data centers operating costs. Also, data center liquid cooling can increase the servers processing density by up to 100% which can result in significant savings in the data center white space.

[0005] High density cooling for data centers can include liquid cooling techniques which can use a special coolant and liquid circuit. The coolants can be expensive and as such, replacement of the coolant can also be expensive. The coolant can pick up the heat from the server and the heat can then be rejected to another liquid loop or cooling air stream. A cooling tower or outdoor dry cooler can be used to reject the heat from the coolant, but these may not be efficient. The water quality in cooling towers which should flow into a liquid circuit to pick up the heat from the coolant should be maintained at a certain level and could become a problem. The accumulation of dissolved minerals in the circulating cooling water can lead to deposits and scaling on the exchange surfaces which reduces performance. Corrosion of metal components and piping in cooling towers can be a common concern.

SUMMARY

[0005a] In one aspect, the present invention provides a conditioning system for controlling conditions in an enclosed space, the conditioning system comprising:

a cooling system disposed outside of the enclosed space, the cooling system comprising:

a scavenger air plenum having an air inlet and outlet, the scavenger air plenum configured to direct scavenger air in an air flow path from the air inlet to the air outlet;

a liquid to air membrane energy exchanger (LAMEE) arranged inside the scavenger air plenum, the LAMEE comprising a cooling fluid flow path separated from the air flow path by a membrane, the LAMEE configured to use the scavenger air to evaporatively cool a cooling fluid in the cooling fluid flow path, a temperature of the cooling fluid at a fluid outlet of the LAMEE is lower than a temperature of the cooling fluid at a fluid inlet of the LAMEE; and

a cooling coil arranged inside the scavenger air plenum downstream of the LAMEE and configured to use the scavenger air to cool the cooling fluid; and

a cooling fluid circuit connected to the cooling fluid flow path of the LAMEE and extending from the scavenger air plenum into the enclosed space, the cooling fluid circuit configured to provide cooling to the enclosed space without moving air from the enclosed space through the cooling system.

[0005b] Disclosed is a conditioning system for controlling conditions in an enclosed space, the conditioning system comprising:

a first cooling system disposed outside of the enclosed space, the first cooling system comprising:

a scavenger air plenum having an air inlet and outlet, the plenum configured to direct scavenger air in an air flow path from the air inlet to the air outlet;

a liquid to air membrane energy exchanger (LAMEE) arranged inside the plenum, the LAMEE comprising a water flow path separated from the air flow path by a membrane, the LAMEE configured to use the scavenger air to reduce a temperature of water in the water flow path;

a second cooling system disposed inside the enclosed space; and

a cooling fluid circuit connected to the water flow path of the LAMEE and to the second cooling system, the cooling fluid circuit providing cooling to the enclosed space without moving air from the enclosed space through the first cooling system.

[0005c] In yet another aspect, the present invention provides a conditioning system for controlling conditions in an enclosed space, the conditioning system comprising:

a cooling system disposed outside of the enclosed space, the cooling system comprising:

a scavenger air plenum having an air inlet and outlet, the scavenger air plenum configured to direct scavenger air in an air flow path from the air inlet to the air outlet;

a liquid to air membrane energy exchanger (LAMEE) arranged inside the scavenger air plenum in the air flow path, the LAMEE comprising a cooling fluid flow path separated from the air flow path by a membrane, the LAMEE configured to use the scavenger air to evaporatively cool a cooling fluid in the cooling fluid flow path, a temperature of the cooling fluid at a fluid outlet of the LAMEE is lower than a temperature of the cooling fluid at a fluid inlet of the LAMEE;

a first cooling unit arranged inside the scavenger air plenum between the air inlet and the LAMEE, the first cooling unit configured to condition the scavenger air prior to the scavenger air entering the LAMEE;

a second cooling unit arranged inside the scavenger air plenum between the LAMEE and the air outlet, the second cooling unit configured to reduce a temperature of the cooling fluid before the cooling fluid enters the LAMEE at the fluid inlet; and

one or more bypass dampers configured to permit scavenger air to enter or exit the air flow path at one or more locations between the air inlet and outlet; and

a cooling fluid circuit connected to the cooling fluid flow path of the LAMEE and extending from the scavenger air plenum into the enclosed space, the cooling fluid circuit configured to provide cooling to the enclosed space without moving air from the enclosed space through the cooling system.

[0005d] In yet another aspect, the present invention provides a method of controlling conditions in an enclosed space comprises:

directing scavenger air through a liquid to air membrane energy exchanger (LAMEE) arranged inside a scavenger air plenum disposed outside of the enclosed space, the scavenger air entering the scavenger air plenum at an air inlet and exiting the scavenger air plenum at an air outlet, the scavenger air plenum and the LAMEE forming a cooling system disposed outside of the enclosed space;

directing water through the LAMEE, the LAMEE comprising a water flow path separate from an air flow path, the LAMEE configured to evaporatively cool the water using the scavenger air and reduce a temperature of the water;

delivering the reduced-temperature water from the LAMEE to a storage tank;

delivering a cooling fluid in a cooling fluid circuit to the enclosed space, the cooling fluid circuit connected to the water flow path of the LAMEE;

providing cooling to the enclosed space with the cooling fluid and without moving air from the enclosed space through the cooling system;

directing scavenger air through a cooling coil located downstream of the LAMEE; and

directing water through the cooling coil after the cooling fluid has been delivered to the enclosed space and before the water is recirculated back through the LAMEE or back to the storage tank.

[0005e] In yet another aspect, the present invention provides a method of controlling conditions in an enclosed space comprises:

directing scavenger air through a pre-cooling unit arranged in a scavenger air plenum disposed outside of the enclosed space, the scavenger air entering the plenum at an air inlet and exiting the scavenger air plenum at an air outlet, the pre-cooling unit configured to condition the scavenger air entering the scavenger air plenum;

directing water and the scavenger air exiting the pre-cooler through a liquid to air membrane energy exchanger (LAMEE) arranged inside the scavenger air plenum, the LAMEE comprising a scavenger air flow path separate from a water flow path by a membrane, the LAMEE configured to evaporatively cool the water in the

water flow path, a temperature of the water at a water outlet of the LAMEE is lower than a temperature of the water at a water inlet;

storing the cooled water exiting the LAMEE in a tank;

delivering a cooling fluid in a cooling fluid circuit to the enclosed space, the cooling fluid circuit connected to the water flow path of the LAMEE, the cooling fluid is the cooled water from the tank or a coolant that is cooled by the cooled water in a liquid to liquid heat exchanger (LLHX);

cooling the enclosed space with the cooling fluid by performing at least one of air cooling of the air in the enclosed space and directly contacting the cooling fluid with one or more components in the enclosed space;

directing increased-temperature water from the enclosed space or from the LLHX through a dry coil arranged inside the scavenger air plenum downstream of the LAMEE, the reduced-temperature scavenger air cooling the water;

recirculating the water exiting the dry coil back through the LAMEE in a first operating mode; and

bypassing the LAMEE and the pre-cooling unit in a second operating mode by directing the water exiting the dry coil back to the tank and directing the scavenger air into the scavenger air plenum at a location downstream of the LAMEE and upstream of the dry coil

[0005f] Disclosed is a conditioning system for providing cooling to a device, the conditioning system comprising:

a cooling system located separate from and remote to the device, the cooling system comprising:

a scavenger air plenum having an air inlet and outlet, the plenum configured to direct scavenger air in an air flow path from the air inlet to the air outlet; and

a liquid to air membrane energy exchanger (LAMEE) arranged inside the plenum, the LAMEE comprising a cooling fluid flow path separated from the air flow path by a membrane, the LAMEE configured to use the scavenger air to evaporatively cool a cooling fluid in the cooling fluid flow path, a temperature of the cooling fluid at a fluid outlet of the LAMEE is lower than a temperature of the cooling fluid at a fluid inlet of the LAMEE; and

a cooling fluid circuit connected to the cooling fluid flow path of the LAMEE and extending from the plenum to the device, the cooling fluid circuit configured to provide cooling to the device.

[0005g] Disclosed is a method of providing cooling to a device, the method comprising:

directing scavenger air through a liquid to air membrane energy exchanger (LAMEE) arranged inside a scavenger air plenum, the scavenger air entering the plenum at an air inlet and exiting the plenum at an air outlet, the scavenger air plenum and the LAMEE forming a cooling system separate from and remote to the device;

directing water through the LAMEE, the LAMEE comprising a water flow path separate from an air flow path, the LAMEE configured to evaporatively cool the water using the scavenger air and reduce a temperature of the water;

storing the reduced temperature water exiting the LAMEE in a tank;

delivering a cooling fluid in a cooling fluid circuit to the device, the cooling fluid circuit connected to the water flow path of the LAMEE, the cooling fluid is the reduced temperature water from the tank or a coolant that is cooled by the reduced temperature water in a liquid to liquid heat exchanger (LLHX);

cooling the device with the cooling fluid; and

recirculating the cooling fluid back to the cooling system or to the LLHX.

OVERVIEW

[0006] The present inventors recognize, among other things, an opportunity for improved performance in cooling an enclosed space, or a device, using a Liquid-to-Air Membrane Energy Exchanger (LAMEE) as an evaporative cooler and using the reduced-temperature water from the LAMEE to provide liquid cooling to the enclosed space or the device. In an example, the enclosed space can be a data center.

[0007] Examples according to the present application can include a liquid-cooling system which can reduce the data center cooling energy consumption by up to 95% compared to conventional air cooling data centers techniques. The liquid cooling system can be significantly smaller in size and lighter compared to other direct evaporative coolers (DEC), including air-cooling DECs. The liquid-cooling system as described herein can reduce the water consumption

What is claimed is:

1. A conditioning system for controlling conditions in an enclosed space, the conditioning system comprising:

a cooling system disposed outside of the enclosed space, the cooling system comprising:

a scavenger air plenum having an air inlet and outlet, the scavenger air plenum configured to direct scavenger air in an air flow path from the air inlet to the air outlet;

a liquid to air membrane energy exchanger (LAMEE) arranged inside the scavenger air plenum, the LAMEE comprising a cooling fluid flow path separated from the air flow path by a membrane, the LAMEE configured to use the scavenger air to evaporatively cool a cooling fluid in the cooling fluid flow path, a temperature of the cooling fluid at a fluid outlet of the LAMEE is lower than a temperature of the cooling fluid at a fluid inlet of the LAMEE; and

a cooling coil arranged inside the scavenger air plenum downstream of the LAMEE and configured to use the scavenger air to cool the cooling fluid; and

a cooling fluid circuit connected to the cooling fluid flow path of the LAMEE and extending from the scavenger air plenum into the enclosed space, the cooling fluid circuit configured to provide cooling to the enclosed space without moving air from the enclosed space through the cooling system.

2. The conditioning system of claim 1 further comprising a cooling unit arranged inside the scavenger air plenum upstream of the LAMEE, the cooling unit configured to condition the scavenger air prior to the scavenger air entering the LAMEE.

3. The conditioning system of claim 2 wherein the cooling unit is configured to receive reduced-temperature cooling fluid from the LAMEE to condition the scavenger air.

4. The conditioning system of claim 1 wherein the cooling fluid circuit is configured to transport the cooling fluid from the LAMEE to the enclosed space to provide cooling to the enclosed space.

5. The conditioning system of claim 1 wherein the cooling fluid in the cooling fluid flow path of the LAMEE is water.

6. The conditioning system of claim 1 wherein the cooling fluid circuit includes a first cooling fluid and a second cooling fluid, and wherein the first cooling fluid is the cooling fluid from the LAMEE.

7. The conditioning system of claim 6 wherein the cooling fluid circuit includes a liquid to liquid heat exchanger configured to receive the first and second cooling fluids to reduce a temperature of the second cooling fluid.

8. The conditioning system of claim 7 wherein the second cooling fluid is delivered to the enclosed space and provides cooling to the enclosed space.

9. The conditioning system of claim 1 further comprising a storage tank to store the cooling fluid from the LAMEE.

10. The conditioning system of claim 9 further comprising a mechanical cooling system to cool the cooling fluid in the storage tank.

11. The conditioning system of claim 1 further comprising a bypass valve configured to control a flow of the cooling fluid, exiting the cooling coil, to at least one of the LAMEE and a tank configured to store the cooling fluid.

12. The conditioning system of claim 11 comprises a first operating mode in which at least a portion of the cooling fluid exiting the cooling coil is recirculated back to the LAMEE and a

second operating mode in which essentially all of the cooling fluid exiting the cooling coil is recirculated back to the storage tank.

13. A conditioning system for controlling conditions in an enclosed space, the conditioning system comprising:

a cooling system disposed outside of the enclosed space, the cooling system comprising:

a scavenger air plenum having an air inlet and outlet, the scavenger air plenum configured to direct scavenger air in an air flow path from the air inlet to the air outlet;

a liquid to air membrane energy exchanger (LAMEE) arranged inside the scavenger air plenum in the air flow path, the LAMEE comprising a cooling fluid flow path separated from the air flow path by a membrane, the LAMEE configured to use the scavenger air to evaporatively cool a cooling fluid in the cooling fluid flow path, a temperature of the cooling fluid at a fluid outlet of the LAMEE is lower than a temperature of the cooling fluid at a fluid inlet of the LAMEE;

a first cooling unit arranged inside the scavenger air plenum between the air inlet and the LAMEE, the first cooling unit configured to condition the scavenger air prior to the scavenger air entering the LAMEE;

a second cooling unit arranged inside the scavenger air plenum between the LAMEE and the air outlet, the second cooling unit configured to reduce a temperature of the cooling fluid before the cooling fluid enters the LAMEE at the fluid inlet; and

one or more bypass dampers configured to permit scavenger air to enter or exit the air flow path at one or more locations between the air inlet and outlet; and

a cooling fluid circuit connected to the cooling fluid flow path of the LAMEE and extending from the scavenger air plenum into the enclosed space, the cooling fluid circuit configured to provide cooling to the enclosed space without moving air from the enclosed space through the cooling system.

14. The conditioning system of claim 13 wherein the cooling fluid circuit includes a tank for storing the cooling fluid from the LAMEE and a pump to deliver the cooling fluid to the enclosed space.

15. The conditioning system of claim 14 further comprising a supplemental cooling system configured to provide additional cooling to the cooling fluid in the tank.

16. The conditioning system of claim 15 wherein the supplemental cooling system is a DX coil located inside the tank.

17. The conditioning system of claim 13 wherein the cooling system includes a bypass valve to control a flow of the cooling fluid to the LAMEE.

18. The conditioning system of claim 13 wherein the cooling fluid in the LAMEE is water.

19. The conditioning system of claim 18 wherein the water is delivered to the enclosed space to directly cool one or more components in the enclosed space or sensibly cool air in the enclosed space.

20. The conditioning system of claim 13 wherein the cooling fluid circuit includes the cooling fluid from the LAMEE, a second cooling fluid, and a liquid to liquid heat exchanger (LLHX), and wherein the cooling fluid from the LAMEE and the second cooling fluid pass through the LLHX to reduce a temperature of the second cooling fluid.

21. The conditioning system of claim 20 wherein the second cooling fluid is delivered to the enclosed space to directly cool one or more components in the enclosed space or sensibly cool air in the enclosed space.

22. The conditioning system of claim 13 wherein the one or more bypass dampers include a first set of bypass dampers configured to direct scavenger air into the air flow path at a location between the first cooling unit and the LAMEE.

23. The conditioning system of claim 13 wherein the one or more bypass dampers include a second set of bypass dampers configured to direct scavenger air into the air flow path at a location between the LAMEE and the second cooling unit.

24. The conditioning system of claim 13 wherein the enclosed space is a data center.

25. A method of controlling conditions in an enclosed space comprises:

directing scavenger air through a liquid to air membrane energy exchanger (LAMEE) arranged inside a scavenger air plenum disposed outside of the enclosed space, the scavenger air entering the scavenger air plenum at an air inlet and exiting the scavenger air plenum at an air outlet, the scavenger air plenum and the LAMEE forming a cooling system disposed outside of the enclosed space;

directing water through the LAMEE, the LAMEE comprising a water flow path separate from an air flow path, the LAMEE configured to evaporatively cool the water using the scavenger air and reduce a temperature of the water;

delivering the reduced-temperature water from the LAMEE to a storage tank;

delivering a cooling fluid in a cooling fluid circuit to the enclosed space, the cooling fluid circuit connected to the water flow path of the LAMEE;

providing cooling to the enclosed space with the cooling fluid and without moving air from the enclosed space through the cooling system;

directing scavenger air through a cooling coil located downstream of the LAMEE; and

directing water through the cooling coil after the cooling fluid has been delivered to the enclosed space and before the water is recirculated back through the LAMEE or back to the storage tank.

26. The method of claim 25 further comprising:

directing the water through a cooling unit arranged inside the scavenger air plenum downstream or upstream of the LAMEE prior to recirculating the water back to the LAMEE.

27. The method of claim 25 wherein delivering the cooling fluid to the enclosed space comprises delivering the reduced-temperature water from the LAMEE to the enclosed space.

28. The method of claim 27 further comprising:

delivering the reduced-temperature water from the LAMEE to a storage tank prior to delivering the reduced-temperature water to the enclosed space.

29. The method of 25 further comprising:

directing the reduced-temperature water from the LAMEE through a liquid to liquid heat exchanger (LLHX) to decrease a temperature of the cooling fluid in the cooling fluid circuit, prior to delivering the cooling fluid to the enclosed space.

30. The method of claim 25 wherein providing cooling to the enclosed space with the cooling fluid includes at least one of directly cooling one or more components in the enclosed space with the cooling fluid or sensibly cooling air in the enclosed space with the cooling fluid.

31. The method of claim 25 further comprising:

directing the reduced-temperature water from the LAMEE through a cooling coil arranged inside the scavenger air plenum upstream of the LAMEE; and

directing the scavenger air through the cooling coil to condition the scavenger air before the scavenger air is directed through the LAMEE.

32. A method of controlling conditions in an enclosed space comprises:

directing scavenger air through a pre-cooling unit arranged in a scavenger air plenum disposed outside of the enclosed space, the scavenger air entering the plenum at an air inlet and exiting the scavenger air plenum at an air outlet, the pre-cooling unit configured to condition the scavenger air entering the scavenger air plenum;

directing water and the scavenger air exiting the pre-cooler through a liquid to air membrane energy exchanger (LAMEE) arranged inside the scavenger air plenum, the LAMEE comprising a scavenger air flow path separate from a water flow path by a membrane, the LAMEE configured to evaporatively cool the water in the

water flow path, a temperature of the water at a water outlet of the LAMEE is lower than a temperature of the water at a water inlet;

storing the cooled water exiting the LAMEE in a tank;

delivering a cooling fluid in a cooling fluid circuit to the enclosed space, the cooling fluid circuit connected to the water flow path of the LAMEE, the cooling fluid is the cooled water from the tank or a coolant that is cooled by the cooled water in a liquid to liquid heat exchanger (LLHX);

cooling the enclosed space with the cooling fluid by performing at least one of air cooling of the air in the enclosed space and directly contacting the cooling fluid with one or more components in the enclosed space;

directing increased-temperature water from the enclosed space or from the LLHX through a dry coil arranged inside the scavenger air plenum downstream of the LAMEE, the reduced-temperature scavenger air cooling the water;

recirculating the water exiting the dry coil back through the LAMEE in a first operating mode; and

bypassing the LAMEE and the pre-cooling unit in a second operating mode by directing the water exiting the dry coil back to the tank and directing the scavenger air into the scavenger air plenum at a location downstream of the LAMEE and upstream of the dry coil.

33. The method of claim 32 further comprising:

bypassing the pre-cooling unit in a third operating mode, when the outdoor air conditions are mild.

34. The method of claim 33 wherein bypassing the pre-cooling unit in a third operating mode includes directing the scavenger air into the scavenger air plenum at a location downstream of the pre-cooling unit and upstream of the LAMEE

35. The method of claim 34 wherein bypassing the pre-cooling unit in a third operating mode includes one of directing all of the water exiting the tank to the enclosed space or directing all of the water to the LLHX.

36. The method of claim 32 wherein the pre-cooling unit uses cooled water from the tank to condition the scavenger air passing through the pre-cooling unit.