(12) UK Patent Application (19) GB (11) 2595739 (13) A

(43) Date of A Publication 08.12.2021

(21) Application No: 2008559.3

(22) Date of Filing: 06.06.2020

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(51) INT CL:
F24F 1/02 (2019.01) ***F24F 1/022*** (2019.01)
F24F 1/029 (2019.01) ***F24F 1/032*** (2019.01)
F24F 1/039 (2019.01) ***F24F 1/42*** (2011.01)
F24F 13/22 (2006.01)

(56) Documents Cited:
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CN 209819837 U **JP 2009216332 A**
JP 2004036914 A
KR 20160026274

(58) Field of Search:
INT CL **F24F**
Other: **WPI, EPODOC**

(54) Title of the Invention: **All in one: air conditioning, energy recovery, and water production device**
Abstract Title: **An apparatus for cooling an air stream**

(57) An apparatus for cooling a first air stream 10, the apparatus comprising: a first air flow path 100 that passes the first air stream sequentially through a first cooling section 13, an evaporator section 14, a low-grade condenser section 21 and a direct evaporative cooling section 16; a second air flow path 200 that passes a second air stream 20 through a high-grade condenser section 24; and a refrigerant circuit interconnecting the evaporator section and the high-grade condenser section, wherein: the first cooling section 13 is configured to cool the first air stream; the evaporator section 14 is configured to cool the first air stream by passing heat from the first air stream to a refrigerant in the refrigerant circuit; the low-grade condenser section 21 is configured to heat the first air stream; the direct evaporative cooling section16 is configured to cool and humidify the first air stream; and the high-grade condenser section 24 is configured to cool the refrigerant of the refrigerant circuit by transferring heat from the refrigerant to the second air stream.

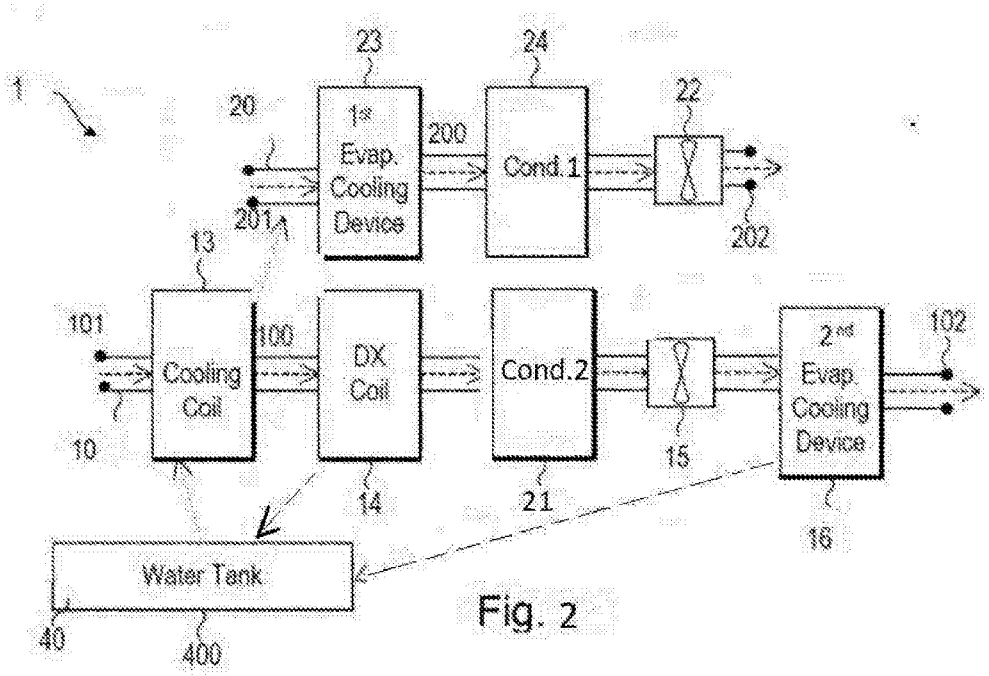

Fig. 2

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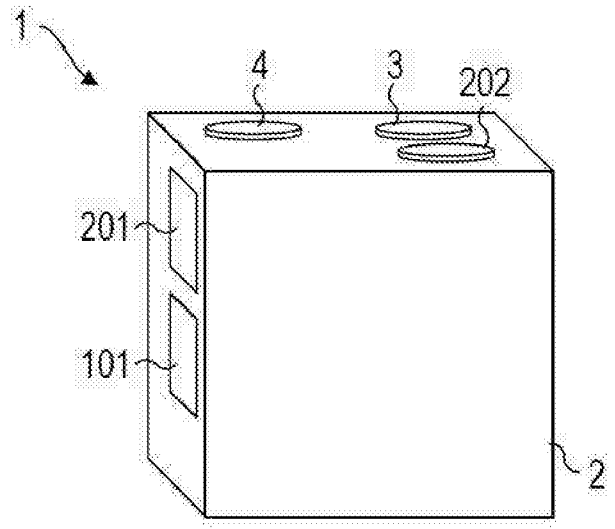

Fig. 1

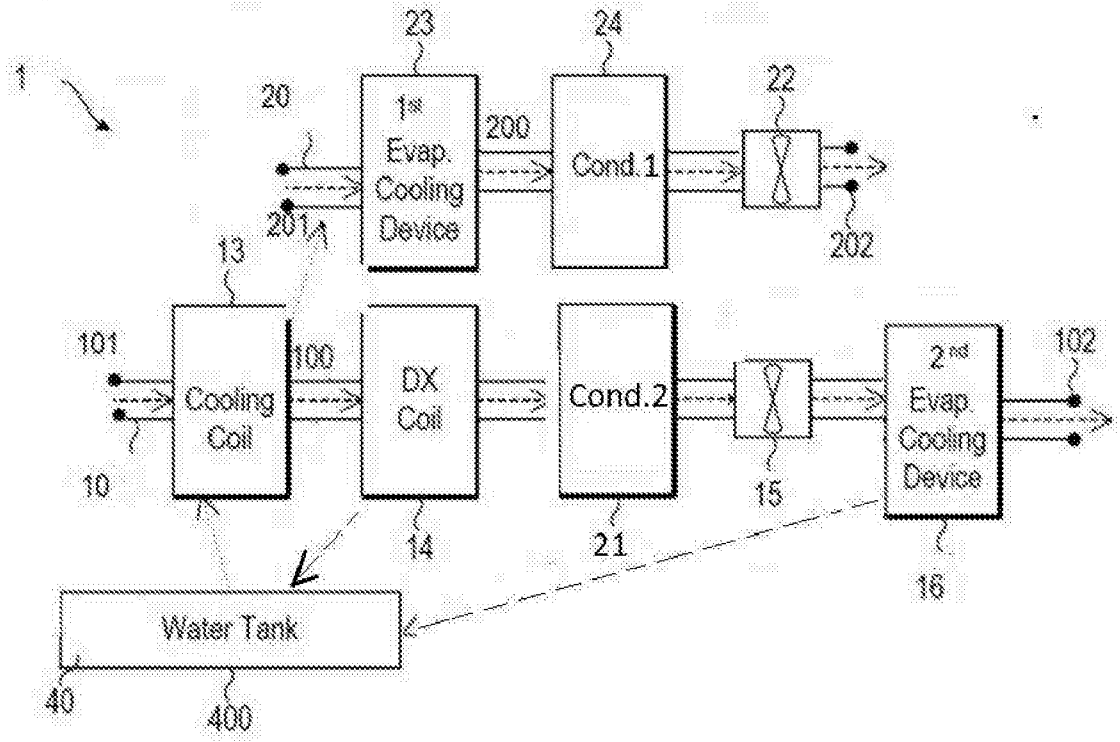
1
20
23
1st
Evap.
Cooling
Device
200
24
Cond.1
22
201
202
13
101
100
Cooling
Coil
DX
Coil
Cond.2
2nd
Evap.
Cooling
Device
102
10
14
21
15
16
Water Tank
40
400

Fig. 2

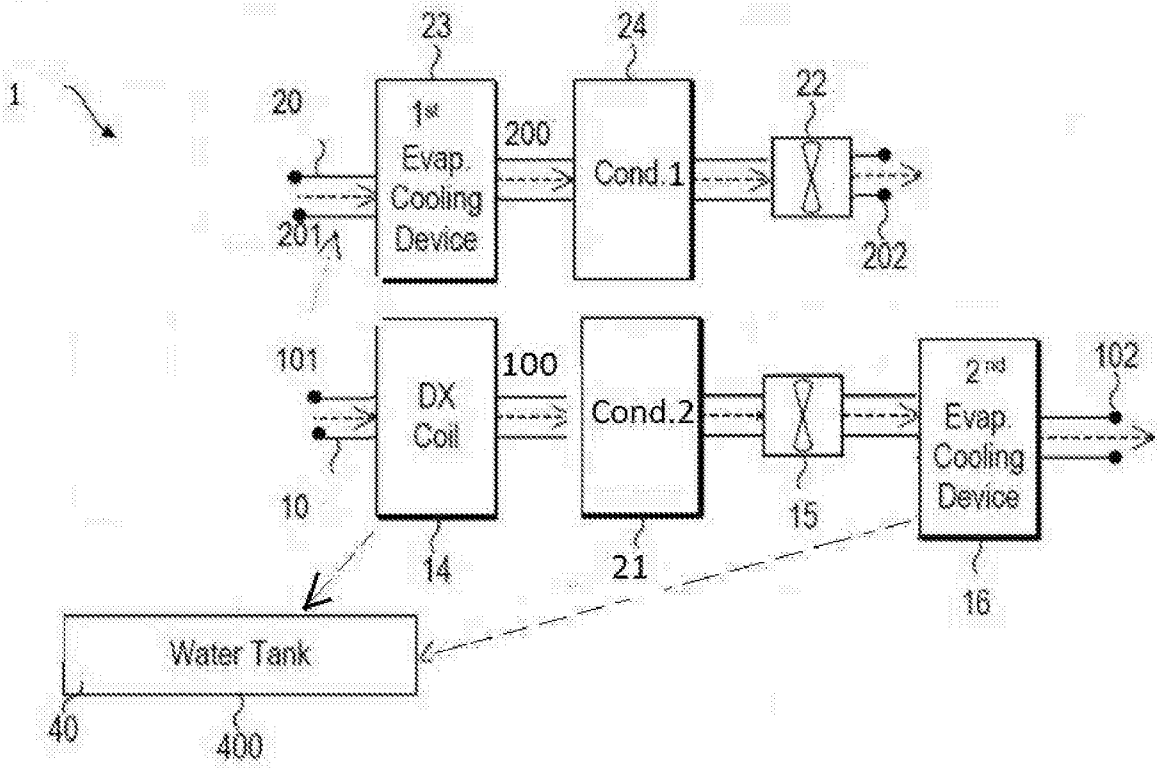
1
20
201
23
1st Evap. Cooling Device
200
24
Cond.1
22
202
101
DX Coil
100
Cond.2
2nd Evap. Cooling Device
102
10
14
21
15
16
Water Tank
40
400

Fig. 3

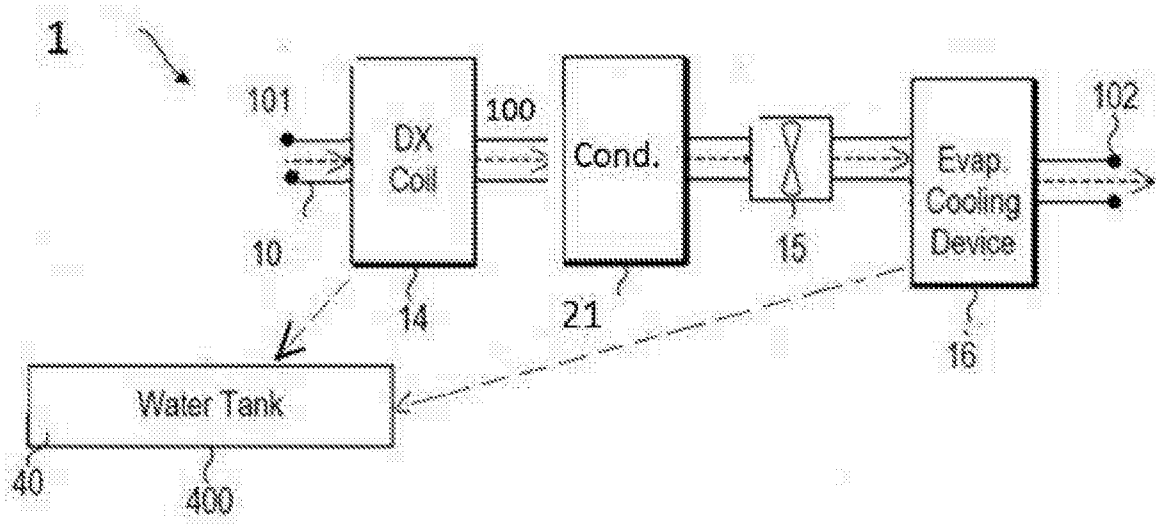
1
101
DX
Coil
100
Cond.
102
Evap.
Cooling
Device
10
14
21
15
16
Water Tank
40
400

Fig.4

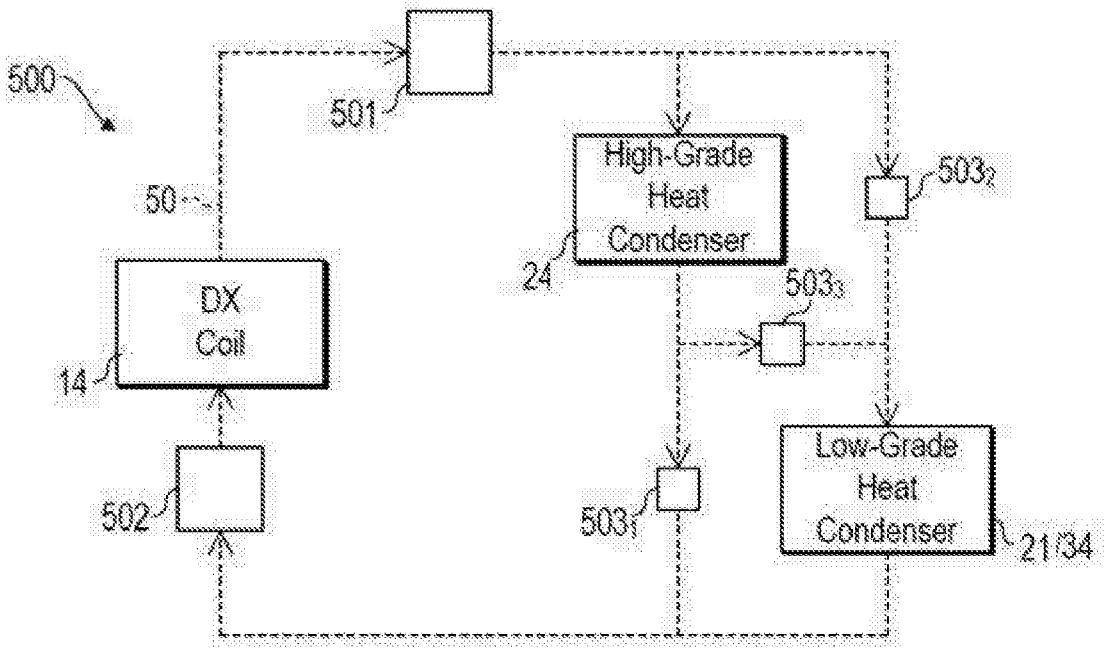
500
501
50
High-Grade
Heat
Condenser
24
503₂
DX
Coil
14
503₃
502
503₁
Low-Grade
Heat
Condenser
21/34

Fig. 5 a

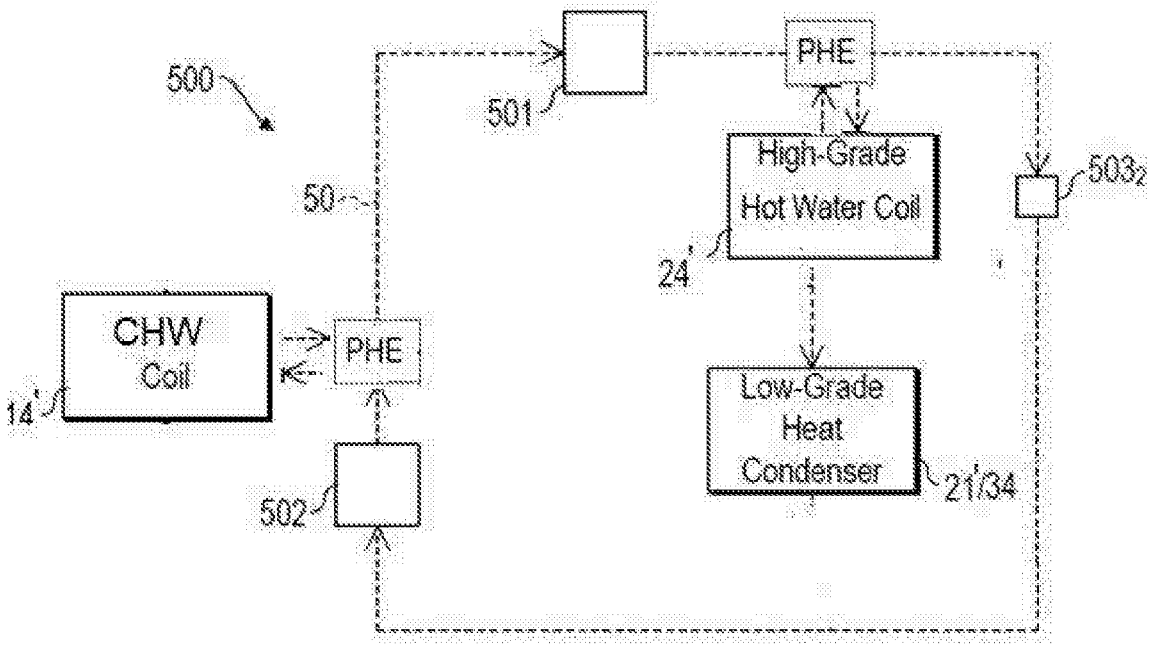
500
501
PHE
High-Grade
Hot Water Coil
24'
503₂
50
CHW
Coil
14'
PHE
Low-Grade
Heat
Condenser
21/34
502

Fig. 5 b

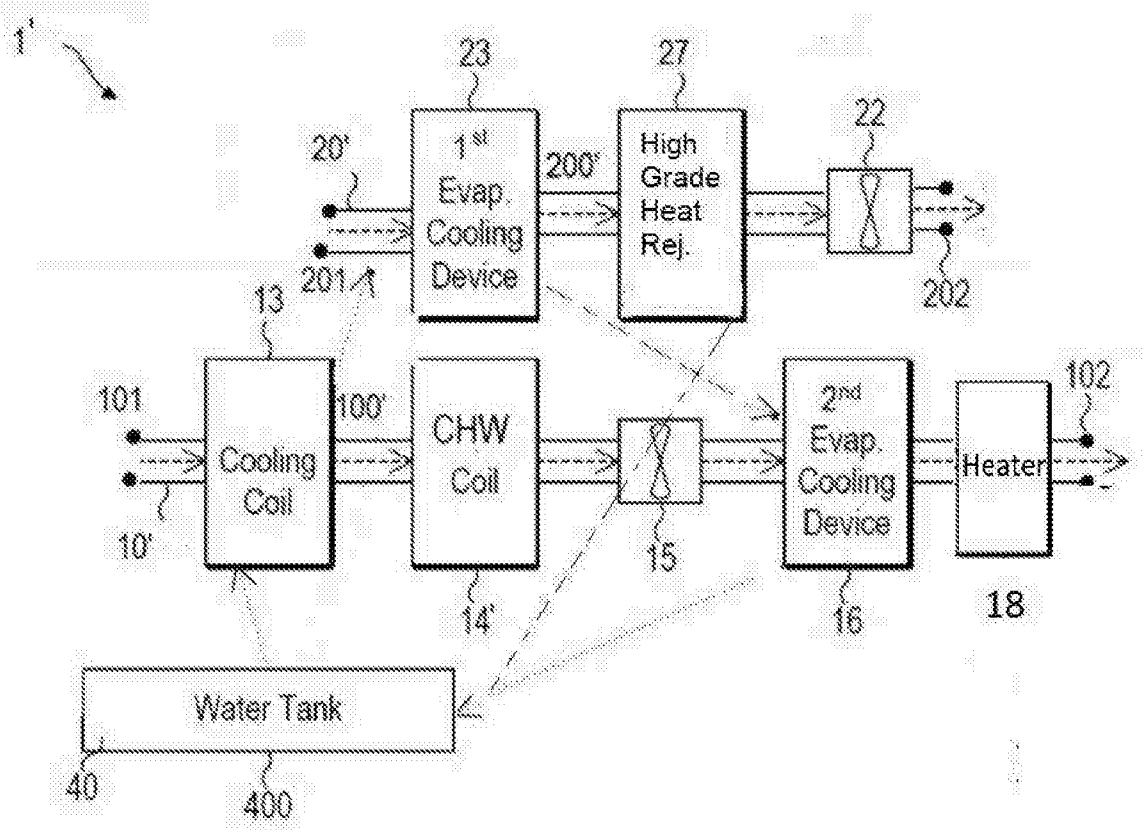
1'
23
27
22
20'
1st
Evap.
Cooling
Device
200'
High
Grade
Heat
Rej.
201
202
13
101
100'
CHW
Coil
2nd
Evap.
Cooling
Device
102
Cooling
Coil
Heater
10'
15
14'
16
18
Water Tank
40
400

Fig. 6

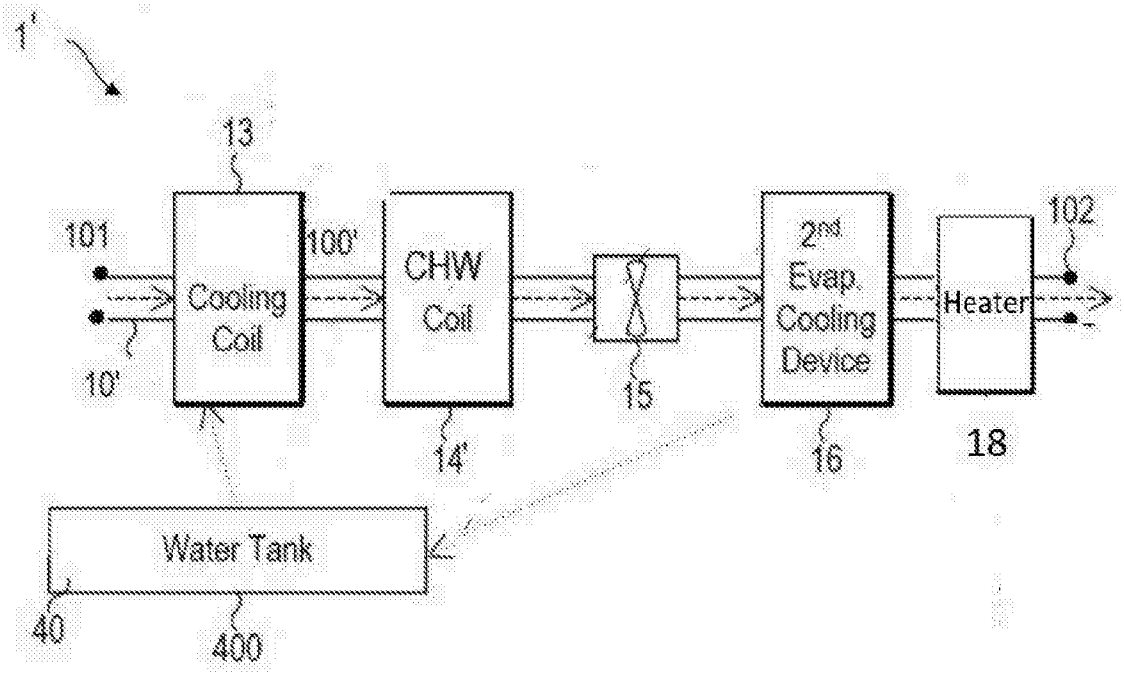
1'
13
101
Cooling Coil
100'
CHW Coil
2nd Evap. Cooling Device
Heater
102
10'
15
14'
16
18
Water Tank
40
400

Fig. 7

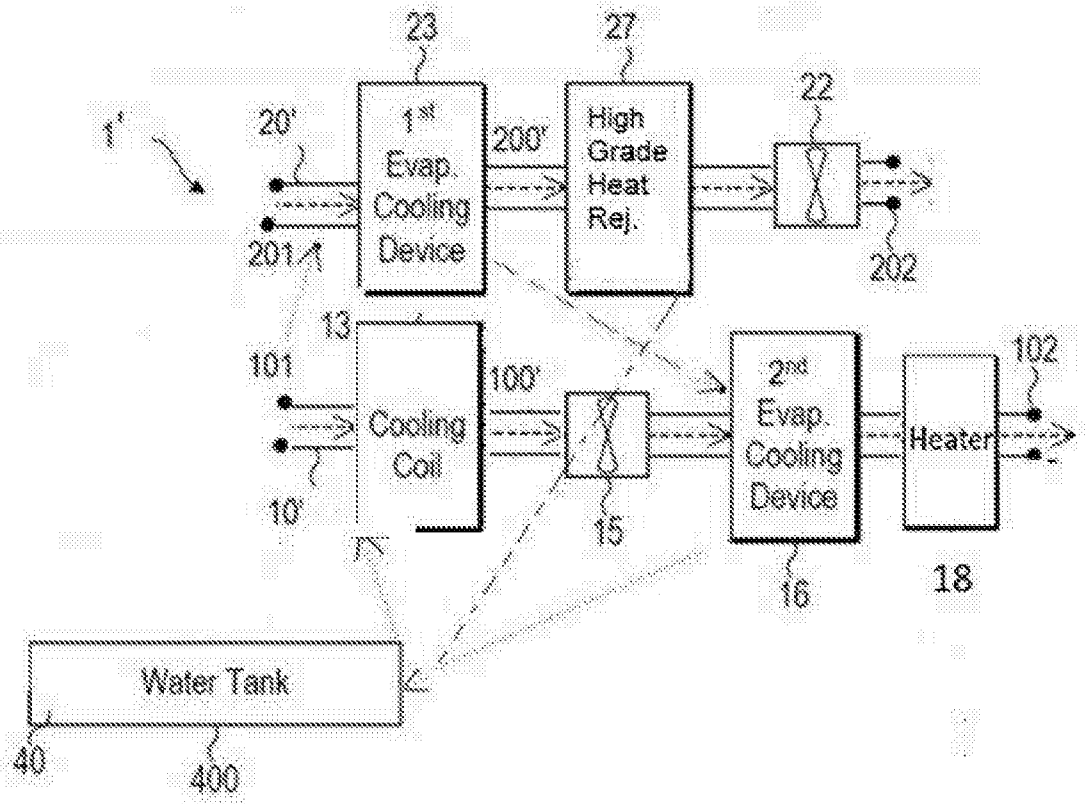
23
27
22
1'
20'
1st Evap. Cooling Device
200'
High Grade Heat Rej.
201
202
13
101
100'
2nd Evap. Cooling Device
102
Cooling Coil
Heater
10'
15
16
18
Water Tank
40
400

Fig. 8

All in One: Air Conditioning, Energy Recovery and Water Production Device

[001] The present application relates to apparatus for climate control (cooling, dehumidification, heating and humidification) of an air stream and water production device and particularly relates mainly to a compact device for efficient and effective climate control that includes multi staged system - dehumidification, cooling and heating. The system also water. The water is either used within the climate control device or supplied for other applications.

[002] Indoor/Outdoor cooling and heating applications remain a challenge as air conditioners is energy intensive especially with high fresh air either in hot humid climate or cold climate, and there is an ongoing effort to improve their efficiency using compact size to meet sustainability targets.

[003] The use of water in cooling and humidification applications remains a challenge to balance both electricity and water tariffs. In some regions, water resources are abundant and the use of water in cooling and humidification is also a challenge.

[004] This invention deals with a compact - All in One- climate control system (dehumidification, cooling, heating, humidification and water production) that utilise less space with low energy and water consumption.

[005] According to an aspect of the present invention, there is provided apparatus for cooling or heating air stream. The apparatus comprises: a first smart controlled pre-cooling section configured to cool the first air stream; a second cooling section configured to cool the

first air stream by transferring heat from the first air stream to a refrigerant comprised in a refrigeration circuit or chilled water coil to cool and dehumidify the air stream; coupled with a third low-grade heat condenser to: further dry or preheat the air stream, to control humidity and to produce water, a fourth direct evaporative cooling section for cooling and humidification. The high-grade condenser is evaporatively cooled by the second air stream. The cooled water is circulated under precisely controlled valves throughout the apparatus. The system utilises condensate water and water recovered from evaporative cooling. The apparatus is configured to use at the condensate water in addition to the water produced by the smart control for precooling the air and evaporatively cools the high-grade condenser. The apparatus can reverse the refrigeration cycle for heating purposes.

[006] Thus, amongst other things, the apparatus can make effective and/or efficient use of water for both indirect and direct evaporative cooling, refrigeration circuit or chilled water system in dehumidifying and cooling the first air stream in summer and the reverse refrigeration cycle for heating purposes in winter.

[007] The first pre-cooling section may utilise evaporatively cooled water from the condensate water or from cooling tower or geothermal.

[008] The second cooling section may be a direct expansion coil or chilled water.

[009] The two cooling sections are connected with smart water control valve to modulate the water quantity, reverse

the water between the two cooling sections based on the weather conditions. The water may first enter the second cooling section and then passed to the first cooling section and vice versa. The water may also by-pass the first cooling section.

[010]

[011] The third section may be a secondary – low-grade-condenser or heating coil .

[012] In the case of refrigerant free cooling system, the low-grade condenser can be replaced by a heating coil which can be electric, steam, hot water generated from a renewable source i.e. solar energy. The DX cooling coil cam be removed or replaced by a chilled water coil. Thus the system is considered efficient and low carbon.

[013] The apparatus may comprise a fourth cooling section configured to evaporatively cool the first air stream and arranged upstream of the third coil to control humidity and compensate the system heat gain. Thus, the first air stream can be conditioned more effectively.

[014] The apparatus may comprise a fifth – upstream-cooling section configured i) to evaporatively cool the second air arranged upstream of the first-high-grade- condenser. Thus, the cooling capacity of the condenser can be increased; ii) to produce cold water to be utilised by the pre-cooling sections.

[015] The fifth cooling section may comprise direct evaporative cooling or hybrid innovative indirect-direct

evaporative cooling to produce colder water for the first or second or fourth cooling sections. Thus, the efficiency of the overall system can be increased.

[016] The pre-cooling sections may use at least some of the same water as the fourth cooling section. Thus, the capacity of the apparatus to cool the first air stream can be increased in an efficient way.

[017] The apparatus may comprise a first, high-grade, condenser configured to cool the refrigerant by transferring heat from the refrigerant to a second air stream. One or each of the first and second pre-cooling sections may be configured to cool the first air stream by transferring heat to the second air stream which is evaporatively cooled, wherein heat is transferred to the second air stream by the condenser. Thus, the efficiency of the refrigeration circuit can be increased (i.e. the low-grade heat condenser) making use of the remaining cooling capacity of the second air stream.

[018] The apparatus may comprise a second condenser, low-grade, configured to further cool the refrigerant by transferring heat from the refrigerant to the first air stream. Thus, the efficiency of the refrigeration circuit can be increased (i.e. the low-grade heat condenser) hence, the system can produce water efficiently.

[019] The pre-cooling sections may comprise a cooling coil configured to transfer heat from the first air stream to the second air stream, the second air stream is evaporatively cooled or

[020] transfer heat from the first air stream to a cooling tower, geothermal or any external energy source.

[021] 019] In the case of refrigerant free (environmentally friendly) apparatus all condensers are removed and the third cooling coil remains and uses chilled water for comfort (i.e. superefficient hybrid indirect-direct evaporative cooling system) conditions or can be removed for relief cooling system (i.e. superefficient indirect-direct evaporative cooling system)

[022] The apparatus is configured to be within compact enclosure that handle air stream from more than one side from smaller footprint of the system.

[023] The system enclosure may comprise a fan to supply the conditioned first air stream to an open or enclosed space and a second fan to exhaust the second air stream to the ambient in complete isolation.

[024] One or each of the first and second pre-cooling sections may comprise a heat pipe or rotating wheel configured to transfer heat from the first air stream to the third air stream, the third air stream is evaporatively cooled (the sixth cooling section) prior to entering the rotating wheel or heat pipe and/or water may be sprayed over the heat pipe/rotating wheel in a cross or counter manner to the third air stream.

[025] One or each of the first and third cooling sections may comprise a two coils with a pump circulates high thermally conducting fluid between the two configured to

transfer heat from the first air stream to the third air stream, the third air stream is evaporatively cooled (the sixth cooling section) prior to the heat exchanger and/or water may be sprayed over the coil in a counter or cross manner to the third air stream.

[026] The refrigeration circuit is generally configured such that the refrigerant is at a higher temperature at the first condenser than at the second condenser.

[027] The refrigeration circuit may interconnect the first and second condensers both in series and in parallel

[028] and may comprise a set of valves to control series and parallel flow of the refrigerant through the first and second condensers. Thus, refrigeration circuit is more controllable.

[029] The first precooling coil and/or the second cooling coil along with the third low-grade heat condenser is so called the drying section.

[030] The first air stream immediately downstream of the drying section may have a lower moisture content and substantially the same temperature as the first air stream immediately upstream of the first precooling coil. These characteristics of the first air stream can be advantageous for the overall effectiveness and/or efficiency of the apparatus.

Brief Description of the Drawings

[031] Certain embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 illustrates a first example of an apparatus for cooling an air stream;

Figure 2 schematically illustrates elements of the apparatus of Figure 1;

Figure 3 schematically illustrates a refrigeration circuit of the apparatus of e.g. Figure 1;

Figure 4 schematically illustrates elements of a second example of an apparatus for cooling an air stream; and

Figure 5 schematically illustrates elements of a third example of an apparatus for cooling an air stream.

Figure 6 schematically illustrates elements of a fourth example of an apparatus for cooling an air stream.

Figure 7 schematically illustrates elements of a fifth example of an apparatus for cooling an air stream.

Detailed Description of the Certain Embodiments

First example of an apparatus 1

[032] Referring to Figures 1, 2, 3 and 4, a first example of an apparatus 1 for cooling a ("first") air stream 10 will now be described.

[033] Referring in particular to Figure 1, the apparatus 1 is a unit having a substantially compact cuboid shape. In particular, the apparatus 1 has a substantially compact case 2 and the other elements of the apparatus 1 are located in (or on or near the surface of) the case 2. The fully assembled

apparatus 1 can fit in an enclosure. The unitariness, the shape, and/or the dimensions of the apparatus 1 may differ in other examples. The apparatus 1 may take more than one inlet or exit to optimise the overall dimensions as per the required space specifications. The apparatus casing may include some of the elements described in Figures 2, 3 and 4.

[034] Referring to Figures 2, 3 and 4, a first example of an apparatus 1 for cooling a ("first") air stream 10 will now be described.

First air stream 10

[035] Referring in particular to Figures 2, 3 and 4, the apparatus 1defines a ("first") path 100 for the first air stream 10. The first path 10 goes from a ("first") input 101, via a ("first") set of elements 13-16 and 21 for Figure 2, 14-16 and 21 for Figures 3 and 4, to a ("first") output 102.

[036] The first air stream 10 may be drawn directly into the first input 101 from a space in which the apparatus 1 is located. The first air stream 10 may be drawn indirectly, e.g. via ducting, from a different space. In either case, the first air stream 10 is typically formed from outside air. In some instances, the first air stream may be formed using at least some recirculated air (i.e. air that has previously been cooled by the apparatus 1).

[037] The first air stream 10 interacts with each of the first set of elements 13-16 and 21, for Figure 2 and 14-16 and 21 for Figures 3 and 4. Amongst other things, the set of elements together cool, heat, dehumidify and humidify the first air stream 10, as will be explained below.

[038] The first air stream 10 may be supplied from the first output 102 to an interior or exterior space. This may be done directly and/or indirectly, e.g. via ducting.

[039] Referring in particular to Figure 2, The precooling coil 13 can utilise water from the evaporative cooling device 23 collected in the water tank 400 or from an external source, i.e. cooling tower, geothermal or ant available energy source.

Second air stream 20

[040] The apparatus 1 uses a further("second") air stream 20.

[041] The apparatus 1 defines a ("second") path 200 for the second air stream 20. The second path 200 goes from a ("second") input 201 via a("second") set of elements 23, 24, 22 to a ("second") output 202.

[042] The second air stream 20 is drawn into the second input 201 and is exhausted from the output 202.

[043] The second air stream 20, which is typically formed from outside air, may be drawn into the input 201 directly from a space in which the apparatus 1 is located and/or indirectly, e.g. via ducting, from a different space.

[044] The second air stream 20 interacts with each of a ("second") set of elements 23, 24 or 26, and 22. The second air stream 20 is used by the second set of elements to facilitate cooling, heating and dehumidification of the first air stream 10 by the first set of elements. As will be explained in more detail below, the element 13 (precooling coil) may utilises the cooled water from the evaporative cooling devices 16 and 23.

[045] The second air stream 20 is exhausted from the output 201 directly to a space in which the apparatus 1 is located and/or indirectly, e.g. via ducting, to a different space.

Refrigeration Circuit 50

[046] The apparatus includes a refrigerant circuit 500 (not shown in Figure 5).

[047] Referring in particular to Figure 5, the refrigeration circuit 500 contains a refrigerant 50. A compressor 501 circulates the refrigerant 50 around the refrigeration circuit 500. After the compressor 501, the refrigerant 50 passes through two condensers 24, 21 (hereinafter referred to as the "high-grade heat condenser" and the "low-grade heat condenser" respectively), which are two of the second set of elements, i.e. interact with the second air stream 20. The refrigerant 50 then passes through an expansion valve 502 and then through a direct expansion coil (DX coil) 14, which is one of the first set of elements, i.e. interacts with the first air stream 10. The refrigerant 50 then returns to the compressor 501, completing the cycle.

[048] The high - and low - grade heat condensers 21, 24 are interconnected both in series and in parallel. A set of valves 503 (e.g. three valves 503_1, 503_2, 503_3) controls series and parallel flow of the refrigerant 50 through the two condensers 24, 21. Due to their relative positions the refrigerant 50 is generally cooler at the low-grade heat condenser 21 than at high-grade heat condenser 24.

[049] The refrigerant 50 may be of any suitable type. In most examples, at least some of the refrigerant 50 changes between liquid and gaseous phases in the refrigeration circuit

500, i.e. is condensed at the condenser 21, 24 and evaporated at the direct expansion coil 14.

[050] Figure 5b illustrates other arrangements of the refrigeration 500 where a plate heat exchanger 25 can be used to generate cold water (e.g. chiller) and hot water (e.g. heat pump) to be circulated through coils 21′ and 24′. The refrigeration system can also produce chilled water to be circulated in coil 14′ for Figures 6-8.

First set of elements

Referring in particular to Figures 2 to 4 again, a("first") set of elements includes sensible cooling coil 13 for Figure 2 only, a direct expansion coil 14, a low-grade condenser 21, a ("first") fan 15, and a ("first"), evaporative cooling device 16. Here, the elements 13, 14, 21, 15 and 16 have been listed in the order in which they interact with the first air stream 10. However, the first fan 15 can be ordered differently i.e. at the air stream entry or at the exit or in between.

[051] Referring in particular to Figure 2, the first air stream 10 flows from the first input 101 to the cooling coil 13.

[052] The cooling coil 13 cools the first air stream 10 by transferring heat from the first air stream 10 to the water 40(which has been cooled, as will be explained below). The cooling of the first air stream 10 corresponds to thermodynamic sensible cooling. Hence the relative humidity of the first air stream 10 is increased by the cooling coil 13 while the humidity ratio remains unchanged.

[053] The cooling coil 13 may have any suitable structure.

For example, the first cooling coil 11 may include a tubed coil or a microchannel coil. The first cooling coil 13 may be made of any suitable materials. For example, the first cooling coil 13 may be made primarily of metal or plastic.

[054] The first cooling coil 13 uses water 40 from a water tank 400 in the apparatus 1. Hence, there is also a water supply system (not shown) including, for example, a pump and a suitable arrangement of piping. The water 40 may be returned to the water tank 400 after the first cooling coil 13 or the water 40 may be expelled from the apparatus 1. The water tank 400 may be filled and/or replenished with water 40 from any suitable source. The water 40 makeup may be groundwater, potable water, or recycled water.

[055] At high humidity in noon times, the first air stream 10 flows from the first cooling coil 13 to the drying section which includes the combination of the DX cooling coil 14 and the low-grade heat condenser 21. At high humidity at night times, the system may be used to generate water i.e. no or less water o circulation for evaporative cooling processes and the first air stream 10 is dehumidified by the drying section which includes the combination of the DX cooling coil 14 and the low-grade heat condenser 21.

[056] Referring in particular to Figures 3 and 4, the first air stream 10 flows from the first input 101 to the DX coil 14, the low-grade condenser 21 and the evaporative cooling 16.

[057] For Figures 2-4, the drying section that includes the combination of 14 and 21, reduces the moisture content of the first air stream 10, while also maintain lower or constant temperature and also reduces the relative humidity of the first air stream 10. An advantageous effect of the combination

of the first cooling coil 13 in Figure 2 and the drying section (the DX coil 14 and the low-grade heat condenser 21) is that the first air stream 10 immediately downstream of the drying section has a lower moisture content and relative humidity the first air stream 10 immediately upstream of the first cooling coil 13.

[058] The water circulation and sequence within the first cooling coil 13 and the evaporative cooling device 23 is circulated and controlled to produce the best system efficiency via temperature and humidity sensors and control valves.

[059] The first air stream 10 is drawn by the first fan 15, which produces the airflow of the first air stream 10. The first air stream 10 then flows to the cooling coil 13, the DX coil 14, the low-grade heating coil 21 and the evaporative cooling device 16.

[060] The first evaporative cooling device 16 further cools and regulates the humidity in the of the first air stream 10 by evaporative cooling. The first evaporative cooling device 16 may have any suitable construction. The first evaporative cooling device 16 also uses water 40 obtained from the water tank 400 but can have its own circulation system. The water 40 is evaporated into (and hence cools) another air stream 201, which is used to cool the first air stream 10 via a heat exchange mechanism. This air stream is then exhausted from the apparatus 1 via an output 3 (shown in Figure 1).

[061] The apparatus 1 is arranged so that water circulation sequence as described below.

[062] Referring in particular to Figure 2, the water is circulated in a close cycle, from water tank 400 to cooling coil 13 to the second evaporative cooling device 23 to the first evaporative cooling device 16 and then back to the tank 400. Water leaves the evaporative cooling device with a temperature equal to the wet-bulb temperature of the second air stream 20. The water then passes the evaporative cooling device 16 and interacts with the cold air stream 10. Thus, the water temperature reduces further to the first cooled air stream 100 wet-bulb temperature. The low water temperature 40 is then circulated through the cooling coil 13. The first air stream 10 is cooled by the cooling coil 13, the first air stream 10 can be cooled below its wet-bulb temperature. The water absorbs the heat from the first air stream 10 and its temperature rises. The high temperature water is then circulated through the evaporative cooling device 23 to lower its temperature as described above.

[063] Referring in particular to Figure 3, the water is circulated in a close cycle, from water tank 400 to the second evaporative cooling device 23 to the first evaporative cooling device 16 and then back to the tank 400.

[064] Referring in particular to Figure 4, the water is circulated in a close cycle, from water tank 400 to the first evaporative cooling device 16 and then back to the tank 400.

Second set of elements

[065] Referring in particular to Figures 2 and 3 The second set of elements includes a (“second”) evaporative

cooling device 23, the high-grade condenser 24, a ("second") fan 22.

[066] The second air stream 20 flows from the second input 201 to the second evaporative cooling device 23 and the high-grade condenser 24.

[067] The second high performance evaporative cooling device 23 cools the second air stream 20 by evaporative cooling advantageously uses water 40 from the water tank 400 as described. Accordingly, the same source of water 40 is used by the first cooling coils 13 and the first and second evaporative cooling devices 16, 23. Hence the apparatus 1 can be manufactured and/or operated more efficiently. The water 40 is evaporated into (and hence cools) the second evaporative cooling device which is used to cool the second air stream 20 via a heat exchange mechanism and mainly produces cold water 40. This air stream is then exhausted from the apparatus 1 via an output 4 (shown in Figure 1).

[068] The second-high performance evaporative cooling device 23 is a unique element in the second set of elements. It consists of a coil with small tubes or channels that cool the water via the second air stream 20. Due to the unique arrangements the air stream 20 is indirect-direct evaporatively cooled, hence the water temperature may drop below the wet-bulb temperature of the air stream 20. It could be made from plastic or metal with special corrosion resistance coating or material.

[069] The second evaporative cooling device 23 may be a conventional direct evaporative cooling device made from

cellulose, plastic, aluminium or any other suitable material.

[070] The second evaporative cooling device 23 may be connected with the sensible cooling device 13 in series as an open or closed loop (indirect evaporative cooling device) using e.g. two coils or heat pipe enhanced by evaporative cooling.

[071] It may be a direct evaporative cooling device that made from cellulose pad, plastic pad, plastic coil or any anti corrosive material.

[072] The second air stream 20 flows from the second evaporative cooling device 23 to the high-grade condenser 24, where it is used as described above.

[073] The second air stream 20 flows from the high-grade condenser 24 to the second fan 22, which produces the airflow of the second air stream 20, and then to the second output 202.

[074] The high-grade and low-grade heat condensers 21 and 24 may have any suitable structure (e.g. including include a tubed coil or a microchannel coil) and may be made from any suitable material.

[075] Referring in particular to Figure 4, there is no second set of elements and apparatus 1 will have one inlet and one exit.

[076] Referring to Figures 6,7 and 8, a second example of an apparatus 1 for cooling a ("first") air stream 10 will now be described. The setup of this device is as the same as describe above except that the DX coil is replaced by chilled water coil and the condenser is replaced by optional hot water coil

First air stream 10'

[077] Referring in particular to Figures 6,7 and 8, the apparatus 1 defines a ("first") path 100' for the first air stream 10'. The first path 10'goes from a ("first") input 101, via a ("first") set of elements 13, 14' (for Figures 6 and 7), 15, 16 and 18 (for heating and humidity control) to a ("first") output 102.

[078] The first air stream 10 is drawn into the first input 101, cooled by the first set of elements, and supplied from the first output 102 as has been previously described for Figures 2-4.

[079] Referring in particular to Figures 6, 7 and 8, the precooling coil 13 can utilise water from the evaporative cooling device 23 collected in the water tank 400 or from an external source, i.e. cooling tower, geothermal or any external energy source.

[080] The first precooling coil 13 uses water 40 from a water tank 400 in the apparatus 1 as described in the previous set of elements.

[081] At high humidity in noon times, the first air stream 10 flows from the first cooling coil 13 to the drying section which includes the combination of the chilled water cooling coil 14′ (Figures 6 and 7) to the fan 15 a second evaporative cooling device 16 and an optional heater 18. At high humidity at night times, the system may be used to generate water i.e. no or less water o circulation for evaporative cooling processes and the first air stream 10′ is dehumidified by the drying section.

[082] The heater 18 could be a low grade heat from the heat pump that produces chilled water to coil 14′ and preheat the air at coil 18.

[083] The drying section reduces the moisture content of the first air stream 10′ as described in the previous example (i.e. previous set of elements)

[084] The water circulation, the first evaporative cooling device 16 and the sequence of operation within the first cooling coil 13 and the evaporative cooling device 23 is as described in the previous example.

Second air stream 20′

[085] Referring in particular to Figures 6 and 8, the apparatus 1 uses another (“second”) air stream 20′.

[086] The apparatus 1 defines a (“second”) path 20′ for the second air stream 201. The second path 20′goes from a (“second”) input 201 via a(“second”) set of elements 23, 27 and 22 to a (“second”) output 202.

[087] The second air stream 20′ interacts with each of a ("second") set of elements 23, 27, and 22. The second air stream 20′ is used by the second set of elements to facilitate cooling of the first air stream 10′ by the first set of elements.

[088] The second evaporative cooling device 23 may be connected with the sensible cooling device 13 in series as an open or closed loop (indirect evaporative cooling device) using e.g. two coils or heat pipe enhanced by evaporative cooling.

First set of elements

[089] Referring in particular to Figures 6,7 and 8 again, the first set of elements includes a cooling coil 13, chilled water coil 14′ (Figures 6 and 7), a ("first") fan 15, and a low grade heating coil Figure 6, ("first"), evaporative cooling device 16. In other words, the first set of elements is as described above, except that the DX coil is replaced by chilled water coil utilising the chilled water as described in the refrigeration cycle Figure 5b or chilled water from external chiller.

[090] The first air stream 10′ flows from the first input 101 to the cooling coil 13, the chilled water coil 14′ (Figures 6 and 7), the first fan 15, and the evaporative cooling device 16, and optional to the low grade heating device 18 to the first output 102. The chilled water coil 14′ further cools the first air stream 10′ by transferring heat to (and at least partly evaporating) the chilled water system. The low-grade heating coil can be used to preheat the air and

also in the case of water production or air drying. The first evaporative cooling device 16 further cools and regulates the humidity of the first air stream 10′ using water 40 from a water tank 400 but its circulation system can be the same system or independent. In other applications where, higher supply temperatures are required, apparatus 1, can be used without the chilled water coil (Figure 8). Thus, the system can be used as indirect-direct evaporative cooling.

Second set of elements

[091] The second set of elements includes a ("second") evaporative cooling device 23, high-grade hot water coil 27 and ("second") fan 22 for Figures 6 and 7.

[092] The second air stream 20′ flows from the second input 201 to the second evaporative cooling device 23.

[093] The second evaporative cooling device 23 cools the second air stream 10′ by evaporative cooling, which was described above in relation to the first example. The second evaporative cooling device 23 also advantageously uses water 40 from the water tank 400 as described above.

[094] The second air stream 20′ flows from the second evaporative cooling device 23 to the high-grade coil 27 where it is used to reject heat of the refrigeration cycle Figure 5b.

[095] The second evaporative cooling device is as described in the previous example.

[096] Water, antifreeze or any nano fluid could be used as heat transfer media between the refrigeration Figure 5b and the heating/chilled water coils.

[097] Referring to Figures 2 to 8, the above described systems are incorporated in an air distribution enclosure, Figure 1.

Further variations

[098] It will be appreciated that there may be many further variations of the examples described above.

[099] Each of the sets of elements described above are arranged in a particular order in relation to a relevant air stream. However, this order may be different.

[0100] One or more of the sets of the system elements described above (e.g. the first, second sets of elements) may have fewer elements. For example, enough cooling of the first air stream 10, 10′, might be achieved with only one or two cooling sections.

[0101] The sequence and order of elements can be changed. For example the evaporative cooling section might be before the fan.

[0102] The refrigeration cycle could be reversed as heat pump to provide heating to air stream 10, 10′ in cold times.

Claims

1. Apparatus for cooling a first air stream, the apparatus comprising: a first cooling section configured to cool the first air stream; a second cooling section configured to cool the first air stream by transferring heat from the first air stream to a refrigerant comprised in a refrigeration circuit; a third a low-grade condenser configured to preheat and dehumidify the air stream, a fourth direct evaporative cooling section to cool and humidify and also high-grade condenser to cool the refrigerant by transferring heat from the refrigerant to a second air stream.

wherein the apparatus is configured to use at least some of the condensate water to cool the condenser and the apparatus is configured to use at least some of the condenser heat to for dehumidification and air preheating.

2. Apparatus according to claim 1 comprising:

a fifth cooling section configured to direct or indirect-direct evaporatively cool the second air stream and produce cold water and arranged upstream of the second (high-grade) condenser.

3. Apparatus according to claims 1 and 2 wherein one or each of the first and fifth cooling sections is water-cooled and uses at least some of the same water as the fourth cooling section.

4. Apparatus according to any claim where the fifth cooling section configured to be a combined direct and indirect-direct evaporatively cooling device to cool the second air stream and produce cold water and arranged upstream of the second (high-grade) condenser.

5. Apparatus according to claim 4 wherein the combined direct and indirect evaporative cooling is a cooling coil or a combination between cooling coil and evaporative pads.

6. Apparatus according to claims 1 to 5 wherein the first cooling section is water-cooled and uses external water source e.g. cooling tower, geothermal or any waste energy source.

7. Apparatus according to claims 1 to 6 wherein the refrigerant cooling coil is replaced by chilled water coil and the condenser is either removed or replaced by hot water coil.

8. Apparatus according to claim 7 wherein the refrigeration is heat pump produces cold and hot water circulated to the apparatus via heat exchangers.

9. Apparatus according to any preceding claim, wherein the water cycled in the following sequence tank, first air stream sensible heat exchanger, second air stream direct or indirect-direct evaporative cooling, first air stream evaporative cooling back to the water tank.

10. Apparatus according to any preceding claim, wherein the cooling system is contained in a compact air distribution enclosure that shapes the local environment and contains the cooling, preheating, dehumidification and humidification system.

11. Apparatus according to any one of claims 1 to 4 wherein the refrigeration circuit is configured such that the refrigerant is at a higher temperature at the first (high-grade) condenser than at the second (low-grade) condenser

12. Apparatus according to any one of any claim wherein the refrigeration circuit interconnects the first and second condensers both in series and in parallel and comprises a set of valves to control series and parallel flow of the refrigerant through the first and second condensers.

13. Apparatus according to any claim wherein the fifth cooling section in claim 2 is connected the first cooling section in series as an open or closed loop using two (dual) coils, heat pipe or sensible wheel configured to transfer heat from the first air stream to the second air stream while the second air stream is evaporatively cooled.

14. Apparatus according to any preceding claim comprising:
a sixth cooling section configured to evaporatively cool the first air stream and arranged downstream of the second cooling section.

15. Apparatus according to any preceding claim, wherein the drying section is arranged downstream of the first cooling section and upstream of the second cooling section.

16. Apparatus according to any claim wherein the first air stream immediately downstream of the drying section has a lower moisture content and substantially the same temperature and relative humidity as the first air stream immediately upstream of the first cooling section.

17. Apparatus according to any preceding claim, wherein the refrigeration system and the chilled water system are removed (i.e. high performance indirect direct evaporative cooling).

18. Apparatus according to claim 16, wherein the apparatus is high performance energy recovery system utilising a first supply fresh air and exhaust fresh air or return air, wherein the exhaust air is evaporatively cooled.

19. Apparatus according to all claims comprising cooling and water recovery coil in the second air stream.

20. Apparatus according to any preceding claim, wherein the water cycled in the following sequence tank, first air stream sensible heat exchanger, second air stream evaporative cooling, first air stream evaporative cooling back to the water tank.

21. Apparatus according to any preceding claims, wherein the apparatus can provide heating and humidity control in cold weather as well as cooling and humidity control in hot weather.

22. Apparatus according to any preceding claim, wherein the air distribution enclosure and the apparatus can for a package system or split system.

23. Apparatus according to any preceding claim, wherein the direct evaporative cooling is removed and/or replaced by fogging system.

24. Apparatus according to any preceding claim, wherein the refrigeration system and the heating coils are enhanced by solar thermal energy to increase the refrigerant temperature or to produce hot water using flat collectors, evacuated tube or any other solar thermal system.

25. Apparatus according to preceding claims wherein the air streams could be fresh air, return air or mixed and at return air, wherein at least one air stream is evaporatively cooled directly or indirectly.

Intellectual Property Office

Application No:	GB2008559.3	**Examiner:**	Ms Janet Kohler
Claims searched:	1-25	**Date of search:**	7 December 2020

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A	-	GB 2576776 A (ESAM ELSARRAG) See whole document, in particular figure 2.
A	-	JP 2004036914 A (EBARA CORP) See figure 1 and paragraphs [0028]-[0038] of Clarivate Analytics English translation.
A	-	KR 20160026274 A (PREXCO CO LTD) See figure 4 and paragraphs [0021] & [0033] of EPO English translation.
A	-	JP 2009216332 A (APISUTE KK) See figure 1 and paragraphs [0006] & [0018-][0019] of EPO English translation
A	-	WO 2018/023923 A1 (ZIBO ENVIRONMENTAL PROTECTION TECH CO LTD) See figure 1-2 and paragraphs [0008] [0047] of EPO translation.
A	-	CN 209819837 U (ZHEJIANG SINOKING AIR CONDITIONING & REFRIGERATION CO LTD) See figure and WPI Abstract Accession No. 2019-A80343.

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Field of Search:

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F24F

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC

Intellectual Property Office

International Classification:

Subclass	Subgroup	Valid From
F24F	0001/02	01/01/2019
F24F	0001/022	01/01/2019
F24F	0001/029	01/01/2019
F24F	0001/032	01/01/2019
F24F	0001/039	01/01/2019
F24F	0001/42	01/01/2011
F24F	0013/22	01/01/2006