

AIR CONDITIONING SYSTEM AND CONTROL METHOD

FIELD OF THE INVENTION

[0001] The present invention relates to system and method to provide cooling and
5 dehumidification to a space.

BACKGROUND OF THE INVENTION

[0002] The rising demand for cooling is putting an enormous strain on the
environment, grid infrastructure, and the global climate. Meeting the world's demand for
cooling while minimizing its negative impacts will be one of the defining challenges of
10 our time. This challenge can be addressed by redesigning today's air conditioning
systems to take advantage of new materials and chemical processes.

[0003] Conventional vapor-compression based air conditioning systems provide
cooling and dehumidification by passing air over a cooling coil. The coil is maintained at
a lower temperature than the air by the flow of refrigerant through the coil. Sensible
15 cooling is achieved by passing air over a cooling coil which is cooler than the entering
air, resulting in heat transfer from the air to the refrigerant and reducing the temperature
of the air. Latent cooling, or dehumidification, is achieved by passing air over a cooling
coil which is below the dewpoint of the entering air. This results in moisture from the air
forming condensate on the coil surface and transferring the latent heat of vaporization to
20 the refrigerant. In such systems, sensible and latent heat removal are coupled such that
either sensible or latent cooling can be controlled, but not both. Furthermore, to meet
high latent loads the cooling coil must operate at very low temperatures, resulting in poor
efficiency of the vapor compression system.

SUMMARY OF THE INVENTION

25 [0004] The present disclosure overcomes the disadvantages of the prior art by
providing a cooling and dehumidification system, comprising: at least one passive heat
transfer device with desiccant coated on some extent of the exposed surface, another
passive heat transfer device without desiccant coating, a compressor through which
refrigerant flows, an expansion device, a refrigerant control valve, and valves to direct
30 airflow in relation to the passive heat transfer devices.

[0005] In an illustrative embodiment, an air-handling system and method
comprises a heat pump configured to move heat energy between a plurality of passive
heat transfer devices. The plurality of passive heat transfer devices, define a first surface

of at least one of the plurality of passive heat transfer devices that is thermally in contact with the heat pump, and a second surface of at least one of the plurality of passive heat transfer devices that is exposed to allow the transfer of heat to or from the heat pump. A desiccant can be in thermal contact with the exposed surface of at least one passive heat transfer device and configured to exchange moisture with air. A plurality of air directing valves are configured to direct process and regeneration air to and from the plurality of passive heat transfer devices with desiccant. A heat pump reversing device can be configured to change the direction of heat flow in the heat pump between two modes of operation, and a control system with communication lines can control air directing valves, reversing device, and heat pump operation. A control operation process can operate a control mode in which desiccant regeneration time is modulated. Illustratively, the passive heat transfer devices can comprise tube and fin heat exchangers or microchannel heat exchangers. The desiccant can form a coating on the exposed surface of the heat exchanger fins, which can be a partial coating with an uncoated section first exposed to airflow followed by a desiccant coated second section exposed to airflow. A passive heat transfer device without desiccant can be configured for exchanging sensible heat with ambient air, and/or the passive heat transfer device without desiccant can be configured for exchanging sensible heat with indoor air. The desiccant can comprise any acceptable material, or combination of materials, including at least one of silica gel, alumina, zeolite or a metal-organic framework (MOF) material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The invention description below refers to the accompanying drawings, of which:

25 [0007] Fig. 1A depicts a cooling and dehumidification system with two desiccant coated passive heat transfer devices and a third uncoated passive heat transfer device in a first mode of operation.

[0008] Fig. 1B depicts a cooling and dehumidification system with two desiccant coated passive heat transfer devices and a third uncoated passive heat transfer device in a second mode of operation.

30 [0009] Fig. 2A depicts a cooling and dehumidification system with two desiccant coated passive heat transfer devices and a third uncoated passive heat transfer device in a first mode of operation.

[0010] Fig. 2B depicts a cooling and dehumidification system with two desiccant coated passive heat transfer devices and a third uncoated passive heat transfer device in a second mode of operation.

[0011] Fig. 3A depicts a cooling and dehumidification system with one desiccant coated passive heat transfer device and two uncoated passive heat transfer devices in a first mode of operation.

[0012] Fig. 3B depicts a cooling and dehumidification system with one desiccant coated passive heat transfer device and two uncoated passive heat transfer devices in a second mode of operation.

10 [0013] Fig. 4A depicts a cooling and dehumidification system with two desiccant coated passive heat transfer devices in a first mode of operation.

[0014] Fig. 4B depicts a cooling and dehumidification system with two desiccant coated passive heat transfer devices in a second mode of operation.

[0015] Figs. 5A-5D depict embodiments of a refrigerant flow and metering device in two modes of operation.

[0016] Fig. 6A depicts a cross sectional view of an embodiment of an indoor cooling and dehumidifying device in a first mode of operation.

[0017] Fig. 6B depicts a cross sectional view of an embodiment of an indoor cooling and dehumidifying device in a second mode of operation.

20 [0018] Fig. 7 depicts a method of control for a desiccant cooling and dehumidification system.

DETAILED DESCRIPTION

[0019] Figures **1A** and **1B** show schematic views of an exemplary desiccant cooling and dehumidification system **100**. In operation, system **100** cycles between two modes of operation: a first mode (also referred to as a first half-cycle), and a second mode (also referred to as a second half-cycle). Figure **1A** illustrates the first mode of operation and **1B** illustrates the second mode of operation. System **100** includes a heat pump comprising compressor **103**, uncoated (i.e., free of desiccant material) passive heat transfer device **104**, refrigerant reversing valve **105**, a first desiccant coated passive heat transfer device **107**, expansion valve **108**, and a second desiccant coated passive heat transfer device **109**. System **100** further includes first air directing valve **113**, second air directing valve **114**, and first fan **115**. System **100** further includes first air duct **119**, third

air directing valve **120**, fourth air directing valve **121**, second fan **122**, and second air duct **123**. System **100** further includes third fan **128**.

[0020] As shown in the example of figures **1A** and **1B**, compressor **103**, uncoated passive heat transfer device **104**, refrigerant reversing valve **105** and fan **128** are located outside of the conditioned space within one or more housing structures and form outdoor device **102**. Desiccant coated passive heat transfer devices **107** and **109**, air directing valves **113**, **114**, **120**, and **121**, fans **115** and **122**, and expansion valve **108** are located inside the conditioned space in one or more housing structures and form indoor device **101**. The indoor space and outdoor space are separated by dividing wall **125**. Indoor device **101** and the outdoor device **102** are thermally connected through refrigerant lines **106** and **110** that pass through the dividing wall **125**. Furthermore, indoor device **101** is physically connected to air ducts **113** and **118** which pass through dividing wall **125** to the outdoor space.

[0021] System **100** operates in a cyclic manner, alternating between two modes of operation, shown by figures **1A** and **1B**. During the first half-cycle, desiccant coated passive heat transfer device **109** is in process mode and desiccant coated passive heat transfer device **107** is in regeneration mode. During the second half-cycle, the roles of desiccant coated passive heat transfer device **109** and desiccant coated passive heat transfer device **107** reverse such that desiccant coated passive heat transfer device **109** is in regeneration mode and desiccant coated passive heat transfer device **107** is in process mode.

[0022] By way of non-limiting example, the desiccant can comprise any appropriate material clear to those of skill, which is designed to capture moisture using a desiccant material such as a silica gel, alumina, zeolite or a metal-organic framework (MOF) material. The desiccant media comprising a plurality of desiccant structures can be manufactured/applied, based upon known techniques and equipment, for example, using a composite material that consists of the active desiccant powder embedded within a rigid binding material such as a ceramic or plastic that does not affect the desiccant material's ability to adsorb moisture. Such is applied to the heat exchanger using conventional coating or layering techniques, or is otherwise applied to, e.g. fins of the heat exchange element.

[0023] Figure **1A** shows the first half-cycle of operation of system **100**. Low-pressure refrigerant at a first pressure state enters compressor **103** and is compressed to a

second pressure state (e.g., high-pressure state) that is higher than the first pressure state. Refrigerant then flows through uncoated passive heat transfer device **104**, releasing some heat to ambient airstream **126**. Refrigerant then flows through refrigerant reversing valve **105** (configured in a first valve state) and is directed to refrigerant line **106**. Refrigerant then flows through refrigerant line **106** from outdoor device **102** to indoor device **101**. Refrigerant then flows through desiccant coated passive heat transfer device **107**, releasing some heat to regeneration airstream **118**. Refrigerant then flows through expansion valve **108** which takes the refrigerant from a high-pressure state to a low-pressure state. Refrigerant then flows through desiccant coated passive heat transfer device **109** absorbing some heat from process air **111**. Refrigerant then flows through refrigerant line **110** from indoor device **101** to outdoor device **102**. Refrigerant then flows through reversing valve **105** (in the first valve state) and back to compressor **103**, completing the circuit.

[0024] Process air **111** to be cooled and dehumidified enters indoor device **101** through air inlet **112** and is directed by air directing valve **113** to desiccant coated passive heat transfer device **109**. Process air passes over the exposed surface of desiccant coated passive heat transfer device **109**, cooling and dehumidifying the air. Moisture from the air is adsorbed onto the desiccant, increasing the moisture content of the desiccant. The heat of adsorption from the desiccant is transferred to passive heat transfer device **109** by conduction, and to the refrigerant flowing through. Sensible heat from the process airstream is also transferred to passive heat transfer device **109** and to the refrigerant flowing through. The cooled and dehumidified air is then drawn through air directing valve **114** by process fan **115**, and passes through air outlet **116** to the conditioned space **117**.

[0025] Regeneration air **118** enters indoor device **101** through inlet duct **119** and is directed by air directing valve **120** to desiccant coated passive heat transfer device **107**. Regeneration air passes over the exposed surface of desiccant coated passive heat transfer device **107**. Heat passes from the refrigerant to passive heat transfer device **107**, and on to the desiccant, causing desorption of moisture from the desiccant to the passing air. In this way the desiccant is regenerated to begin the next cycle. Regeneration air is then drawn through air directing valve **121** by fan **122** and through outlet duct **123** to the outdoor space **124**.

[0026] Ambient air **126** from the environment enters outdoor device **102** through inlet **127**. Air passes over the exposed surface of passive heat transfer device **104**. Heat passes from the refrigerant to passive heat transfer device **104**, and from passive heat transfer device **104** to the air. Air is drawn by fan **128** from passive heat transfer device **104** through outlet **129** and back to the outdoor space **130**.

[0027] Figure **1B** shows the second half-cycle of operation of system **100**. Low-pressure refrigerant at a first pressure state enters compressor **103** and is compressed to a second pressure state (e.g., high-pressure state) that is higher than the first pressure state. Refrigerant then flows through uncoated passive heat transfer device **104**, releasing some heat to ambient airstream **126**. Refrigerant then flows through refrigerant reversing valve **105** (configured in a second valve state) and is directed to refrigerant line **110**. Refrigerant then flows through refrigerant line **110** from outdoor device **102** to indoor device **101**. Refrigerant then flows through desiccant coated passive heat transfer device **109**, releasing some heat to regeneration airstream **118**. Refrigerant then flows through expansion valve **108** which takes the refrigerant from a high-pressure state to a low-pressure state. Refrigerant then flows through desiccant coated passive heat transfer device **107** absorbing some heat from process air **111**. Refrigerant then flows through refrigerant line **106** from indoor device **101** to outdoor device **102**. Refrigerant then flows through reversing valve **105** (in the second valve state) and back to compressor **103**, completing the circuit.

[0028] Process air **111** to be cooled and dehumidified enters indoor device **101** through air inlet **112** and is directed by air directing valve **113** to desiccant coated passive heat transfer device **107**. Process air passes over the exposed surface of desiccant coated passive heat transfer device **107**, cooling and dehumidifying the air. Moisture from the air is adsorbed onto the desiccant, increasing the moisture content of the desiccant. The heat of adsorption from the desiccant is transferred to passive heat transfer device **107** by conduction, and to the refrigerant flowing through. Sensible heat from the process airstream is also transferred to passive heat transfer device **107** and to the refrigerant flowing through. The cooled and dehumidified air is then drawn through air directing valve **114** by process fan **115**, and passes through air outlet **116** to the conditioned space **117**.

[0029] Regeneration air **118** enters indoor device **101** through inlet duct **119** and is directed by air directing valve **120** to desiccant coated passive heat transfer device **109**.

Regeneration air passes over the exposed surface of desiccant coated passive heat transfer device **109**. Heat passes from the refrigerant to passive heat transfer device **109**, and on to the desiccant, causing desorption of moisture from the desiccant to the passing air. In this way the desiccant is regenerated to begin the next cycle. Regeneration air is drawn
5 through air directing valve **121** by fan **122** and through outlet duct **123** to the outdoor space **124**.

[0030] Ambient air **126** from the environment enters outdoor device **102** through inlet **127**. Air passes over the exposed surface of passive heat transfer device **104**. Heat passes from the refrigerant to passive heat transfer device **104**, and from passive heat
10 transfer device **104** to the air. Air is drawn by fan **128** from passive heat transfer device **104** through outlet **129** and back to the outdoor space **130**.

[0031] In some embodiments of system **100**, a common fan is used to perform the functions of fans **115** and **122**. In some embodiments of system **100**, fan **122** may be placed at any other location along the airflow path between **118** and **124**, similarly fan
15 **115** may be placed at any other location along the airflow path between **111** and **117**.

[0032] Figures **2A** and **2B** show schematic views of an exemplary desiccant cooling and dehumidification system **200**. In operation, system **200** cycles between two modes of operation: a first mode (also referred to as a first half-cycle), and a second mode (also referred to as an a second half-cycle). Figure **2A** illustrates the first mode of
20 operation and **2B** illustrates the second mode of operation. System **200** includes a heat pump comprising compressor **203**, uncoated passive heat transfer device **209**, refrigerant reversing valve **204**, a first desiccant coated passive heat transfer device **206**, refrigerant flow directing and metering device **208**, and a second desiccant coated passive heat transfer device **211**. System **200** further includes first air directing valve **215**, second air
25 directing valve **216**, and first fan **217**. System **200** further includes first air duct **221**, third air directing valve **222**, fourth air directing valve **223**, second fan **224**, and second air duct **225**. System **200** further includes third fan **230**.

[0033] As shown in the example of figures **2A** and **2B**, compressor **203**, uncoated passive heat transfer device **209**, refrigerant flow directing and metering device **208**,
30 refrigerant reversing valve **204** and fan **230** are located outside of the conditioned space within one or more housing structures and form outdoor device **202**. Desiccant coated passive heat transfer devices **206** and **211**, air directing valves **215**, **216**, **222**, and **223**, and fans **217** and **224** are located inside the conditioned space within one or more

housing structures and form indoor device **201**. The indoor space and outdoor space are separated by dividing wall **227**. Indoor device **201** and outdoor device **202** are thermally connected through refrigerant lines **205**, **207**, **210**, and **212** that pass through the dividing wall **227**. Furthermore, indoor device **201** is physically connected to air ducts **221** and **225** which pass through dividing wall **227** to the outdoor space.

[0034] System **200** operates in a cyclic manner, alternating between two modes of operation, shown by figures **2A** and **2B**. During the first half-cycle, desiccant coated passive heat transfer device **211** is in process mode and desiccant coated passive heat transfer device **206** is in regeneration mode. During the second half-cycle, desiccant coated passive heat transfer device **211** and desiccant coated passive heat transfer device **206** reverse such that desiccant coated passive heat transfer device **211** is in regeneration mode and desiccant coated passive heat transfer device **206** is in process mode. In both modes, refrigerant flow directing and metering device **208** passes high pressure refrigerant first through uncoated passive heat transfer device **209** and then through an expansion valve contained therein. Figure **3** shows possible embodiments of refrigerant flow directing and metering device **208**.

[0035] Figure **2A** shows the first half-cycle of operation of system **200**. Low-pressure refrigerant at a first pressure state enters compressor **203** and is compressed to a second pressure state (e.g., high-pressure state) that is higher than the first pressure state. Refrigerant then flows through refrigerant reversing valve **204** (configured in a first valve state) and is directed to refrigerant line **205**. Refrigerant then flows through refrigerant line **205** from outdoor device **202** to indoor device **201**. Refrigerant then flows through desiccant coated passive heat transfer device **206**, releasing some heat to regeneration airstream **220**. Refrigerant then flows through refrigerant line **207** from indoor device **201** to outdoor device **202**. Refrigerant then flows through refrigerant flow directing and metering device **208** to uncoated passive heat transfer device **209** releasing some heat to ambient airstream **228** and then through an expansion valve in refrigerant flow directing and metering device **208**. Refrigerant then flows through refrigerant line **210** from outdoor device **202** to indoor device **201**. Refrigerant then flows through desiccant coated passive heat transfer device **211**, absorbing some heat from process air **213**. Refrigerant then flows through refrigerant line **212** from indoor device **201** to outdoor device **202**. Refrigerant then flows through reversing valve **204** (in the first valve state) and back to compressor **203**, completing the circuit.

[0036] Process air **213** to be cooled and dehumidified enters indoor device **201** through air inlet **214** and is directed by air directing valve **215** to desiccant coated passive heat transfer device **211**. Process air passes over the exposed surface of desiccant coated passive heat transfer device **211**, cooling and dehumidifying the air. Moisture from the air is adsorbed onto the desiccant, increasing the moisture content of the desiccant. The heat of adsorption from the desiccant is transferred to passive heat transfer device **211** by conduction, and to the refrigerant flowing through. Sensible heat from the process airstream is also transferred to passive heat transfer device **211** and to the refrigerant flowing through. The cooled and dehumidified air is then drawn through air directing valve **216** by process fan **217**, and passes through air outlet **218** to the conditioned space **219**.

[0037] Regeneration air **220** enters indoor device **201** through inlet duct **221** and is directed by air directing valve **222** to desiccant coated passive heat transfer device **206**. Regeneration air passes over the exposed surface of desiccant coated passive heat transfer device **206**. Heat passes from the refrigerant to passive heat transfer device **206**, and on to the desiccant, causing desorption of moisture from the desiccant to the passing air. In this way the desiccant is regenerated to begin the next cycle. Regeneration air is then drawn through air directing valve **223** by fan **224** and through outlet duct **225** to the outdoor space **226**.

[0038] Ambient air **228** from the environment enters outdoor device **202** through inlet **229**. Air passes over the exposed surface of passive heat transfer device **209**. Heat passes from the refrigerant to passive heat transfer device **209**, and from passive heat transfer device **209** to the air. Air is drawn by fan **230** from passive heat transfer device **209** through outlet **231** and back to the outdoor space **232**.

[0039] Figure **2B** shows the second half-cycle of operation of system **200**. Low-pressure refrigerant at a first pressure state enters compressor **203** and is compressed to a second pressure state (e.g., high-pressure state) that is higher than the first pressure state. Refrigerant then flows through refrigerant reversing valve **204** (configured in a second valve state) and is directed to refrigerant line **212**. Refrigerant then flows through refrigerant line **212** from outdoor device **202** to indoor device **201**. Refrigerant then flows through desiccant coated passive heat transfer device **211**, releasing some heat to regeneration airstream **220**. Refrigerant then flows through refrigerant line **210** from indoor device **201** to outdoor device **202**. Refrigerant then flows through refrigerant flow

directing and metering device **208** to uncoated passive heat transfer device **209** releasing some heat to ambient airstream **228** and then through an expansion valve in refrigerant flow directing and metering device **208**. Refrigerant then flows through refrigerant line **207** from outdoor device **202** to indoor device **201**. Refrigerant then flows through
5 desiccant coated passive heat transfer device **206**, absorbing some heat from process air **213**. Refrigerant then flows through refrigerant line **205** from indoor device **201** to outdoor device **202**. Refrigerant then flows through reversing valve **204** (in the second valve state) and back to compressor **203**, completing the circuit.

[0040] Process air **213** to be cooled and dehumidified enters indoor device **201**
10 through air inlet **214** and is directed by air directing valve **215** to desiccant coated passive heat transfer device **206**. Process air passes over the exposed surface of desiccant coated passive heat transfer device **206**, cooling and dehumidifying the air. Moisture from the air is adsorbed onto the desiccant, increasing the moisture content of the desiccant. The heat of adsorption from the desiccant is transferred to passive heat transfer device **206** by
15 conduction, and to the refrigerant flowing through. Sensible heat from the process airstream is also transferred to passive heat transfer device **206** and to the refrigerant flowing through. The cooled and dehumidified air is then drawn through air directing valve **216** by process fan **217**, and passes through air outlet **218** to the conditioned space **219**.

20 [0041] Regeneration air **220** enters indoor device **201** through inlet duct **221** and is directed by air directing valve **222** to desiccant coated passive heat transfer device **211**. Regeneration air passes over the exposed surface of desiccant coated passive heat transfer device **211**. Heat passes from the refrigerant to passive heat transfer device **211**, and on to the desiccant, causing desorption of moisture from the desiccant to the passing air. In this
25 way the desiccant is regenerated to begin the next cycle. Regeneration air is then drawn through air directing valve **223** by fan **224** and through outlet duct **225** to the outdoor space **226**.

[0042] Ambient air **228** from the environment enters outdoor device **202** through inlet **229**. Air passes over the exposed surface of passive heat transfer device **209**. Heat
30 passes from the refrigerant to passive heat transfer device **209**, and from passive heat transfer device **209** to the air. Air is drawn by fan **230** from passive heat transfer device **209** through outlet **231** and back to the outdoor space **232**.

[0043] In some embodiments of system **200**, refrigerant flow directing and metering device **208** is located within indoor device **201** instead of outdoor device **202**.

[0044] In some embodiments of systems **100** and **200** the air switching valves are arranged in an alternative configuration such that two inlet air valves are arranged to
5 select between return air from the conditioned space and outside air through an inlet air duct. Furthermore two exit valves are arranged to select between the conditioned space supply duct and to outside air through an exhaust air duct. In this embodiment each desiccant coated passive heat transfer device is associated with a single inlet air valve and a single exit air valve.

10 [0045] Figures **3A** and **3B** show schematic views of an exemplary desiccant cooling and dehumidification system **300**. In operation, system **300** cycles between two modes of operation: a first mode (also referred to as a first half-cycle), and a second mode (also referred to as an a second half-cycle). Figure **3A** illustrates the first mode of operation and **3B** illustrates the second mode of operation. System **300** includes a heat
15 pump comprising compressor **304**, uncoated passive heat transfer device **305**, refrigerant reversing valve **307**, desiccant coated passive heat transfer device **320**, expansion valve **308**, and a second uncoated passive heat transfer device **310**. System **300** further includes first air directing valve **319**, second air directing valve **322**, and first fan **321**. System **300** further includes air ducts **331** and **332**, second fan **327**, and third fan **314**.

20 [0046] As shown in the example of figures **3A** and **3B**, compressor **304**, uncoated passive heat transfer device **305**, and fan **327** are located outside of the conditioned space within one or more housing structures and form outdoor device **303**. Desiccant coated passive heat transfer device **320**, air directing valves **319**, and **322**, fan **321**, reversing valve **307**, and expansion valve **308** are located inside the conditioned space in one or
25 more housing structures and form indoor device **302**. Uncoated passive heat transfer device **310** and fan **314** are located inside the conditioned space in one or more housing structures and form indoor device **301**. The indoor space and outdoor space are separated by dividing wall **334**. Indoor device **301** is thermally connected to indoor device **302** through refrigerant line **335**. Indoor device **301** is thermally connected to outdoor device
30 **303** through refrigerant line **311** that passes through the dividing wall **334**. Indoor device **302** is thermally connected to outdoor device **303** through refrigerant line **306** that passes through the dividing wall **334**. Furthermore, indoor device **302** is physically connected to air ducts **331** and **332** which pass through dividing wall **334** to the outdoor space.

[0047] System 300 operates in a cyclic manner, alternating between two modes of operation, shown by figures 3A and 3B. During the first half-cycle, desiccant coated passive heat transfer device 320 is in process mode. During the second half-cycle, desiccant coated passive heat transfer device 320 is in regeneration mode.

5 [0048] Figure 3A shows the first half-cycle of operation of system 300. Low-pressure refrigerant at a first pressure state enters compressor 304 and is compressed to a second pressure state (e.g., high-pressure state) that is higher than the first pressure state. Refrigerant then flows through uncoated passive heat transfer device 305, releasing some heat to ambient airstream 325. Refrigerant then flows through refrigerant line 306 from
10 outdoor device 303 to indoor device 302. Refrigerant then flows through reversing valve 307 (configured in a first valve state) and is directed to expansion valve 308, which takes the refrigerant from a high-pressure state to a low-pressure state. Refrigerant then flows through desiccant coated passive heat transfer device 320 absorbing some heat from process air 317. Refrigerant then flows through reversing valve 307 (in the first valve
15 state) and is directed to refrigerant line 335. Refrigerant flows through refrigerant line 335 from indoor device 302 to indoor device 301. Refrigerant then flows through uncoated passive heat transfer device 310 absorbing heat from process air 312. Refrigerant then flows through refrigerant line 311 from indoor device 301 to outdoor device 303 and returns to compressor 304, completing the refrigerant circuit.

20 [0049] Process air 312 to be cooled enters indoor device 301 through air inlet 313 and passes over the exposed surface of uncoated passive heat transfer device 310, cooling the air.

[0050] Process air 317 to be cooled and dehumidified enters indoor device 302 through air inlet 318 and is directed by air directing valve 319 to desiccant coated passive
25 heat transfer device 320. Process air passes over the exposed surface of desiccant coated passive heat transfer device 320, cooling and dehumidifying the air. Moisture from the air is adsorbed onto the desiccant, increasing the moisture content of the desiccant. The heat of adsorption from the desiccant is transferred to passive heat transfer device 320 by conduction, and to the refrigerant flowing through. Sensible heat from the process
30 airstream is also transferred to passive heat transfer device 320 and to the refrigerant flowing through. The cooled and dehumidified air is then blown through air directing valve 322 by process fan 321, and passes through air outlet 323 to the conditioned space 324.

[0051] Ambient air 325 from the environment enters outdoor device 303 through inlet 326. Air passes over the exposed surface of passive heat transfer device 305. Heat passes from the refrigerant to passive heat transfer device 305, and from passive heat transfer device 305 to the air. Air is drawn by fan 327 from passive heat transfer device 305 through outlet 328 and back to the outdoor space 329.

[0052] Figure 3B shows the second half-cycle of operation of system 300. Low-pressure refrigerant at a first pressure state enters compressor 304 and is compressed to a second pressure state (e.g., high-pressure state) that is higher than the first pressure state. Refrigerant then flows through uncoated passive heat transfer device 305, releasing some heat to ambient airstream 325. Refrigerant then flows through refrigerant line 306 from outdoor device 303 to indoor device 302. Refrigerant then flows through reversing valve 307 (configured in a second valve state) and is directed to desiccant coated passive heat transfer device 320. Refrigerant then flows through desiccant coated passive heat transfer device 320, releasing some heat to regeneration airstream 333. Refrigerant then flows through expansion valve 308, which takes the refrigerant from a high-pressure state to a low-pressure state. Refrigerant then flows through reversing valve 307 (in the second valve state) and is directed to refrigerant line 335. Refrigerant flows through refrigerant line 335 from indoor device 302 to indoor device 301. Refrigerant then flows through uncoated passive heat transfer device 310 absorbing heat from process air 312. Refrigerant then flows through refrigerant line 311 from indoor device 301 to outdoor device 303 and returns to compressor 304, completing the refrigerant circuit.

[0053] Process air 312 to be cooled enters indoor device 301 through air inlet 313 and passes over the exposed surface of uncoated passive heat transfer device 310, cooling the air.

[0054] Regeneration air 333 enters indoor device 302 through inlet duct 332 and is directed by air directing valve 319 to desiccant coated passive heat transfer device 320. Regeneration air passes over the exposed surface of desiccant coated passive heat transfer device 320. Heat passes from the refrigerant to passive heat transfer device 320, and on to the desiccant, causing desorption of moisture from the desiccant to the passing air. In this way the desiccant is regenerated to begin the next cycle. Regeneration air is then blown through air directing valve 322 by fan 321 and through outlet duct 331 to the outdoor space 330.

[0055] Ambient air **325** from the environment enters outdoor device **303** through inlet **326**. Air passes over the exposed surface of passive heat transfer device **305**. Heat passes from the refrigerant to passive heat transfer device **305**, and from passive heat transfer device **305** to the air. Air is drawn by fan **327** from passive heat transfer device **305** through outlet **328** and back to the outdoor space **329**.

[0056] In some embodiments of system **300**, indoor devices **301** and **302** may be combined within a common housing structure. Various embodiments are possible with devices **301**, **302**, and **303** located inside or outside the conditioned space as separate devices or combined in a common housing structure. In some operating modes of system **300**, uncoated passive heat transfer device **310** may be operated below the dewpoint of process air **312**. Such an operating mode allows uncoated passive heat transfer device **310** to dehumidify process air **312** as well as cooling it. In some embodiments, an additional expansion valve is added to refrigerant line **335** between reversing valve **307** and uncoated passive heat transfer device **310**.

[0057] Figures **4A** and **4B** show schematic views of an exemplary desiccant cooling and dehumidification system **400**. In operation, system **400** cycles between two modes of operation: a first mode (also referred to as a first half-cycle), and a second mode (also referred to as an a second half-cycle). Figure **4A** illustrates the first mode of operation and **4B** illustrates the second mode of operation. System **400** includes a heat pump comprising compressor **402**, refrigerant reversing valve **403**, first desiccant coated passive heat transfer device **406**, expansion valve **405**, and a second desiccant coated passive heat transfer device **404**. System **400** further includes first air directing valve **409**, second air directing valve **415**, first fan **410**, second fan **416**, and air duct **419**.

[0058] As shown in the example of figures **4A** and **4B**, all components are located inside the conditioned space in one or more housing structures and form indoor device **401**. The indoor space and outdoor space are separated by dividing wall **417**. Indoor device **401** is physically connected to air duct **419** which passes through dividing wall **417** to the outdoor space.

[0059] System **400** operates in a cyclic manner, alternating between two modes of operation, shown by figures **4A** and **4B**. During the first half-cycle, desiccant coated passive heat transfer device **404** is in process mode and desiccant coated passive heat transfer device **406** is in regeneration mode. During the second half-cycle, desiccant

coated passive heat transfer device **404** is in regeneration mode and passive heat transfer device **406** is in process mode.

[0060] Figure **4A** shows the first half-cycle of operation of system **400**. Low-pressure refrigerant at a first pressure state enters compressor **402** and is compressed to a second pressure state (e.g., high-pressure state) that is higher than the first pressure state. Refrigerant then flows through reversing valve **403** (configured in a first valve state) and is directed to desiccant coated passive heat transfer device **406**. Refrigerant then flows through desiccant coated passive heat transfer device **406** releasing some heat to regeneration airstream **413**. Refrigerant then flows through expansion valve **405**, which takes the refrigerant from a high-pressure state to a low-pressure state. Refrigerant then flows through desiccant coated passive heat transfer device **404** absorbing some heat from process air **407**. Refrigerant then flows through reversing valve **403** (in the first valve state) and returns to compressor **402**, completing the refrigerant circuit.

[0061] Process air **407** to be cooled and dehumidified enters indoor device **401** through air inlet **408**. Process air passes over the exposed surface of desiccant coated passive heat transfer device **404**, cooling and dehumidifying the air. Moisture from the air is adsorbed onto the desiccant, increasing the moisture content of the desiccant. The heat of adsorption from the desiccant is transferred to passive heat transfer device **404** by conduction, and to the refrigerant flowing through. Sensible heat from the process airstream is also transferred to passive heat transfer device **404** and to the refrigerant flowing through. The cooled and dehumidified air is then drawn through air directing valve **409** by process fan **410**, and passes through air outlet **411** to the conditioned space **412**.

[0062] Regeneration air **413** enters indoor device **401** through inlet duct **414**. Regeneration air passes over the exposed surface of desiccant coated passive heat transfer device **406**. Heat passes from the refrigerant to passive heat transfer device **406**, and on to the desiccant, causing desorption of moisture from the desiccant to the passing air. In this way the desiccant is regenerated to begin the next cycle. Regeneration air is then drawn through air directing valve **415** by fan **416** and through outlet duct **418** to the outdoor space **419**.

[0063] Figure **4B** shows the second half-cycle of operation of system **400**. Low-pressure refrigerant at a first pressure state enters compressor **402** and is compressed to a second pressure state (e.g., high-pressure state) that is higher than the first pressure state.

Refrigerant then flows through reversing valve **403** and is directed to desiccant coated passive heat transfer device **404**. Refrigerant then flows through desiccant coated passive heat transfer device **404** releasing some heat to regeneration airstream **407**. Refrigerant then flows through expansion valve **405**, which takes the refrigerant from a high-pressure state to a low-pressure state. Refrigerant then flows through desiccant coated passive heat transfer device **406** absorbing some heat from process air **413**. Refrigerant then flows through reversing valve **403** (configured in a second valve state) and returns to compressor **402**, completing the refrigerant circuit.

[0064] Process air **413** to be cooled and dehumidified enters indoor device **401** through air inlet **414**. Process air passes over the exposed surface of desiccant coated passive heat transfer device **406**, cooling and dehumidifying the air. Moisture from the air is adsorbed onto the desiccant, increasing the moisture content of the desiccant. The heat of adsorption from the desiccant is transferred to passive heat transfer device **406** by conduction, and to the refrigerant flowing through. Sensible heat from the process airstream is also transferred to passive heat transfer device **406** and to the refrigerant flowing through. The cooled and dehumidified air is then drawn through air directing valve **415** by process fan **410**, and passes through air outlet **411** to the conditioned space **412**.

[0065] Regeneration air **407** enters indoor device **401** through inlet duct **408**. Regeneration air passes over the exposed surface of desiccant coated passive heat transfer device **404**. Heat passes from the refrigerant to passive heat transfer device **404**, and on to the desiccant, causing desorption of moisture from the desiccant to the passing air. In this way the desiccant is regenerated to begin the next cycle. Regeneration air is then drawn through air directing valve **409** by fan **416** and through outlet duct **418** to the outdoor space **419**.

[0066] In some embodiments of system **400**, air inlets **408** and **414** are shared and the process air splits to passive heat transfer devices **404** and **406** after entering the device. In some embodiments of system **400**, all or some components of the device are located outside the conditioned space and achieve air exchange with the indoor space through additional ducts through dividing wall **417**. In some embodiments of system **400**, a second duct through dividing wall **417** and two additional air directing valves are included so in regeneration mode air is supplied from the outdoor space instead of the indoor space.

[0067] In some embodiments of systems **100 – 400**, a liquid-line suction line heat exchanger is used. The direction of airflow through the desiccant coated passive heat transfer devices shown schematically in systems **100-400** is arbitrary. Specifically, each system includes embodiments in which the direction of airflow through the desiccant coated passive heat transfer devices is the same in both modes of operation (parallel flow) and in which the direction of airflow through the desiccant coated passive heat transfer devices reverses between the first and second modes of operation (counterflow).

[0068] Figures **5A** through **5D** shows details of two embodiments of refrigerant flow directing and metering device **208** in two modes of operation. Figure **5A** shows embodiment **A** in mode **1**. Figure **5B** shows embodiment **A** in mode **2**. Figure **5C** shows embodiment **B** in mode **1**. Figure **5D** shows embodiment **B** in mode **2**. Embodiment **A** is comprised of refrigerant check valves **502**, **503**, **506**, and **508**, expansion valve **509**, and refrigerant lines **501**, **504**, **505**, and **507**. Embodiment **B** is comprised of refrigerant check valves **510** and **515**, expansion valves **511** and **514**, and refrigerant lines **510**, **514**, **516**, and **517**.

[0069] As shown in figure **5A**, in mode **1** of embodiment **A**, high pressure refrigerant enters the device through refrigerant line **501**. Refrigerant passes through check valve **502** and is blocked from passing through check valve **503**. Refrigerant flows out of device **208** through refrigerant line **504**. High pressure refrigerant enters the device through refrigerant line **505**, then passes through expansion valve **509**, which takes the refrigerant from a high-pressure state to a low-pressure state. Low pressure refrigerant then passes through check valve **506** and is blocked from passing through check valve **508**. Refrigerant then flows out of device **208** through refrigerant line **507**.

[0070] As shown in figure **5B**, in mode **2** of embodiment **A**, high pressure refrigerant enters the device through refrigerant line **507**. Refrigerant passes through check valve **508** and is blocked from passing through check valve **506**. Refrigerant flows out of device **208** through refrigerant line **504**. High pressure refrigerant enters the device through refrigerant line **505**, then passes through expansion valve **509**, which takes the refrigerant from a high-pressure state to a low-pressure state. Low pressure refrigerant then passes through check valve **503** and is blocked from passing through check valve **502**. Refrigerant then flows out of device **208** through refrigerant line **501**.

[0071] As shown in figure **5C**, in mode **1** of embodiment **B**, high pressure refrigerant enters the device through refrigerant line **517**. Refrigerant passes through

check valve **510**. Refrigerant flows out of device **208** through refrigerant line **512**. High pressure refrigerant enters the device through refrigerant line **513**. Refrigerant is blocked from passing through check valve **515** and passes through expansion valve **514**, which takes the refrigerant from a high-pressure state to a low-pressure state. Low pressure refrigerant then flows out of device **208** through refrigerant line **516**.

[0072] As shown in figure **5D**, in mode **2** of embodiment **B**, high pressure refrigerant enters the device through refrigerant line **516**. Refrigerant passes through check valve **515**. Refrigerant flows out of device **208** through refrigerant line **513**. High pressure refrigerant enters the device through refrigerant line **512**. Refrigerant is blocked from passing through check valve **510** and passes through expansion valve **511**, which takes the refrigerant from a high-pressure state to a low-pressure state. Low pressure refrigerant then flows out of device **208** through refrigerant line **517**.

[0073] Figures **6A** and **6B** show two modes of operation of one embodiment of an indoor unit of system **100**, **200**, **300**, or **400** in cross-section view. In this embodiment the desiccant coated passive heat transfer device is a fin-and-tube heat exchanger with desiccant partially coated on the fins of the heat exchanger, and the fan is a crossflow fan.

[0074] As shown in figure **6A**, in mode **1** heat exchanger **604** is in process mode. Return air **601** from the conditioned space enters device **600** through opening **602** and passes through air directing valve **603** in a first position to heat exchanger **604**. The air is first exposed to the uncoated fin surface **610**, cooling the air. At surface **610**, sensible heat is transferred from the air to heat exchanger **604** and to the refrigerant flowing through. The air is then exposed to desiccant coated fin surface **605**, cooling and dehumidifying the air. At surface **605**, moisture from the air is adsorbed onto the desiccant, increasing the moisture content of the desiccant. The heat of adsorption from the desiccant is transferred to heat exchanger **604** by conduction, and to the refrigerant flowing through. Sensible heat from the process airstream is also transferred to heat exchanger **604** and to the refrigerant flowing through. Air is then drawn through crossflow fan **606** and passes by air directing valve **607** in a first position through opening **608** to the conditioned space **609**.

[0075] As shown in figure **6B**, in mode **2** heat exchanger **604** is in regeneration mode. Outdoor air **614** enters device **600** through opening **611** and passes through air directing valve **603** in a second position to heat exchanger **604**. The air is first exposed to the uncoated fin surface **610**, heating the air. At surface **610**, sensible heat is transferred

from refrigerant flowing through heat exchanger **604** to the exposed surface **610** and onward to the air. The air is then exposed to desiccant coated fin surface **605**, heating and humidifying the air. At surface **605**, heat is transferred from refrigerant flowing through heat exchanger **604** to the desiccant coated on surface **605** causing desorption of moisture
5 from the desiccant to the passing air. Air is then drawn through crossflow fan **606** and passes by air directing valve **607** in a second position through opening **612** to the outdoor space **613**.

[0076] In some embodiments of device **600** an additional operation mode allows outdoor air to be drawn from ambient air **614** through opening **611** while heat exchanger
10 **604** is in process mode to cool and ventilate the conditioned space.

[0077] In the examples described above, at least a portion or an entire surface of any of the passive heat transfer device(s) described above can be at least partially or completely coated with a desiccant material according to various examples. In one example, a surface of the passive heat transfer device can be between at least one tenth
15 covered (e.g., 10% covered) and up to completely covered (100% covered) with desiccant material, or any coverage value in between the described range.

[0078] Figure 7 depicts a method of control for a desiccant cooling and dehumidification system as described in the examples above. In an example, the method can be implemented by a process(or) and a non-transitory storage medium (e.g., memory)
20 having instructions stored thereon and configured to be executed by the processor. Upon startup **701**, the system measures the temperature and humidity of the indoor and outdoor space **702**. These measurements are used to set system parameters for a default operating mode **703**. During default operating mode, the temperature and humidity at the inlet and outlet of each desiccant coated passive heat transfer device is measured. After some time,
25 the desiccant of the process stream will become saturated and the rate of moisture removal from the process airstream will decrease. At this time, the outlet humidity ratio will approach the inlet humidity ratio. The control system logs this as the required desiccant load time **704**. Similarly, after some time, the desiccant of the regeneration stream will become desaturated, and the rate of moisture addition to the regeneration
30 airstream will decrease. At this time, the outlet humidity ratio will approach the inlet humidity ratio. The control system logs this as the required desiccant unload time **704**.

[0079] While the system is running in default mode **703**, the indoor temperature and humidity are measured over time, and the sensible and latent load are determined

705. In one operating mode, sensible cooling is adjusted to match sensible load, and latent cooling is adjusted to match latent load. In one embodiment, sensible cooling is adjusted by modulating process fan speed. In one embodiment, latent cooling is adjusted by modulating the process duty cycle, defined as the required loading time over the switching time. In a preferred operating mode, the required desiccant unload time is modulated to equal the switching time by controlling the compressor speed and regeneration fan speed.

[0080] The foregoing has been a detailed description of illustrative embodiments of the invention. Various modifications and additions can be made without departing from the spirit and scope of this invention. Features of each of the various embodiments described above may be combined with features of other described embodiments as appropriate in order to provide a multiplicity of feature combinations in associated new embodiments. Furthermore, while the foregoing describes a number of separate embodiments of the apparatus and method of the present invention, what has been described herein is merely illustrative of the application of the principles of the present invention. For example, as used herein, the terms “process” and/or “processor” should be taken broadly to include a variety of electronic hardware and/or software based functions and components (and can alternatively be termed functional “modules” or “elements”). Moreover, a depicted process or processor can be combined with other processes and/or processors or divided into various sub-processes or processors. Such sub-processes and/or sub-processors can be variously combined according to embodiments herein. Likewise, it is expressly contemplated that any function, process and/or processor herein can be implemented using electronic hardware, software consisting of a non-transitory computer-readable medium of program instructions, or a combination of hardware and software. Additionally, as used herein various directional and dispositional terms such as “vertical”, “horizontal”, “up”, “down”, “bottom”, “top”, “side”, “front”, “rear”, “left”, “right”, and the like, are used only as relative conventions and not as absolute directions/dispositions with respect to a fixed coordinate space, such as the acting direction of gravity. Additionally, where the term “substantially” or “approximately” is employed with respect to a given measurement, value or characteristic, it refers to a quantity that is within a normal operating range to achieve desired results, but that includes some variability due to inherent inaccuracy and error within the allowed

tolerances of the system (e.g. 1-5 percent). Accordingly, this description is meant to be taken only by way of example, and not to otherwise limit the scope of this invention.

[0081] What is claimed is:

CLAIMS

- 2 1. An air-handling system comprising:
3 a heat pump configured to move heat energy between a plurality of passive heat
4 transfer devices;
5 the plurality of passive heat transfer devices, defining a first surface of at least one of the
6 plurality of passive heat transfer devices that is thermally in contact with the heat pump
7 and a second surface of at least one of the plurality of passive heat transfer devices that is
8 exposed to allow the transfer of heat to or from the heat pump;
9 a desiccant in thermal contact with the exposed surface of at least one passive
10 heat transfer device and configured to exchange moisture with air;
11 a plurality of air directing valves configured to direct process and regeneration air
12 to and from the plurality of passive heat transfer devices with desiccant;
13 a heat pump reversing device configured to change the direction of heat flow in
14 the heat pump between two modes of operation;
15 a control system with communication lines to control air directing valves,
16 reversing device, and heat pump operation; and
17 a control operation process operating a control mode in which desiccant
18 regeneration time is modulated.
- 1 2. The system of claim 1 wherein the passive heat transfer devices comprise tube
2 and fin heat exchangers or microchannel heat exchangers.
- 1 3. The system of claim 2 wherein the desiccant forms a coating on the exposed
2 surface of the heat exchanger fins.
- 1 4. The system of claim 3 wherein the desiccant forms a partial coating with an
2 uncoated section first exposed to airflow followed by a desiccant coated second section
3 exposed to airflow.
- 1 5. The system of claim 1, further comprising, a passive heat transfer device without
2 desiccant configured for exchanging sensible heat with ambient air.

1 6. The system of claim 1, further comprising, a passive heat transfer device without
2 desiccant configured for exchanging sensible heat with indoor air.

1 7. The system of claim 1 wherein the desiccant comprises at least one of silica gel,
2 alumina, zeolite or a metal-organic framework (MOF) material.

1 8. A method for handling air in a space comprising the steps of:
2 moving, with a heat pump, heat energy between a plurality of passive heat
3 transfer devices, in which a first surface of at least one of the plurality of passive heat
4 transfer devices is thermally in contact with the heat pump and a second surface of at
5 least one of the plurality of passive heat transfer devices is exposed to allow the transfer
6 of heat to or from the heat pump;
7 providing a desiccant in thermal contact with the exposed surface of at least one
8 passive heat transfer device and configured to exchange moisture with air;
9 directing, through a plurality of air directing valves, process and regeneration air
10 to and from the plurality of passive heat transfer devices with desiccant;
11 changing a direction of heat flow in the heat pump between two modes of
12 operation; and
13 controlling the plurality air directing valves, reversing device, and heat pump
14 operation in a control operation mode to modulate desiccant regeneration time.

1 9. The method of claim 8 wherein the passive heat transfer devices comprise tube
2 and fin heat exchangers or microchannel heat exchangers.

1 10. The method of claim 9 wherein the desiccant forms a coating on the exposed
2 surface of the heat exchanger fins.

1 11. The method of claim 10 wherein the desiccant forms a partial coating with an
2 uncoated section first exposed to airflow followed by a desiccant coated second section
3 exposed to airflow.

1 12. The method of claim 8, further comprising, exchanging, using a passive heat
2 transfer device without desiccant, sensible heat with ambient air.

1 13. The method of claim 8, further comprising, exchanging, using a passive heat
2 transfer device without desiccant, sensible heat with indoor air.

14. The method of claim 8 wherein the desiccant comprises at least one of silica gel,
alumina, zeolite or a metal-organic framework (MOF) material.