

having a power consumption capacity of 1 MW. Further, the traditional chiller plant is typically designed to cool the entire data center, as opposed to a few selected areas within the data center. As a result, the traditional chiller plant spends a considerable amount of energy on areas that do not need to be cooled. Further, one of the design constraints used to implement the traditional chiller plant is the power consumption capacity of the entire data center. For that reason, if the data center does not run at its power consumption capacity due to load fluctuation, the efficiency of the traditionally chiller plant drops significantly.

[0004] Currently, several cooling systems exist in the market having a more modular design approach compared to the traditional, large, oversized cooling electrical infrastructures that allow them to treat selected areas of a large data center at a reduced cost. For instance, an air-cooled “free cooling” system (also referred to as a straight air-cooled system) uses ambient air as a medium to cool server racks or containers of server racks in a large data center. However, one of the drawbacks of the air-cooled “free cooling” system is that it operates only in a cool, dry-climate environment thereby restricting its use to limited geographical areas in the world.

[0005] An adiabatic-assisted system is another cooling system that rivals the traditional, large, oversized cooling electrical infrastructures. The adiabatic-assisted system is a cooling system assisted by adiabatic water, having a more expanded geographical reach than the air-cooled “free cooling” system. However, the adiabatic-assisted system has certain cooling tolerance limitations and is incapable of providing sufficient cooling to high density data centers, e.g., data centers having IT rack loads of 40 kW per IT rack.

SUMMARY

[0006] The embodiments of the modular data pod systems and the associated cooling systems of the present disclosure may provide significant improvements over traditional data centers and their cooling systems including, for example, (1) a lower cost per kilowatt (kW) to build, deploy, and operate a data center, (2) faster deployment than stick-built construction, (3) more easily restacked and redeployed to allow the data center to keep up with new technological advances in server technology, (4) expandability, (5) compatibility with very high efficiency systems to gain the highest power use efficiency

(PUE) factor, (6) space saving and efficient in its space requirements allowing higher density capabilities (i.e., more kilowatts per square foot), (7) scalability, (8) efficiency in mechanical cooling, (9) multi-use characteristics for single deployment, large indoor warehousing, or large outdoor applications, such as data center farms, (10) energy-efficiency in the containment of hot and cold aisles, (11) flexibility in its use of different types of cooling systems, and (12) capability of being modified to meet data center tier requirements for redundancy.

[0007] ~~In one aspect, the present disclosure features a modular data center. In one embodiment, the modular data center includes a first cooling circuit that has a primary cooling device and a plurality of modular data pods. Each modular data pod includes a plurality of servers, a heat exchange member coupled to the first cooling circuit, and a second cooling circuit coupled to the heat exchange member. The second cooling circuit is configured to cool the plurality of servers. The second cooling circuit includes a secondary cooling device configured to cool fluid flowing through the second cooling circuit.~~ According to a first aspect of the present invention, there is provided a modular data center, comprising: a first cooling circuit including a primary cooling device; a plurality of modular data pods, each modular data pod comprising: a plurality of servers; a heat exchange member coupled to the first cooling circuit; and a second cooling circuit coupled to the heat exchange member and configured to cool the plurality of servers, the second cooling circuit including a secondary cooling device configured to cool fluid flowing through the second cooling circuit.

[0008] ~~In another aspect, the present disclosure features a modular data pod. The modular data pod includes a plurality of servers, at least one heat exchange member and a second cooling circuit. The at least one heat exchange member is configured to couple to a first cooling circuit which includes a free cooling device. The second cooling circuit is coupled to the heat exchange member. Further, the second cooling circuit is in thermal communication with the plurality of servers. The second cooling circuit includes a mechanical cooling device.~~ According to a second aspect of the present invention, there is provided a modular data pod, comprising: a plurality of servers; at least one heat exchange member configured to couple to a first cooling circuit including a free-cooling device; and a second cooling circuit coupled to the heat exchange member and in thermal communication with the plurality of servers, the second cooling circuit including a mechanical cooling device.

[0009] There is disclosed ~~In another embodiment, the modular data center includes a central cooling system and a plurality of modular data pods. Each modular data pod includes a plurality of servers, a heat exchange assembly coupled to the central cooling system, and a distributed cooling system coupled to the heat exchange assembly. The heat exchange assembly is configured to cool the plurality of servers.~~

[0010] There is also disclosed ~~in another embodiment, the modular data pod includes an enclosure, a plurality of computer racks arranged within the enclosure. The enclosure includes wall members contiguously joined to one another along at least one edge of each wall member. The wall members are formed in the shape of a polygon. The enclosure also~~

includes a data pod covering member. The plurality of computer racks forms a first volume formed between the inner surface of the wall members and first sides of the computer racks. The plurality of racks also forms a second volume formed between the inner surface of the wall members and second sides of the computer racks. The modular data pod further includes a computer rack covering member which is configured to enclose the second volume. The computer rack covering member and the data pod covering member form a third volume. The third volume couples the first volume to the second volume. The modular data pod may also include an air circulator which is configured to continuously circulate air through the first, second, and third volumes.

[0011] There is also disclosed an another embodiment, the modular data center includes a central fluid and electrical circuit, a chain of modular data pods and a central cooling device. Each modular data pod in the chain of modular data pods includes a shared cooling fluid circuit section and an unshared cooling fluid circuit. The unshared cooling fluid circuit is coupled to the shared fluid and electrical circuit section. The shared fluid and electrical circuit section form a part of a shared fluid and electrical circuit. The shared fluid and electrical circuit are coupled at one end to the central fluid and electrical circuit. The central cooling device is coupled to the central cooling fluid circuit. The central cooling device is configured to support at least a portion of the cooling requirements of the first chain of modular data pods.

~~[0012] In yet another aspect, the present disclosure features a cooling system for a modular data center. The cooling system includes a first cooling circuit which includes a primary cooling device. The cooling system also includes a plurality of modular data pods. Each modular data pod includes an enclosure that includes a plurality of server racks, a heat exchange member coupled to the first cooling circuit, and a second cooling circuit coupled to the heat exchange member. The second cooling circuit is configured to cool the enclosure. The second cooling circuit includes a secondary cooling device configured to cool fluid flowing through the second cooling circuit.~~According to a third aspect of the present invention, there is provided a cooling system for a modular data center, comprising: a first cooling circuit including a primary cooling device; a plurality of modular data pods, each modular data pod comprising: an enclosure including a plurality of server racks; a heat exchange member coupled to the first cooling circuit; and a second cooling circuit coupled to the heat exchange member and configured to cool the enclosure, the second cooling circuit including a secondary cooling device configured to cool fluid flowing through the second cooling circuit.

~~[0013] There is also disclosed~~In yet another aspect, the present disclosure features a system for cooling electronic equipment. The system includes a free-cooling system and a mechanical sub-cooling system. The free-cooling system is configured to cool a first fluid in thermal communication with electronic equipment using atmospheric air. The mechanical sub-

cooling system is coupled to the free-cooling system. The mechanical system is configured to cool a second fluid flowing in the free-cooling system as a function of an amount by which the free-cooling system has exceeded its maximum cooling capacity.

[0014] There is also disclosed~~In yet another embodiment, the present disclosure~~ features a cooling system for cooling electronic equipment. The cooling system includes a first fluid circuit, a second fluid circuit and a third fluid circuit. The first fluid circuit is configured to cool electronic equipment using a first fluid flowing through the first fluid circuit. The second fluid circuit is configured to free cool a second fluid flowing through the second fluid circuit. Further, the second fluid circuit is configured to cool the first fluid using the free-cooled second fluid. The third fluid circuit is configured to mechanically cool the second fluid as a function of the difference between the wet bulb temperature of atmospheric air and a first predetermined wet bulb temperature when the wet bulb temperature exceeds the first predetermined wet bulb temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Various embodiments of the present disclosure are described with reference to the accompanying drawings wherein:

[0016] FIG. 1 is a schematic diagram of a modular data center according to embodiments of the present disclosure;

[0017] FIG. 2A is an illustration of a modular data pod having a pentagonal wall configuration according to one embodiment of the present disclosure;

[0018] FIG. 2B is an illustration of a modular data pod having a hexagonal wall configuration according to another embodiment of the present disclosure;

[0019] FIG. 2C is an illustration of a modular data pod having a heptagonal wall configuration according to yet another embodiment of the present disclosure;

[0020] FIG. 2D is an illustration of a modular data pod having an octagonal wall configuration according to one embodiment of the present disclosure;

[0021] FIG. 2E is an illustration of a modular data pod having a nonagonal wall configuration according to one embodiment of the present disclosure;

[0022] FIG. 2F is an illustration of a modular data pod having a decagonal wall configuration according to yet another embodiment of the present disclosure;

cooling device configured to cool fluid flowing through the second cooling circuit.

21. The cooling system according to claim 20, wherein the secondary cooling device is configured to cool a portion of a heat load within the enclosure that the primary cooling device cannot cool.

22. The cooling system according to claim 20, wherein the secondary cooling device is configured to cool the portion of the heat load within the enclosure as a function of the atmospheric conditions.

23. The cooling system according to claim 20, wherein the first and second cooling circuits have a cooling capacity of at least 40 kW per server rack of the plurality of server racks.

24. The cooling system according to claim 20, wherein the first and second cooling circuits are independent cooling circuits.

~~25. A modular data center, comprising:~~

~~a central cooling system;~~

~~a plurality of modular data pods, each modular data pod comprising:~~

~~a plurality of servers;~~

~~a heat exchange assembly coupled to the central cooling system, the heat exchange assembly configured to cool the plurality of servers; and~~

~~a distributed cooling system coupled to the heat exchange assembly.~~

~~26. The modular data center according to claim 25, wherein the central cooling system is a free-cooling system and the distributed cooling system is a mechanical cooling system.~~

27. The modular data center according to claim 26, wherein the distributed cooling system is configured to cool a portion of a heat load of the modular data pod that exceeds the cooling capacity of the free-cooling system.

28. The modular data center according to claim 25, wherein the heat exchange assembly includes a heat exchange member and a cooling circuit in thermal communication with the heat exchange member, the cooling circuit further in thermal communication with the plurality of servers.

29. A system for cooling electronic equipment, comprising:

a free-cooling system configured to cool a first fluid in thermal communication with electronic equipment using atmospheric air; and

a mechanical sub-cooling system coupled to the free-cooling system, the mechanical system configured to cool a second fluid flowing in the free-cooling system as a function of an amount by which the free-cooling system has exceeded its maximum cooling capacity.

30. The system according to claim 29, wherein the free-cooling system comprises:

a free-cooling device configured to cool the second fluid using atmospheric air; and

a main heat exchanger in fluid communication with the free-cooling device, the main heat exchanger configured to enable heat transfer from the first fluid to the second fluid.

31. The system according to claim 30, wherein the mechanical sub-cooling system is configured to cool the second fluid flowing into the main heat exchanger as a function of the temperature of the second fluid.

32. The system according to claim 30, wherein the mechanical sub-cooling system comprises:

a first heat exchanger configured to enable heat transfer from the second fluid flowing into the main heat exchanger to a third fluid flowing through the first heat exchanger;

a compressor in fluid communication with the first heat exchanger and configured to compress the third fluid flowing out of the first heat exchanger;

a second heat exchanger in fluid communication with the compressor and configured to enable heat transfer from the compressed third fluid to the second fluid flowing out of the main heat exchanger; and

a pressure reducing unit fluidly coupled between the first heat exchanger and the second heat exchanger, the pressure reducing unit configured to reduce the temperature of the second fluid flowing from the second heat exchanger to the first heat exchanger.

33. The cooling system according to claim 32, further comprising

a temperature sensor configured to sense a wet bulb temperature of atmospheric air; and

a controller coupled to the sensor and the compressor, the controller configured to vary the speed of the compressor as a function of the sensed wet bulb temperature of atmospheric air.

34. The system according to claim 32, further comprising:

a fluid receiver configured to receive the first fluid flowing out of the main heat exchanger;

a sensor configured to sense the liquid level of the first fluid contained in the fluid receiver; and

a second mechanical sub-cooling system configured to cool the first fluid when the liquid level of the first fluid contained in the fluid receiver falls below a predetermined level.

35. The system according to claim 34, wherein the second mechanical sub-cooling system comprises:

a third heat exchanger disposed in the fluid receiver and configured to enable heat transfer from the first fluid contained in the fluid receiver to a fourth fluid flowing through the third heat exchanger;

a second compressor in fluid communication with the third heat exchanger and configured to compress the fourth fluid flowing out of the third heat exchanger;

a fourth heat exchanger in fluid communication with the second compressor and configured to enable heat transfer from the compressed fourth fluid to the second fluid; and

a pressure reducing unit fluidly coupled between the third heat exchanger and the fourth heat exchanger, the pressure reducing unit configured to reduce the temperature of the fourth fluid flowing from the fourth heat exchanger to the third heat exchanger.

36. The cooling system according to claim 35, wherein the first fluid, the third fluid, and the fourth fluid contain a refrigerant and the second fluid contains water.

37. The cooling system according to claim 36, wherein the refrigerant is R134A and the second fluid is condenser water, chilled water, or a glycol solution.

38. The cooling system according to claim 37, wherein the mechanical sub-cooling system is closely coupled to the electronic equipment..

39. A method of cooling electronic equipment, comprising:

cooling electronic equipment using a first fluid;

free cooling the first fluid by enabling heat transfer from the first fluid to a second fluid that has been cooled using atmospheric air; and

mechanically cooling the second fluid to the extent that free cooling the first fluid is insufficient to cool the first fluid.

40. The method according to claim 39, wherein mechanically cooling the second fluid includes mechanically cooling the second fluid as a function of the temperature of the second fluid.

41. The method according to claim 39, wherein mechanically cooling the second fluid comprises:

cooling the second fluid before using the second fluid to free cool the first fluid by enabling heat transfer from the second fluid to a third fluid;

compressing the third fluid;

condensing the compressed third fluid by enabling heat transfer from the compressed third fluid to the second fluid after using the second fluid to free cool the first fluid; and

reducing the pressure of the condensed third fluid to reduce the temperature of the third fluid.

42. The method according to claim 41, further comprising

sensing a wet bulb temperature of the atmospheric air; and

varying the speed of compressing the third fluid as a function of the sensed wet bulb temperature to vary the temperature of the second fluid.

43. The method according to claim 41, further comprising

receiving the free-cooled first fluid in a fluid receiver;

sensing the liquid level of the first fluid contained in the fluid receiver;

mechanically cooling the first fluid to condense the first fluid when the sensed liquid level falls below a first predetermined liquid level; and

deactivating mechanical cooling when the sensed liquid level reaches a second predetermined liquid level higher than the first predetermined liquid level.

44. The method according to claim 43, wherein mechanically cooling the first fluid comprises:

cooling the first fluid in the fluid receiver by enabling heat transfer from the first fluid in the fluid receiver to a fourth fluid;

compressing the fourth fluid;

condensing the compressed fourth fluid by enabling heat transfer from the compressed fourth fluid to the second fluid that has been cooled using atmospheric air, and

reducing the pressure of the condensed fourth fluid to reduce the temperature of the fourth fluid.

45. The method according to claim 44, wherein the first fluid, the third fluid, and the fourth fluid contain a refrigerant and the second fluid contains water.

46. The method according to claim 45, wherein the refrigerant is R134A and the second fluid is condenser water, chilled water, or a glycol solution.

47. The method according to claim 39, further comprising:
sensing the temperature of the free-cooled first fluid; and
regulating the flow rate of the second fluid as a function of the temperature of the free-cooled first fluid.

48. A cooling system for cooling electronic equipment, comprising:
a first fluid circuit configured to cool electronic equipment using a first fluid flowing through the first fluid circuit;
a second fluid circuit configured to free cool a second fluid flowing through the second fluid circuit, the second fluid circuit further configured to cool the first fluid using the free-cooled second fluid; and
a third fluid circuit configured to mechanically cool the second fluid as a function of the difference between the wet bulb temperature of atmospheric air and a first predetermined wet bulb temperature when the wet bulb temperature exceeds the first predetermined wet bulb temperature.

49. The cooling system according to claim 48, wherein the first fluid circuit includes a fluid receiver, further comprising:

a sensor configured to sense the liquid level of the first fluid contained in the fluid receiver; and

a fourth fluid circuit in thermal communication with the first fluid contained in the fluid receiver, the fourth fluid circuit configured to mechanically cool and condense the first fluid when the sensed liquid level falls below a predetermined liquid level.

50. A modular data pod, comprising:

an enclosure including wall members contiguously joined to one another along at least one edge of each wall member in the shape of a polygon and a data pod covering member;

a plurality of computer racks arranged within the enclosure to form a first volume between the inner surface of the wall members and first sides of the computer racks and a second volume formed of second sides of the computer racks;

a computer rack covering member configured to enclose the second volume, the computer rack covering member and the data pod covering member forming a third volume coupling the first volume to the second volume; and

an air circulator configured to continuously circulate air through the first, second, and third volumes.

51. The modular data pod according to claim 50, wherein the polygon includes at least five wall members.

52. The modular data pod according to claim 51, wherein at least two of the at least five wall members have different lengths.

53. The modular data pod according to claim 50, wherein the polygon is a hexagon or an octagon.

54. The modular data pod according to claim 50, wherein the plurality of computer racks is arranged in a U-shape, circular shape, or elliptical shape.

55. The modular data pod according to claim 50, wherein the air circulator is coupled to the computer rack covering member.

56. The modular data pod according to claim 50, wherein the air circulator includes a plurality of fans.

57. The modular data pod according to claim 50, further comprising a variable fan drive configured to vary the speed of the air circulator depending on the environmental conditions associated with the modular data pod.

58. The modular data pod according to claim 50, further comprising a heat exchange member disposed in the first volume adjacent to the plurality of computer racks.

59. The modular data pod according to claim 58, further comprising a second heat exchange member disposed in the third volume.

60. The modular data pod according to claim 59, wherein the second heat exchange member is disposed adjacent to the air circulator.

61. The modular data pod according to claim 50, further comprising a dedicated electrical power supply electrically coupled to the plurality of computer racks.

62. The modular data pod according to claim 61, wherein the dedicated electrical power supply includes at least one battery.

63. The modular data pod according to claim 61, further comprising at least one DC/AC inverter electrically coupled to the dedicated electrical power supply.

64. The modular data pod according to claim 62, wherein the dedicated electrical power supply is configured to supply electrical power to an external electrical grid via the at least one DC/AC inverter.

65. A method of cooling a plurality of computer racks, comprising:

arranging a plurality of computer racks within an enclosure having the shape of a polygon to form a first volume between the wall members of the enclosure and first sides of the plurality of computer racks and to form a second volume between second sides of the computer racks; and

enclosing the second volume to form a third volume coupling the first volume to the second volume; and

circulating air between the first volume and the second volume via the third volume and the computer racks.

66. The method according to claim 65, wherein circulating air through the first, second, and third volumes includes varying the speed of the air depending on the environmental conditions.

67. The method according to claim 65, further comprising disposing a heat exchange member in the first volume adjacent to the plurality of computer racks.

68. The method according to claim 67, further comprising disposing a second heat exchange member in the third volume.

69. A method of deploying a plurality modular data pods to form a data center, comprising:

coupling a plurality of shared fluid and electrical circuit sections of a respective plurality of modular data pods in series to form a shared fluid and electrical circuit having a first end and a second end;

coupling an unshared fluid and electrical circuit of each modular data pod of the plurality of modular data pods to a respective shared fluid and electrical circuit section; and

coupling a shared fluid and electrical circuit section at the first end of the shared fluid and electrical circuit to a central fluid and electrical circuit.

70. The method according to claim 69, wherein the shared fluid and electrical circuit includes at least one fluid supply line and at least one fluid return line.

71. The method according to claim 70, wherein the at least one fluid supply line and the at least one fluid return line are in a reverse-return configuration.

72. The method according to claim 69, further comprising coupling a central cooling device to the central fluid and electrical circuit, the central cooling device configured to satisfy at least a portion of the cooling requirements of the plurality of modular data pods.

73. The method according to claim 72, wherein the plurality of shared fluid and electrical circuit sections are a plurality of first shared fluid and electrical circuit sections and the shared fluid and electrical circuit is a first shared fluid and electrical circuit, further comprising:

coupling a plurality of second shared fluid and electrical circuit sections of a respective second plurality of modular data pods in series to form a second shared fluid and electrical circuit having a first end and a second end;

coupling an unshared fluid and electrical circuit of each modular data pod of the second plurality of modular data pods to respective second shared fluid and electrical circuit sections; and

coupling a second shared fluid and electrical circuit section at the first end of the second shared fluid and electrical circuit to a first shared fluid and electrical circuit section at the second end of the shared fluid and electrical circuit.

74. The method according to claim 69, further comprising:

coupling shared fluid and electrical circuit sections of a second plurality of modular data pods in series to form a second shared fluid and electrical circuit having a first end and a second end;

coupling an unshared fluid and electrical circuit of each modular data pod of the second plurality of modular data pods to respective second shared fluid and electrical circuit sections; and

coupling a second shared fluid and electrical circuit section of a modular data pod of the second plurality of modular data pods at the first end of the second shared fluid and electrical circuit to the central fluid and electrical circuit.

75. The method according to claim 74, wherein the central cooling device is a first central cooling device, further comprising coupling a second central cooling device to the central fluid and electrical circuit if the first central cooling device cannot satisfy at least a portion of the cooling requirements of the second plurality of modular data pods.

76. The method according to claim 69, wherein each modular data pod of the plurality of modular data pods includes a data enclosure and an auxiliary enclosure containing a respective shared fluid and electrical circuit, and wherein the shared fluid and electrical circuit forms a linear path, further comprising coupling the data enclosures to the auxiliary enclosures on alternating sides of the shared fluid and electrical circuit.

77. The method according to claim 76, wherein adjacent data enclosures on the same side of the shared fluid and electrical circuit form a pathway providing a user access to the auxiliary enclosure.

78. The method according to claim 69, wherein the central fluid and electrical circuit includes at least one fluid supply line and at least one fluid return line in a reverse-return configuration.

79. A modular data center, comprising:

a central fluid and electrical circuit;

a chain of modular data pods, each modular data pod in the chain of modular data pods including a shared cooling fluid circuit section and an unshared cooling fluid circuit coupled to the shared fluid and electrical circuit section, the shared fluid and electrical circuit section forming a part of a shared fluid and electrical circuit, the shared fluid and electrical circuit coupled at one end to the central fluid and electrical circuit;

a central cooling device coupled to the central cooling fluid circuit, the central cooling device configured to support at least a portion of the cooling requirements of the first chain of modular data pods;

80. The modular data center according to claim 79, wherein the shared fluid and electrical circuit includes at least one fluid supply line and at least one fluid return line.

81. The modular data center according to claim 79, wherein each modular data pod of the chain of modular data pods includes an auxiliary enclosure that contains the respective shared fluid and electrical circuit section.

82. The modular data center according to claim 81, wherein each modular data pod of the chain of modular data pods includes a data enclosure that includes a portion of the respective unshared fluid and electrical circuit, and wherein the shared fluid and electrical circuit forms a linear path and the data enclosures are positioned on alternating sides of the shared fluid and electrical circuit.

83. The modular data center according to claim 82, wherein adjacent data enclosures on the same side of the shared fluid and electrical circuit form a pathway providing access to the auxiliary enclosure.

84. The modular data center according to claim 82, wherein the data enclosure is in the shape of a polygon.

85. The modular data center according to claim 84, wherein the polygon is a hexagon or an octagon.

86. The modular data center according to claim 80, wherein the at least one fluid supply line and the at least one fluid return line are in a reverse-return configuration.

87. The modular data center according to claim 79, further comprising:

a second chain of modular data pods, each modular data pod in the second chain of modular data pods including a shared fluid and electrical circuit section and an unshared fluid and electrical circuit coupled to the shared fluid and electrical circuit section, the shared fluid and electrical circuit section forming a portion of a second shared fluid and electrical circuit, the second shared fluid and electrical circuit coupled at one end to the central fluid and electrical circuit; and

a second central cooling device coupled to the central fluid and electrical circuit, the second central cooling device configured to support at least a portion of the cooling requirements of the second chain of modular data pods.

88. The modular data center according to claim 87, wherein the central fluid and electrical circuit includes at least one fluid supply line and at least one return line in a reverse-return configuration.