

MULTISTAGE LIQUID COOLING SYSTEM AND CONFIGURATION

This Patent Application claims priority benefit of US Patent Application 63/346,804, filed on 27 May 2022.

FIELD OF THE INVENTION

[0001] The present disclosure relates generally to a multistage liquid cooling system and configuration, and more particularly to the structure of a multistage liquid cooling system incorporated with evaporative cooling and sensible cooling components with enhanced efficiency.

BACKGROUND

[0002] Evaporative cooling, also known as swamp cooling, leverages a decrease in air temperature that happens when the state change of water from liquid to gas absorbs energy. Evaporative coolers are useful in data centers, for example, where server or infrastructure heat loads are high and frequent downtimes are not acceptable. Additionally, evaporative coolers can be relatively low cost to operate.

[0003] Since data centers use relatively large amounts of electricity, and data centers are a rapidly growing market, there is a need to increase energy efficiency when cooling such data centers. Evaporative cooling is widely adopted in many applications due to its reliability in delivering high efficiencies, which can translate to considerable savings and relatively lower energy footprint over conventional vapour compression systems. The evaporative cooling uses the latent heat of vaporization of water to achieve a water temperature reduction that is close to the passing air wet bulb temperature whilst increasing the moisture content and reducing the temperature of the passing air. However, this advantage is limited by the ambient air psychrometric conditions, in this regard it works best in hot and dry weather conditions but not in humid climates without supplemental cooling equipment. Thus, there exists a need for the data center operators to increase the data center power usage effectiveness. The energy efficiency of the data center should be increased by reducing the energy

consumption of the cooling equipment through the adoption of alternative cooling technologies to supplement or replace the existing cooling infrastructure.

[0004] PCT/SG2022/05032 describes an efficient liquid cooling unit having a cold-water generation unit (CGU) adapted to receive outdoor air from a first outdoor air inlet through a first air stream and to cool water; and a main cooling unit (MCU) adapted to receive outdoor air from a second outdoor air inlet through a second air stream and to cool the outdoor air so received from the second outdoor air inlet. The cold-water generation unit comprises a first evaporative media configured to circulate evaporative cooling water therethrough, wherein airflow through first air stream is separate from airflow through the second streams such that the airflows do not mix with one another, and the main cooling unit and the cold-water generation unit are arranged in fluid communication with the water management system via a first fluid stream. While this design advantageously increases energy efficiency, known designs sometimes have a problem with short-circuiting of exhaust air from a heat recovery unit back when fed into a main cooling unit or to a cold-water generation unit. A need, therefore, exists to design an improved liquid cooling apparatus which reduces problems associated with short-circuiting, while reducing the overall system physical footprint.

SUMMARY OF THE INVENTION

[0005] In accordance with a first aspect, a multistage liquid cooling system has a top and a bottom, and sides connecting the top to the bottom. The multistage liquid cooling system comprises a first fluid inlet adapted to receive warm fluid to be cooled, a first air inlet adapted to receive first air, and a first air outlet adapted to exhaust the first air, a second air inlet adapted to receive second air, such that the second air is isolated in the multistage liquid cooling system from the first air, and a second air outlet adapted to exhaust the second air, a heat recovery unit, a cold-water generation unit, and a main cooling unit. The heat recovery unit is adapted to receive second air from main cooling unit and fluid from the first fluid inlet and cool the fluid at a first stage of cooling. The cold-water generation unit is adapted to receive the first air from the first air inlet, and cooled fluid from the heat recovery unit and further cool the fluid at a second stage of cooling. The main cooling unit is adapted to receive the second air

from the second air inlet, further cooled fluid from the cold-water generation unit, and provide a third stage further cooling the fluid. The first air inlet and the second air inlet are each positioned on the side, and the first air outlet is positioned on the top.

[0006] From the foregoing disclosure and the following more detailed description of various embodiments it will be apparent to those skilled in the art that the present invention provides a significant advance in the technology of evaporative coolers. Particularly significant in this regard is the potential the invention affords for enhancing energy efficiency and reducing the risk of short circuiting where hot waste air is inadvertently reintroduced into the evaporative cooler. Additional elements and advantages of various embodiments will be better understood in view of the detailed description provided below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Fig. 1 shows a schematic diagram of a multistage liquid cooling system in accordance with one embodiment where the cold-water generation unit (CGU) and the main cooling unit (MCU) are separated by an airflow divider.

[0008] Fig. 2 shows a schematic diagram of a multistage liquid cooling system in accordance with another embodiment where the CGU is positioned above the MCU.

[0009] Fig. 3 shows a schematic diagram of another embodiment of a multistage liquid cooling system, with first air exhaust outlet(s) and second air outlet(s) positioned on a top of the cooler

[0010] Fig. 4 shows a fluid trace for the embodiment of Fig. 3.

[0011] Fig. 5 shows a plan schematic view of the top of a multistage liquid cooling system showing a pair of first air outlets and a second air outlet.

[0012] Fig. 6 shows a plan schematic view of the top of an embodiment of the

multistage liquid cooling system showing four first air outlets and a second air outlet.

[0013] Fig. 7 shows a plan schematic view of the top of an embodiment of the multistage liquid cooling system showing six first air outlets and a second air outlet.

[0014] It should be understood that the appended drawings are not necessarily to scale, presenting a somewhat simplified representation of various features illustrative of the basic principles of the invention. The specific design features of the multistage liquid cooling system as disclosed here, including, for example, the specific dimensions of the inlets and outlets will be determined in part by the particular intended application and use environment. Certain features of the illustrated embodiments have been enlarged or distorted relative to others to help provide clear understanding. In particular, thin features may be thickened, for example, for clarity of illustration. All references to direction and position, unless otherwise indicated, refer to the orientation illustrated in the drawings.

DETAILED DESCRIPTION OF CERTAIN EMBODIMENTS

[0015] It will be apparent to those skilled in the art, that is, to those who have knowledge or experience in this area of technology, that many uses and design variations are possible for the multistage liquid cooling system disclosed here. The following detailed discussion of various alternate elements and embodiments will illustrate the general principles of the invention with reference to a multistage liquid cooling system with improved energy efficiency. Other embodiments suitable for other applications will be apparent to those skilled in the art given the benefit of this disclosure.

[0016] Multistage liquid cooling systems described herein can be used in tandem with other equipment, to serve as a key or supplementary cooling system in data centers, for example. With a combination of fluid pathways within the cooling system of different configurations, it serves to provide a comprehensive suite of cooling solutions of different efficiencies to suit varying ambient conditions and load requirements.

[0017] Turning now to the drawings, Fig. 1 shows a multistage liquid cooling system 100 in accordance with one embodiment comprising a Cold-Water Generation Unit (CGU) 102, a Main Cooling Unit (MCU) 114, and a Heat Recovery Unit (HRU) 112. Relatively hot fluid flows into the cooler 100 via a fluid inlet 81 (shown in Fig. 4) and through a series of heat transfer steps (through first heat exchanger 108 to first evaporative media 104 to 2nd evaporative media 106 to a second water tank 118). Representative temperature reduction of the liquid can be from a temperature at the fluid inlet of about 31°C, to about 30°C at the first heat exchanger 108, to about 28-29°C at the 1st evaporative media 104 to about 26°C at the 2nd evaporative media 106, for example. The multistage liquid cooling system is shown having a bottom wall 160, a top wall 150, and side walls 152, 154 operatively connecting the bottom wall to the top wall. An airflow divider 120 positioned in the cooler cooperates with one or more of the walls to separate a cold-water generation unit (CGU) 102 from a main cooling unit (MCU) 114 and a heat recovery unit (HRU) 112. The multistage liquid cooling system is also shown with at least one first fan 122, at least one second fan 124, a first water tank 116 positioned in the CGU, and a second water tank 118 positioned in the MCU. The CGU 102 further comprises a first evaporative media 104 for evaporative cooling water circulating. Side wall 154 has a first air inlet 71, and top wall 150 has a first air outlet 79. The first fan 122 pulls air from inlet 71 through the first evaporative media 104 and expels the heated air through outlet 79. Advantageously, the first fan 122 in the CGU 102 is arranged in such way that the air leaves the first evaporative media 104 in an upwards direction, and away from the 2nd air inlet 91. The side walls in this embodiment can have an upper side 152 and a lower side 153 on the left side (as shown in Fig. 1), and an upper side 154 and lower side 155 on the right side (as shown in Fig. 1). The 2nd air inlet is shown on one of the side walls 152, below the airflow divider, at the MCU. The side walls are generally perpendicular with respect to the bottom wall 160 and to the top wall 150 and can have, for example, four side walls and a rectangular cross section. The second air is isolated in the multistage liquid cooling system from the first air. That is the two air streams travel different paths in the multistage liquid cooling system until each air stream reaches a separate outlet.

[0018] The main cooling unit MCU 114 comprises a second evaporative media 106

for evaporative cooling water/fluid circulating therethrough and is provided with a second heat exchanger 110. The heat recovery unit HRU 112 is provided with of a first heat exchanger 108. The second fan 124 is used for moving air through the MCU 114 and the HRU 112 from 2nd air inlet 91 to 2nd air outlet 99. The first water tank 116 and the second water tank 118, can comprise containers to hold the water that is being circulated in the multistage liquid cooling system 100. A water pump used for circulating the fluid/water is typically provided. The airflow divider 120 acts to separate the first airflow in the CGU 102 from the second airflow of the MCU 114 and the HRU 112. The MCU 114 and GCU 102 are arranged in fluid communication as discussed in greater detail in Fig. 4 below.

[0019] In the embodiment of Fig. 1, the CGU 102 is positioned next to the MCU 114 (which is below the HRU 112) such that the CGU is between side wall 154 and airflow divider 120. The overall height of the CGU 102 can be equivalent to a total height of the MCU 114 and the HRU 112 such that the multistage liquid cooling system 100 fully uses available headroom while reducing the physical footprint. As shown in Fig. 1, the first water tank 116 is placed below the CGU 102 and the second water tank 118 is below the MCU 114. The components such as the first water tank 116, the second water tank 118, the CGU 102, the MCU 114 can be arranged in numerous ways. The first air fans 122 and second air fans 124 (with corresponding air outlets) may be arranged as shown in Fig. 1, with the first air fan outlet on the top wall, and the second air fan outlet at side wall 152. More generally the fan outlets are positioned generally remote from the air inlets. Alternatively, all of the fan outlets may be positioned on the top wall, and can take on one of several different geometries – such as a shape similar to a polygonal prism, having four, six or eight vertical faces. The first fan 122 in the CGU 102 can be located above the first evaporative media 104 such that the air leaves the first evaporative media 104 i.e., airflows (airflow 1) in a net upwards direction as shown in Fig. 1 towards the top. This configuration has advantage over a horizontal or downward air flow direction as it reduces the chances of water droplets being drawn together with the airflow, thus reducing water lift off and eliminating the need to install drift eliminators. This configuration also allows the face velocity of the air through the evaporative media to be higher than the other two flow orientation, thus advantageously contributing to a smaller overall surface area which leads to an overall

smaller unit footprint.

[0020] The first water tank 116 is located at the base of the CGU 102, which collects the water that flows from the first evaporative media 104 in the CGU 102, before pumping it to the next stage of the cooling process, which is the second evaporative media 106 of the MCU 114. In this embodiment, a pump can be in the first water tank 116 to circulate the water to the MCU 114. Some of the water flows directly to the second water tank 118 that is positioned below the MCU 114. In another embodiment, all the water from the CGU 102 passes through the second evaporative media 106 of the MCU 114, such that all the water is cooled to a lower temperature after passing through the MCU unit 114. The first water tank 116 and second water tank 118 may not be directly fluidly connected to achieve a lower final water temperature. As shown in the embodiments herein, an internal second fluid flow may be provided from the 2nd water tank 118 to the second heat exchanger 110, to the first evaporative media 104, from there to the first water tank 116, from there to the 2nd evaporative media 106 and back to the 2nd water tank 118. This second fluid flow allows the second air/second airflow to be pre-cooled first in the second heat exchanger 110, so that upon contact with water at the second evaporative media 106, the final water temperature leaving the second evaporative media can be materially lowered. Second airflow after the first evaporative media is in a net upward direction towards the top.

[0021] The MCU 114 is positioned at side wall 153 adjacent to the CGU 102 and separated by and positioned below the airflow divider 120. This arrangement helps to reduce leakage of air flows between the CGU 102 and the MCU 114. Below the MCU 114 is the second water tank 118 at or near bottom wall 160, which collects the water from the second evaporative media 106 in the MCU 114. In the second water tank 118 final cold water is collected, to be circulated to an external unit using this cold water, via an external pump or gravity feed, depending on the application. Inside the second water tank 118 is also another circulation pump, which is used to circulate the cold water generated into the second heat exchanger 110 of the MCU 114 for pre-cooling the air, before flowing to the first evaporative media 104 in the CGU 102 for regeneration.

[0022] In the embodiment of Fig. 1, in the main cooling unit 114, the second heat exchanger 110 is positioned at 2nd air inlet 91 so as to be upstream of the second evaporative media 106. The function of the second heat exchanger 110 is to pre-cool the ambient air that is drawn by the second fan 124 through the 2nd inlet 91, such that the air temperature of the second air stream is lowered before being fed to the second evaporative media 106. This has the effect of cooling the water in the second evaporative media 106 to a temperature lower than the ambient wet bulb. The size ratio of the second heat exchanger 110 to the second evaporative media 106 is preferably 1:1, in order that the capacity of the second heat exchanger 110 and the second evaporative media 106 is kept uniform. Optionally the size ratio could be changed to increase or decrease the cooling capacity of each component to suit the cooling requirements. Specifically, if the size of the second evaporative media 106 is larger than the second heat exchanger 110, the temperature of the water entering the second water tank 118 is even lower and more water can also flow to the second evaporative media 106. If the second heat exchanger 110 size is larger than the second evaporative media 106, the air temperature exiting the second heat exchanger 110 is relatively lower, allowing the water temperature to be lower albeit at a lower flow rate.

[0023] In the embodiment of Fig. 1 the HRU 112 is positioned above the MCU 114 that houses heat exchanger 108. As shown, the HRU is positioned above the MCU and above an airflow divider 120, generally adjacent side wall 152, such that the overall size of the heat exchanger 108 is similar to the size of the second heat exchangers 110 in the MCU 114. This arrangement helps preserve a face velocity of fluid flowing through the heat exchangers, increasing cooling performance. The first heat exchanger 108 in the HRU 112 allows the return heated water from which the liquid cooling apparatus 100 supplies cold water to be partially regenerated by using the cool air that is generated from the MCU 114 section to pre-cool the water before circulating the water to the CGU 102 for further cooling and regeneration. Cooling capacity loss is low and the cool air that is generated as a by-product of cooling water in the MCU 114 is recycled to cool the heated water, thereby reducing the regeneration needed in the CGU 102, and allowing the size of the CGU 102 to be further trimmed.

[0024] The 2nd air fan 124 is positioned between the MCU 114 and the HRU 112 unit, such that the MCU 114 is upstream of the fan 124 and the HRU 112 is downstream. This orientation specifically saves most of the space and the fan 124 takes up unused space in the centre of the HRU 112, while maintaining a net upwards airflow direction for air existing the MCU second evaporative media 106 i.e., airflow 2 (shown in Fig.1). The exhaust air is therefore expelled from the perimeter of the HRU 112 back into ambient. In another embodiment the fan 124 is placed either upstream of both the MCU 114 and the HRU 112, or downstream of both the MCU 114 and the HRU 112, without any significant performance variation. While the 2nd air outlet 99 may be positioned generally adjacent the side wall 152, 2nd air outlet 99 may also be extended away from the side wall via additional ducting or separators to bring the exhaust air further away from the air intakes. The location of the 2nd fan 124 downstream of the second evaporative media 106 is placed to create a more uniform face velocity profile on the second evaporative media 106, which aids in increasing the heat transfer efficiency of the whole second evaporative media 106.

[0025] Fig. 2 shows another embodiment of a multistage liquid cooling system 200 where the CGU 202 is positioned directly above the HRU 212, between side walls 252 and 254, and top wall 250. The CGU 202 is positioned above the HRU 212, which is in turn positioned above the MCU 214. The first fan 222 and the second fan 224, as well as the first water tank (not shown in Fig. 2), and the second water tank 218 can be also arranged in numerous ways. The physical footprint is reduced as all components are stacked on top of one another, providing a tall and lean embodiment. The airflow divider 220 is therefore placed under the CGU 202 to separate the airflow flowing in the CGU 202 and that of the MCU 214 and the HRU 212. Similar to the first configuration, the first water tank can be positioned at the bottom of the CGU 202, using gravity to collect the water that is fed to the first evaporative media 204, before further flowing it to the second evaporative media 206, in the MCU 214. Also, in this second configuration, a water pump is not required in the first water tank thus saving on costs and energy.

[0026] In this embodiment, the second fan 224 is used to draw air from 2nd air inlet 291 and move air from the MCU 214 to the HRU 212, and can be placed between the

MCU 214 and the HRU 212 to rationalize use of space. To overcome issues with short-circuiting of exhaust air from the HRU 212 back into the MCU 214 or to the CGU 202, the size of the first heat exchangers 208 in the HRU 212 and/or the second heat exchangers 210 is/are reduced to increase the effective face velocity or introduce additional ducting or separators to bring the exhaust air further from the air intakes. Further, the position of the second fan 224 can be relocated such that short-circuiting of the exhaust air is kept low without the need to either reduce the heat exchanger surface area or introduce additional air separators.

[0027] Fig. 3 shows another embodiment of a multistage liquid cooling system 300, where the CGU 302 is positioned above the MCU 314, while the HRU 312 is located centrally remote from side walls 352/353 and 354/355. The HRU is shown at least partially surrounded by both the CGU 302 and the MCU 314, thus using the empty chamber created by the surrounding components of the MCU 314 to house the HRU 312 components. The relative position of the first heat exchanger 308 of the HRU is such that it can be higher compared to the MCU components, that is, at least a portion of the first heat exchanger 308 is closer to the top wall 350 than the second heat exchanger 310, thus ensuring a net upward flow of the air passing through the second evaporative media 306, and ensuring that the size of the evaporative media can be kept low to reduce the physical footprint. The first heat exchanger 308 can be configured to be at an angle to further increase the use of the empty chamber space to house the component and cater for smoother airflow transition from one component to the next. As shown, the sides are perpendicular to the top and the bottom, so as to be aligned generally vertically during normal operation, and the first heat exchangers 308 are positioned at an acute angle with respect to the sides. This configuration advantageously reduces size of the multistage liquid cooling system. Also in this configuration, the second fans 324 are placed downstream of the MCU 314 and HRU 312 and on the top wall of the apparatus 300 such that the air that is drawn past these two components are exhausted in an upwards direction at outlets 399, to prevent any recirculation back into the apparatus, either via the air inlet to first air/Airflow 1 or the air inlet to second air/Airflow 2. The first air outlet 379 may be positioned at a portion of the top 360 which forms an acute angle with the sides 352/354. As shown in Fig. 3, the first fan 322 may be positioned at an approximately 45° angle with the side walls.

The first air inlet is on the first side wall opposite the second side wall, and the second air inlet is also on the first side wall. In Fig. 3, the first side wall is 354/355, the second side wall is 352/353. First air inlet 371 is at 354 above second air inlet 391 at 355. Both side walls may be generally perpendicular to the top wall 350 and to the bottom wall 360.

[0028] Fig. 4 shows the embodiment of Fig. 3 with a trace of a water circuit. Fluid in a first fluid stream enters the multistage liquid cooling system at a fluid inlet 81, typically on one of the side walls. From there, the fluid travels through a series of heat transfer steps. First is the first heat exchanger 308 in the HRU, and from there to the first evaporative media 304, shown in this embodiment at least partially above the first heat exchanger 308 (that is, closer to the top wall 350). From there fluid can travel to the 2nd evaporative media 306 and then be collected in the second water tank 318. From there the cooled water may be directed out of the multistage liquid cooling system. The configuration of the HRU with respect to the MCU and CGU advantageously reduces water lift-off from the first and second evaporative media 304, 306 and increases face velocity to achieve a compact system physical footprint. The airflow divider 320 separates the airflow in the CGU 302 from that of the MCU 314 and HRU 312, such that two separate air streams driven by different fans 322, 324. The embodiment shown in Figs. 3-4 allow for enhanced control and flexibility of both airflow streams, allowing individual control of the capacity for the CGU 302, the MCU 314, and the HRU 312. This embodiment allows flexibility for a variable capacity multistage liquid cooling system in differing modes of operation, whereby the power consumption is reduced, that is, few components of the liquid cooling apparatus 300 are non-functional to reduce power. For example, if the cooling capacity generated from the CGU 302 is sufficient for the application, then the second fan 324 for the MCU 314 and the HRU 312 is not operatable, hence providing additional electrical savings. Similarly, the MCU 314 and the HRU 312 also operate individually without the CGU 302 operation.

[0029] As shown in the embodiments herein, an internal second fluid flow may be provided from the 2nd water tank 318 to the second heat exchanger 310, to the first evaporative media 304, from there to the first water tank 316, from there to the 2nd

evaporative media 306 and back to the 2nd water tank 318. This second fluid flow allows the second airflow to be pre-cooled first in the second heat exchanger 310, so that upon contact with water at the second evaporative media 306, the final water temperature leaving the second evaporative media can be materially lowered.

[0030] As shown in Figs. 3-4, the airflow divider 320 is placed to separate the airflow flowing in the CGU 302 from that of the MCU 314 and the HRU 312. With the first heat exchanger 308 positioned at an acute angle with respect to vertical (that is, perpendicular to a plane formed by the bottom and/or the top wall), the airflow divider can also be at a slanted position to help smooth airflow within the system and eliminate any dead space. The first fan 322 of this embodiment is also placed above the first evaporative media 304 of the CGU 302 (closer to the top wall than the first evaporative media 304) and on top of the multistage liquid cooling system 300 such that the air exhausted is upwards and away from the apparatus air intakes.

[0031] Similar to the first and second embodiments, in the embodiment of Figs. 3-4, the air outlets 379, 399 can have any number of sides for air intake. The first air inlet and the second air inlet can be on the same side or a different side. Fig. 5 shows one example which can be used with any of the embodiments discussed above. Fig. 5 is a plan view of a pair of first fans 322 and a second fan 324 positioned between the two first fans 322. The first fans 322 and second fan 324 are both positioned on the top wall 350 of the apparatus. Optionally the first fans may be presented on a portion of the top wall forming an acute angle with another portion of the top wall where the second air outlet and second fan is located. The MCU 314 and the HRU 312 are shown as a combined section with airflow divider 320 positioned between the CGU 302 and the combined section (314 and 312). The multistage liquid cooling system disclosed here may have a generally rectangular cross section, at least near the top wall.

[0032] Fig. 6 shows a plan view another exhaust fan arrangement where four first fans 322 are positioned at 90° intervals around a centrally located second fan. As with the embodiment of Fig. 5, all the fans are positioned on the top wall and the portions

may not necessarily be uniformly planar taken together. Air dividers 320 are shown isolating the CGU from the MCU/HRU sections. The multistage liquid cooling system disclosed here may have a generally square cross section, at least near the top wall. The plurality of first exhaust fans 322 may advantageously spread the relatively hot exhaust air and further reduce potential issues with short circuiting. Since the first air outlet corresponds to the first fan, when there are four first fans, there are four first air outlets positioned circumferentially around the second air outlet.

[0033] Fig. 7 shows a plan view of another exhaust fan arrangement where six first fans 322 are positioned at 60° intervals on the top wall circumferentially surrounding a centrally located second fan 324. As with the embodiments of Figs. 5-6, all the fans are positioned on the top wall and the portions of the top wall may not necessarily be uniformly planar taken together. Air dividers 320 are shown isolating the CGU from the MCU/HRU sections. The multistage liquid cooling system disclosed here may have a generally hexagonal cross section, at least near the top wall. The plurality of first exhaust fans 322 may advantageously spread the relatively hot exhaust air and further reduce potential issues with short circuiting. Since the first air outlet corresponds to the first fan, when there are six first fans, there are six corresponding first air outlets, and these first air outlets may be positioned circumferentially and equidistantly on the top around the second air outlet.

[0034] The liquid cooling apparatus 300 contains a Cold-Water Generation Unit (CGU) 302, a Heat Recovery Unit (HRU) 312, a Main Cooling Unit (MCU) 314, water tanks 316, 318, fans 322 and 324 for moving first and second air streams, respectively, a circulation water pump and an airflow divider 320 to separate the airflow in the Cold-Water Generation Unit 302 from the Main Cooling Unit 314 and the heat recovery unit HRU 312. Fluid flow through the multistage liquid cooling systems disclosed herein to cool circulating water to a temperature lower than ambient wet bulb can comprise a multi-stage process of temperature reduction. At a first stage warm to hot first fluid is introduced into the multistage liquid cooling system at a fluid inlet 81, passing the first fluid through the first heat exchanger 308 positioned in the HRU and exchanging heat with the second air stream there to cool the fluid. From there at a second stage the fluid travels to the first evaporative media 304 positioned in the CGU where heat is

exchanged with the first air stream, further reducing the temperature of the fluid, and is collected in the first water tank 316. In the third stage of heat transfer, the fluid is transferred to the MCU and second evaporative media 306, and heat is exchanged with the second air stream to cool the fluid a third time. Once the third stage is complete, the cooled fluid is collected in the second water tank 318, and eventually pumped or otherwise delivered to the outlet for use, such as for cooling data centers and other places where substantially cooling is required. Water may drip from or otherwise be operatively connected to the second evaporative media 306 into the second water tank, so a direct physical connection is not required.

[0035] The ability to cool the water to a temperature sufficiently low (in this case, close or below to the wetbulb temperature) and then send out to provide cooling is advantageous by reducing the cooling load and dependency on conventional cooling technology (such as refrigerants and chiller water, which runs on compressors and are energy intensive). For example, in data centers, heat from the data hall is traditionally passed to the chilled water running in a cooling unit or a fan coil unit. With the inventions disclosed herein, the cooled water may also be sent to the fan coil unit and take up some of the heat load, (for example, around 40-50% of the total load), so that less load needs to be cooled by the chilled water, which runs on compressors. Advantageously, therefore, the multistage liquid cooling systems disclosed herein can help data centers reduce their electricity consumption and attendant costs. From the foregoing disclosure and detailed description of certain embodiments, it will be apparent that various modifications, additions and other alternative embodiments are possible without departing from the true scope of the invention. The embodiments discussed were chosen and described to provide the best illustration of the principles of the invention and its practical application to thereby enable one of ordinary skill in the art to use the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the invention as determined by the appended claims when interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled.

CLAIMS

What is claimed is:

1. A multistage liquid cooling system having a top and a bottom, and sides connecting the top to the bottom, comprising, in combination:
 - a first fluid inlet adapted to receive warm fluid to be cooled;
 - a first air inlet adapted to receive first air, and a first air outlet adapted to exhaust the first air;
 - a second air inlet adapted to receive second air, such that the second air is isolated from the first air, and a second air outlet adapted to exhaust the second air;
 - a heat recovery unit, a cold-water generation unit, and a main cooling unit;wherein
 - the heat recovery unit is adapted to receive second air from main cooling unit and fluid from the first fluid inlet and cool the fluid at a first stage of cooling;
 - the cold-water generation unit is adapted to receive the first air from the first air inlet, and cooled fluid from the heat recovery unit, and further cool the fluid at a second stage of cooling; and
 - the main cooling unit is adapted to receive the second air from the second air inlet, further cooled fluid from the cold-water generation unit, and provide a third stage further cooling the fluid; and
 - the first air inlet and the second air inlet are each positioned on one of the sides, and the first air outlet is positioned on the top.
2. The multistage liquid cooling system of claim 1, wherein the second air outlet is also positioned on the top.
3. The multistage liquid cooling system of claim 1, wherein the first air outlet comprises at least two first air outlets.
4. The multistage liquid cooling system of claim 3, wherein the second air outlet is positioned on the top centrally between the at least two first air outlets.

5. The multistage liquid cooling system of claim 3, wherein the first air outlet comprises at least four first air outlets positioned circumferentially around the second air outlet.
6. The multistage liquid cooling system of claim 1, wherein the second air inlet and the second air outlet are positioned on the same side.
7. The multistage liquid cooling system of claim 6, wherein the first air inlet is on the same side as the second air inlet.
8. The multistage liquid cooling system of claim 1, wherein the sides comprise a first side wall and a second side wall, opposite the first side wall, and both the first air inlet and the second air inlet are on the first side wall.
9. The multistage liquid cooling system of claim 1 wherein the top has a portion which forms an acute angle with at least one of the sides, and the first air outlet is on the portion.
10. The multistage liquid cooling system of claim 1 wherein the heat recovery unit has a first heat exchanger adapted to transfer heat from the first fluid to the second air.
11. The multistage liquid cooling system of claim 1 wherein the cold-water generation unit has a first evaporative media adapted to transfer heat from the first fluid to the first air.
12. The multistage liquid cooling system of claim 11 wherein the first fan is positioned closer to the top than the first evaporative media.
13. The multistage liquid cooling system of claim 11 wherein a direction of air flow after the first evaporative media is in an upward direction towards the top.

14. The multistage liquid cooling system of claim 1 wherein the main cooling unit has a second evaporative media adapted to transfer heat from the first fluid to the second air.

15. The multistage liquid cooling system in claim 14 wherein the direction of air flow after the second evaporative media is in an upward direction towards the top.

16. The multistage liquid cooling system of claim 14 further comprising a second heat exchanger in the main cooling unit positioned between the second air inlet and second evaporative media.

17. The multistage liquid cooling system of claim 1 further comprising an airflow divider separating the first air from the second air, and the cold-water generation unit from the heat recovery unit.

18. The multistage liquid cooling system of claim 1 wherein the sides are perpendicular to the bottom, and a first heat exchanger is positioned at acute angle with respect to the sides in the heat recovery unit.