path between the LAMEE inlet and outlet, and essentially all of the energy removed from the air is transferred to the desiccant;

a regeneration system in fluid connection with the LAMEE and having a regeneration inlet configured to receive a dilute desiccant stream, the regeneration system configured to separate liquid 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 liquid water stream; and

one or more cooling components arranged inside the plenum, wherein at least a portion of the liquid water stream from the regeneration system is used by the one or more cooling components as make up water for operation of the one or more cooling components.

[0006b] Another aspect of the present disclosure provides a system for conditioning air for an enclosed space, the system comprising:

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 being separated in the LAMEE by a membrane, wherein the LAMEE facilitates an energy exchange between the air and the desiccant, and the desiccant collects essentially all of the energy removed from the air;

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; and

a fluid circuit coupled to the desiccant dryer LAMEE and the evaporative cooler, the fluid circuit comprising a regenerator configured to separate liquid water and desiccant in a desiccant stream, wherein the fluid circuit is configured to transport at least a portion of the liquid 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.

[0006c] Another aspect of the present disclosure provides a method of conditioning air for an enclosed space, the method comprising:

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;

directing a desiccant through the LAMEE, the desiccant and air separated by a membrane of the LAMEE;

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, and transferring energy in the LAMEE includes removing water from the air using the desiccant, a first concentration of water in the desiccant being lower at a LAMEE inlet compared to a second concentration of water in the desiccant at a LAMEE outlet, the desiccant at the LAMEE outlet being a dilute desiccant;

regenerating a portion of the dilute desiccant in a regenerator to separate liquid ~~the~~ water from the desiccant;

directing a concentrated desiccant exiting the regenerator to a fluid circuit for the desiccant dryer LAMEE; and

directing distilled liquid water from the regenerator to one or more evaporative coolers in the conditioning system.

[0006d] Another aspect of the present disclosure provides a system for conditioning air for an enclosed space, the system comprising:

a plurality of conditioning units, each conditioning unit comprising:

a liquid-to-air membrane energy exchanger (LAMEE) arranged inside a plenum configured to pass an air stream there through, the LAMEE comprising a desiccant flow path separated from the air flow path by a membrane, the LAMEE 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; and

an evaporative cooling component arranged inside the plenum downstream of the LAMEE;

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 liquid 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 liquid water stream;

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; and

a distilled water storage system configured to receive and store the distilled liquid water stream from the regenerator system, the distilled water storage system supplying liquid water to the evaporative cooling component of each conditioning unit as needed for operation of the evaporative cooling component.

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).

CLAIMS

What is claimed is:

1. A system for conditioning air for an enclosed space, the system comprising:

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;

a liquid-to-air membrane energy exchanger (LAMEE) arranged inside the plenum, the LAMEE comprising a desiccant flow path separated from the air flow path by a membrane, the LAMEE configured to circulate a desiccant through the desiccant flow path and remove water from air in the air flow path, wherein an energy reduction of the air in the air flow path between a LAMEE inlet and outlet is 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;

a regeneration system in fluid connection with the LAMEE and having a regeneration inlet configured to receive a dilute desiccant stream, the regeneration system configured to separate liquid 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 liquid water stream; and

one or more cooling components arranged inside the plenum, wherein at least a portion of the liquid water stream from the regeneration system is used by the one or more cooling components as make up water for operation of the one or more cooling components.

2. The system of claim 1 wherein the regeneration system comprises a regeneration unit that thermally separates the liquid water and the desiccant in the dilute desiccant stream.

3. The system of claim 2 wherein 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.

4. The system of claim 3 wherein 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.

5. The system of claim 2 wherein the regeneration system comprises a heat source to increase a temperature of the dilute desiccant stream.

6. The system of claim 5 wherein the heat source is solar.

7. The system of claim 1 wherein the regeneration system comprises a regeneration unit that utilizes non-thermal energy to separate the liquid water and the desiccant in the dilute desiccant stream.

8. The system of claim 1 wherein 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.

9. The system of claim 8 wherein 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.

10. The system of claim 9 wherein the output stream from the desiccant tank is transported to at least one of the regeneration system and to the LAMEE for recirculation.

11. The system of claim 10 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.

12. The system of claim 11 wherein less than 50 percent by volume of the output stream from the desiccant tank is transported to the regeneration system.

13. The system of claim 11 wherein less than 25 percent by volume of the output stream from the desiccant tank is transported to the regeneration system.

14. The system of claim 10 wherein 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, and wherein the heat exchanger reduces a temperature of the output stream from the desiccant tank.

15. The system of claim 8 wherein 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.

16. The system of claim 15 wherein the first and second portions are variable during operation of the system.

17. The system of claim 1 wherein 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.

18. The system of claim 1 wherein a temperature of the desiccant at the LAMEE outlet is higher than a temperature of the desiccant at the LAMEE inlet.

19. The system of claim 1 wherein 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.

20. The system of claim 1 wherein the one or more cooling components comprises an evaporative cooler arranged downstream of the LAMEE.

21. The system of claim 20 wherein a quantity of liquid 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.

22. The system of claim 20 wherein the LAMEE arranged inside the plenum is a first LAMEE, and the evaporative cooler arranged downstream is a second LAMEE.

23. The system of claim 22 wherein 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.

24. The system of claim 20 wherein the one or more cooling components comprises an evaporative cooler configured to cool the desiccant prior to circulating the desiccant through the LAMEE.

25. The system of claim 24 wherein the evaporative cooler is external to the plenum.

26. The system of claim 20 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.

27. The system of claim 1 wherein 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.

28. The system of claim 27 wherein 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, and wherein the reduced temperature water is transported to an LAHX arranged in the second plenum, and the reduced temperature water is used to cool the process air stream flowing through the LAHX.

29. A system for conditioning air for an enclosed space, the system comprising:

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 being separated in the LAMEE by a membrane, wherein the LAMEE facilitates an energy exchange between the air and the desiccant, and the desiccant collects essentially all of the energy removed from the air;

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; and

a fluid circuit coupled to the desiccant dryer LAMEE and the evaporative cooler, the fluid circuit comprising a regenerator configured to separate liquid water and desiccant in a desiccant stream, wherein the fluid circuit is configured to transport at least a portion of the liquid 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.

30. The system of claim 29 wherein the fluid circuit receives an output desiccant stream from a desiccant tank in fluid connection with an outlet of the LAMEE.

31. The system of claim 30 wherein 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.

32. The system of claim 31 wherein 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, and wherein the output desiccant stream from the desiccant tank is directed to a modulating valve configured to distribute the output desiccant stream to the first desiccant circuit and the second desiccant circuit.

33. The system of claim 32 wherein a larger percentage by weight of the output desiccant stream is directed to the second desiccant circuit compared to the first desiccant circuit.

~~34. The system of claim 29 wherein the regenerator comprises a thermal separation unit.~~

~~35. The system of claim 34 wherein 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.~~

~~36. The system of claim 35 wherein the one or more heat sources includes solar energy.~~

~~37. The system of claim 35 wherein the one or more heat sources includes a heat exchanger configured to use a liquid to transfer heat to the desiccant stream.~~

~~38. The system of claim 37 wherein 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.~~

~~39. The system of claim 37 wherein 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.~~

~~40~~34. The system of claim 29 wherein the fluid circuit comprises a concentrated desiccant storage tank configured to receive a concentrated desiccant stream output from the regenerator.

~~41~~35. The system of claim 34~~40~~ wherein the concentrated desiccant storage tank delivers concentrated desiccant to at least one of a mixing tank and the LAMEE.

~~42~~36. The system of claim 35~~41~~ wherein the concentrated desiccant is delivered intermittently as needed to increase a concentration of the desiccant in an input stream to the LAMEE.

~~43. The system of claim 29 wherein 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.~~

~~44. The system of claim 29 wherein 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.~~

~~45. The system of claim 29 wherein the desiccant dryer LAMEE is a first LAMEE and the evaporative cooler is a second LAMEE.~~

~~46~~37. A method of conditioning air for an enclosed space, the method comprising:

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;

directing a desiccant through the LAMEE, the desiccant and air separated by a membrane of the LAMEE;

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, and transferring energy in the LAMEE includes removing water from the air using the desiccant, a first concentration of water in the desiccant being lower at a LAMEE inlet compared to a second concentration of water in the desiccant at a LAMEE outlet, the desiccant at the LAMEE outlet being a dilute desiccant;

regenerating a portion of the dilute desiccant in a regenerator to separate liquid~~the~~ water from the desiccant;

directing a concentrated desiccant exiting the regenerator to a fluid circuit for the desiccant dryer LAMEE; and

directing distilled liquid water from the regenerator to one or more evaporative coolers in the conditioning system.

~~47~~38. The method of claim 37~~46~~ wherein 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.

~~48~~39. The method of claim ~~47~~38 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.

~~49~~40. The method of claim 39~~48~~ wherein the first portion is greater than the second portion.

~~50~~41. The method of claim ~~48~~39 further comprising regulating and varying the first and second portions.

42~~51~~. The method of claim ~~47~~38 further comprising:

directing the concentrated desiccant to a concentrated desiccant storage tank prior to transporting the concentrated desiccant to the mixing tank.

~~52~~43. The method of claim ~~47~~38 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.

~~53~~44. The method of claim ~~52~~43 wherein 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.

~~54~~45. The method of claim 44~~53~~ 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.

~~55~~46. The method of claim ~~54~~45 wherein 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.

~~56. The method of claim 46 wherein the one or more evaporative coolers comprises an evaporative cooler arranged in the plenum downstream of the desiccant dryer LAMEE.~~

~~57. The method of claim 56 wherein the desiccant dryer LAMEE is a first LAMEE and the evaporative cooler downstream is a second LAMEE.~~

~~58~~47. The method of claim ~~56~~37 further comprising:

using the distilled liquid water from the regenerator as make up water for operation of the evaporative cooler.

~~59~~48. The method of claim ~~56~~37 wherein directing air through a process plenum includes directing scavenger air through a first plenum, and the method further comprises:

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.

~~60~~49. The method of claim ~~59~~48 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.

~~61~~50. A system for conditioning air for an enclosed space, the system comprising:

a plurality of conditioning units, each conditioning unit comprising:

a liquid-to-air membrane energy exchanger (LAMEE) arranged inside a plenum configured to pass an air stream there through, the LAMEE comprising a desiccant flow path separated from the air flow path by a membrane, the LAMEE 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; and

an evaporative cooling component arranged inside the plenum downstream of the LAMEE;

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 liquid 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 liquid water stream;

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; and

a distilled water storage system configured to receive and store the distilled liquid water stream from the regenerator system, the distilled water storage system supplying liquid water to the evaporative cooling component of each conditioning unit as needed for operation of the evaporative cooling component.

~~62~~51. The system of claim 50~~61~~ wherein 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.

~~63~~52. The system of claim 51~~62~~ wherein 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.

~~64~~53. The system of claim 52~~63~~ wherein a volume of the first portion is greater than a volume of the second portion.

~~65~~54. The system of claim ~~61~~50 wherein the enclosed space is a data center.

~~66~~55. The system of claim 50~~61~~ wherein 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.

~~67~~56. The system of claim 50~~61~~ further comprising an external source of treated water for delivery to the conditioning units as needed for backup.

57~~68~~. The system of claim 50~~61~~ wherein the LAMEE of each conditioning unit is a first LAMEE and the evaporative cooling component of each conditioning unit is a second LAMEE.

~~69~~58. The system of claim ~~68~~57 wherein 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, and wherein the second LAMEE produces reduced-temperature water and the reduced temperature water is transported to the second plenum to cool process air in the process air stream.