

COMPRESSORLESS AIR CONDITIONING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of and priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 63/307,391, filed February 7, 2022, entitled “COMPRESSORLESS AIR CONDITIONING SYSTEM,” the disclosure of which is hereby incorporated by reference in its entirety herein.

FIELD

[0002] This application discloses an invention which is related, generally and in various aspects, to an air conditioning system.

BACKGROUND

[0003] Conventional air conditioning systems utilized in residential homes (residential air conditioning systems) typically include a compressor, a condenser, an evaporator and a metering device, connected to one another via a closed loop of piping/tubing which is charged with a refrigerant gas. For such systems, the condenser typically includes a coil and a fan which are positioned outside of the home, and the evaporator typically includes a coil and a fan which are positioned inside of the home. The coil and the fan of the condenser are often bundled together in a form commonly known as a condensing unit. In general, the compressor and the condenser are often referred to as being a high pressure side of the air conditioning system, and the metering device and the evaporator are often referred to as being a low pressure side of the air conditioning system.

[0004] In operation, on a call for cooling, typically signaled by a thermostat positioned inside of the home, the compressor is energized with electricity and acts to take a

low pressure, low temperature refrigerant vapor at the inlet of the compressor and compress the refrigerant vapor to form a high pressure, high temperature refrigerant vapor leaving the outlet of the compressor. The high pressure, high temperature refrigerant vapor is effectively “pushed” from the outlet of the compressor to the inlet of the condenser by the compressor. As the refrigerant vapor passes through the piping/tubing of the condenser, and outdoor air (which is at a lower temperature) is drawn through the condenser coil by the condenser fan, heat is transferred from the refrigerant to the outdoor air. The heat transfer reduces the temperature of the refrigerant, eventually resulting in the refrigerant changing into a liquid state which is still at a high pressure. The high pressure, liquid refrigerant exits the condenser and moves on to the metering device.

[0005] As the high pressure, liquid refrigerant passes through the metering device, both the pressure and the temperature of the liquid refrigerant are reduced prior to the liquid refrigerant exiting the metering device and entering the evaporator. As the liquid refrigerant passes through the piping/tubing of the evaporator, and as indoor air (which is at a higher temperature) is drawn or blown through the evaporator coil by the evaporator fan, heat and moisture are removed from the indoor air, effectively lowering the temperature of the air supplied to the conditioned space. The air supplied to the conditioned space is typically transported from the evaporator to the conditioned space via ductwork. The removed heat is transferred to the liquid refrigerant, increasing the temperature of the refrigerant and eventually causing the refrigerant to change back into a refrigerant vapor. The refrigerant vapor exiting the evaporator is then “pulled” back to the compressor, and the above described “refrigeration cycle” is repeated for as many times as needed to satisfy the call for cooling.

[0006] Similar to conventional residential air conditioning systems, many conventional air conditioning systems utilized in commercial or industrial buildings (commercial air conditioning systems) also include a compressor, a condenser, an evaporator and a metering device, connected to one another via a closed loop of

pipings/tubings which is charged with a refrigerant gas. Although the compressor and the other components of such commercial air conditioning systems can be larger in number (e.g., multiple compressors) and/or larger in size than those of conventional residential air conditioning systems, the basic principles of operation are essentially the same. For example, the compressor is utilized to raise the pressure and temperature of a refrigerant, heat is transferred to and from the refrigerant as the refrigerant moves through the air conditioning system, and heat and moisture removed from the indoor air acts to lower the temperature of the air supplied to the air conditioned space.

[0007] Regardless of whether the air conditioning system is residential or commercial in nature, there are a number of concerns associated with such systems. For example, a conventional air conditioning system as described above is typically one of the largest consumers of electricity in the building, and of all of the components of the air conditioning system, the compressor is by far the largest consumer of electricity. In a number of conventional air conditioning systems, the compressor can consume up to about 90% or more of the electricity consumed by the air conditioning system. Also, based on the type of power source (e.g., coal, oil, natural gas, etc.) utilized to generate the electricity ultimately consumed by the air conditioning system, in many instances the air conditioning system is also, by extension, the largest emitter of greenhouse gases associated with the building. Such greenhouse gases produced by the generation of the electricity can include, for example, carbon dioxide, methane, nitrous oxide and/or fluorinated gases.

[0008] Additionally, although conventional air conditioning systems have gained widespread acceptance and do an adequate job of keeping a conditioned space at a desired temperature, they are relatively inefficient in the way they remove humidity from the indoor air. It is very common for conventional air conditioning systems to cool the air crossing the evaporator coil to a temperature much lower than needed in order to realize a commonly specified level of relative humidity (e.g., 50% - 55% relative humidity). Such “excess

cooling” operates to cause conventional air conditioning systems to consume much more energy than is needed to reach a desired temperature at a desired relative humidity in the conditioned space. In general, the lower the targeted level of relative humidity in the conditioned space, which can vary greatly from application to application, the lower the temperature the conventional air conditioning system has to cool the air crossing the evaporator coil to in order to meet the targeted level of relative humidity in the conditioned space.

[0009] Furthermore, with conventional air conditioning systems such as those described above, due to the removal of heat and moisture from the air crossing the evaporator coil, the interior of the evaporator tends to be a cool, damp, space with condensation often present on the evaporator coil, the drain pan, etc. The cool, damp space is very conducive to the growth of unwanted mold and bacteria, and such mold and bacteria are often transported into the conditioned space by the evaporator fan via the ductwork. In the process, unwanted mold and bacteria can also take up residence on the interior surfaces of the ductwork and grow there, with the likelihood of at least some of the mold and bacteria in the ductwork being subsequently “peeled off” and carried into conditioned space by the air flowing from the evaporator to the conditioned space.

[0010] In view of the above, it would be desirable for air conditioning systems to eliminate high electricity usage, and by extension, high electricity costs and high greenhouse gas emissions associated therewith while meeting targeted levels of temperature and humidity in a conditioned space. It would also be desirable to mitigate the transportation of unwanted mold and/or bacteria from the evaporator and/or the associated ductwork into the conditioned space.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The novel features of the aspects described herein are set forth with

particularity in the appended claims. The aspects, however, both as to organization and methods of operation may be better understood by reference to the following description, taken in conjunction with the accompanying drawings.

[0012] FIG. 1 illustrates a compressorless air conditioning system, in accordance with at least one aspect of the present disclosure;

[0013] FIG. 2 illustrates a collector of the compressorless air conditioning system of FIG. 1, in accordance with at least one aspect of the present disclosure;

[0014] FIG. 3 illustrates a regenerator of the compressorless air conditioning system of FIG. 1, in accordance with at least one aspect of the present disclosure;

[0015] FIG. 4A illustrates an example of the fluidic coupling of the collector of FIG. 2 and the regenerator of FIG. 3, in accordance with at least one aspect of the present disclosure;

[0016] FIG. 4B illustrates another example of the fluidic coupling of the collector of FIG. 2 and the regenerator of FIG. 3, in accordance with at least aspect of the present disclosure;

[0017] [0015] FIG. 5 illustrates a mass-to-heat converter of the compressorless air conditioning system of FIG. 1, in accordance with at least one aspect of the present disclosure; and

[0018] [0016] FIG. 6 illustrates a control system of the compressorless air conditioning system of FIG. 1, in accordance with at least one aspect of the present disclosure.

DETAILED DESCRIPTION

[0019] It is to be understood that at least some of the figures and descriptions of the invention have been simplified to illustrate elements that are relevant for a clear understanding of the invention, while eliminating, for purposes of clarity, other elements that

those of ordinary skill in the art will appreciate may also comprise a portion of the invention. However, because such elements are well known in the art, and because they do not facilitate a better understanding of the invention, a description of such elements is not provided herein.

[0020] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols and reference characters typically identify similar components throughout several views, unless context dictates otherwise. The illustrative aspects described in the detailed description, drawings and claims are not meant to be limiting. Other aspects may be utilized, and other changes may be made, without departing from the scope of the technology described herein.

[0021] The following description of certain examples of the technology should not be used to limit its scope. Other examples, features, aspects, embodiments and advantages of the technology will become apparent to those skilled in the art from the following description, which is by way of illustration, one of the best modes contemplated for carrying out the technology. As will be realized, the technology described herein is capable of other different and obvious aspects, all without departing from the technology. Accordingly, the drawings and descriptions should be regarded as illustrative in nature and not restrictive.

[0022] It is further understood that any one or more of the teachings, expressions, aspects, embodiments, examples, etc. described herein may be combined with any one or more of the other teachings, expressions, aspects, embodiments, examples, etc. that are described herein. The following described teachings, expressions, aspects, embodiments, examples, etc. should therefore not be viewed in isolation relative to each other. Various suitable ways in which the teachings herein may be combined will be readily apparent to those of ordinary skill in the art in view of the teachings herein. Such modifications and variations are intended to be included within the scope of the claims.

[0023] Before explaining the various aspects of a compressorless air conditioning system in detail, it should be noted that the various aspects disclosed herein are

not limited in their application or use to the details of construction and arrangement of parts illustrated in the accompanying drawings and description. Rather, the disclosed aspects may be positioned or incorporated in other aspects, variations and modifications thereof, and may be practiced or carried out in various ways. Accordingly, aspects of the compressorless air conditioning system disclosed herein are illustrative in nature and are not meant to limit the scope or application thereof. Furthermore, unless otherwise indicated, the terms and expressions employed herein have been chosen for the purpose of describing the aspects for the convenience of the reader and are not meant to limit the scope thereof. In addition, it should be understood that any one or more of the disclosed aspects, expressions of aspects, and/or examples thereof, can be combined with any one or more of the other disclosed aspects, expressions of aspects, and/or examples thereof, without limitation.

[0024] Also, in the following description, it is to be understood that terms such as outward, inward, above and the like are words of convenience and are not to be construed as limiting terms. Terminology used herein is not meant to be limiting insofar as devices described herein, or portions thereof, may be attached or utilized in other orientations. The various aspects will be described in more detail with reference to the drawings.

[0025] FIG. 1 illustrates a compressorless air conditioning system 10, in accordance with at least one aspect of the present disclosure. In general, the compressorless air conditioning system 10 is configured to control the humidity and temperature of a conditioned space 12 without the use of a compressor or a refrigerant. According to various aspects, the compressorless air conditioning system 10 is further configured to control the humidity and temperature of the conditioned space 12 without the use of any ductwork. In general, the conditioned space 12 is an indoor space in a home, in a building, etc. The compressorless air conditioning system 10 includes a heat-to-mass extractor 14, a mass-to-heat converter 16 and a control system 18. The heat-to-mass extractor 14 and the mass-to-heat converter 16 are physically disconnected from / decoupled with one another. Stated

differently, the heat-to-mass extractor 14 and the mass-to-heat converter 16 are not physically connected to or coupled with one another. The control system 18 is communicably coupled to the heat-to-mass extractor 14 and to the mass-to-heat converter 16. According to various aspects, the heat-to-mass extractor 14 and the mass-to-heat converter 16 are wirelessly connected with the control system 18, and the control system 18 is configured to control the operation of the heat-to-mass extractor 14 and the mass-to-heat converter 16. The control system 18 will be described in more detail hereinbelow with respect to FIG. 6.

[0026] Though the heat-to-mass extractor 14 and the mass-to-heat converter 16 are physically uncoupled, according to various aspects, the control system 18 operates the heat-to-mass extractor 14 and the mass-to-heat converter 16 cooperatively to control the humidity and temperature of the air in the conditioned space 12. Only the air within the conditioned space 12, which facilitates relatively fast heat and mass transfer within the conditioned space 12, bridges the heat-to-mass extractor 14 and the mass-to-heat converter 16 to one another. More specifically, lower humidity air A2 exiting the heat-to-mass extractor 14 mixes with the air in the conditioned space 12 and is subsequently drawn into the mass-to-heat converter 16 as input air B1. Similarly, lower temperature air B2 exiting the mass-to-heat converter 16 mixes with the air in the conditioned space 12 and is subsequently drawn into the heat-to-mass extractor 14 as input air A1. For aspects where the system 10 includes multiple mass-to-heat converters 16 (e.g. a mass-to-heat converter in each room of a building), the mass-to-heat converters 16 are independent and physically uncoupled. Only air within the conditioned space 12 bridges the mass-to-heat converters 16 to one another. In view of the above, it will be appreciated that the air in the conditioned space 12 may be considered to be a medium of the system 10 that ties the heat-to-mass extractor 14 and the mass-to-heat converter 16 together. In contrast to a conventional air conditioning system, which utilizes ductwork for moving humidity and temperature conditioned air into and

around the conditioned space 12, with the system 10, the air within the conditioned space 12 acts as the medium for the transfer of heat and mass to facilitate humidity and temperature control of the air within the conditioned space 12.

[0027] The heat-to-mass extractor 14 includes a collector 20, a regenerator (or extractor) 22 and liquid desiccant 24. In general, the heat-to-mass extractor 14 is configured to lower the humidity of air from the conditioned space 12 and return the “drier” air to the conditioned space 12, without the use of a compressor or a refrigerant. According to various aspects, the heat-to-mass extractor 14 is further configured to lower the humidity of air from the conditioned space 12 and return the “drier” air to the conditioned space 12, without the use of any ductwork. According to various aspects, the collector 20 is positioned within the conditioned space 12 and the regenerator 22 is positioned external to the conditioned space 12. However, as shown in FIG. 1, according to other aspects, a portion 20a (shown by dashed lines) of the collector 20 is positioned external to the conditioned space 12. In such instances, the collector 20 can be referred to as a split collector. The collector 20 will be described in more detail hereinbelow with respect to FIG. 2, and the regenerator 22 will be described in more detail hereinbelow with respect to FIG. 3.

[0028] For purposes of clarity, the liquid desiccant 24 is not shown in FIG. 1 (See FIGS. 2, 3 and 4). The liquid desiccant 24 may be any suitable type of liquid desiccant 24. For example, according to various aspects, the liquid desiccant 24 comprises a hygroscopic material such as, for example, lithium chloride, lithium bromide, calcium chloride, etc. A first portion of the liquid desiccant 24 (hereinafter referred to as the liquid desiccant 24a) is associated with the collector 20 and a second portion of the liquid desiccant 24 (hereinafter referred to as the liquid desiccant 24b) is associated with the regenerator 22. As explained in more detail hereinbelow, the liquid desiccant 24a in the collector 20 interacts with the air from the conditioned space 12, and the liquid desiccant 24b in the regenerator 22 interacts with the air from outside the conditioned space 12 (ambient/outdoor

air, air from an unconditioned space, etc.). As also explained in more detail herein with respect to FIGS. 4A and 4B, the liquid desiccant 24a and the liquid desiccant 24b are fluidically coupled to one another. Thus, the collector 20 and the regenerator 22 may be considered to be fluidically coupled to one another by liquid desiccant moving therebetween. Due to the fluidic coupling between the liquid desiccant 24a and the liquid desiccant 24b, the liquid desiccant 24a and the liquid desiccant 24b will seek to achieve equilibrium with one another. Stated differently, the liquid desiccant 24 of the heat-to-mass extractor 14 will always try to achieve equilibrium throughout the liquid desiccant 24.

[0029] Although only one heat-to-mass extractor 14 is shown in FIG. 1, it will be appreciated that the compressorless air conditioning system 10 may include any number of heat-to-mass extractors 14. For example, according to various aspects, when a given application requires a relatively large amount of moisture to be extracted from air of the conditioned space 12, a plurality of heat-to-mass extractors 14 may be utilized to collectively extract the moisture. According to other aspects, when a given application requires a relatively large amount of moisture to be extracted from air of the conditioned space 12, the size of the heat-to-mass extractor 14 may be scaled up so that only one heat-to-mass extractor 14 is utilized to extract the moisture.

[0030] The mass-to-heat converter 16 is configured to cool air from the conditioned space 12, without the use of a compressor or refrigerant. According to various aspects, the mass-to-heat converter 16 is further configured to cool air from the conditioned space 12, and return the cooled air into the conditioned space 12, without the use of ductwork. The mass-to-heat converter 16 will be described in more detail hereinbelow with respect to FIG. 5. Although only one mass-to-heat converter 16 is shown in FIG. 1, it will be appreciated that the compressorless air conditioning system 10 may include any number of mass-to-heat converters 16. For example, based on the amount of cooling required, the compressorless air conditioning system 10 may include multiple mass-to-heat converters 16.

Multiple mass-to-heat converters 16 can be spaced apart within a space (e.g., within the conditioned space 12). According to various aspects, a different mass-to-heat converter 16 can be placed in each room in a house or building, for example, or multiple mass-to-heat converters 16 can be spaced apart within a large open-concept space, for example.

[0031] FIG. 2 illustrates the collector 20 of the heat-to-mass extractor 14, in accordance with at least one aspect of the present disclosure. In general, the collector 20 is configured to extract moisture from air from the conditioned space 12, thereby lowering the humidity of the air from the conditioned space 12, and further configured to transfer the extracted moisture to the liquid desiccant 24 in the collector 20. According to various aspects, the collector 20 is further configured to extract moisture from air from the conditioned space 12, thereby lowering the humidity of the air from the conditioned space 12, and transfer the extracted moisture to the liquid desiccant 24a in the collector 20, without the use of any ductwork.

[0032] According to various aspects, the collector 20 includes the first portion of the liquid desiccant 24a, a sump 26, a pump 28, a media 30 and a fan 32. The sump 26 may be of any suitable size and shape, and is configured to hold the liquid desiccant 24a. The pump 28 may be any suitable type of pump, and is configured to move liquid desiccant 24a from the sump 26 to the media 30, where the liquid desiccant 24a flows over the media 30, saturates the media 30 and returns to the sump 26. The fan 32 may be any suitable type of fan (e.g., centrifugal, axial, etc.) and is configured to move air from the conditioned space 12, over the media 30, and back to the conditioned space 12. According to various aspects, the fan 32 draws the air over the media 30. According to other aspects, the fan 32 blows the air over the media 30.

[0033] The air flowing over the media 30 flows in a direction opposite the direction the liquid desiccant 24a flows over the media 30. For example, according to various aspects, the air flows “upward” over the media 30 and the liquid desiccant 24a

flows “downward” over the media 30. As the air flowing over the media 30 interacts with the liquid desiccant 24a flowing over the media 30 (or with the liquid desiccant 24a which saturates the media 30), moisture is extracted from the air and is transferred to the liquid desiccant 24a. The extraction of the moisture from the air operates to remove latent heat from the air from the conditioned space 12, lower the humidity of the air being returned to the conditioned space 12 (e.g., air exhausted from the collector 20), lower the concentration of the liquid desiccant 24a, increase the temperature of the liquid desiccant 24a and increase the vapor pressure of the liquid desiccant 24a. In general, the vapour pressure of the liquid desiccant 24a is proportional to temperature of the liquid desiccant 24a and inversely proportional to the level of concentration of the liquid desiccant 24a. Stated differently, when the concentration level of the liquid desiccant 24a is decreased or the temperature of the liquid desiccant 24a is increased, the vapour pressure of the liquid desiccant 24a increases.

[0034] The media 30 may be any suitable type of media. For example, the media 30 may include fibrous pads, membranes, etc. In general, the media 30 is configured so as to have a large surface area which comes in contact with the liquid desiccant 24a, and becomes saturated by the liquid desiccant 24a. According to various aspects, the liquid desiccant 24a flows “downward” over the media 30 (e.g., from a mister). According to other aspects, the liquid desiccant 24a flows into a media bed/bath which supports the media 30. As the air flowing over the media 30 interacts with the liquid desiccant 24a flowing over the media 30 (or with the liquid desiccant 24a which saturates the media 30), the inherent biocidal nature of the liquid desiccant 24a operates to scrub the air of pollutants, molds, bacteria, viruses, etc., resulting in purified air being returned to the conditioned space 12. Thus, according to various aspects, the collector 20, and by extension the heat-to-mass extractor 14 (FIG. 1), are also configured to purify air from the conditioned space 12. In various aspects of the present disclosure, the collector 20 of the heat-to-mass extractor 14 can circulate air within the

conditioned space 12 to provide any number of air changes per hour within the conditioned space 12. For example, according to various aspects, depending on the size of the system 10 and the conditioned space 12, the collector 20 of the heat-to-mass extractor 14 can provide up to one air change per hour, up to two air changes per hour, up to five air changes per hour, up to ten air changes per hour, up to twenty air changes per hour, etc. The liquid desiccant 24 purifies the air as it contacts the air moving through the collector 20 of the heat-to-mass extractor 14. Air purification can be further facilitated by the mass-to-heat converter(s) 16, as further described herein.

[0035] As shown in FIG. 2, according to various aspects, the media 30 and the fan 32 are positioned in the conditioned space 12, and the pump 28 and the sump 26 are positioned outside of the conditioned space 12. For such aspects, the collector 20 includes two or more fluid conduits or tubes connecting the internal portion of the collector 20 and the external portion 20a of the collector 20. For example, the heat-to-mass extractor 14 also includes two tubes 34a, 34b. The tube 34a provides a path for the liquid desiccant 24a to flow from the media 30 to the portion of the sump 26. The tube 34b provides a path for the liquid desiccant 24a to flow from the pump 28 to the media 30. For purposes of clarity, only a portion of the tubes 34a, 34b are shown in FIG. 2. The tubes 34a, 34b may be any suitable type of tubes. According to various aspects, the tubes 34a, 34b comprises a plastic such as, for example, a polyethylene.

[0036] For aspects where the pump 28 and the sump 26 are positioned outside of the conditioned space 12, the pump 28 and the sump 26 may be incorporated into and housed within the regenerator 22. According to other aspects, a first portion of the sump 26 may be positioned within the conditioned space 12 (e.g., housed within the collector 20) and a second portion of the sump 26 may be positioned external to the conditioned space 12 (e.g., housed within the regenerator 22). According to yet other aspects, the sump 26, the pump 28, the media 30 and the fan 32 are all positioned in the conditioned space 12. Thus, whereas the

regenerator 22 is considered to be positioned external to the conditioned space 12, the collector 20 may be considered to be fully positioned within the conditioned space 12, or partially positioned within and partially positioned external to the conditioned space 12.

[0037] FIG. 3 illustrates the regenerator 22 of the heat-to-mass extractor 14, in accordance with at least one aspect of the present disclosure. The regenerator 22 is configured to extract moisture from the liquid desiccant 24b and transfer the extracted moisture to air external to the conditioned space 12 (e.g., ambient air, outside air, air from an unconditioned space, etc.). The regenerator 22 is also configured to receive low grade heat from a heat source 36. According to various aspects, low grade heat may be considered heat which is less than 277 degrees Celsius. According to other aspects, low grade heat may be considered heat which is less than 200 degrees Celsius. The heat source 36 may be any suitable type of heat source which is capable of providing low grade heat. For example, the heat source 36 may comprise a solar thermal collector, an industrial process, a geothermal system, a hot water system of a home or building, etc.

[0038] The regenerator 22 includes a sump 38, the liquid desiccant 24b, a pump 40, a heat exchanger 42, a media 44 and a fan 46. The sump 38 may be of any suitable size and shape, and is configured to hold the liquid desiccant 24b. The pump 40 may be any suitable type of pump, and is configured to move liquid desiccant 24b from the sump 38 to the heat exchanger 42 and subsequently to the media 44, where the liquid desiccant 24b flows over the media 44, saturates the media 44 and returns to the sump 38. The fan 46 may be any suitable type of fan (e.g., centrifugal, axial, etc.) and is configured to move air external to the conditioned space 12, over the media 44, and back to air external to the conditioned space 12. According to various aspects, the fan 46 draws the air over the media 44. According to other aspects, the fan 46 blows the air over the media 44.

[0039] The heat exchanger 42 is configured to receive the low grade heat from the heat source 36 in one portion of the heat exchanger 42 and the liquid desiccant 24b from

the sump 38 in a second portion of the heat exchanger 42. The heat exchanger 42 is further configured to extract heat from the low grade heat and transfer the extracted heat to the liquid desiccant 24b, thereby increasing the temperature and the vapor pressure of the liquid desiccant 24b. The heat exchanger 42 may be any suitable type of heat exchanger. For example, according to various aspects, the direction of flow of the low grade heat through the heat exchanger 38 may be opposite the direction of flow of the liquid desiccant 24b through the heat exchanger 42 (i.e., counter-flow as shown in FIG. 3). According to other aspects, the flows may crossflow. According to yet other aspects, the flows may be a combination of crossflow and counter-flow.

[0040] The low grade heat received by the heat exchanger 42 provides energy to the system 10. By heating and concentrating the liquid desiccant 24b in the regenerator 22, diffusion (and gravity) can affect the transfer of mass between the liquid desiccant 24b of the regenerator 22 and the liquid desiccant 24a of the collector 20, which allows for the collector 20 to dehumidify the air within the conditioned space 12. Because diffusion of liquid desiccant 24 toward equilibrium is a passive process, the control of the humidity within the conditioned space 12 can be achieved with reduced energy requirements.

[0041] The air flowing over the media 44 flows in a direction opposite the direction the liquid desiccant 24b flows over the media 44. For example, according to various aspects the air flows “upward” over the media 44 and the liquid desiccant 24b flows “downward” over the media 44. As the air flowing over the media 44 interacts with the liquid desiccant 24b flowing over the media 44 (or with the liquid desiccant 24b which saturates the media 44), moisture is extracted from the liquid desiccant 24b and is transferred to the air which is subsequently exhausted external to the conditioned space 12 (e.g., air exhausted from the regenerator 22). The extraction of the moisture from the liquid desiccant 24b operates to lower the temperature of the liquid desiccant 24b, lower the vapor pressure of the liquid desiccant 24b and increase the concentration of the liquid desiccant 24b, thereby

regenerating the liquid desiccant 24b.

[0042] The media 44 may be any suitable type of media. For example, the media 44 may include fibrous pads, membranes, etc. In general, the media 44 is configured so as to have a large surface area which comes in contact with the liquid desiccant 24b, and becomes saturated by the liquid desiccant 24b. According to various aspects, the liquid desiccant 24b flows “downward” over the media 44 (e.g., via a mister). According to other aspects, the liquid desiccant 24b flows into a media bed/bath which supports the media 44. Once the liquid desiccant 24b is moved to the media 44, the liquid desiccant 24b flows over the media 44, saturates the media 44 and returns to the sump 38.

[0043] As shown in FIG. 3, according to various aspects, the sump 38, the liquid desiccant 24b, the pump 40, the heat exchanger 42, the media 44 and the fan 46 are positioned outside of the conditioned space 12 and are housed within the regenerator 22. As described hereinabove, for aspects where the sump 26 and the pump 28 are positioned external to the conditioned space 12, the sump 26 and the pump 28 may be incorporated into the regenerator 22 and/or housed within the regenerator 22.

[0044] According to various aspects, the regenerator 22 may also include a small compressor (not shown for purposes of simplicity) which can be utilized as a heat source to provide heat to the heat exchanger 42, either in lieu of or in addition to the heat provided by the heat source 36. For such aspects, the small compressor is thermally coupled with the liquid desiccant 24b via the heat exchanger 42. The small compressor may be configured to elevate a free source of heat (e.g., outdoor air) to a temperature which is high enough to allow for the regeneration of the liquid desiccant 24b as described hereinabove. In certain environmental conditions, the small compressor can act as a backup or stand-by heat source to the heat source 36. For aspects which include the small compressor, the compressorless air conditioning system 10 may simply be referred to as an air conditioning system. Other than the inclusion of the small compressor, such an air conditioning system is otherwise similar to

the compressorless air conditioning system 10 as described herein.

[0045] In view of the above, it will be appreciated that the heat-to-mass extractor 14 may also be considered to be a sensible-to-latent extractor.

[0046] FIG. 4A illustrates an example of the fluidic coupling of the liquid desiccant 24a associated with the collector 20 and the liquid desiccant 24b associated with the regenerator 22, in accordance with at least one aspect of the present disclosure. According to the non-limiting aspect of FIG. 4A, the sumps 26, 38 are positioned adjacent to one another, abut one another and/or share a common wall. The sumps 26, 38 define respective openings 48, 50 which are aligned with one another (or which may be the same opening). The openings 48, 50 allow for the liquid desiccants 24a and 24b to be fluidically coupled to one another. As shown by the arrow 52, diffusion occurs from the higher pressure, higher temperature, less concentrated liquid desiccant 24a in the sump 26 to the lower pressure, lower temperature, more concentrated liquid desiccant 24b in the sump 38, and such diffusion occurs until the liquid desiccant 24a in the sump 26 is at equilibrium with the liquid desiccant 24b in the sump 38.

[0047] FIG. 4B illustrates another example of the fluidic coupling of the liquid desiccant 24a associated with the collector 20 and the liquid desiccant 24b associated with the regenerator 22, in accordance with at least one aspect of the present disclosure. According to the non-limiting aspect of FIG. 4B, the sumps 26, 38 are physically separated from one another by a distance and the liquid desiccants 24a, 24b are fluidically coupled to one another via at least one a pipe or tube connected to each of the sumps 26, 38. For example, the sumps 26, 38 may be connected by a supply tube 53, a return tube 55, and/or a balancing tube 51. The supply tube 53 may serve to transport the liquid desiccant 24b from the sump 38 to the sump 26. The return tube 55 may serve to transport the liquid desiccant 24a from the sump 26 to the sump 38. The balancing tube 51 may serve to equalize the liquid level across the sumps 26, 38. In some aspects, a pump (not shown) may be included

along the supply tube 53 to transport the liquid desiccant 24b from the sump 38 to the sump 26 and/or a pump (not shown) may be included along the return tube 55 to transport liquid desiccant 24a from the sump 26 to the sump 38. The supply tube 53 and the return tube 55 can promote the circulation of the liquid desiccants 24a, 24b between the sumps, 26, 38. In some aspects, the sump 26 may be positioned inside of the conditioned space 12 (e.g., housed within the collector 20), positioned external to the conditioned space 12 (e.g., housed within the regenerator 22), or a first portion of the sump 26 may be positioned inside of the conditioned space and a second portion of the sump 26 may be positioned external to the conditioned space 12. For such aspects where the sump 26 is positioned inside of the conditioned space 12, the supply tube 53, the return tube 55, and/or the balancing tube 51 can pass through a floor, a ceiling or a perimeter wall of the conditioned space 12 to span whatever distance is between the sumps 26, 38.

[0048] FIG. 5 illustrates the mass-to-heat converter 16 of the compressorless air conditioning system 10, in accordance with at least one aspect of the present disclosure. The mass-to-heat converter 16 is configured to reduce the temperature of the air within the conditioned space 12 via the evaporation of water (water can absorb a relatively large amount of heat in order to evaporate). The mass-to-heat converter 16 is further configured to receive water. According to various aspects, the mass-to-heat converter 16 is coupled to a water source 60. The water source 60 may be any suitable type of water source which is capable of providing water to the mass-to-heat converter 16. For example, the water source 60 may comprise a public water system and the mass-to-heat converter 16 may be fluidically coupled to the water source 60 via an automatic valve (not shown for purposes of clarity). According to other aspects, the water may be manually supplied to the mass-to-heat converter 16 (e.g., by a person), and such manual supply of water may occur periodically (e.g., once per day, once per week, etc.).

[0049] The mass-to-heat converter 16 includes a sump 62, a pump 64, a media 66

and a fan 68. The sump 62 may be of any suitable size and shape, and is configured to hold water 70 provided by the water source 60 or provided manually (e.g., by a person) to the mass-to-heat converter 16. The pump 64 may be any suitable type of pump, and is configured to move the water 70 from the sump 62 to the media 66, where the water 70 flows over the media 66, saturates the media 66 and returns to the sump 62. The fan 68 may be any suitable type of fan (e.g., centrifugal, axial, etc.) and is configured to move air from the conditioned space 12, over the media 66, and back to the conditioned space 12. According to various aspects, the fan 68 draws the air over the media 66. According to other aspects, the fan 68 blows the air over the media 66. As the mass-to-heat converter 16 does not have any ductwork associated therewith, the fan 68 does not have to overcome the static pressure associated with such ductwork. Thus, the fan 68 (and/or the electric motor which powers the fan 68) can be much smaller and, thus, much quieter than fans in traditional refrigerant/compressor-based air conditioning systems which include ductwork. The fan 68 merely circulates the air within the conditioned space 12 and through the mass-to-heat converter 16 and is not required to push conditioned air through ductwork.

[0050] The air flowing over the media 66 flows in a direction opposite the direction the water 70 flows over the media 66. For example, according to various aspects the air flows “upward” over the media 66 and the water 70 flows “downward” over the media 66. As the air flowing over the media 66 interacts with the water 70 flowing over the media 66 (or with the water which saturates the media 66), heat from the air is absorbed by the water 70, causing the water 70 to evaporate. The absorption of the heat from the air operates to lower the temperature of the air being returned into the conditioned space 12.

[0051] The media 66 may be any suitable type of media. For example, the media 66 may include fibrous pads, membranes, etc. In general, the media 66 is configured so as to have a large surface area which comes in contact with the water 70, and becomes saturated by the water 70. According to various aspects, water 70 flows “downward” over the media 66

(e.g., via a mister). According to other aspects, the water 70 flows into a media bed/bath which supports the media 66. Once the water 70 is moved to the media 66, the water 70 flows over the media 66, saturates the media 66 and returns to the sump 62.

[0052] As shown in FIG. 1, the mass-to-heat converter 16 is positioned within the conditioned space 12 and, as previously described, the compressorless air conditioning system 10 may include a plurality of mass-to-heat converters 16. In general, the number of mass-to-heat converters 16 included in the compressorless air conditioning system 10 is dependent, at least in part, on the cooling load. For example, for a relatively small cooling load of approximately one ton (i.e., 3.5 kilowatts or 12,000 btuh), the compressorless air conditioning system 10 may include only one of the mass-to-heat converters 16. However, for a larger cooling load of approximately three tons (i.e., 10.5 kilowatts or 36,000 btuh), the compressorless air conditioning system 10 may include three of the mass-to-heat converters 16. In general, the larger the cooling load, the more mass-to-heat converters 16 included in the compressorless air conditioning system 10.

[0053] In view of the above, it will be appreciated that the mass-to-heat converter 16 may also be considered to be a latent-to-sensible converter.

[0054] In various instances, the mass-to-heat converter 16 can also include a liquid desiccant or salt solution (not shown for purposes of clarity) that comes into contact with the air passing through the mass-to-heat converter 16 to purify air in the conditioned space 12. For example, the mass-to-heat converter 16 can include a liquid desiccant at a reduced concentration, i.e. less than the concentration of the liquid desiccant 24, which can act as a liquid-based purifier for the air in the conditioned space 12. Liquid desiccant or another salt solution in the mass-to-heat converter 16 can prevent the growth of mold and/or mildew therein, for example. According to various aspects, sodium chloride (NaCl), commonly known as table salt, can be utilized to purify air in the conditioned space 12. Such a salt, when utilized in a high enough concentration, can act as a disinfectant without being

very hygroscopic.

[0055] In various aspects, the water 70 in the mass-to-heat converter 16 may be chlorinated. For example, the mass-to-heat converter 16 may include an electrolyzer 61 configured to produce chlorine from the water 70 (*e.g.*, from salt in the water). Although the electrolyzer 61 is shown in FIG. 5 as receiving water 70 supplied from the sump 62 and returning chlorinated water 70 to the sump 62, the electrolyze 61 may be positioned at various other locations along the water 70 loop of the mass-to-heat converter 16 (*e.g.*, upstream or downstream of the pump 64, along the return from the media 66, *etc.*). As another example, the water 70 may be chlorinated by metering or dosing chlorine into the water 70 or the water source 60. In various aspects, the mass-to-heat converter 16 may include an outlet filter 63. The outlet filter 63 can serve to filter air as it exits an outlet of the mass-to-heat converter 16. In at least one aspect, the outlet filter 63 can be a carbon filter. The carbon filter can be configured to collect chlorine that may be transferred from the water 70 to the air flowing through the mass-to-heat converter 16, thereby capturing the chlorine before it exits the mass-to-heat converter 16.

[0056] FIG. 6 illustrates the control system 18, in accordance with at least one aspect of the present disclosure. The control system 18 is configured to control the operation of the compressorless air conditioning system 10, including the operation of the heat-to-mass extractor 14 and the mass-to-heat converter 16, which includes the operation of the associated fans 32, 46, 68, the associated pumps 28, 40, 64, and the introduction of the low grade heat into the regenerator 22. According to various aspects, the control system 18 is also configured to control the introduction of the water 70 into the mass-to-heat converter 16 from the water source 60.

[0057] According to various aspects, the control system 18 is also configured to control the operation of any other valves, motors and the like associated with the compressorless air conditioning system 10. For aspects of the compressorless air

conditioning system 10 which include the small compressor to provide heat to the heat exchanger 42, the control system 18 is also configured to control the operation of the small compressor.

[0058] According to various aspects, the control system 18 includes a control circuit 80, a temperature measuring device 82 and a humidity measuring device 84. According to various aspects, the control system 18 may also include a pressure measuring device 86, a concentration measuring device 88 and/or a fluid level measuring device 90. Although only one temperature measuring device 82, one humidity measuring device 84, one pressure measuring device 86, one concentration measuring device 88 and one fluid level measuring device 90 are shown in FIG. 6, it will be appreciated the control system 18 may include any number of these devices.

[0059] The temperature measuring device 82 is configured to measure a temperature and communicate a signal indicative of the measured temperature to the control circuit 80.

[0060] Temperature measuring devices 82 may be utilized to measure the temperature of, for example, the air within the conditioned space 12, the ambient/outside air, the liquid desiccant 24 at one or more points (e.g., in the sump 26, in the sump 38, entering or exiting the heat exchanger 42, exiting the media 30, exiting the media 44, etc.), and of the water 70 in the mass-to-heat converter 16 at one or more points (e.g., entering the sump 62 from the water source 60, in the sump 62, exiting the media 66, etc.). For each of these temperature measurements, the associated temperature measuring device 82 is configured to communicate a signal indicative of the measured temperature to the control circuit 80. According to various aspects, the temperature measuring device 82 comprises a thermostat or a temperature sensor.

[0061] The humidity measuring device 84 is configured to measure a humidity and communicate a signal indicative of the measured humidity to the control circuit 80.

Humidity measuring devices 84 may be utilized to measure the humidity of, for example, the air within the conditioned space 12, the ambient/outside air, and of the liquid desiccant 24 at one or more points (e.g., in the sump 26, in the sump 38, entering or exiting the heat exchanger 42, exiting the media 30, exiting the media 44, etc.). For each of these humidity measurements, the associated humidity measuring device 84 is configured to communicate a signal indicative of the measured humidity to the control circuit 80. According to various aspects, the humidity measuring device 84 comprises a humidistat or a humidity sensor.

[0062] The pressure measuring device 86 is configured to measure a vapor pressure and communicate a signal indicative of the measured vapor pressure to the control circuit 80. Pressure measuring devices 86 may be utilized to measure the vapor pressure of, for example, the liquid desiccant 24 at one or more points (e.g., in the sump 26, in the sump 38, entering or exiting the heat exchanger 42, exiting the media 30, exiting the media 44, etc.). For each of these vapor pressure measurements, the associated pressure measuring device 86 is configured to communicate a signal indicative of the measured vapor pressure to the control circuit 80.

[0063] The concentration measuring device 88 is configured to measure a concentration level and communicate a signal indicative of the measured concentration level to the control circuit 80. Concentration measuring devices 88 may be utilized to measure the concentration level of, for example, the liquid desiccant 24 at one or more points (e.g., in the sump 26, in the sump 38, entering or exiting the heat exchanger 42, exiting the media 30, exiting the media 44, etc.). For each of these concentration level measurements, the associated concentration measuring device 88 is configured to communicate a signal indicative of the measured concentration level to the control circuit 80.

[0064] The fluid level measuring device 90 is configured to measure a fluid level and communicate a signal indicative of the measured fluid level to the control circuit 80. Fluid level measuring devices 90 may be utilized to measure the fluid level of, for example,

the liquid desiccant 24 in the sump 26 and in the sump 38, and the water 70 in the sump 62. For each of these fluid level measurements, the associated fluid level measuring device 90 is configured to communicate a signal indicative of the measured fluid level to the control circuit 80.

[0065] According to various aspects, the respective signals communicated from the temperature measuring devices 82, the humidity measuring devices 84, the pressure measuring devices 86, the concentration measuring devices 88 and the fluid level measuring devices 90 may be communicated to the control circuit 80 wirelessly via a network 92.

[0066] The network 92 may include any type of delivery system including, but not limited to, a local area network (e.g., Ethernet), a wide area network (e.g. the Internet and/or World Wide Web), a telephone network (e.g., analog, digital, wired, wireless, PSTN, ISDN, GSM, GPRS, and/or xDSL), a packet-switched network, a radio network, a television network, a cable network, a satellite network, and/or any other wired or wireless communications network configured to carry data. The network 92 may include elements, such as, for example, intermediate nodes, proxy servers, routers, switches, and adapters configured to direct and/or deliver data. In general, temperature measuring devices 82, the humidity measuring devices 84, the pressure measuring devices 86, the concentration measuring devices 88 and the fluid level measuring devices 90 are configured to communicate with the control circuit 80 via the network 92 using various communication protocols (e.g., HTTP, TCP/IP, TelNet, UDP, WAP, WebSockets, WiFi, Bluetooth) and/or to operate within or in concert with one or more other communications systems.

[0067] The control circuit 80 includes a processing circuit 100, a memory circuit 102, a wireless or cellular communication module 104, and a temperature-humidity module 106. The processing circuit 100 is configured to process the signals communicated by the temperature measuring devices 82, the humidity measuring devices 84, the pressure measuring devices 86, the concentration measuring devices 88 and the fluid level measuring

devices 90. The processing circuit 100 may be, for example, hardwired circuitry, programmable circuitry (e.g., a computer processor including one or more individual instruction processing cores, processing unit, processor, microcontroller, microcontroller unit, controller, digital signal processor (DSP), programmable logic device (PLD), programmable logic array (PLA), or field programmable gate array (FPGA)), state machine circuitry, firmware that stores instructions executed by programmable circuitry, and any combination thereof.

[0068] The processing circuit 100 may, collectively or individually, be embodied as circuitry that forms part of a larger system, for example, an integrated circuit (IC), an application-specific integrated circuit (ASIC), a system on-chip (SoC), desktop computers, laptop computers, tablet computers, servers, smart phones, etc. Accordingly, the processing circuit 100 may include, but is not limited to, electrical circuitry having at least one discrete electrical circuit, electrical circuitry having at least one integrated circuit, electrical circuitry having at least one application specific integrated circuit, electrical circuitry forming a general purpose computing device configured by a computer program (e.g., a general purpose computer configured by a computer program which at least partially carries out processes and/or devices described herein, or a microprocessor configured by a computer program which at least partially carries out processes and/or devices described herein), electrical circuitry forming a memory device (e.g., forms of random access memory), and/or electrical circuitry forming a communications device (e.g., a modem, communications switch, or optical-electrical equipment). Those having skill in the art will recognize that the subject matter described herein may be implemented in an analog or digital fashion or some combination thereof.

[0069] The memory circuit 102 is coupled to the processing circuit 100 and may include more than one type of memory. For example, according to various aspects, the memory circuit 102 may include volatile memory and non-volatile memory. The volatile

memory can include random access memory (RAM), which can act as external cache memory. According to various aspects, the random access memory can be static random access memory (SRAM), dynamic random access memory (DRAM), synchronous dynamic random access memory (SDRAM), double data rate synchronous dynamic random access memory (DDR SDRAM), enhanced synchronous dynamic random access memory (ESDRAM), Synchlink dynamic random access memory (SLDRAM), direct Rambus random access memory (DRRAM) and the like. The non-volatile memory can include read-only memory (ROM), programmable read-only memory (PROM), electrically programmable read-only memory, electrically erasable programmable read-only memory (EEPROM), flash memory and the like.

[0070] According to various aspects, the memory circuit 102 can also include removable/non-removable, volatile/non-volatile storage media, such as for example disk storage. The disk storage can include, but is not limited to, devices like a magnetic disk drive, a floppy disk drive, a tape drive, a Jaz drive, a Zip drive, a LS-60 drive, a flash memory card, or a memory stick. In addition, the disk storage can include storage media separately or in combination with other storage media including, but not limited to, an optical disc drive such as a compact disc ROM device (CD-ROM), a compact disc recordable drive (CD-R Drive), a compact disc rewritable drive (CD-RW Drive), a digital versatile disc ROM drive (DVD-ROM) and the like. Although only one processing circuit 100 and one memory circuit 102 are shown in FIG. 6, it will be appreciated that the control circuit 80 may include any number of these components.

[0071] The wireless communication module 104 is configured to enable communication between the control circuit 80 and the temperature measuring devices 82, the humidity measuring devices 84, the pressure measuring devices 86, the concentration measuring devices 88 and the fluid level measuring devices 90 via the network 92, where the communications between the wireless communications module 104 and the network 92 are

wireless communications. The wireless communication module 104 is also configured to enable communication between the control circuit 80 and the heat-to-mass extractor 14 and the mass-to-heat converter 16 via the network 92. For such aspects, the heat-to-mass extractor 14 and the mass-to-heat converter 16 may each include one or more wireless communication modules (not shown) which are similar or identical to the wireless communications module 104, and the communications between the wireless communications module 104 and the one or more wireless communication modules of the heat-to-mass extractor 14 and the mass-to-heat converter 16 via the network 92 are wireless communications.

[0072] The wireless communication module 104 can employ any suitable wireless communication technology. For example, according to various aspects, the wireless communication module 104 can employ, Bluetooth, Z-Wave, Thread, ZigBee, and the like.

[0073] Similarly, the wireless communication module 104 can employ any one of a number of wireless communication standards or protocols, including but not limited to Wi-Fi (IEEE 802.11 family), WPA2, WPA3, WiMAX (IEEE 802.16 family), IEEE 802.20, long-term evolution (LTE), and Ev-DO, HSPA+, HSDPA+, HSUPA+, EDGE, GSM, GPRS, CDMA, TDMA, DECT, and

[0074] Ethernet derivatives thereof, as well as any other wireless protocols that are designated as 3G, 4G, 5G, and beyond.

[0075] The temperature-humidity module 106 is configured to determine, based on the signals communicated by the temperature measuring devices 82, the humidity measuring devices 84, the pressure measuring devices 86, the concentration measuring devices 88 and/or the fluid level measuring devices 90, when to energize the fans 32, 46, 68, when to energize the pumps 28, 40, 64, when to introduce the low grade heat into the regenerator 22, and when to introduce water 70 into the mass-to-heat converter 16. According

to various aspects, the temperature-humidity module 106 executes an algorithm which analyzes the signals communicated by the temperature measuring devices 82, the humidity measuring devices 84, the pressure measuring devices 86, the concentration measuring devices 88 and/or the fluid level measuring devices 90, determines which actions to take, and communicates control signals to the applicable fans 32, 46, 68, pumps 28, 40, 64 and/or valves associated with the introduction of the low grade heat into the regenerator 22, and the introduction of the water 70 into the mass-to-heat converter 16. For example, if the humidity of the air in the conditioned space 12 is below a predetermined value, the control system 18 may communicate a control signal to have water added to the mass-to-heat converter 16. On the other hand, if the humidity of the air in the conditioned space 12 is above a predetermined value, the control system 18 may communicate one or more control signals to the heat-to-mass extractor 14 to operate to extract moisture from the air in the conditioned space 12. If the temperature of the air in the conditioned space 12 is above a predetermined value, the control system 18 may communicate one or more control signals to the mass-to-heat converter 16 to operate until the temperature reaches the predetermined value.

[0076] According to various aspects, the temperature-humidity module 106 may utilize a look-up table setting forth the specific action to be taken (e.g., energize the fan 32 vs. do not energize the fan 32, et.) for various combinations of measured temperatures, humidities, pressures, concentrations and/or fluid levels.

[0077] The modules 104 and 106 may be implemented in hardware, firmware, software and in any combination thereof. Software aspects may utilize any suitable computer language (e.g., C, C++, Java, JavaScript, Python, etc.) and may be embodied permanently or temporarily in any type of machine, component, physical or virtual equipment, storage medium, or propagated signal capable of delivering instructions to a device. The modules 104 and 106 may be stored on a computer-readable medium (e.g., disk, device, and/or propagated signal) such that when a computer reads the medium, the functions described herein are

performed. The above-described functionality of the modules 104 and 106 may be combined into fewer modules, distributed differently amongst the modules, spread over additional modules, etc.

[0078] In view of the above, it will be appreciated that the compressorless air conditioning system 10 utilizes two independent “systems” (which are not physically connected to or coupled with one another) to control the humidity and the temperature of the air in the conditioned space 12, namely the heat-to-mass extractor 14 and the mass-to-heat converter 16. Though not physically connected, the heat-to-mass extractor 14 and the mass-to-heat converter 16 operate in tandem and synergistically to control humidity and temperature of the air in the conditioned space 12 without requiring a compressor or refrigerants due, in large part, to the flow of heat and mass within the conditioned space 12. Stated differently, while the heat-to-mass extractor 14 and the mass-to-heat converter 16 are independent systems, the air in the conditioned space 12 acts as a medium which bridges the two systems together.

[0079] Referring again to FIG. 1, the collector 20 of the heat-to-mass extractor 14 takes in air A1 from the conditioned space 12 and extracts mass (humidity) from the air A1 in the manner as generally described hereinabove. The air A2 exiting the collector 20 of the heat-to-mass extractor 14 is at a lower humidity than the rest of the air in the conditioned space 12. The air A2 exiting the collector 20 of the heat-to-mass extractor 14 mixes with the rest of the air in the conditioned space 12, thereby lowering the humidity of the air in the conditioned space 12 without increasing the temperature of the air in the conditioned space 12. Either before, after or concurrently therewith, the mass-to-heat converter 16 takes in air B1 from the conditioned space 12 and “cools” the air B1 in the manner as generally described hereinabove. The air B2 exiting the mass-to-heat converter 16 is at a lower temperature than the rest of the air in the conditioned space 12. The air B2 exiting the mass-to-heat converter 16 mixes with the rest of the air in the conditioned space 12, thereby lowering the temperature

of the air within the conditioned space. In general, the heat-to-mass extractor 14 can lower the humidity of the air in the conditioned space 12 more quickly than the mass-to-heat converter 16 can lower the temperature of the air within the conditioned space 12.

[0080] Although the heat-to-mass extractor 14 and the mass-to-heat converter 16 are physically separated and unconnected from one another, they are bridged together by the air in the conditioned space 12, and they cooperate to control the humidity and the temperature of the air within the conditioned space 12.

[0081] In one example, on a call for cooling the conditioned space 12, the mass-to-heat converter 16 draws air B1 from the conditioned space 12 (e.g. with fan 68 in FIG. 5). Heat in the air B1 is absorbed (e.g. by water 70 in FIG. 5), thereby lowering the temperature of the air B1. The temperature of the air B2 exiting the mass-to-heat converter 16 is lower than the temperature of the rest of the air in the conditioned space 12. The lower temperature air B2 mixes with the rest of the air in the conditioned space 12, thereby cooling the air in the conditioned space 12. Either before, after or concurrently therewith, the collector 20 of the heat-to-mass extractor 14 draws air A1 from the conditioned space 12 (e.g. with fan 32 in FIG. 2) and utilizes the liquid desiccant 24a to extract moisture from the air A1. The air A2 exiting the collector 20 is at a lower humidity than the rest of the air in the conditioned space 12. The air A2 exiting the collector 20 mixes with the rest of the air in the conditioned space 12, thereby lowering the humidity of the air within the conditioned space 12 without increasing the temperature of the air within the conditioned space 12. As described hereinabove, the liquid dessicant 24a of the collector 20 seeks to achieve equilibrium with the liquid dessicant 24b of the regenerator 22, and the regenerator 22 operates to regenerate the liquid desiccant 24b. The collector 20 and the regenerator 22 are fluidically coupled by the liquid desiccant 24 (e.g. openings 48, 50 in sumps 26, 38, respectively, in FIG. 4A), which seeks to achieve equilibrium via diffusion therebetween. In the foregoing example, the mass-to-heat converter 16 and the heat-to-mass extractor 14 cooperate to reduce the temperature

and humidity of the air in the conditioned space 12. Because mass and heat flow relatively quickly in the conditioned space 12, the heat- to-mass extractor 14 and the mass-to-heat converter 16 can efficiently dehumidify and cool the air of the conditioned space 12 without a compressor/refrigerant and without any ductwork for funneling or otherwise directing the conditioned air throughout the conditioned space 12.

[0082] In other instances, the system 10 can be used in reverse so that the system 10 functions as a heating unit. For example, when the ambient/outside air is cooler than the air in the conditioned space 12, the mass-to-heat extractor 14 can be reversed to extract moisture from cooler ambient/outside air to humidify the conditioned space 12. A heating element (e.g. heating coil) can be added to the mass-to-heat converter 16 to increase the temperature of the air drawn through the mass-to-heat converter 16 in the conditioned space 12. According to various aspects, the heating element can be provided with heat from a solar heating system or a geothermal heating system. In various instances, a heating element can be added to each mass-to-heat converter 16 in the system 10. The heating element can be utilized in conjunction with the “evaporative cooling” provided by the water and/or a lower concentration liquid desiccant in a “reheat” application, or as a heating-only application without the “evaporative cooling” provided by the water and/or lower concentration liquid desiccant. For example, de-energizing the pump that controls the flow of the water and/or lower concentration liquid desiccant in the mass-to-heat converter 16 can prevent any “cooling effect” from being introduced to the indoor air, for example.

[0083] In lieu of a control system 18 as described above, according to other aspects, the control system 18 may simply include a control device (e.g., a thermostat) which is associated with the mass-to-heat converter 16 and is utilized to control the temperature of the air in the conditioned space 12, and a control device (e.g., a humidistat) which is associated with the heat-to-mass extractor 14 and is utilized to control the humidity of the air in the conditioned space 12. For purposes of simplicity, the two control devices

will hereinafter be referred to as the thermostat and the humidistat. For such aspects, the thermostat may be positioned on the mass-to-heat converter 16 and operates to control the mass-to-heat converter 16 (its fan 68, pump 64, etc.) in a manner which controls the temperature of the air in the conditioned space 12.

[0084] Similarly, the humidistat may be positioned on the heat-to-mass extractor 14 and operates to control the heat-to-mass extractor 14 (its fan 32, pump 28, etc.) in a manner which controls the humidity of the air in the conditioned space 12. Therefore, in contrast to the control system 18 as shown in FIG. 6, where the “centralized” control circuit 80 utilizes the collective signals from the temperature measuring device 82 and the humidity measuring device 84 (and potentially from the pressure measuring device 86, the concentration measuring device 88 and/or the fluid level measuring device 90) to determine which specific actions to take regarding the control of both the heat-to-mass extractor 14 and the mass-to-heat converter 16, for these aspects, the control of the mass-to-heat converter 16 is dependent on the thermostat and is independent of the control of the heat-to-mass extractor 14. Similarly, the control of the heat-to-mass extractor 14 is dependent on the humidistat and is independent of the control of the mass-to-heat converter 16.

[0085] For instances of these aspects which include more than one mass-to-heat converter 16 and/or more than one heat-to-mass extractor 14, the control system 18 includes a separate and independent thermostat for each mass-to-heat converter 16 and a separate and independent humidistat for each heat-to-mass extractor 14.

EXAMPLES

[0086] Example 1 - A compressorless air conditioning system is provided. The compressorless air conditioning system comprises a heat-to-mass extractor, a mass-to-heat converter and a control system. The heat-to-mass extractor is configured to extract moisture from air in a conditioned space without increasing the temperature of the air, and comprises

a liquid desiccant, a collector, and a regenerator. The regenerator and the collector are fluidically coupled via the liquid desiccant. The mass-to-heat converter is configured to reduce a temperature of the air in the conditioned space via evaporation of water, and is physically disconnected from the heat-to-mass extractor. The control system is communicably coupled to the heat-to-mass extractor and the mass-to-heat converter.

[0087] Example 2 - The compressorless air conditioning system of Example 1, wherein the control system is wirelessly coupled with the heat-to-mass extractor and the mass-to-heat converter.

[0088] Example 3 - The compressorless air conditioning system of Examples 1 or 2, wherein the compressorless air conditioning system comprises a ductless air conditioning system.

[0089] Example 4 - The compressorless air conditioning system of Examples 1, 2 or 3, wherein the liquid desiccant is configured to purify air in the conditioned space.

[0090] Example 5 - The compressorless air conditioning system of Examples 1, 2, 3 or 4, further comprising a plurality of heat-to-mass extractors.

[0091] Example 6 - The compressorless air conditioning system of Examples 1, 2, 3, 4 or 5, further comprising a plurality of mass-to-heat converters.

[0092] Example 7 - A compressorless air conditioning system is provided. The compressorless air conditioning system comprises a heat-to-mass extractor, a mass-to-heat converter and a control system. The heat-to-mass extractor is configured to utilize a liquid desiccant to control humidity in a conditioned space, wherein the heat-to-mass extractor utilizes low grade heat as a source of energy. The mass-to-heat converter is configured to utilize water to control temperature in the conditioned space. The control system is communicably coupled to the heat-to-mass extractor and the mass-to-heat converter.

[0093] Example 8 - The compressorless air conditioning system of Example 7, wherein the low grade heat is associated with one of the following: a solar thermal

collector, an industrial process, a geothermal system, and a hot water system.

[0094] Example 9 - The compressorless air conditioning system of Examples 7 or 8, wherein the mass-to-heat converter is physically disconnected from the heat-to-mass extractor.

[0095] Example 10 - The compressorless air conditioning system of Examples 7, 8 or 9, wherein the compressorless air conditioning system is a ductless air conditioning system.

[0096] Example 11 - The compressorless air conditioning system of Examples 7, 8, 9 or 10, wherein the liquid desiccant is configured to purify air in the conditioned space.

[0097] Example 12 - The compressorless air conditioning system of Examples 7, 8, 9, 10 or 11, , further comprising a plurality of heat-to-mass extractors.

[0098] Example 13 - The compressorless air conditioning system of Examples 7, 8, 9, 10, 11 or 12, , further comprising a plurality of mass-to-heat converters.

[0099] Example 14 - A compressorless air conditioning system is provided. The compressorless air conditioning system comprises a heat-to-mass extractor, a mass-to-heat converter and a control system. The heat-to-mass extractor is configured to utilize a liquid desiccant to purify air in a conditioned space. The mass-to-heat converter is configured to reduce a temperature of the air in the conditioned space via evaporation of water, and is physically disconnected from the heat-to-mass extractor. The control system is wirelessly coupled with the heat-to-mass extractor and the mass-to-heat converter.

[0100] Example 15 - The compressorless air conditioning system of Example 14, wherein the liquid desiccant comprises a first liquid desiccant at a first concentration, wherein the mass-to-heat converter comprises a second liquid desiccant at a second concentration to further purify air in the conditioned space, and wherein the second concentration is less than the first concentration.

[0101] Example 16 - The compressorless air conditioning system of Examples 14 or 15, further comprising a plurality of heat-to-mass extractors.

[0102] Example 17 - The compressorless air conditioning system of Examples 14, 15 or 16, further comprising a plurality of mass-to-heat converters.

[0103] Example 18 - A compressorless air conditioning system is provided. The compressorless air conditioning system comprises a heat-to-mass extractor, a mass-to-heat converter and a control system. The heat-to-mass extractor is configured to utilize a liquid desiccant to extract moisture from air in a conditioned space. The mass-to-heat converter is configured to utilize water to reduce a temperature of the air in the conditioned space. The control system comprises a humidistat coupled to the heat-to-mass extractor and a thermostat coupled to the mass-to-heat converter, wherein the compressorless air conditioning system is a ductless air conditioning system.

[0104] Example 19 - The compressorless air conditioning system of Example 18, wherein the heat-to-mass extractor and the mass-to-heat converter are physically uncoupled.

[0105] Example 20 - The compressorless air conditioning system of Examples 18 or 19, wherein (1) air output from the mass-to-heat converter mixes with air in the conditioned space and (2) air output from the heat-to-mass extractor mixes with the air in the conditioned space.

[0106] Example 21 - The compressorless air conditioning system of Examples 18, 19 or 20, further comprising a plurality of heat-to-mass extractors.

[0107] Example 22 - The compressorless air conditioning system of Examples 18, 19, 20 or 21, further comprising a plurality of mass-to-heat converters.

[0108] Example 23 - An air conditioning system is provided. The air conditioning system comprises an extractor, a converter and a control system. The extractor is configured to move moisture between a conditioned space and an external space and

comprises a liquid desiccant, a collector and a regenerator. The regenerator comprises a compressor and is fluidically coupled with the collector via the liquid desiccant. The converter is positioned in the conditioned space and is physically disconnected from the extractor. The control system is communicably coupled with the extractor and the converter.

[0109] Example 24 - The air conditioning system of Example 23, wherein the regenerator further comprises a heat exchanger coupled with the compressor.

[0110] Example 25 - The air conditioning system of Examples 23 or 24, wherein the compressor is thermally coupled with the liquid desiccant.

[0111] Example 26 - The air conditioning system of Examples 23, 24, or 25, wherein the converter is configured for evaporative cooling, the converter comprising: media; a sump configured to hold water; a pump configured to pump the water from the sump to the media, wherein the water flows over the media and returns to the sump; a compartment configured to hold air, wherein the compartment comprises an inlet and an outlet; a fan configured to draw air from the conditioned space into the compartment through the inlet and force air out of the compartment to the conditioned space through the outlet; means for chlorinating the water; and a carbon filter positioned to collect chlorine from the air moving through the outlet.

[0112] Example 27 - The air conditioning system of Examples 26, wherein the means for chlorinating water comprises an electrolyzer.

[0113] Example 28 - An air conditioning system, comprising: a regenerator positioned in an external environment; a split collector spanning a conditioned environment and the external environment; a first sump associated with the split collector and at least partially positioned in the conditioned environment; a second sump associated with the regenerator and positioned in the external environment; liquid desiccant; and a plurality of separate and discrete tubes extending between the first sump and the second sump, wherein the plurality of tubes comprises: a supply tube; a return tube; and a balancing tube

configured to equalize fluid levels between the first sump and the second sump.

[0114] Example 29 - A water evaporator, comprising: media; a sump configured to hold water; a pump configured to pump the water from the sump to the media, wherein the water flows over the media and returns to the sump; a fan configured to force air across the media; means for chlorinating the water; and a carbon filter positioned to collect chlorine from air after the air is forced across the media.

[0115] Example 30 - The water evaporator of Example 29, wherein the means for chlorinating the water comprises an electrolyzer.

[0116] Although the various aspects of the compressorless air conditioning system 10 have been described herein in connection with certain disclosed aspects, many modifications and variations to those aspects may be implemented. Also, where materials are disclosed for certain components, other materials may be used in certain instances. Furthermore, according to various aspects, a single component may be replaced by multiple components, and multiple components may be replaced by a single component, to perform a given function or functions. The foregoing description and the appended claims are intended to cover all such modifications and variations as falling within the scope of the disclosed aspects.

[0117] While this invention has been described as having exemplary designs, the described invention may be further modified within the spirit and scope of the disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles.

[0118] Any patent, patent application, publication, or other disclosure material, in whole or in part, that is said to be incorporated by reference herein is incorporated herein only to the extent that the incorporated materials does not conflict with existing definitions, statements, or other disclosure material set forth in this disclosure. As such, and to the extent necessary, the disclosure as explicitly set forth herein supersedes any conflicting material

incorporated herein by reference. Any material, or portion thereof, that is said to be incorporated by reference herein, but which conflicts with existing definitions, statements, or other disclosure material set forth herein will only be incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material.

CLAIMS

What is claimed is:

1. A compressorless air conditioning system, comprising:
a heat-to-mass extractor configured to extract moisture from air in a conditioned space without increasing the temperature of the air, the heat-to-mass extractor comprising:
a liquid
desiccant; a
collector; and
a regenerator, wherein the regenerator and the collector are fluidically coupled via the liquid desiccant;
a mass-to-heat converter configured to reduce a temperature of the air in the conditioned space via evaporation of water, wherein the mass-to-heat converter is physically disconnected from the heat-to-mass extractor; and
a control system communicably coupled with the heat-to-mass extractor and the mass-to- heat converter.
2. The compressorless air conditioning system of Claim 1, wherein the control system is wirelessly coupled with the heat-to-mass extractor and the mass-to-heat converter.
3. The compressorless air conditioning system of Claim 1, wherein the compressorless air conditioning system comprises a ductless air conditioning system.
4. The compressorless air conditioning system of Claim 1, wherein the liquid desiccant is configured to purify air in the conditioned space.

5. The compressorless air conditioning system of Claim 1, further comprising a plurality of heat-to-mass extractors.

6. The compressorless air conditioning system of Claim 1, further comprising a plurality of mass-to-heat converters.

7. A compressorless air conditioning system, comprising:
a heat-to-mass extractor configured to utilize a liquid desiccant to control humidity in a conditioned space, wherein the heat-to-mass extractor utilizes low grade heat as a source of energy;
a mass-to-heat converter configured to utilize water to control temperature in the conditioned space; and
a control system communicably coupled with the heat-to-mass extractor and the mass-to- heat converter.

8. The compressorless air conditioning system of Claim 7, wherein the low grade heat is associated with one of the following:

a solar thermal
collector; an
industrial process;
a geothermal system;
and a hot water
system.

9. The compressorless air conditioning system of Claim 7, wherein the mass-to-heat converter is physically disconnected from the heat-to-mass extractor.

10. The compressorless air conditioning system of Claim 7, wherein the compressorless air conditioning system is a ductless air conditioning system.

11. The compressorless air conditioning system of Claim 7, wherein the liquid desiccant is configured to purify air in the conditioned space.

12. The compressorless air conditioning system of Claim 7, further comprising a plurality of heat-to-mass extractors.

13. The compressorless air conditioning system of Claim 7, further comprising a plurality of mass-to-heat converters.

14. A compressorless air conditioning system, comprising:
a heat-to-mass extractor configured to utilize a liquid desiccant to purify air in a conditioned space;
a mass-to-heat converter configured to reduce a temperature of the air in the conditioned space via evaporation of water, wherein the mass-to-heat converter is physically disconnected from the heat-to-mass extractor; and
a control system wirelessly coupled with the heat-to-mass extractor and the mass-to-heat converter.

15. The compressorless air conditioning system of Claim 14, wherein the liquid desiccant comprises a first liquid desiccant at a first concentration, wherein the mass-to-heat converter comprises a second liquid desiccant at a second concentration to further purify air in the conditioned space, and wherein the second concentration is less than the first concentration.

16. The compressorless air conditioning system of Claim 14, further comprising a plurality of heat-to-mass extractors.

17. The compressorless air conditioning system of Claim 14, further comprising a plurality of mass-to-heat converters.

18. A compressorless air conditioning system, comprising:
a heat-to-mass extractor configured to utilize a liquid desiccant to extract moisture from air in a conditioned space;
a mass-to-heat converter configured to utilize water to reduce a temperature of the air in the conditioned space; and
a control system comprising:
a humidistat coupled to the heat-to-mass extractor; and
a thermostat coupled to the mass-to-heat converter, wherein the compressorless air conditioning system is a ductless air conditioning system.

19. The compressorless air conditioning system of Claim 18, wherein the heat-to-mass extractor and the mass-to-heat converter are physically uncoupled.

20. The compressorless air conditioning system of Claim 18, wherein:

air output from the mass-to-heat converter mixes with air in the conditioned space;
and air output from the heat-to-mass extractor mixes with the air in the conditioned space.

21. The compressorless air conditioning system of Claim 18, further comprising a plurality of heat-to-mass extractors.

22. The compressorless air conditioning system of Claim 18, further comprising a plurality of mass-to-heat converters.

23. An air conditioning system, comprising:
an extractor configured to move moisture between a conditioned space and an external space, the extractor comprising:
a liquid
desiccant; a
collector; and
a regenerator, wherein the regenerator comprises a compressor, and wherein the regenerator and the collector are fluidically coupled via the liquid desiccant;
a converter positioned in the conditioned space and physically disconnected from the extractor; and
a control system communicably coupled with the extractor and the converter.

24. The air conditioning system of Claim 23, wherein the regenerator further comprises a heat exchanger coupled with the compressor.

25. The air conditioning system of Claim 23, wherein the compressor is

thermally coupled with the liquid desiccant.

26. The air conditioning system of Claim 23, wherein the converter is configured for evaporative cooling, the converter comprising:

media;

a sump configured to hold water;

a pump configured to pump the water from the sump to the media, wherein the water flows over the media and returns to the sump;

a compartment configured to hold air, wherein the compartment comprises an inlet and an outlet;

a fan configured to draw air from the conditioned space into the compartment through the inlet and force air out of the compartment to the conditioned space through the outlet;

means for chlorinating the water; and

a carbon filter positioned to collect chlorine from the air moving through the outlet.

27. The air conditioning system of Claim 26, wherein the means for chlorinating water comprises an electrolyzer.

28. An air conditioning system, comprising:

a regenerator positioned in an external environment;

a split collector spanning a conditioned environment and the external environment;

a first sump associated with the split collector and at least partially positioned in the conditioned environment;

a second sump associated with the regenerator and positioned in the external environment;

liquid desiccant; and

a plurality of separate and discrete tubes extending between the first sump and the second sump, wherein the plurality of tubes comprises:

a supply tube;

a return tube; and

a balancing tube configured to equalize fluid levels between the first sump and the second sump.

29. A water evaporator, comprising:

media;

a sump configured to hold water;

a pump configured to pump the water from the sump to the media, wherein the water flows over the media and returns to the sump;

a fan configured to force air across the media;

means for chlorinating the water; and

a carbon filter positioned to collect chlorine from air after the air is forced across the media.

30. The water evaporator of Claim 29, wherein the means for chlorinating the water comprises an electrolyzer.