membrane Energy Exchanger (LAMEE) as a dehumidifier to dry the air in an air stream passing through the first LAMEE, thus lowering the enthalpy and dew point of the air, and then passing the air through a second LAMEE (or another type of evaporative cooler). In an example, the second LAMEE can be used to condition the air stream so that the conditioned air can be provided to the enclosed space. In another example, the second LAMEE can be used to cool a water stream flowing through the LAMEE such that the water stream can be delivered to a second plenum for cooling a process air stream. The inventor(s) also recognize an opportunity to use the water removed from the process air stream by the first LAMEE as a source of water supply for evaporative coolers in the system, including, for example, the second LAMEE (or other evaporative cooler) downstream, to reduce or eliminate the need for an external water supply.

[0016] Examples according to the present application can include a system for conditioning air for an enclosed space and the system can include a LAMEE, arranged inside a plenum configured to direct an air flow path from an inlet to an outlet, and a regeneration system in fluid connection with the LAMEE. The system can also include one or more cooling components arranged inside the plenum. The LAMEE can comprise a desiccant flow path separated from an air flow path by a membrane and the desiccant can remove water from the air in the air flow path. The regeneration system can be configured to separate a portion of the water from the desiccant such that the regeneration system can output a concentrated desiccant stream and a distilled water stream. The concentrated desiccant stream can be returned for recirculation through the LAMEE. In an example, only a portion of the dilute desiccant from the LAMEE is regenerated. The one or more cooling components can utilize at least a portion of the distilled water stream recovered in regeneration for use as make up water. This can reduce or eliminate

an external water supply for the conditioning system. In an example, the one or more cooling components can include an evaporative cooler arranged inside the plenum downstream of the dryer LAMEE. In an example, the downstream evaporative cooler can be a second LAMEE.

[0017] The dryer LAMEEs disclosed herein are designed such that the desiccant can remove at least one of moisture and heat from the air stream. Essentially all of the energy removed from the air stream can be transferred to the desiccant. The LAMEE can thus be a two-fluid design with the first fluid being the air and the second fluid being the desiccant.

[0018] In an example, the conditioning system can include a liquid to liquid heat exchanger (LLHX) or a liquid to air heat exchanger (LAHX) configured to cool the desiccant prior to circulating the desiccant through the LAMEE. In an example, the LAHX or LLHX can be configured outside of the plenum. In an example, the LAHX can include evaporative cooling capabilities and can use water from the regenerator as make up water. In an example, the LAHX can use outdoor air to cool the desiccant.

[0019] In an example, the regeneration system can include a thermally driven regeneration unit. In an example, the regeneration system can use non-thermal sources of energy to separate the water and the desiccant in the desiccant stream.

[0020] In an example, the conditioning system can include a single plenum and a single working air stream. The air stream can be hot process air from the enclosed space and the air can be conditioned inside the plenum such that the process air can be returned to the enclosed space at a reduced temperature or humidity. The air stream can be outdoor air that can be conditioned such that it can be delivered to the enclosed space at a reduced temperature or humidity. The air stream can be a combination of outdoor air and process air.

[0021] In an example, the conditioning system can include two plenums and two working air streams. A first plenum can receive a scavenger air stream and direct the scavenger air through a dryer LAMEE and an evaporative cooler downstream of the dryer LAMEE. The evaporative cooler can produce reduced-temperature water for cooling. The second plenum can receive a process air stream from the enclosed space and direct the process air through an LAHX in the second plenum, using the reduced-temperature water from the first plenum to cool the process air. The process air can then be returned to the enclosed space.

[0022] Examples according to the present application can include a system for conditioning air for an enclosed space and the system can include a desiccant dryer LAMEE arranged inside a plenum, the desiccant dryer LAMEE configured for air to pass there through and use a desiccant flowing there through to remove water from the air. The desiccant and air can be separated in the LAMEE by a membrane and the LAMEE can facilitate an energy exchange between the air and the desiccant such that the desiccant collects essentially all of the energy removed from the air. The conditioning system can also include an evaporative cooler arranged inside the plenum

downstream of the desiccant dryer LAMEE and configured to cool at least one of the air and water circulating through the evaporative cooler. The conditioning system can also include a fluid circuit coupled to the desiccant dryer LAMEE and the evaporative cooler, and including a regenerator configured to separate water and desiccant in a desiccant stream. The fluid circuit is configured to transport at least a portion of the water removed from the air by the desiccant dryer LAMEE and separated in the regenerator to the evaporative cooler for use as make up water for operation of the evaporative cooler. In an example, the regenerator comprises a thermal separation unit. In an example, the regenerator comprises one or more heat sources to heat the desiccant prior to passing the desiccant into the thermal separation unit. In an example, the regenerator comprises a separation unit that is driven by a non-thermal energy source.

[0023] Examples according to the present application can include a method of conditioning air for an enclosed space and the method can include directing air through a process plenum, directing the air through a LAMEE inside the plenum and directing a desiccant through the LAMEE, the desiccant and air separated by a membrane of the LAMEE. The method can include transferring energy in the LAMEE from the desiccant to the air, an energy reduction of the air between a LAMEE inlet and outlet being about equal to an energy gain of the desiccant between the LAMEE inlet and outlet. The energy transfer includes removing water from the air using the desiccant such that a first concentration of water in the desiccant is lower at a LAMEE inlet compared to a second concentration of water in the desiccant at a LAMEE outlet. The method can include regenerating a portion of the dilute desiccant in a regenerator to separate the water from the desiccant, directing a concentrated desiccant exiting the regenerator to a fluid circuit for the desiccant dryer LAMEE, and directing distilled water from the regenerator to one or more evaporative coolers in the conditioning system. The method can include regulating the portion of the dilute desiccant (from the dryer LAMEE) that is regenerated. The one or more evaporative coolers in the conditioning system can include an evaporative cooler arranged downstream of the dryer LAMEE and configured to cool the air passing through the plenum. In an example, the downstream evaporative cooler can be a second LAMEE.

[0024] The methods disclosed herein can markedly reduce or eliminate an external water supply for operation of the conditioning system. In an example, the enclosed space can be a data center. In an example, the conditioning systems disclosed herein can be used in residential and commercial applications.

[0025] Examples according to the present application can include a system for conditioning air for an enclosed space and the system can comprise a plurality of conditioning units. Each conditioning unit can include a plenum having a LAMEE and an evaporative cooler downstream of the LAMEE. The system can comprise a regeneration system in fluid connection with the

LAMEE outlet of each conditioning unit such that the regeneration system can regenerate at least a portion of the dilute desiccant from the outlet of the LAMEE of each unit. The system can comprise a concentrated desiccant storage system to receive and store the concentrated desiccant from the regenerator system and a distilled water storage system to receive and store the distilled water from the regenerator system. Concentrated desiccant can be supplied to each conditioning unit as needed for operation of the LAMEE of each conditioning unit. Distilled water can be supplied to an evaporative cooler of each unit as needed for operation of the evaporative cooling component. The system can markedly reduce or eliminate an external water supply for operation of multiple conditioning units.

[0026] This overview is intended to provide an overview of subject matter of the present patent application. It is not intended to provide an exclusive or exhaustive explanation of the invention. The detailed description is included to provide further information about the present patent application.

DETAILED DESCRIPTION

[0027] The present application relates to systems and methods for conditioning air for an enclosed space, and includes using a liquid to air membrane energy exchanger (LAMEE) as a desiccant dryer in combination with a regeneration system to collect water from an air stream for use as make up water for one or more evaporative coolers in the conditioning system. This can reduce or eliminate an external water supply for operation of the conditioning system and markedly improve the water usage efficiency as compared to existing designs of evaporative coolers. The desiccant dryer LAMEE can circulate a liquid desiccant, such as for example, lithium chloride, to remove moisture from the air stream passing through the LAMEE. The liquid desiccant and the LAMEE are described in further detail below. In an example, the conditioning system can include an evaporative cooler (arranged in a plenum downstream of the desiccant dryer LAMEE and the evaporative cooler can be configured to provide cooling to the air stream passing through the plenum or to a water stream passing through the evaporative cooler. The evaporative cooler can use the water from the air stream, recovered in regeneration, as the make up water for the evaporative cooler. In an example, the evaporative cooler can be a LAMEE, operating as an evaporative cooler. In such an example, the desiccant dryer LAMEE is a first LAMEE and the evaporative cooler LAMEE is a second LAMEE.

[0028] In an example, the conditioning system can include a liquid to air heat exchanger (LAHX), such as a cooling coil, arranged between the desiccant dryer LAMEE and the evaporative cooler, and configured to pre-cool the air stream prior to passing the air stream through the evaporative cooler. In an example, the LAHX/pre-cooler can use the water from the

air stream, recovered in regeneration, as the cooling fluid for circulation through the LAHX/pre-cooler.

[0029] The desiccant exiting the LAMEE can be a dilute desiccant stream. The conditioning system can operate effectively with only a portion of the dilute desiccant going through the regeneration system. In an example, a desiccant storage tank can be used to mix the dilute desiccant (exiting the LAMEE) with a concentrated desiccant stream from the regeneration system.

[0030] In an example, the conditioning system can be configured to condition hot process air (return air) from an enclosed space and return the process air to the enclosed space as cold, or reduced temperature process air (supply air). In another example, the conditioning system can condition outdoor air and deliver the conditioned air to an enclosed space. In yet another example, the conditioning system can condition a combination of process air and outdoor (make up) air for delivery to an enclosed space.

[0031] A liquid to air membrane energy exchanger (LAMEE) can be used as part of a conditioning system to transfer heat and moisture between a liquid and an air stream, both flowing through the LAMEE, in order to condition the temperature and humidity of the air or to reduce a temperature of the liquid. In an example, the membrane in the LAMEE can be a non-porous film having selective permeability for water, but not for other constituents that may be present in the liquid. Many different types of liquids can be used in combination with the non-porous membrane, including, for example, water, liquid desiccants, glycols. In an example, the membrane in the LAMEE can be semi-permeable or vapor permeable, and generally anything in a gas phase can pass through the membrane and generally anything in a liquid phase cannot pass through the membrane. In an example, the membrane in the LAMEE can be micro-porous such that one or more gases can pass through the membrane. In an example, the membrane can be a selectively-permeable membrane such that some constituents, but not others, can pass through the membrane. It is recognized that the LAMEEs included in the conditioning systems disclosed herein can use any type of membrane suitable for use with an evaporative cooler LAMEE or a desiccant dryer LAMEE.

[0032] In an example, the LAMEE can use a flexible polymer membrane, which is vapor permeable, to separate air and water. Relative to other systems/devices, the water flow rate and air flow rate through the LAMEE may not be limited by concerns such as droplet carryover at high face velocities. In addition, the LAMEE can operate with water flow rates that enable the transport of thermal energy into the cooler similar to a cooling tower, and the elevated inlet water temperatures can boost the evaporative cooling power of the LAMEE.

[0033] The desiccant dryer LAMEE can circulate any type of liquid desiccant suitable for removing moisture from the air. In an example, the cooling fluid is a liquid desiccant that is a

high concentration salt solution. The presence of salt can sanitize the cooling fluid to prevent microbial growth. In addition, the desiccant salt can affect the vapor pressure of the solution and allow the cooling fluid to either release or absorb moisture from the air. Examples of salt-based desiccants usable herein include lithium chloride, magnesium chloride, calcium chloride, lithium bromide, lithium iodide, potassium fluoride, zinc bromide, zinc iodide, calcium bromide, sodium iodide and sodium bromide. In an example, the liquid desiccant can include an acetate salt, such as, but not limited to, an aqueous potassium acetate and an aqueous sodium acetate.

[0034] In an example, the liquid desiccant can include a glycol or glycol-water solution. Glycols can be unsuitable for use in a direct contact exchanger because the glycol can evaporate into the air stream. A glycol based liquid desiccant can be used here with a non-porous membrane since the membrane can prevent the transfer of the glycol into the air. In an example, the liquid desiccant can include glycols, or glycol-based solutions, such as triethylene glycol and propylene glycol, which are non-toxic, compatible with most metals and comparatively low in cost. Glycols can be strongly hygroscopic at higher concentrations. For example, a 95% solution of triethylene glycol has a comparable drying/dehumidification potential to lithium chloride near saturation. Triethylene glycol and tripropylene glycol can have low vapor pressures, but can be expensive. Less expensive and higher vapor pressure glycols, such as ethylene glycol, diethylene glycol, propylene glycol and dipropylene glycol, can be used herein.

[0035] Other examples of liquid desiccants usable in the desiccant dryer LAMEE described herein include, but are not limited to, hygroscopic polyol based solutions, sulfuric acid and phosphoric acid. Glycerol is an example of a hygroscopic polyol usable herein. It is recognized that mixtures of desiccants can be used as the liquid desiccant in the desiccant dryer LAMEEs described herein. In addition to the desiccants listed above, the liquid desiccant can include, but is not limited to, an acetate salt solution, a halide salt solution, a hygroscopic polyol based solution, a glycol based solution, a sulfuric acid solution, a phosphoric acid solution, and any combinations thereof.

[0036] In an example, the conditioning system can include a regeneration system configured to increase a concentration of the liquid desiccant exiting the desiccant dryer LAMEE, prior to recirculating the liquid desiccant through the desiccant dryer LAMEE. The present application discloses systems and methods for recovering the water from the air stream (which is absorbed by the liquid desiccant in the desiccant dryer LAMEE) and using the recovered water as make up water for one or more cooling devices in the system, including, for example, the evaporative cooler located downstream of the desiccant dryer LAMEE. The systems and methods disclosed herein can eliminate or markedly reduce an external water consumption of the evaporative cooler

[0037] In an example, a LAMEE can circulate an evaporative cooling fluid through the LAMEE and the LAMEE can operate as an evaporative cooler, using the cooling potential in both air and the cooling fluid (for example, water) to reject heat. As described above, the evaporative cooler located downstream of the desiccant dryer LAMEE can be an evaporative cooler LAMEE. In an example in which the LAMEE is an evaporative cooler, as air flows through the LAMEE, water, or both the air and the water, can be cooled to temperatures approaching the inlet air wet bulb (WB) temperature. Due to the evaporative cooling process in the LAMEE, a temperature of the water at the outlet of the LAMEE can be less than a temperature of the water at the inlet, or the temperature of the water may not be changed, but the air may be cooled. Other types of evaporative cooling fluids, including those listed above, can be used in combination with water or as an alternative to water.

[0038] A LAMEE can offer advantages over conventional cooling systems, such as cooling towers, for example. The membrane separation layer in the LAMEE can reduce maintenance, can eliminate the requirement for chemical treatments, and can reduce the potential for contaminant transfer to the liquid loop. The use of LAMEEs along with an upstream and/or downstream cooling coil (or other LAHX) can result in a lower temperature of the water leaving the LAMEE and a higher cooling potential. Various configurations of conditioning systems having one or more LAMEEs are described herein and can boost performance in many climates.

[0039] FIG. 1 depicts an example regeneration system 11, which can be part of a conditioning system 10 to condition air for delivery to an enclosed space. The conditioning system 10 can be used in commercial and industrial applications, as well as residential applications. The conditioning system 10 can be used for cooling air that is hot because of surrounding equipment and conditions in the enclosed space. The conditioning system 10 can be used for comfort cooling in residential and commercial applications. The conditioning system 10 can receive hot process air from the enclosed space and condition the process air such that it can be returned to the enclosed space as reduced-temperature or reduced-humidity supply air. The conditioning system 10 can receive outdoor air and condition the outdoor air prior to delivering the outdoor air to the enclosed space. In other examples, the conditioning system 10 can receive a mix or combination of outdoor air and process air.

[0040] In an example in which the conditioning system 10 receives process air from the enclosed space, the conditioning system 10 can sometimes be referred to as a 100% recirculation system, which generally means that the air within the enclosed space recirculates through the conditioning system 10 in a continuous cycle of being cooled by the system 10 to a target supply air temperature, supplied to the space, heated by elements in the space (for example, computers, servers, and other electronics), and returned to the system 10 for cooling. Although not shown or described in detail, in such an example, the conditioning system 10 can

include a make-up air unit or system, to continuously or periodically refresh the air within the space to satisfy ventilation requirements.

[0041] The conditioning system 10 can include a desiccant dryer LAMEE 6 arranged in a plenum 4 and an evaporative cooler (EC) 8 arranged in the plenum 4 downstream of the LAMEE 6. The plenum 4 can be configured to receive an air stream through a plenum inlet 12 and release the air stream through a plenum outlet 14. Associated and generally collocated with the inlet 12 and outlet 14 can be dampers 18 and 20, respectively. Although not shown in FIG. 1, a fan can be arranged inside the plenum 4 upstream of the desiccant dryer LAMEE 6 or in some other location. In an example, the conditioning system 10 can be configured to receive a scavenger air stream if the system 10 has two working air streams (and two plenums) or to receive a return air stream (from an enclosed space) if the system 10 has one working air stream (and one process plenum). In another example, the air entering the process plenum 4 can be outdoor air. In yet another example, the air entering the process plenum 4 can be a mixture of outdoor air and process air from the enclosed space.

[0042] The regeneration system 11 can be configured for use with a variety of conditioning systems that include a desiccant dryer LAMEE 6 in combination with an evaporative cooler 8 downstream of the dryer LAMEE 6; such conditioning systems can include additional components not shown in FIG. 1. The conditioning system 10 can include one or more features, such as dampers, that can facilitate bypass of the desiccant dryer LAMEE 6.

[0043] The evaporative cooler 8 can be any type of evaporative cooler suitable for use inside the process plenum 4 for cooling an air stream or cooling an evaporative fluid circulating through the evaporative cooler 8 such that the fluid can be used to condition a separate air stream in a second plenum. In an example, the evaporative cooler 8 can be a LAMEE, also referred to herein as an evaporative cooler LAMEE. The evaporative cooler LAMEE is a non-contact evaporative cooler because the membrane in the LAMEE separates (and maintains separation between) the evaporative fluid (water) and the air. In such an example in which the evaporative cooler 8 is a LAMEE, the desiccant dryer LAMEE 6 can also be referred to herein as a first LAMEE 6 and the evaporative cooler LAMEE 8 can also be referred to herein as a second LAMEE 8. In other examples, the evaporative cooler 8 can include, but is not limited to, a wetted media or spray atomizer system, both of which are examples of direct-contact evaporative coolers since the evaporative fluid (water) directly contacts the air to cool the air. In another example, the evaporative cooler 8 can include a wet deck or other flooded fill material (similar to what can be used in a cooling tower) – these are additional examples of direct-contact coolers since the evaporative fluid directly contacts the air.

[0044] The conditioning system 10 can circulate a liquid desiccant through the LAMEE 6 to reduce a humidity level of the air stream entering the plenum 4, prior to passing the air stream

through the evaporative cooler 8. After circulating through the LAMEE 6, the liquid desiccant can be diluted due to absorbed moisture from the air. A reduction in the concentration of the desiccant can thereby reduce the drying ability of the LAMEE 6. The regeneration system 11, which can include a regenerator 52, can be configured to regenerate the liquid desiccant prior to recirculating the liquid desiccant back through the LAMEE 6.

[0045] After the liquid desiccant exits the LAMEE 6 at a LAMEE outlet 28, the liquid desiccant can be discharged into a desiccant tank 26 configured for storage of the liquid desiccant. The desiccant can be transported from the desiccant tank 26, via a pump 42, to the regenerator 52 and a liquid to air heat exchanger (LAHX) or a liquid to liquid heat exchanger (LLHX) 32. The LAHX or LLHX 32 can be configured to reduce a temperature of the desiccant prior to passing the desiccant into the LAMEE 6 at a LAMEE inlet 34. The LAHX or LLHX 32 and the regenerator 52, in combination, can thus decrease a temperature and increase a concentration of the liquid desiccant prior to circulating the desiccant through the LAMEE 6. Both capabilities can be important in order for the desiccant to effectively remove moisture from the air stream passing through the LAMEE 6. A modulating valve 68 can control and vary a distribution of the desiccant from the tank 26 to the regenerator 52 and the LAHX or LLHX 32, as described further below.

[0046] The regeneration system 11 can include a portion of a first desiccant circuit 24 and a second desiccant circuit 66 in fluid connection with the first desiccant circuit 24. The LAHX or LLHX 32 can be part of the first desiccant circuit 24. The tank 26 can be part of the first desiccant circuit 24 and the second desiccant circuit 66. The regenerator 52 can be part of the second desiccant circuit 66. The regenerator 52 can include an energy input to facilitate separation of the water and desiccant. For example, such energy input can include, but is not limited to, heat, mechanical power, electrical power, or a combination thereof.

[0047] The desiccant exiting the tank 26 can be transported to the regenerator 52 via the second desiccant circuit 66 and enter the regenerator 52 at an inlet 70. The regenerator 52 can separate a portion of the water from the desiccant such that a first exit stream 71 exiting the regenerator 52 at a first outlet 72 can be concentrated desiccant and a second exit stream 73 exiting the regenerator 52 at a second outlet 74 can be distilled water. (Concentration levels C1-C3 of the desiccant are described below.) The first exit stream 71 can be part of the second desiccant circuit 66. In an example, the first exit stream 71 can be transported back to the tank 26 via a pump 76.

[0048] The second exit stream 73 (distilled water) can be transported to a tank 36 for the evaporative cooler 8, via a pump 78, and used in a first water circuit 30 for the evaporative cooler 8. Thus the water in the air stream passing through the plenum 4 can be absorbed by the desiccant in the desiccant dryer LAMEE 6, separated from the desiccant in the regenerator 52,

and then used as make up water for the evaporative cooler 8. The evaporative cooler 8 can still be connected to an external water supply – this is shown in FIG. 1 as external water supply to the tank 36. External water can be provided to the evaporative cooler 8 as needed; however the use by the evaporative cooler 8 of the recovered water from the desiccant can result in a significant reduction or elimination of water for operation of the evaporative cooler 8. In other examples, the water in the second exit stream 73 can be used by more than one cooling unit in a conditioning system.

[0049] The dilute desiccant exiting the LAMEE 6 at the LAMEE outlet 28 can have a first desiccant concentration C1. The dilute desiccant can be mixed with existing desiccant in the tank 26 such that a concentration of desiccant in the tank 26 can be at a second concentration C2 that is greater than the first concentration C1. In an example, a difference in concentration between the first concentration C1 and the second concentration C2 can be small. The desiccant at the second concentration C2 can be regenerated in the regenerator 52 such that a third concentration C3 of the desiccant in the first exit stream 71 can be markedly greater than the second concentration C2. The concentrated desiccant in the first exit stream 71 (at the third concentration C3) can then be mixed with the dilute desiccant exiting the LAMEE 6 (at the first concentration C1), and with the desiccant already in the tank 26, to increase the second concentration C2 of the mixed desiccant. As such, the second concentration C2 in the tank 26 can depend on the concentrations C1 and C3, and the volume/flow rate of each, as well as the volume of desiccant in the tank 26.

[0050] Even though the mixed desiccant in the tank 26 can be at the second concentration C2, which is higher than the first concentration C1 of the dilute desiccant exiting the LAMEE 6, the mixed desiccant can be referred to herein as “dilute desiccant” relative to the concentrated desiccant exiting the regenerator 52 at the concentration C3. Similarly, the desiccant entering the LAMEE can be referred to herein as “concentrated desiccant” relative to the dilute desiccant exiting the LAMEE 6, even though the concentration C2 of the desiccant entering the LAMEE can be less than the concentration C3 of the desiccant exiting the regenerator 52.

[0051] FIG. 1 shows an exemplary design for the regeneration system 11 in which the dilute desiccant exiting the LAMEE 6 can be mixed with the concentrated desiccant from the regenerator 52, and a portion of the desiccant exiting the tank 26 can be circulated back through the LAMEE 6 and a portion can be regenerated. The valve 68 can control a distribution of the desiccant exiting the tank 26 to the LAMEE 6 and to the regeneration system 11. In other examples, the conditioning system 10 can be configured such that all or a portion of the dilute desiccant exiting the LAMEE 6 can be transported directly to the regenerator 52, rather than mixing the dilute desiccant in the tank 26 with the concentrated desiccant coming back from the regenerator 52. This is shown in FIG. 6 and described below.

[0052] A dehumidification capacity of the LAMEE 6 can depend on a flow rate, a temperature, and a concentration of the liquid desiccant passing through the LAMEE 6. In an example, the conditioning system 10 can operate with a set point temperature and a set point concentration of the liquid desiccant at the LAMEE inlet 34; the flow rate of the desiccant through the LAMEE 6 can be generally constant. The load on the LAMEE 6 can vary as the conditions of the air stream passing through the plenum 4 vary. If the air stream increases in humidity, the load on the LAMEE 6 can increase. As a result, the liquid desiccant exiting the LAMEE 6 at the outlet 28 can require more regeneration, relative to if the LAMEE 6 receives a low humidity air stream. The regeneration system 11 can be configured such that as additional regeneration of the desiccant is required, the flow rate of liquid desiccant to the regenerator 52 can be increased via the modulating valve 68. In an example, the modulating valve 68 can be controlled by a system controller 50, described below.

[0053] An increase in the flow rate of liquid desiccant to the regenerator 52 can result in an increase in the flow rate of concentrated liquid desiccant back to the tank 26 at the concentration C3. The increased amount of concentrated liquid desiccant can mix with the liquid desiccant in the tank 26 to increase the concentration C2 of the liquid desiccant that is transported back to the LAMEE 6 (after passing through the LAHX or LLHX 32). The flow rate of desiccant to the regenerator 52 can be controlled such that the concentration C2 can be at or near the set point concentration for the LAMEE 6 at the LAMEE inlet 34. In an example, the concentration C2 can vary (up or down) depending, at least in part, on the load of the system (i.e. the outdoor air conditions).

[0054] As an alternative or in addition to using a regeneration system, the concentration of the liquid desiccant in the first desiccant circuit 24 can be increased by introducing a concentrated desiccant into the desiccant tank 26. This can be done intermittently as needed or throughout operation of the system 10.

[0055] The system 10 can be designed such that only a portion of the desiccant is regenerated in the regenerator 52. Thus, in an example, the system 10 can continue operating efficiently without requiring all of the desiccant to flow through the regenerator 52. The valve 68 can direct all or a portion of the desiccant from the tank 26 directly back to the LAMEE 6. This is a result in part to the mixing in the tank 26 of concentrated desiccant from the regeneration system with dilute desiccant from the LAMEE 6. This is also a result of the design of the LAMEE 6 which operates at high flow rates of liquid desiccant through the LAMEE 6. Because the flow rate of liquid desiccant through the LAMEE 6 is high, a concentration decrease of the desiccant in the desiccant stream between the inlet 34 and the outlet 28 of the LAMEE 6 is small, compared to if the desiccant flow rate was low. As such, in an example, only a minor portion of the desiccant from the tank 26 can be diverted for regeneration.

[0056] The LAMEE 6 is configured such that the desiccant removes at least one of water and heat from the air stream. It is recognized that if the desiccant only removes water from the air (i.e. the air remains at a generally constant temperature between the LAMEE inlet and outlet), a temperature of the desiccant at an outlet of the LAMEE 6 can still be higher than a temperature of the desiccant at an inlet of the LAMEE 6. The temperature increase of the desiccant is due to the latent heat of condensation of the moisture from the air.

[0057] The design of the LAMEE 6 allows for the desiccant to not only remove water from the air stream, but the desiccant can also remove heat from the air stream. The LAMEE 6 can be configured such that essentially all of the energy removed from the air stream is transferred to the desiccant stream. In other words, an energy reduction of the air in the air stream between the LAMEE inlet and outlet can be about equal to an energy gain of the liquid desiccant in the desiccant stream between the LAMEE inlet and outlet. It is recognized that there may be some loss inherent in the system and 100% of the energy removed from the air stream may not be transferred to the desiccant stream. For purposes herein, the term “essentially all of the energy” or “all of the energy” recognizes and accounts for such losses in the system. Similarly, for purposes herein, “about equal” in reference to the energy reduction of the air relative to the energy gain of the desiccant recognizes and accounts for the system not being 100% efficient and having some loss. The LAMEE 6 can be configured such that a single fluid (the desiccant) can be used to remove heat and water from the air. Thus the LAMEE 6 can be a two-fluid design – the first fluid is the air stream and the second fluid is the desiccant. Additional fluids are not included for reducing the energy of the air, and the single desiccant stream in the LAMEE 6 can sufficiently remove heat and water from the air stream passing there through. The heat from the air stream can primarily be latent heat, although some sensible heat can also be removed from the air by the desiccant. Because the flow rate of liquid desiccant through the LAMEE 6 is high, a temperature increase of the desiccant stream between the inlet 34 and the outlet 28 of the LAMEE 6 is small, compared to if the flow rate was low.

[0058] In an example, the flow of liquid desiccant to the LAHX or LLHX 32 can be relatively constant and the flow of liquid desiccant through the modulating valve 68 can be variable. It is recognized that in other examples the flow of liquid desiccant to the LAHX or LLHX 32 can also be variable.

[0059] The regenerator 52 can include any type of device capable of separating liquid water from the liquid desiccant. For example, the regenerator 52 can include, but is not limited to, vacuum multi-effect membrane distillation (VMEMD), electro-dialysis, reverse osmosis filtration, a gas boiler with condenser, a vacuum assisted generator, multi-stage flash, membrane distillation, and combinations thereof. The type of energy input to the regenerator 52 can include, for example, electrical power, mechanical power, or heat. The type of energy

input depends on the technology used for regeneration of the liquid desiccant. Although the regenerator 52 is shown as a single unit in FIG. 1, the regenerator 52 can represent more than one unit operation. For example, the regeneration system 11 can include a heat recovery unit upstream of the regeneration unit. This is described further below in reference to FIGS. 2 and 4.

[0060] The LAHX or LLHX 32 can include any type of device suitable for cooling the liquid desiccant. For example, the LAHX or LLHX 32 can include, but is not limited to, a polymer fluid cooler (with evaporative cooling capability), a plate exchanger, and combinations thereof. In an example, the LAHX or LLHX 32 can provide air cooling to the liquid desiccant, using the outdoor air outside of the conditioning system 10. In another example, the LAHX or LLHX 32 can provide liquid cooling to the liquid desiccant using another cooling fluid. In an example, the LAHX or LLHX 32 can be located external to the process plenum 4 or the other components of the conditioning system 10. In an example, the LAHX or LLHX 32 can be supplemented with an evaporative cooler for use as needed, depending on outdoor air conditions. For example, the LAHX can be supplemented with evaporative cooling sprays such that the tubes can be sprayed with water to enhance the cooling. In an example, an evaporative cooler LAHX 32 can use water recovered from the regeneration system 11 as make up water for the LAHX 32.

[0061] The design of the regeneration system 11 in combination with the desiccant dryer LAMEE 6 can facilitate operation of the conditioning system 10 with little to no external water consumption. The LAMEE 6 can remove the water from the air stream and use that water (which is separated from the desiccant for regeneration of the desiccant) as the make up water supply for one or more evaporative coolers in the conditioning system 10. The recovered water can be stored in the tank 36 and can be used as needed. Operation of evaporative coolers, like the evaporative cooler 8, can commonly require a significant amount of water. The conditioning system 10 having the regeneration system 11 can eliminate or markedly decrease the external water needed to operate the system 10. In an example, the system 10 can be generally water neutral. In an example, the system 10 can include an external water supply as back up in the event that additional water is needed.

[0062] In an example, the LAHX or LLHX 32 may require make up water in an example in which the LAHX or LLHX 32 includes evaporative cooling for use as needed. The evaporative cooling can be utilized when the outdoor air is at high dry bulb temperatures and air cooling of the liquid desiccant is not sufficient to meet a set point temperature for the desiccant delivered to the LAMEE 6. It is recognized that the recovered water from the regenerator system 11 can be sufficient in some cases to provide the make up water requirements for the evaporative cooler 8, as well as an evaporative cooler LAHX 32.

[0063] The design of the regeneration system 11 in combination with the desiccant dryer LAMEE 6 can also improve operation of the evaporative cooler 8 since water can be collected

directly from the atmosphere. As such, the water recovered from the liquid desiccant in the regenerator 52 can be high quality water, which can be ideal for many cooling applications, including evaporative coolers. Such high quality water can increase the lifespan of the media in the evaporative cooler 8 and can decrease required maintenance on the cooler. In contrast, if the water supplied to the evaporative cooler 8 is potable water from wells or surface water sources, in some cases, mineral build up or scaling can occur, which may require the system 10 to include management of mineral concentrations or other water treatment units. In summary, the design described herein can reduce or eliminate overall water consumption of the conditioning system 10, as well as improve operation of the evaporative cooler 8.

[0064] The system controller 50 can manage operation of the conditioning system 10, including the regeneration system 11. The system controller 50 can include hardware, software, and combinations thereof to implement the functions attributed to the controller herein. The system controller 50 can be an analog, digital, or combination analog and digital controller including a number of components. As examples, the controller 50 can include ICB(s), PCB(s), processor(s), data storage devices, switches, relays, etcetera. Examples of processors can include any one or more of a microprocessor, a controller, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field-programmable gate array (FPGA), or equivalent discrete or integrated logic circuitry. Storage devices, in some examples, are described as a computer-readable storage medium. In some examples, storage devices include a temporary memory, meaning that a primary purpose of one or more storage devices is not long-term storage. Storage devices are, in some examples, described as a volatile memory, meaning that storage devices do not maintain stored contents when the computer is turned off. Examples of volatile memories include random access memories (RAM), dynamic random access memories (DRAM), static random access memories (SRAM), and other forms of volatile memories known in the art. The data storage devices can be used to store program instructions for execution by processor(s) of the controller 50. The storage devices, for example, are used by software, applications, algorithms, as examples, running on and/or executed by the controller 50. The storage devices can include short-term and/or long-term memory, and can be volatile and/or non-volatile. Examples of non-volatile storage elements include magnetic hard discs, optical discs, floppy discs, flash memories, or forms of electrically programmable memories (EPROM) or electrically erasable and programmable (EEPROM) memories.

[0065] The system controller 50 can be configured to communicate with conditioning system 10 and components thereof via various wired or wireless communications technologies and components using various public and/or proprietary standards and/or protocols. For example, a power and/or communications network of some kind may be employed to facilitate communication and control between the controller 50 and the conditioning system 10. In one

example, the system controller 50 may communicate with the conditioning system 10 via a private or public local area network (LAN), which can include wired and/or wireless elements functioning in accordance with one or more standards and/or via one or more transport mediums. In one example, the system 10 can be configured to use wireless communications according to one of the 802.11 or Bluetooth specification sets, or another standard or proprietary wireless communication protocol. Data transmitted to and from components of the system 10, including the controller 50, can be formatted in accordance with a variety of different communications protocols. For example, all or a portion of the communications can be via a packet-based, Internet Protocol (IP) network that communicates data in Transmission Control Protocol/Internet Protocol (TCP/IP) packets, over, for example, Category 5, Ethernet cables.

[0066] The system controller 50 can include one or more programs, circuits, algorithms or other mechanisms for controlling the operation of the conditioning system 10. For example, the system controller 50 can be configured to control the valve 68 in order to regulate, and vary, as needed, a volume of desiccant diverted to the regeneration system. In an example, the system controller 50 can control the components to maintain a low humidity level or low temperature of the supply air. Such control can be based on variable sensible and latent loads in the enclosed space. The controller 50 can respond to changing outdoor air conditions or changing requirements for ventilation to the enclosed space. In an example, the system controller 50 can control or vary an amount of outdoor air added to the plenum 4.

[0067] FIG. 2 depicts another example conditioning system 100 including a regeneration system 111. The conditioning system 100 can include many of the components and functions of the conditioning system 10 of FIG. 1. The conditioning system 100 can include a heat recovery exchanger (HRE) 180, in combination with a regenerator or regeneration unit 152, both of which can be part of the regeneration system 111. The HRE 180 is not required for operation of the conditioning system 100, but, as described below, can facilitate improved efficiency and performance of the regeneration system 111. A second desiccant circuit 166 can include the HRE 180 and the regenerator 152.

[0068] As stated above in reference to FIG. 1, the regenerator 152 can include any type of device capable of separating water from the desiccant. An example is described below and illustrated in FIG. 3 which uses a thermally driven separation process. The regenerator 152 can include a heat source 151 configured to heat up the desiccant in order to vaporize the water in the desiccant. (See FIG. 3.) The HRE 180 can pre-heat the desiccant before the desiccant is heated up by the heat source 151. Given the inclusion of the HRE 180, less heat may be required from the heat source 151 to vaporize the water in the desiccant stream, as compared to if the regenerator 152 operated without the HRE 180.

[0069] In FIG. 2, the desiccant from the tank 126 passes through the HRE 180 prior to passing into the regenerator 152. In contrast, the regenerator 52 in FIG. 1 is shown receiving the desiccant directly from the tank 26 at the inlet 70. The HRE 180 can be configured to exchange heat between the concentrated desiccant exiting the regenerator 152 and the desiccant entering the regenerator 152. The desiccant can enter the HRE 180 at an inlet 181 and at a temperature T1. The desiccant can exit the HRE 180 at an outlet 182 and at a temperature T2 which can be higher than the temperature T1. The concentrated desiccant can enter the HRE 180 at an inlet 183 and at a temperature T3. The concentrated desiccant can exit the HRE 180 at an outlet 184 and at a temperature T4 that can be lower than the temperature T3. In other words, the HRE 180 can be configured for the concentrated desiccant coming from the regenerator 152 to reject heat to the mixed desiccant coming from the tank 126. As a result, the mixed desiccant exiting the HRE 180 at the outlet 182 can be pre-heated prior to entering the regenerator 152.

[0070] The concentrated desiccant exiting the HRE 180 at the outlet 184 can be transported to the tank 126 for storage and for circulation back to the LAMEE 106. It can be advantageous for the concentrated desiccant to be at a reduced temperature T4 to decrease or maintain a temperature of the desiccant in the tank 126. The temperature of the desiccant in the tank 126 can directly impact an amount of heat that has to be rejected from the desiccant in the heat exchanger 132. Thus the HRE 180 can serve two benefits - heating the mixed desiccant prior to regeneration and cooling the concentrated desiccant prior to circulation through the heat exchanger 132 and the LAMEE 106.

[0071] The heat source 151 is shown generally as being provided to the regenerator 152. FIG. 3 shows an exemplary heat source and the path of the desiccant through the HRE 180 and then through the one or more heat sources 151, prior to entering the regenerator 152.

[0072] As described above, the conditioning system 100 can receive a scavenger air stream or a process air stream, or a combination thereof. In an example, the conditioning system 100 can include two working air streams (and two plenums) or one working air stream and one plenum. In such an example with two working air streams, the outdoor (scavenger) air can be used to produce cold water in the evaporative cooler (EC) 108 (arranged in the first plenum 104) and such cold water can be used to provide cooling to a process air stream passing through a second (process air) plenum.

[0073] The following numbers are example conditions for the conditioning system 100, based on a modeled conditioning system.

[0074] The outdoor air enters the plenum 104 at a dry bulb temperature of 90 degrees Fahrenheit (32.2 degrees Celsius), a wet bulb temperature of 85 degrees Fahrenheit (29.4 degrees Celsius), a moisture content of 25.2 g/kg, and a flow rate of 30,000 SCFM. The liquid

desiccant enters the desiccant dryer LAMEE 106 at the inlet 134 at a temperature of 34 degrees Celsius, a concentration of 38% lithium chloride (LiCl) and a flow rate of 250 GPM.

[0075] After exiting the desiccant dryer LAMEE 106, the scavenger air is at a dry bulb temperature of 35.6 degrees Celsius and a moisture content of 15.2 g/kg. The moisture removal rate is 613.4 kg/hr (0.170 kg/s) and the total cooling is 377 kW.

[0076] The desiccant exits the LAMEE 106 at the outlet 128 at a temperature of 40.4 degrees Celsius and the concentration C1 is 37.7% LiCl. The dilute desiccant enters the tank 126 at the concentration C1 and mixes with desiccant in the tank 126. The concentration C2 of the mixed desiccant exiting the tank 126 is 38.0% LiCl and the mixed desiccant is transported from the tank 126, via the pump 142, at a flow rate of 275 GPM. A modulating valve 168 can divert 25 GPM or 1.58 L/s of desiccant to the HRE 180. The remaining 250 GPM (15.8 L/s) of desiccant can flow to the heat exchanger 132 (and then to the LAMEE 106). In this particular example, nine percent (9%) of the desiccant exiting the tank 126 is diverted to the regenerator 152. As described above, in an example, the flow to the heat exchanger 132 can be generally constant and a flow to the HRE 180 can be variable, depending, for example, on the regeneration load.

[0077] The heat exchanger 132 can decrease a temperature of the desiccant in the first desiccant circuit 124 such that the temperature of the desiccant at the inlet 134 is 34 degrees Celsius.

[0078] The desiccant (at the concentration C2) entering the HRE 180 at the inlet 181 is heated up in the HRE 180 from the temperature T1 (40.6 degrees Celsius) to the temperature T2 (55.3 degrees Celsius) at the outlet 182. The increased-temperature desiccant then enters the regenerator 152 at an inlet 153. As a result of the separation process that occurs in the regenerator 152 (see FIG. 3 and description below), the desiccant exits the regenerator 152 at an outlet 155 with the concentration C3 equal to 41.7% LiCl and the temperature T3 (60.0 degrees Celsius) greater than the temperature T2. The concentrated desiccant stream (C3) can be transported to the tank 126 via the pump 176. The temperature T1 (40.6 degrees Celsius) at the inlet 181 of the HRE 180 can be slightly higher than the temperature at the LAMEE outlet 128 (40.4 degrees Celsius) because the desiccant from the outlet 128 mixes with the hot, concentrated desiccant coming back to the tank 126 at the temperature T4 (43.5 degrees Celsius). The values provided above for the temperatures T1-T4 are exemplary based on the modeled system. It is recognized that temperatures can depend on, at least in part, the concentration C2, the concentration C1 and the concentration target for the inlet 134 to the LAMEE 106.

[0079] The collected water can exit the regenerator 152 at the outlet 174 at a rate of 0.17 L/s or 2.7 GPM. The water can be transported to the tank 136, via the pump 178, for use as make up water by the evaporative cooler 108.

[0080] The concentrated desiccant at the concentration C3 can exit the HRE 180 at the outlet 184 and at the temperature T4 (43.5 degrees Celsius) and can then be delivered back to the tank 126 at a rate of 1.41 L/s or 22.3 GPM. The concentrated desiccant (C3) at 41.7% LiCl mixes with the dilute desiccant (C1) at 37.7% LiCl to produce the concentration C2 at 38.0% LiCl.

[0081] These are exemplary values. It is recognized that the capacity for the heat exchanger 132, HRE 180 and regenerator 152 can vary depending on the load on the desiccant dryer LAMEE 106. Operation of the system 100 can be controlled, in an example, by a system controller 150 that can operate similar to the system controller 50 described above. As described above in reference to FIG. 1, the modulating valve 168 can be used to control the flow of desiccant from the tank 126 through the regenerator and thereby control the concentration C2, including maintaining the concentration C2 at or near a target concentration for the inlet 134.

[0082] FIG. 3 depicts a portion of the regeneration system 111 of FIG. 2 that includes the HRE 180, the regeneration unit 152 and one or more heat sources 151. As described above in reference to FIG. 2, the HRE 180 can receive the mixed desiccant (from the tank 136) at the inlet 181 (at an increased temperature) and the concentrated desiccant (from the regenerator 152) at the inlet 183. The concentrated, increased-temperature desiccant exiting the regenerator 152 (C3, T3) can transfer heat to the mixed desiccant from the tank 136 (C2, T1). The concentrated desiccant at the outlet 184 (C3, T4) can flow back to the tank 136. The mixed desiccant at the outlet 182 (C2, T2) can flow to the regeneration unit 152.

[0083] In an example, the one or more heat sources 151 can include solar collectors 185 and an auxiliary heater 187. Prior to passing into the regeneration unit 152, the mixed desiccant can flow through the one or more solar collectors 185 that can use energy from the sun 186 to further increase a temperature of the desiccant before the desiccant flows through the regenerator 152. In an example, the two collectors 185 of FIG. 3 can be evacuated tube solar collectors that can circulate the desiccant through the tubes prior to passing the desiccant to the regenerator 152. In another example, the solar collectors can be a flat plate design.

[0084] The regeneration system 111 can include an auxiliary heater 187 located between the solar collectors 185 and the regeneration unit 152. The auxiliary heater 187 can use various sources to increase a temperature of the desiccant before the desiccant enters the regeneration unit 152. Such sources can include, but are not limited to, gas, waste heat, and combustion of a

fuel. The auxiliary heater 187 can run intermittently depending on, at least in part, the load of the regeneration unit 152 and heating (if any) provided by the solar collectors 185.

[0085] The solar collectors 185 and the heater 187 can increase a temperature of the desiccant prior to separating the water and the desiccant in the regeneration unit 152. The vapor pressure can increase quickly as the desiccant temperature increases, resulting in a large flux of water vapor out of the desiccant stream. It is not required that the regeneration system 111 include both the tube collectors 185 and the auxiliary heater 187. In other examples, either the tube collectors 185 or the auxiliary heater 187 can be used. In other examples, other forms of heating can be used for heat sources 151 in addition or as an alternative to the tube collectors 185 and auxiliary heater 187.

[0086] The desiccant exiting the auxiliary heater 187 can enter the regeneration unit 152 as hot desiccant. In an example, a temperature at an inlet of the regenerator 152 can be approximately 80 degrees Celsius. In order for the regenerator 152 to be effective, the desiccant stream has to be hot enough to vaporize the water from the desiccant stream. In an example, the regeneration unit 152 can separate the water and desiccant using a membrane distillation separation process. In such an example, and as detailed below, the regeneration unit 152 can include a vaporizing section 188 and a condensing section 179.

[0087] The vaporizing section 188 can have a plurality of channels 189 and a corresponding membrane 190 for each of the channels 189. The desiccant can be directed into each of the channels and can flow inside and down the channels 189. The materials that form the membrane can be permeable to water but not permeable for the desiccant. Each membrane 190 can contact an exterior of its corresponding channel such that the membrane 190 creates a seal around the channel 189. As the hot desiccant travels down the channels 189, water can be released from the desiccant, as water vapor. The water vapor can permeate through the membranes 190, and thus out of the channels 189. The desiccant, which can remain in liquid form, can be contained inside the channels 189 by the membranes 190 and can travel down the channels to the manifold 191. The manifold 191 can transport the increased concentration desiccant (C3) out of the regenerator 152 and to the HRE 180. As discussed above, the increased concentration desiccant can be cooled in the HRE 180 prior to being transported to the tank 136.

[0088] The water vapor from the vaporizing section 188 can travel to the condensing section 179, which can include a plurality of channels 192 that function as cooling channels 192. Although not shown in FIG. 3, the regeneration unit 152 can include an inlet to and an outlet from the channels 192 for the air source used to provide cooling to the water vapor. The water vapor can pass over the outside of the channels 192 and the water vapor can condense on the surface of the cooling channels 192 as a result of a cooling fluid flowing inside the channels 192.

The cooling fluid can be any fluid (liquid or gas) suitable for cooling the surrounding material such that the water vapor condenses on the exterior surfaces that form the channels 192. In an example, the cooling fluid can be air. The air can be from any source that is at favorable conditions for providing air cooling to the water vapor. Examples of the air source can include, but are not limited to, outdoor air or exhaust air from an outlet of the heat exchanger 132. In an example, a regeneration unit similar to unit 152 can be used in a conditioning system for a process air stream and such conditioning system can include an exhaust air stream that includes an exhaust LAMEE. In such an example, the exhaust air from the exhaust LAMEE outlet can be used as the air source for the air cooling channels 192. The air circulating through the channels 192 can be relatively humid, so long as the air is still relatively cool. In an example, the cooling fluid can be water.

[0089] The condensate (distilled water) can be collected through gravity by a water collection sump 193 at the bottom of the regeneration unit 152. The sump 193 can be at the bottom of or connected to the outlet 174 of the regeneration unit 152 and the distilled water can be transported from the sump 193 to other parts of the conditioning system, such as, for example, one or more evaporative coolers. In an example, as shown in FIG. 3, the water can be delivered to the tank 136 for use as make up water for the evaporative cooler 108. This can reduce or eliminate an external water supply for operating the conditioning system 100.

[0090] FIG. 3 illustrates one example of a regeneration unit that can include a thermally-driven separation process. It is recognized that other types of regeneration can be used to separate the desiccant from the water, including, but not limited to, those listed above in reference to FIG. 1.

[0091] FIG. 4 depicts another example conditioning system 200 including a regeneration system 211. FIG. 4 illustrates exemplary sources of heat that can be used to drive operation of a regenerator 252 in the regeneration system 211. FIG. 4 also illustrates an exemplary design having a concentrated desiccant storage tank 294 and a distilled water storage tank 296, described further below.

[0092] A desiccant dryer LAMEE 206 is shown in FIG. 4 and, in an example, can be used in combination with an evaporative cooler located downstream of the LAMEE 206, as described above in reference to FIGS. 1 and 2. In other examples, other coolers can be included in the system 200, such as, for example, a liquid to air heat exchanger (LAHX) located between the desiccant dryer LAMEE and the evaporative cooler.

[0093] As described above in reference to FIGS. 2 and 3, the desiccant from the LAMEE 206 can be directly heated (using any type of heat source) prior to circulating the desiccant through the regeneration unit 152. In another example, the desiccant can be heated up using a heat

transfer fluid. The heat transfer fluid can be heated and then transfer heat to the desiccant – this is shown in FIG. 4.

[0094] The conditioning system 200 can include a heating fluid circuit 298 for circulating a heating fluid through the regenerator 252 of the regeneration system 211. The heating fluid circuit 298 can include a solar thermal array 285 and an auxiliary heater 287. In an example, the solar thermal array 285 can be configured similar to the solar collectors 185 of FIG. 3. The solar thermal array 285 can include first and second solar devices 285a and 285b, which can include, for example, flat plate collectors or evacuated tube collectors. The auxiliary heater 287 can be similar to the auxiliary heater 187 of FIG. 3.

[0095] The regenerator or regeneration unit 252 can be similar to the unit 152 shown in FIG. 3, but can also include a liquid-to-liquid heat exchanger (LLHX) contained within the heating fluid circuit 298. The LLHX can be inside the regenerator unit 252 upstream of the vaporizing section (see section 188 of FIG. 3) or the LLHX can be external to the regeneration unit 252 and located upstream of the desiccant inlet to the regeneration unit. Instead of heating up the desiccant with the solar thermal array 285 or auxiliary heater 287, the solar thermal array 285 or auxiliary heater 287 can heat up the heating fluid and then the heating fluid can transfer heat to the desiccant in the LLHX. The hot desiccant can then be processed through the regenerator 252 as described above in reference to FIG. 3.

[0096] In an example, the heating fluid can be a glycol solution. The heating fluid can be any type of liquid suitable for transferring heat to the desiccant such that the desiccant is heated up prior to passing through the vaporizing section in the regenerator 252. Other examples include, but are not limited to, water and oil.

[0097] One or both of the solar thermal array 285 and the heater 287 can be an intermittent or continuous heat source. In an example, the auxiliary heater 287 can use waste heat from another source within the system 200. In another example, the auxiliary heater 287 can use gas as a heat source.

[0098] In an example, the regenerator system 211 can operate when heat (solar heat, waste heat, etc.) is available to operate the regenerator and separate the water from the desiccant. The concentrated desiccant from the regenerator 252 can be transported to a concentrated desiccant storage tank 294. Similarly, the distilled water from the regenerator 252 can be transported to a distilled water storage tank 296. The concentrated desiccant can be drawn from the storage tank 294 as needed and supplied to a desiccant tank 226 (as shown in FIG. 4) via a pump 295. Alternatively, the concentrated desiccant can be transported directly to the heat exchanger 232 or to the LAMEE 206. Similarly, the distilled water can be drawn from the storage tank 296 as needed and supplied to one or more evaporative coolers in the conditioning

system 200 via a pump 297. One or both of the tanks 294 and 296 can be included in the other conditioning systems described herein and shown in FIGS. 1 and 2.

[0099] The regeneration system 211 can operate similar to the regen systems 11 and 111 of FIGS. 1 and 2, respectively, and a portion of the desiccant from the tank 226 can be transported to the regenerator 252 for regeneration. A larger portion of the desiccant from the tank 226 can be transported to the heat exchanger 232 and back to the LAMEE 206. Instead of a modulating valve (see valves 68 and 168) as shown in FIGS. 1 and 2, the system 200 can include two pumps in fluid connection with the desiccant tank 226. A first pump 242 can deliver desiccant from the tank 226 to the LAMEE 206 and a second pump 243 can deliver desiccant from the tank 226 to the regenerator 252. This two pump design of FIG. 4 can also be used in the design of FIGS. 1 and 2. Similarly, the modulating valve design of FIGS. 1 and 2 can also be used in the design of FIG. 4. A system controller can control a flow rate of the desiccant to the LAMEE 206 and a flow rate of the desiccant to the regenerator 252. One or both of such flow rates can be constant or variable.

[00100] Although a heat recovery exchanger is not shown in FIG. 4, it is recognized that an HRE could be included in the conditioning system 200 upstream of the regenerator 252 and operate similar to the HRE 180 of FIG. 2.

[00101] FIG. 5 depicts an example system 300, which can include a plurality of desiccant dryer LAMEEs 306. Each of the desiccant dryer LAMEEs 306a, 306b and 306c can be part of a conditioning unit 301a, 301b and 301c, respectively, that can include an air plenum containing the desiccant dryer LAMEE and an evaporative cooler (EC) downstream of the desiccant dryer LAMEE. Each conditioning unit 301a, 301b and 301c can thus function similar to any of the conditioning systems described herein, including the conditioning systems 10 and 100 of FIGS. 1 and 2, respectively.

[00102] Instead of each conditioning unit 301a, 301b and 301c having its own regeneration system, the system 300 can include a centralized regenerator plant 303 having capacity to regenerate a portion of the desiccant from each of the LAMEEs 306a, 306b and 306c. The regenerator plant 303 can include some or all of the components described herein such as a heat recovery exchanger, heating fluid, solar thermal array, etc. For simplicity, these additional components are not specifically shown in FIG. 5, but rather a heat input to the plant 303 is generically shown in the schematic.

[00103] Each conditioning unit 301a, 301b and 301c can have a desiccant circuit 366a, 366b and 366c in fluid connection with a tank 326a, 326b and 326c and with the centralized regenerator plant 303. The desiccant in the desiccant circuits 366a, 366b and 366c can be at a concentration C2 at an inlet 370 to the regenerator plant 303. The desiccant can be regenerated in the plant 303 (as described above) such that a first outlet stream 371 exiting the plant 303 at

an outlet 372 can be concentrated desiccant at a concentration C3 and a second outlet stream 373 exiting the plant 303 at an outlet 374 can be distilled water. The concentrated desiccant can be transported to a concentrated desiccant storage tank 394 and the distilled water can be transported to a distilled water storage tank 396.

[00104] As described above in reference to FIG. 4, the concentrated desiccant from the storage tank 394 can be transported back to each of the units 301 via a centralized output stream 367 from the tank 394. The stream 367 can be fluidly connected to an input stream that forms part of the desiccant circuit 366 for each of the units 301. In an example, the concentrated desiccant at the concentration C3 can be delivered back to the tank 326 for each conditioning unit 301. The distilled water from the storage tank 396 can be supplied to each conditioning unit 301 via a water stream 375 from the storage tank 396. As described above, the distilled water can be used as make up water for one or more evaporative coolers in the conditioning units 301. The system 300 can also include an external water supply of potable/treated water which can be delivered via a water stream 377 that is in fluid connection with the water stream 375. Such external water can be used as backup for the conditioning system 300 if and when the distilled water is not sufficient as the make up water for the conditioning units 301.

[00105] In an example, the conditioning units 301 can be used to provide cooling for a data center, and the conditioning units 301 can be located on a roof of the data center. The example of FIG. 5 shows three conditioning unit 301. It is recognized that the system 300 can include any number of conditioning units. Depending on the number of conditioning units 301, more than one regenerator plant 303 can be used in combination with the conditioning units 301. In one example, the regenerator plant 303 can be housed within a desiccant treatment room that can be contained within the data center or external to the data center.

[00106] As shown in FIG. 5, each conditioning unit 301 can receive concentrated desiccant from the tank 394 and distilled water from the tank 396. In another example, each conditioning unit 301 can have a dedicated desiccant tank and dedicated water tank.

[00107] FIG. 6 shows an example conditioning system 400 that can be similar to the conditioning systems 10, 100 and 200 but can include an alternative design for the fluid circuits for regeneration. Only a portion of the system 400 is shown in FIG. 6 for simplicity and it is recognized that additional components can be included. For example, only a portion of a system cabinet 402 and plenum 404 is shown in FIG. 6, but it is recognized that the plenum 404 can include some or all of the additional components shown and described above in reference to FIGS. 1, 2 and 4.

[00108] The desiccant dryer LAMEE 406 can operate similar to the desiccant dryer LAMEEs described above. The dilute desiccant exiting the desiccant dryer LAMEE 406 at an outlet 428

can be split into two flow paths – a first flow path to a tank 426 or a second flow path directly to a regenerator 452 (via a desiccant circuit 466). The regenerator 452 can operate similar to the regenerators described above. The desiccant entering the regenerator 452 at an inlet 470 can be at a first concentration C1. The concentrated desiccant exiting the regenerator 452 at an outlet 472 can be at a third concentration C3 and can be transported to the tank 426 for mixing with the desiccant already in the tank 426. As such, the desiccant in the tank 426 can be at a second concentration C2 that is greater than the first concentration C1 and less than the third concentration C3.

[00109] In contrast to the designs shown in FIGS. 1, 2 and 4, instead of the dilute desiccant (at the concentration C1) mixing with the desiccant in the tank and then flowing to the regenerator (at the second concentration C2), the dilute desiccant exiting the LAMEE 406 in FIG. 6 is transported directly to the regenerator 452 at the first concentration C1 (via a pump 467). All of the desiccant exiting the tank 426 at the second concentration C2 is circulated through the heat exchanger 432 and back through the LAMEE 406, rather than selectively directing a portion of the desiccant at the second concentration C2 to the regenerator 452. Thus in the design of FIG. 6 the split of the desiccant flow path is at the outlet 428 of the LAMEE 406, rather than at an outlet of the tank 426.

[00110] The pump 467 is shown in the desiccant circuit 466 and is an example of a device for regulating or controlling a flow of the dilute desiccant to the regenerator 452. As described above in reference to the other example conditioning systems, in an example, generally during operation of the system only a portion of the dilute desiccant exiting the LAMEE 406 is sent to the regenerator 452. The amount of desiccant transported to the regenerator 452 can be variable and a percentage of the desiccant at the outlet 428 can be directed to the regenerator and a remaining percentage of the desiccant at the outlet 428 can be directed to the tank 426. Such percentages can depend in part on a load of the conditioning system 400.

[00111] FIG. 7 illustrates an example method 700 for conditioning air for delivery to an enclosed space according to the example conditioning systems described above. The method 700 can reduce or eliminate an external water supply to the conditioning systems. The method 700 can include at 702 directing air through a desiccant dryer LAMEE arranged in a process plenum and at 704 directing a concentrated desiccant into and through the LAMEE to remove moisture from the air. In an example, the LAMEE at 702 can also be configured such that the desiccant can also remove heat from the air, such that a temperature of the desiccant at the LAMEE outlet is higher than a temperature of the desiccant at the LAMEE inlet. The air stream flowing through the LAMEE can be outdoor air, hot supply air from the enclosed space, or a combination thereof. The conditioning systems can include one working air stream (which

passes through the process plenum) or two working air streams – a first air stream containing scavenger air and a second air stream containing process air.

[00112] The method 700 can include at 706 regenerating the diluted desiccant exiting the LAMEE to separate the water from the desiccant, before recirculating the desiccant back through the LAMEE. In an example, only a portion of the desiccant exiting the LAMEE can be regenerated. The regeneration step can result in a concentrated desiccant output stream and a distilled water output stream.

[00113] The method 700 can include at 708 directing concentrated desiccant from the regenerator back to a fluid circuit for the desiccant dryer LAMEE. In an example, the concentrated desiccant can be directed to a desiccant tank which can also receive the diluted desiccant exiting the LAMEE. The diluted desiccant and concentrated desiccant can mix such that the desiccant in the tank can be at a concentration higher than the diluted desiccant exiting the LAMEE and lower than the concentrated desiccant exiting the regenerator. The desiccant tank can be contained within the desiccant fluid circuit that passes through the LAMEE.

[00114] The method 700 can include at 710 directing distilled water from the regenerator to one or more evaporative coolers in the conditioning system. In an example, the one or more evaporative coolers can include an evaporative cooler arranged in the plenum downstream of the desiccant dryer LAMEE, and the recovered water from the regenerator can be used as make up water for operation of the evaporative cooler. In an example in which the conditioning system uses two working air streams and two plenums, the evaporative cooler in the first plenum can be used to cool the water passing there through and the cooled water can be delivered to an LAHX in the second plenum to cool a process air stream passing through the second plenum. In an example, the one or more evaporative coolers can include a LAHX in the desiccant circuit, which can be configured to cool the desiccant prior to flowing the desiccant through the desiccant dryer LAMEE. The LAHX can be internal or external to the plenum containing the desiccant dryer LAMEE. The LAHX can include evaporative cooling capabilities and can use recovered water from the regenerator as make up water for operation of the evaporative cooler LAHX. The use of the water recovered from regeneration by one or more evaporative coolers in the system can markedly reduce or eliminate the external water supply for operation of the conditioning system.

[00115] It is recognized that the method 700 for conditioning the air can include other steps not included in FIG. 7. Such other steps can include, but are not limited to, directing air through a pre-cooler or LAHX arranged in the process plenum downstream of the LAMEE and upstream of the evaporative cooler. In an example, directing air through the LAMEE in 702 can include mixing process air with outdoor air upstream of the LAMEE to create a mixed air stream that passes through the process plenum. In an example, the method 700 can include removing a

portion of the air in the mixed stream, at a location downstream of the pre-cooler and upstream of the evaporative cooler, to create an exhaust air stream and utilizing the exhaust air stream to cool the cooling fluid circulating through the pre-cooler. In an example, the method 700 can include directing cooled water from the evaporative cooler in the first plenum to an LAHX in the second plenum to cool process air passing through the second plenum.

[00116] The above detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments in which the invention can be practiced. These embodiments are also referred to herein as “examples.” Such examples can include elements in addition to those shown or described. However, the present inventors also contemplate examples in which only those elements shown or described are provided. Moreover, the present inventors also contemplate examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

[00117] All publications, patents, and patent documents referred to in this document are incorporated by reference herein in their entirety, as though individually incorporated by reference. In the event of inconsistent usages between this document and those documents so incorporated by reference, the usage in the incorporated reference(s) should be considered supplementary to that of this document; for irreconcilable inconsistencies, the usage in this document controls.

[00118] In this document, the terms “a” or “an” are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of “at least one” or “one or more.” In this document, the term “or” is used to refer to a nonexclusive or, such that “A or B” includes “A but not B,” “B but not A,” and “A and B,” unless otherwise indicated. In this document, the terms “including” and “in which” are used as the plain-English equivalents of the respective terms “comprising” and “wherein.” Also, in the following claims, the terms “including” and “comprising” are open-ended, that is, a system, device, article, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

[00119] Method examples described herein can be machine or computer-implemented at least in part. Some examples can include a computer-readable medium or machine-readable medium encoded with instructions operable to configure an electronic device to perform methods as described in the above examples. An implementation of such methods can include

code, such as microcode, assembly language code, a higher-level language code, or the like. Such code can include computer readable instructions for performing various methods. The code may form portions of computer program products. Further, the code can be tangibly stored on one or more volatile or non-volatile tangible computer-readable media, such as during execution or at other times. Examples of these tangible computer-readable media can include, but are not limited to, hard disks, removable magnetic disks, removable optical disks (e.g., compact disks and digital video disks), magnetic cassettes, memory cards or sticks, random access memories (RAMs), read only memories (ROMs), and the like.

[00120] Examples, as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules may be hardware, software, or firmware communicatively coupled to one or more processors in order to carry out the operations described herein. Modules may hardware modules, and as such modules may be considered tangible entities capable of performing specified operations and may be configured or arranged in a certain manner. In an example, circuits may be arranged (e.g., internally or with respect to external entities such as other circuits) in a specified manner as a module. In an example, the whole or part of one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware processors may be configured by firmware or software (e.g., instructions, an application portion, or an application) as a module that operates to perform specified operations. In an example, the software may reside on a machine-readable medium. In an example, the software, when executed by the underlying hardware of the module, causes the hardware to perform the specified operations. Accordingly, the term hardware module is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically configured (e.g., hardwired), or temporarily (e.g., transitorily) configured (e.g., programmed) to operate in a specified manner or to perform part or all of any operation described herein. Considering examples in which modules are temporarily configured, each of the modules need not be instantiated at any one moment in time. For example, where the modules comprise a general-purpose hardware processor configured using software; the general-purpose hardware processor may be configured as respective different modules at different times. Software may accordingly configure a hardware processor, for example, to constitute a particular module at one instance of time and to constitute a different module at a different instance of time. Modules may also be software or firmware modules, which operate to perform the methodologies described herein.

[00121] The above description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more aspects thereof) may be used in combination with each other. Other embodiments can be used, such as by one of ordinary skill in the art upon reviewing the above description. Also, in the above Detailed Description, various

features may be grouped together to streamline the disclosure. This should not be interpreted as intending that an unclaimed disclosed feature is essential to any claim. Rather, inventive subject matter may lie in less than all features of a particular disclosed embodiment. Thus, the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separate embodiment, and it is contemplated that such embodiments can be combined with each other in various combinations or permutations. The scope of the invention should be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

[00122] The present application provides for the following exemplary embodiments or examples, the numbering of which is not to be construed as designating levels of importance:

[00123] Example 1 provides a system for conditioning air for an enclosed space. The system can include a plenum having a plenum inlet and outlet, the plenum configured to direct an air flow path from the plenum inlet to the plenum outlet, and a liquid-to-air membrane energy exchanger (LAMEE) arranged inside the plenum. The LAMEE can comprise a desiccant flow path separated from the air flow path by a membrane. The LAMEE can be configured to circulate a desiccant through the desiccant flow path and remove water from air in the air flow path. An energy reduction of the air in the air flow path between a LAMEE inlet and outlet can be about equal to an energy gain of the desiccant in the desiccant flow path between the LAMEE inlet and outlet, and essentially all of the energy removed from the air is transferred to the desiccant. The system can also include a regeneration system in fluid connection with the LAMEE and having a regeneration inlet configured to receive a dilute desiccant stream. The regeneration system can be configured to separate water from desiccant in the dilute desiccant stream, the regeneration system having a first outlet for discharging a concentrated desiccant stream and a second outlet for discharging a water stream. The system can also include one or more cooling components arranged inside the plenum, and at least a portion of the water stream from the regeneration system can be used by the one or more cooling components as make up water for operation of the one or more cooling components.

[00124] Example 2 provides the system of Example 1 optionally configured such that the regeneration system comprises a regeneration unit that thermally separates the water and the desiccant in the dilute desiccant stream.

[00125] Example 3 provides the system of Example 2 optionally configured such that the regeneration system comprises a heat exchanger arranged upstream of the regeneration unit and configured to increase a temperature of the dilute desiccant stream before the dilute desiccant stream enters the regeneration unit.

[00126] Example 4 provides the system of Example 3 optionally configured such that the heat exchanger receives the concentrated desiccant stream from the regeneration unit and uses the concentrated desiccant stream to transfer heat to the dilute desiccant stream.

[00127] Example 5 provides the system of any of Examples 2-4 optionally configured such that the regeneration system comprises a heat source to increase a temperature of the dilute desiccant stream.

[00128] Example 6 provides the system of Example 5 optionally configured such that the heat source is solar.

[00129] Example 7 provides the system of Example 1 optionally configured such that the regeneration system comprises a regeneration unit that utilizes non-thermal energy to separate the water and the desiccant in the dilute desiccant stream.

[00130] Example 8 provides the system of any of Examples 1-7 optionally configured such that the concentrated desiccant stream is transported to a desiccant tank configured to receive the concentrated desiccant stream and a dilute desiccant stream exiting the LAMEE.

[00131] Example 9 provides the system of Example 8 optionally configured such that an output stream from the desiccant tank is at a concentration higher than a concentration of the desiccant in the dilute desiccant stream and lower than a concentration of the desiccant in the concentrated desiccant stream.

[00132] Example 10 provides the system of Example 9 optionally configured such that the output stream from the desiccant tank is transported to at least one of the regeneration system and to the LAMEE for recirculation.

[00133] Example 11 provides the system of Example 10 optionally further comprising a modulating valve configured to control a distribution of the output stream from the desiccant tank to the regeneration system and to the LAMEE.

[00134] Example 12 provides the system of Example 11 optionally configured such that less than 50 percent by volume of the output stream from the desiccant tank is transported to the regeneration system.

[00135] Example 13 provides the system of Example 11 optionally configured such that less than 25 percent by volume of the output stream from the desiccant tank is transported to the regeneration system.

[00136] Example 14 provides the system of any of Examples 10-13 optionally configured such that a portion of the output stream from the desiccant tank being transported to the LAMEE passes through a heat exchanger prior to being circulated through the LAMEE. The heat exchanger can reduce a temperature of the output stream from the desiccant tank.

[00137] Example 15 provides the system of Example 8 optionally configured such that a first portion of the dilute desiccant stream exiting the LAMEE is transported to the desiccant tank

and a second portion of the dilute desiccant stream exiting the LAMEE is transported to the regeneration system.

[00138] Example 16 provides the system of Example 15 optionally configured such that the first and second portions are variable during operation of the system.

[00139] Example 17 provides the system of any of Examples 1-16 optionally configured such that a concentration of water in the desiccant at the LAMEE outlet is higher than a concentration of water in the desiccant at the LAMEE inlet.

[00140] Example 18 provides the system of any of Examples 1-17 optionally configured such that a temperature of the desiccant at the LAMEE outlet is higher than a temperature of the desiccant at the LAMEE inlet.

[00141] Example 19 provides the system of any of Examples 1-18 optionally configured such that the LAMEE is a two-fluid LAMEE having a first fluid and a second fluid, and wherein the first fluid is the air in the air flow path and the second fluid is the desiccant in the desiccant flow path.

[00142] Example 20 provides the system of any of Examples 1-19 optionally configured such that the one or more cooling components comprises an evaporative cooler arranged downstream of the LAMEE.

[00143] Example 21 provides the system of any of Examples 1-20 optionally configured such that a quantity of water from the regeneration system is sufficient as the make up water for operation of the evaporative cooler such that the evaporative cooler operates without an external water supply.

[00144] Example 22 provides the system of any of Example 20 or 21 optionally configured such that

[00145] the LAMEE arranged inside the plenum is a first LAMEE, and the evaporative cooler arranged downstream is a second LAMEE.

[00146] Example 23 provides the system of Example 22 optionally configured such that the second LAMEE adiabatically cools the air passing through the process plenum such that the air exiting the second LAMEE is conditioned air for delivery to an enclosed space.

[00147] Example 24 provides the system of any of Examples 1-23 optionally configured such that the one or more cooling components comprises an evaporative cooler configured to cool the desiccant prior to circulating the desiccant through the LAMEE.

[00148] Example 25 provides the system of Example 24 optionally configured such that the evaporative cooler is external to the plenum.

[00149] Example 26 provides the system of any of Examples 21-25 optionally further comprising a liquid to air heat exchanger (LAHX) arranged between the LAMEE and the

evaporative cooler, the LAHX configured to pre-cool the air prior to passing the air through the evaporative cooler.

[00150] Example 27 provides the system of any of Examples 1-26 optionally configured such that the plenum is a first plenum configured to receive a scavenger air stream, and the system further comprises a second plenum configured to receive a process air stream from an enclosed space.

[00151] Example 28 provides the system of Example 27 optionally configured such that the one or more cooling components comprises an evaporative cooler arranged downstream of the LAMEE in the first plenum, the evaporative cooler configured to produce reduced temperature water. The reduced temperature water can be transported to an LAHX arranged in the second plenum, and the reduced temperature water can be used to cool the process air stream flowing through the LAHX.

[00152] Example 29 provides a system for conditioning air for an enclosed space, the system can include a plenum configured to direct air from an inlet to an outlet thereof, a desiccant dryer liquid-to-air membrane energy exchanger (LAMEE) arranged inside the plenum and configured for the air to pass there through, the desiccant dryer LAMEE configured to use a desiccant flowing there through to remove water from the air. The desiccant and air can be separated in the LAMEE by a membrane. The LAMEE can facilitate an energy exchange between the air and the desiccant, and the desiccant can collect essentially all of the energy removed from the air. The system can also include an evaporative cooler arranged inside the plenum downstream of the desiccant dryer LAMEE and configured for the air to pass there through, the evaporative cooler configured to cool at least one of the air and water circulating through the evaporative cooler. The system can also include a fluid circuit coupled to the desiccant dryer LAMEE and the evaporative cooler. The fluid circuit can comprise a regenerator configured to separate water and desiccant in a desiccant stream. The fluid circuit can be configured to transport at least a portion of the water removed from the air by the desiccant dryer LAMEE and separated in the regenerator to the evaporative cooler for use as make up water for operation of the evaporative cooler.

[00153] Example 30 provides the system of Example 29 optionally configured such that the fluid circuit receives an output desiccant stream from a desiccant tank in fluid connection with an outlet of the LAMEE.

[00154] Example 31 provides the system of Example 30 optionally configured such that the desiccant tank is in fluid connection with an outlet of the regenerator such that the desiccant tank receives a concentrated input desiccant stream discharged from the regenerator and a dilute input desiccant stream exiting the LAMEE.

[00155] Example 32 provides the system of Example 31 optionally configured such that the fluid circuit is a first desiccant circuit and the system further comprises a second desiccant circuit, the LAMEE being contained within the second desiccant circuit. The output desiccant stream from the desiccant tank can be directed to a modulating valve configured to distribute the output desiccant stream to the first desiccant circuit and the second desiccant circuit.

[00156] Example 33 provides the system of Example 32 optionally configured such that a larger percentage by weight of the output desiccant stream is directed to the second desiccant circuit compared to the first desiccant circuit.

[00157] Example 34 provides the system of any of Examples 29-33 optionally configured such that the regenerator comprises a thermal separation unit.

[00158] Example 35 provides the system of Example 34 optionally configured such that the regenerator comprises one or more heat sources to increase a temperature of the desiccant stream prior to passing the desiccant stream into the thermal separation unit.

[00159] Example 36 provides the system of Example 35 optionally configured such that the one or more heat sources includes solar energy.

[00160] Example 37 provides the system of Example 35 or 36 optionally configured such that the one or more heat sources includes a heat exchanger configured to use a liquid to transfer heat to the desiccant stream.

[00161] Example 38 provides the system of Example 37 optionally configured such that the liquid is a concentrated desiccant stream exiting the regenerator, and the concentrated desiccant stream increases a temperature of the desiccant stream prior to passing the desiccant stream into the thermal separation unit.

[00162] Example 39 provides the system of Example 37 optionally configured such that the liquid is a heat transfer fluid configured to transfer heat to the desiccant stream prior to passing the desiccant stream into the thermal separation unit.

[00163] Example 40 provides the system of any of Examples 29-39 optionally configured such that the fluid circuit comprises a concentrated desiccant storage tank configured to receive a concentrated desiccant stream output from the regenerator.

[00164] Example 41 provides the system of Example 40 optionally configured such that the concentrated desiccant storage tank delivers concentrated desiccant to at least one of a mixing tank and the LAMEE.

[00165] Example 42 provides the system of Example 41 optionally configured such that the concentrated desiccant is delivered intermittently as needed to increase a concentration of the desiccant in an input stream to the LAMEE.

[00166] Example 43 provides the system of any of Examples 29-42 optionally configured such that the fluid circuit comprises a distilled water storage tank configured to receive a

distilled water output stream from the regenerator and store the distilled water for delivery to the evaporative cooler as needed for make up water.

[00167] Example 44 provides the system of any of Examples 29-43 optionally configured such that the energy gain of the desiccant between the LAMEE inlet and outlet results in a temperature of the desiccant at an outlet of the LAMEE being higher than a temperature of the desiccant at an inlet of the LAMEE.

[00168] Example 45 provides the system of any of Examples 29-44 optionally configured such that the desiccant dryer LAMEE is a first LAMEE and the evaporative cooler is a second LAMEE.

[00169] Example 46 provides a method of conditioning air for an enclosed space, and the method can include directing air through a process plenum having a plenum inlet and outlet, directing the air through a liquid-to-air energy exchanger (LAMEE) arranged inside the plenum, and directing a desiccant through the LAMEE, the desiccant and air separated by a membrane of the LAMEE. The method can also include transferring energy in the LAMEE from the desiccant to the air, an energy reduction of the air between a LAMEE inlet and outlet being about equal to an energy gain of the desiccant between the LAMEE inlet and outlet. Transferring energy in the LAMEE can include removing water from the air using the desiccant. A first concentration of water in the desiccant can be lower at a LAMEE inlet compared to a second concentration of water in the desiccant at a LAMEE outlet, and the desiccant at the LAMEE outlet can be a dilute desiccant. The method can also include regenerating a portion of the dilute desiccant in a regenerator to separate the water from the desiccant, directing a concentrated desiccant exiting the regenerator to a fluid circuit for the desiccant dryer LAMEE, and directing distilled water from the regenerator to one or more evaporative coolers in the conditioning system.

[00170] Example 47 provides the method of Example 46 optionally configured such that directing the concentrated desiccant exiting the regenerator to a fluid circuit for the desiccant dryer LAMEE includes transporting the concentrated desiccant to a mixing tank that receives the dilute desiccant from the LAMEE outlet.

[00171] Example 48 provides the method of Example 47 optionally further comprising directing a first portion of the dilute desiccant from the LAMEE outlet to the mixing tank and directing a second portion of the dilute desiccant from the LAMEE outlet to the regenerator.

[00172] Example 49 provides the method of Example 48 optionally configured such that the first portion is greater than the second portion.

[00173] Example 50 provides the method of Example 48 or 49 optionally further comprising regulating and varying the first and second portions.

[00174] Example 51 provides the method of any of Examples 47-50 optionally further comprising directing the concentrated desiccant to a concentrated desiccant storage tank prior to transporting the concentrated desiccant to the mixing tank.

[00175] Example 52 provides the method of Example 47 optionally further comprising mixing the dilute desiccant and the concentrated desiccant in the mixing tank to form a mixed desiccant having a concentration of desiccant higher than a concentration of the dilute desiccant and lower than a concentration of the concentrated desiccant.

[00176] Example 53 provides the method of Example 52 optionally configured such that regenerating a portion of the dilute desiccant includes transporting a first portion of the mixed desiccant to the LAMEE and transporting a second portion of the mixed desiccant to the regenerator.

[00177] Example 54 provides the method of Example 53 optionally further comprising regulating a volume of the second portion of the mixed desiccant transported to the regenerator relative to a volume of the first portion of the mixed desiccant transported to the LAMEE.

[00178] Example 55 provides the method of Example 54 optionally configured such that regulating the volume of the second portion of the mixed desiccant transported to the regenerator comprises transporting less than 25 percent by volume of the mixed desiccant exiting the tank to the regenerator.

[00179] Example 56 provides the method of any of Examples 46-55 optionally configured such that the one or more evaporative coolers comprises an evaporative cooler arranged in the plenum downstream of the desiccant dryer LAMEE.

[00180] Example 57 provides the method of Example 56 optionally configured such that the desiccant dryer LAMEE is a first LAMEE and the evaporative cooler downstream is a second LAMEE.

[00181] Example 58 provides the method of Example 56 or 57 optionally further comprising using the distilled water from the regenerator as make up water for operation of the evaporative cooler.

[00182] Example 59 provides the method of any of Examples 56-58 optionally configured such that directing air through a process plenum includes directing scavenger air through a first plenum. The method can also include directing process air through a second plenum, the process air coming from an enclosed space at an increased-temperature, the second plenum configured to cool the process air for delivery back to the enclosed space at a reduced-temperature.

[00183] Example 60 provides the method of Example 59 optionally further comprising delivering reduced-temperature water exiting the evaporative cooler to an LAHX arranged in the second plenum to cool the process air being directed through the second plenum.

[00184] Example 61 provides a system for conditioning air for an enclosed space and the system can comprise a plurality of conditioning units. Each conditioning unit can comprise a liquid-to-air membrane energy exchanger (LAMEE) arranged inside a plenum configured to pass an air stream there through and an evaporative cooling component arranged inside the plenum downstream of the LAMEE. The LAMEE can comprise a desiccant flow path separated from the air flow path by a membrane. The LAMEE can be configured to circulate a desiccant through the desiccant flow path and remove water from the air stream, a concentration of water in the desiccant at a LAMEE outlet being higher than a concentration of water in the desiccant at a LAMEE inlet. The system can further comprise a regeneration system in fluid connection with the LAMEE outlet of each conditioning unit, the regeneration system having a regeneration inlet configured to receive a dilute desiccant stream, the regeneration system configured to separate water from desiccant in the dilute desiccant stream, the regeneration system having a first outlet for discharging a concentrated desiccant stream and a second outlet for discharging a distilled water stream. The system can further comprise a concentrated desiccant storage system configured to receive and store the concentrated desiccant stream from the regenerator system, the concentrated desiccant storage system supplying concentrated desiccant to each conditioning unit as needed for operation of the LAMEE of each conditioning unit. The system can further comprise a distilled water storage system configured to receive and store the distilled water stream from the regenerator system, the distilled water storage system supplying water to the evaporative cooling component of each conditioning unit as needed for operation of the evaporative cooling component.

[00185] Example 62 provides the system of Example 61 optionally configured such that each conditioning unit further comprises a mixing tank configured to receive the concentrated desiccant from the concentrated desiccant storage system and a dilute desiccant from the LAMEE outlet.

[00186] Example 63 provides the system of Example 62 optionally configured such that a first portion of a desiccant output stream from the mixing tank of each conditioning unit is transported back to the LAMEE inlet for recirculation and a second portion of the desiccant output stream from the mixing tank of each conditioning unit is transported to the regeneration system.

[00187] Example 64 provides the system of Example 63 optionally configured such that a volume of the first portion is greater than a volume of the second portion.

[00188] Example 65 provides the system of any of Examples 61-64 optionally configured such that the enclosed space is a data center.

[00189] Example 66 provides the system of any of Examples 61-65 optionally configured such that each conditioning unit receives process air from the enclosed space at an increased-temperature and delivers the process air back to the enclosed space at a reduced-temperature.

[00190] Example 67 provides the system of any of Examples 61-66 optionally further comprising an external source of treated water for delivery to the conditioning units as needed for backup.

[00191] Example 68 provides the system of any of Examples 61-67 optionally configured such that the LAMEE of each conditioning unit is a first LAMEE and the evaporative cooling component of each conditioning unit is a second LAMEE.

[00192] Example 69 provides the system of Example 68 optionally configured such that the plenum of each conditioning unit is a first plenum and each conditioning unit further comprises a second plenum configured to pass a process air stream there through. The second LAMEE can produce reduced-temperature water and the reduced temperature water can be transported to the second plenum to cool process air in the process air stream.

[00193] Example 70 provides a system or method of any one or any combination of Examples 1-69, which can be optionally configured such that all steps or elements recited are available to use or select from.

[00194] Various aspects of the disclosure have been described. These and other aspects are within the scope of the following claims.