An energy exchange system is configured to provide dry supply air to an enclosed structure. The system may include an energy transfer device having a first portion configured to be disposed within a supply air flow path and a second portion configured to be disposed within a regeneration air flow path. The energy transfer device is configured to decrease a humidity level of supply air. The energy transfer device is configured to be regenerated with regeneration air. The system may also include a first heat exchanger configured to be disposed within the supply air flow path downstream from the energy transfer device and within the regeneration air flow path upstream from the second portion of the energy transfer device. The first heat exchanger is configured to transfer sensible energy between the supply air and the regeneration air. The supply air is configured to be supplied to the enclosed structure after passing through the energy transfer device and the first heat exchanger.
FIG. 13

Reduce humidity of supply air with energy transfer device

Transfer sensible energy between the supply air and conditioning air with a heat exchanger

Regenerate energy transfer device with conditioning air

Supply reduced humidity supply air to an enclosed structure

Exhaust conditioning air to atmosphere

FIG. 14
SYSTEM AND METHOD FOR PROVIDING CONDITIONED AIR TO AN ENCLOSED STRUCTURE

BACKGROUND OF THE DISCLOSURE

[0001] Embodiments of the present disclosure generally relate to a system and method for providing conditioned air to an enclosed structure, and more particularly, relate to an energy exchange system and method configured to provide conditioned air to a commodities storage structure, such as a grain silo or bin, for example.

[0002] Enclosed structures, such as occupied buildings, factories, and animal barns, typically include a heating/ventilation/air conditioning (HVAC) system that is configured to condition ventilated and/or recirculated air in the structure. The HVAC system includes a supply path and a return and/or exhaust path. The supply path receives air, for example outside or ambient air, re-circulated air, or outside or ambient air mixed with re-circulated air, and channels and distributes the air into the enclosed structure. The air is conditioned by the HVAC system to provide a desired temperature and humidity of supply air discharged into the enclosed structure. The exhaust path discharges air back to the environment outside the structure. Without energy recovery, conditioning the supply air typically requires a significant amount of auxiliary energy. This is especially true in environments having extreme outside air conditions that are much different than the required supply air temperature and humidity. Accordingly, energy exchange or recovery systems are typically used to recover energy from the exhaust path. Energy recovered from air in the exhaust path is utilized to reduce the energy required to condition the supply air.

[0003] A commodities storage or depository structure, such as a silo or bin that holds wheat, rice, corn, or the like is another example of an enclosed structure in which it is desirable to maintain certain temperature and humidity levels. When commodities, such as cotton, coffee, or grain (such as wheat, corn, rice, or the like) are harvested, individuals such as farmers generally closely monitor the moisture content of the commodities. If grain, that is too moist, is stored in a grain silo or bin, the grain may spoil. Therefore, if the moisture level of the grain is too high, farmers typically wait for the grain to further ripen before harvesting the grain.

[0004] Certain methods have been developed, however, that allow for grain having relatively high moisture levels not to be harvested and stored. As the grain spoils, the grain generates heat and carbon dioxide. In some silos and bins, sensors are used to detect the generated heat and carbon dioxide levels, thereby alerting an individual that the grain should be removed from the bin before additional spoiling occurs.

[0005] Additionally, air blowers or fans have been used to dry the grain within the silos or bins. Typically, an air blower channels outdoor air into the bottom of the silo or bin. The channelled outdoor air cools the grain and generally removes moisture from the silo or bin. However, systems that utilize air blowers typically take several days, weeks, or even months to adequately dry a bin full of grain, depending on the moisture content of the outdoor air. Moreover, a great deal of energy may be used to run the air blowers or fans over such long periods. Accordingly, the cost of energy, whether in the form of electricity, diesel fuel, or the like, used to power the air blowers or fans may be a major expense.

[0006] As an alternative to air blower or fan systems, a natural gas or propane fired tower dryer may be used to dry grain within a silo or bin. In a tower dryer system, air is heated using a gas burner. The heated air is blown through a tower, which typically receives grain at a top portion and allows the grain to fall downward toward a base. The tower dryer system may dry grain faster than an air blower or fan system, but the tower dryer system typically requires an individual to continuously move grain from bins to the tower device. Additionally, a typical tower dryer system consumes a relatively large amount of energy, both in terms of the continuous movement of grain from bin(s) to tower, as well operation of the gas-fired burner.

[0007] Also, in a tower dryer system, in order to adequately dry grain, the air temperature is typically heated between 140°F to 175°F. A hotter temperature generally allows for quicker drying of the grain. However, if the grain is not continuously moved through the tower, the heat may partially or fully cook protein inside kernels of the grain, thereby reducing the nutritional value of the grain. Further, some crops, such as mustard, generally require even lower heating temperatures, such as below 115°F. Accordingly, the tower dryer system and method may generate temperatures that are too high for certain crops and grains.

[0008] Therefore, currently-known systems and methods may inefficiently and detrimentally dry grain within a silo or bin. For example, air blowers or fans may dry grain by using a relatively large amount of energy over a relatively long period of time. Tower dryer systems typically require individuals to continually transfer grain between bins or silos and a tower. Further, tower dryer systems may overheat the grain, thereby reducing its nutritional value.

SUMMARY OF EMBODIMENTS OF THE DISCLOSURE

[0009] Certain embodiments of the present disclosure provide an energy exchange system configured to provide supply air to an enclosed structure. The system may include an energy transfer device having a first portion configured to be disposed within a supply air flow path and a second portion configured to be disposed within a regeneration airflow path. The energy transfer device may be configured to decrease a humidity level of the supply air. The energy transfer device is configured to be regenerated with regeneration air. The system may also include a first heat exchanger configured to be disposed within the supply air flow path downstream from the energy transfer device and within the regeneration air flow path upstream from the second portion of the energy transfer device. The first heat exchanger is configured to transfer sensible energy between the supply air and the regeneration air. The energy exchange system is configured to supply the supply air to the enclosed structure after the supply air passes through the energy transfer device and the first heat exchanger.

[0010] The enclosed structure may include a grain bin that for retaining grain. The energy exchange system is configured to provide the supply air to the grain bin in order to dry grain.

[0011] The system may also include one or more bypass ducts configured to be disposed within one or both of the supply air flow path or the regeneration air flow path. The bypass duct(s) are configured to bypass at least a portion of one or both of the supply air and the regeneration air around the energy transfer device.

[0012] The system may also include a heater configured to be disposed within a portion of the regeneration airflow path upstream from the energy exchange device. The heater is
configured to heat the regeneration air before it encounters the energy exchange device. The system may also include a heater configured to be positioned within the supply air flow path downstream from the first heat exchanger. [0013] The energy transfer device may include a desiccant wheel. Optionally, the energy transfer device may include a supply liquid-to-air membrane energy exchanger (LAMEE) configured to be positioned within the supply air flow path, and a regeneration LAMEE configured to be positioned within the regeneration air flow path.

[0014] The system may also include a housing that contains the energy transfer device and the first heat exchanger. A wheeled base may be connected to the housing. The wheeled base is configured to provide a mobile energy exchange system. The housing may be configured to be operatively connected to a plurality of enclosed structures. A duct may be configured to connect a regeneration air inlet to the regeneration air flow path to an air outlet of the enclosed structure.

[0015] The system may also include a second heat exchanger having a first portion that is configured to be disposed within the regeneration air flow path downstream from the first heat exchanger and a second portion that is configured to be disposed within a return air path. The second heat exchanger is configured to transfer sensible energy between the regeneration air and return air from an enclosed structure.

[0016] Certain embodiments of the present disclosure provide a method of providing supply air to an enclosed structure. The method may include decreasing a humidity level of supply air with an energy transfer device having a first portion disposed within a supply air flow path, transferring sensible energy between the supply air and regeneration air with a first heat exchanger that is within the supply air flow path downstream from the energy transfer device and within the regeneration air flow path upstream from the second portion of the energy transfer device, regenerating the energy transfer device with the regeneration air that passes through a second portion of the energy transfer device disposed within a regeneration air flow path, and supplying the supply air to the enclosed structure after the decreasing and transferring operations.

[0017] The enclosed structure may include a grain bin that retains grain. The method may also include drying the grain within the grain bin with the supply air that is supplied to the grain bin.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0018] FIG. 1 illustrates a simplified schematic view of an energy exchange system connected to an enclosed structure, according to an embodiment of the present disclosure.

[0019] FIG. 2 illustrates a schematic view of an energy transfer device, according to an embodiment of the present disclosure.

[0020] FIG. 3 illustrates a perspective view of a damper, according to an embodiment of the present disclosure.

[0021] FIG. 4 illustrates a simplified perspective view of a plate heat exchanger, according to an embodiment of the present disclosure.

[0022] FIG. 5 illustrates a psychrometric chart with respect to an energy exchange system, according to an embodiment of the present disclosure.

[0023] FIG. 6 illustrates a simplified schematic view of an energy exchange system connected to an enclosed structure, according to an embodiment of the present disclosure.

[0024] FIG. 7 illustrates a side perspective view of a liquid-to-air membrane energy exchanger, according to an embodiment of the present disclosure.

[0025] FIG. 8 illustrates a front view of panels within an energy exchange cavity of a liquid-to-air membrane energy exchanger, according to an embodiment of the present disclosure.

[0026] FIG. 9 illustrates a psychrometric chart with respect to an energy exchange system, according to an embodiment of the present disclosure.

[0027] FIG. 10 illustrates a lateral view of an energy exchange system operatively connected to a grain bin, according to an embodiment of the present disclosure.

[0028] FIG. 11 illustrates a simplified schematic view of an energy exchange system connected to an enclosed structure, according to an embodiment of the present disclosure.

[0029] FIG. 12 illustrates a psychrometric chart with respect to an energy exchange system, according to an embodiment of the present disclosure.

[0030] FIG. 13 illustrates a simplified overhead view of an energy exchange system operatively connected to a plurality of enclosures, according to an embodiment of the present disclosure.

[0031] FIG. 14 illustrates a flow chart of a method of providing conditioned air to an enclosed structure, according to an embodiment of the present disclosure.

**DETAILED DESCRIPTION OF THE DRAWINGS**

[0032] The foregoing summary, as well as the following detailed description of certain embodiments will be better understood when read in conjunction with the appended drawings. As used herein, an element or step recited in the singular and proceeded with the word “a” or “an” should be understood as not excluding plural of the elements or steps, unless such exclusion is explicitly stated. Furthermore, references to “one embodiment” are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Moreover, unless explicitly stated to the contrary, embodiments “comprising” or “having” an element or a plurality of elements having a particular property may include additional such elements not having that property.

[0033] FIG. 1 illustrates a simplified schematic view of an energy exchange system 100 operatively connected to an enclosed structure 102, according to an embodiment of the present disclosure. The energy exchange system 100 may include a housing 104, such as a self-contained module or unit that may be mobile (for example, the housing 104 may be moved among a plurality of enclosed structures), operatively connected to the enclosed structure 102, such as through a connection line 106, such as a duct, tube, pipe, conduit, plenum, or the like. The housing 104 may be configured to be removable connected to the enclosed structure 102. Alternatively, the housing 104 may be permanently secured to the enclosed structure 102. As an example, the housing 104 may be mounted to a roof, outer wall, or the like, of the enclosed structure 102. The enclosed structure 102 may be a room of a building, a commodities storage structure, or the like.

[0034] The housing 104 includes a supply air inlet 108 that connects to a supply air flow path 110. The supply air flow path 110 may be formed by ducts, conduits, plenum, channels, tubes, or the like, which may be formed by metal and/or plastic walls. The supply air flow path 110 is configured to
deliver supply air 112 to the enclosed structure 102 through a supply air outlet 114 that connects to the connection line 106.

The housing 104 also includes a regeneration air inlet 116 that connects to a regeneration air flow path 118. The regeneration air flow path 118 may be configured to channel regeneration air 120 received from the atmosphere (for example, outside air) back to the atmosphere through an exhaust air outlet 122.

As shown in FIG. 1, the supply air inlet 108 and the regeneration air inlet 116 may be at opposite ends of a linear column or row of ductwork. A separating wall 124 may separate the supply air flow path 110 from the regeneration air flow path 118 within the column or row. Similarly, the supply air outlet 114 and the exhaust air outlet 122 may be at opposite ends of a linear column or row of ductwork. A separating wall 126 may separate the supply air flow path 110 from the regeneration air flow path 118 within the column or row.

The supply air inlet 108 may be positioned above the exhaust air outlet 122, and the supply air flow path 110 may be separated from the regeneration air flow path 118 by a partition 128. Similarly, the regeneration air inlet 116 may be positioned above the supply air outlet 114, and the supply air flow path 110 may be separated from the regeneration air flow path 118 by a partition 130. Thus, the supply air flow path 110 and the regeneration air flow path 118 may cross one another proximate to a center of the housing 104. While the supply air inlet 108 may be at the top and left of the housing 104 (as shown in FIG. 1), the supply air outlet 114 may be at the bottom and right of the housing 104 (as shown in FIG. 1).

Further, while the regeneration air inlet 116 may be at the top and right of the housing 104 (as shown in FIG. 1), the exhaust air outlet 122 may be at the bottom and left of the housing 104 (as shown in FIG. 1).

Alternatively, the supply air flow path 110 and the regeneration air flow path 118 may be inverted and/or otherwise re-positioned. For example, the exhaust air outlet 122 may be positioned above the supply air inlet 108. Additionally, the exhaust air outlet 114 may be inverted and/or otherwise re-positioned. For example, the exhaust air outlet 122 may be positioned above the supply air inlet 108.

An energy transfer device 134 may be positioned within the supply air flow path 110 downstream from the supply air inlet 108. The energy transfer device 134 may span between the supply air flow path 110 and the regeneration air flow path 118. For example, a supply portion or side 135 of the energy transfer device 134 may be within the supply air flow path 110, while a regenerating portion or side 137 of the energy transfer device 134 may be within the regeneration air flow path 118. The energy transfer device 134 may be a desiccant wheel, for example. However, the energy transfer device 134 may be various other systems and assemblies, such as including liquid-to-air membrane energy exchangers (LAMEEs), as described below.

A heat exchanger 136 is disposed within the supply air flow path 110 downstream from the energy transfer device 134. The heat exchanger 136 may be a sensible heat exchanger and may be positioned at the junction of the separating walls 124, 126 and the partitions 128, 130. The heat exchanger 136 may be positioned within both the supply air flow path 110 and the regeneration air flow path 118. As such, the heat exchanger 136 is configured to transfer energy between the supply air 112 and the regeneration air 120. The heat exchanger 136 may include a flat plate, a sensible wheel, a heat pipe, a run-around glycol loop, and/or the like.

One or more fans 138 may be positioned within the supply air flow path 110 downstream from the heat exchanger 136. The fan(s) 138 is configured to move the supply air 112 from the supply air inlet 108 and out through the supply air outlet 114 (and ultimately into the enclosed structure 102). Alternatively, the fan(s) 138 may be located at various other areas of the supply air flow path 110, such as proximate to the supply air inlet 108. Also, alternatively, the energy exchange system 100 may not include the fan(s).

The energy exchange system 100 may also include a bypass duct 140 having an inlet end 142 upstream from the energy transfer device 134 within the supply air flow path 110. The inlet end 142 connects to an outlet end 144 that is downstream from the energy transfer device 134 within the supply air flow path 110. An inlet damper 146 may be positioned at the inlet end 142, while an outlet damper 148 may be positioned at the outlet end 144. The dampers 146 and 148 may be actuated between open and closed positions to provide a bypass line for the supply air 112 to bypass around the energy transfer device 134. Further, a damper 150 may be disposed within the supply air flow path 110 downstream from the inlet end 142 and from the energy transfer device 134. The damper 150 may be closed in order to allow the supply air 112 to flow into the bypass duct 140 around the energy transfer device 134. The dampers 146, 148, and 150 may be modulated between fully-open and fully-closed positions to allow a portion of the supply air 112 to pass through the energy transfer device 134 and a remaining portion of the supply air 112 to bypass the energy transfer device 134. As such, the bypass dampers 146, 148, and 150 may be operated to control the temperature and humidity of the supply air 112 as it is delivered to the enclosed structure 102. Examples of bypass ducts and dampers are further described in U.S. patent application Ser. No. 13/426,793, entitled “System and Method for Regeneration air In An Enclosed Structure,” which was filed Mar. 22, 2012, and is hereby incorporated by reference in its entirety. Alternatively, the energy exchange system 100 may not include the bypass duct 140 and dampers 146, 148, and 150.
As shown in FIG. 1, the supply air 112 enters the supply air flow path 110 through the supply air inlet 108. The supply air 112 is then channeled through the energy transfer device 134, which preconditions the supply air 112. After passing through the energy transfer device 134, the supply air 112 is pre-conditioned and passes through the heat exchanger 136, which conditions the pre-conditioned supply air 112. The fan(s) 138 may then move the supply air 112, which has been conditioned by the heat exchanger 136, through the heat exchanger 136 and into the enclosed structure 102 through the supply air outlet 114.

With respect to the regeneration air flow path 118, an air filter 152 may be disposed within the regeneration air flow path 118 proximate to the regeneration air inlet 116. The air filter 152 may be a standard HVAC filter configured to filter contaminants from the regeneration air 120. Alternatively, the energy exchange system 100 may not include the air filter 152.

The heat exchanger 136 is disposed within the regeneration air flow path 118 downstream from the air filter 152. As noted, the heat exchanger 136 may be a sensible heat exchanger and may be positioned at the junction of the separating walls 124, 126 and the partitions 128, 130. The heat exchanger 136 is positioned within both the supply air flow path 110 and the regeneration air flow path 118. As such, the heat exchanger 136 is configured to transfer sensible energy between the regeneration air 120 and the supply air 112.

A heater 154 may be disposed within the regeneration air flow path 118 downstream from the heat exchanger 136. The heater 154 may be a natural gas, propane, or electric heater that is configured to heat the regeneration air 120 before it encounters the energy transfer device 134. Optioned, the energy exchange system 100 may not include the heater 154.

The energy transfer device 134 is positioned within the regeneration air flow path 118 downstream from the heater 154. As noted, the energy transfer device 134 may span between the regeneration air flow path 118 and the supply air flow path 110.

As shown in FIG. 1, the supply side 135 of the energy transfer device 134 is disposed within the supply air flow path 110 proximate to the supply air inlet 108, while the regeneration side 137 of the energy transfer device 134 is disposed within the regeneration air flow path 110 proximate to the exhaust air outlet 122. Accordingly, the supply air 112 encounters the supply side 135 as the supply air 112 enters the supply air flow path 110 from the outside, while the regeneration air 120 encounters the regeneration side 137 just before the regeneration air 120 is exhausted out of the regeneration air flow path 118 through the exhaust air outlet 122.

One or more fans 156 may be positioned within the regeneration air flow path 118 downstream from the energy transfer device 134. The fan(s) 156 is configured to move the regeneration air 120 from the regeneration air inlet 116 and out through the exhaust air outlet 122 (and ultimately into the atmosphere). Alternatively, the fan(s) 156 may be located at various other areas of the regeneration air flow path 118, such as proximate to the regeneration air inlet 116. Also, alternatively, the energy exchange system 100 may not include the fan(s).

The energy exchange system 100 may also include a bypass duct 158 having an inlet end 160 upstream from the energy transfer device 134 within the regeneration air flow path 118. The inlet end 160 connects to an outlet end 162 that is downstream from the energy transfer device 134 within the regeneration air flow path 118. An inlet damper 164 may be positioned at the inlet end 160, while an outlet damper 166 may be positioned at the outlet end 162. The dampers 164 and 166 may be actuated between open and closed positions to provide a bypass line for the regeneration air 120 to flow around the energy transfer device 134. Further, a damper 168 may be disposed within the regeneration air flow path 118 downstream from the heat exchanger 136 and upstream from the energy transfer device 134. The damper 168 may be closed in order to allow the regeneration air to bypass into the bypass duct 158 around the energy transfer device 134. The dampers 164, 166, and 168 may be modulated between fully-open and fully-closed positions to allow a portion of the regeneration air 120 to pass through the energy transfer device 134 and a remaining portion of the regeneration air 120 to bypass the energy transfer device 134. Alternatively, the energy exchange system 100 may not include the bypass duct 158 and dampers 164, 166, and 168.

As shown in FIG. 1, the regeneration air 120 enters the regeneration air flow path 118 through the regeneration air inlet 116. The regeneration air 120 is then channeled through the heat exchanger 136. After passing through the heat exchanger 136, the regeneration air 120 passes through the heater 154, where it is heated, before encountering the energy transfer device 134. The fan(s) 156 may then move the regeneration air 120 through the energy transfer device 134 and into the atmosphere through the exhaust air outlet 122.

FIG. 2 illustrates a schematic view of an energy transfer device 212, according to an embodiment of the present disclosure. The energy transfer device 212 may be used as the energy transfer device 134, shown in FIG. 1. A portion of the energy transfer device 212 is disposed within a supply air flow path 206 (such as the supply air flow path 110 of FIG. 1) while another portion of the energy transfer device 212 is disposed within a regeneration air flow path 236 (such as the regeneration air flow path 118 of FIG. 1). The energy transfer device 212 is configured to transfer heat and/or moisture between the supply air flow path 206 and the regeneration air flow path 236. The energy transfer device 212 may be one or more of various types of energy transfer devices, such as, for example, an enthalpy wheel, a sensible wheel, a desiccant wheel, a plate heat exchanger, a plate energy (heat and moisture) exchanger, a heat pipe, a run-around loop, a passive or active run-around membrane energy exchanger (RAMEE), a liquid-to-air membrane energy exchanger (LAMEE), or the like. As shown in FIG. 2, the energy transfer device 212 may be an enthalpy or desiccant wheel.

An enthalpy wheel is a rotary air-to-air heat exchanger. As shown, supply air 208 within the supply air flow path 206 passes in a counter-flow direction with respect to regeneration air 234 within the regeneration air flow path 236. For example, the supply air 208 may flow through the lower half of the wheel, while the regeneration air 234 flows through the upper half of the wheel, or vice versa. The wheel may be formed of a heat-conducting material with a desiccant coating.

In general, the wheel may be filled with an air permeable material that provides a large surface area. The surface area is the medium for sensible energy transfer. As the wheel rotates between the supply and regeneration air flow paths 206 and 236, respectively, the wheel picks up heat energy and releases it into the colder air stream. Enthalpy exchange may be accomplished through the use of desiccants.
on an outer surface of the wheel. Desiccants transfer moisture through the process of adsorption, which is driven by the difference in the partial pressure of vapor within the opposing air streams.

[0056] Additionally, the rotational speed of the wheel also changes the amount of heat and moisture transferred. A slowly-turning desiccant coated wheel primarily transfers moisture. A faster turning desiccant coated wheel provides for both heat and moisture transfer.

[0057] Optionally, the energy transfer device 212 may be a sensible wheel, a dehumidification wheel, a plate exchanger, a heat pipe, a run-around apparatus, a refrigeration loop having a condenser and evaporator, a chilled water coil, or the like.

[0058] Alternatively, the energy transfer device 212 may be a flat plate exchanger. A flat plate exchanger is generally a fixed plate that has no moving parts. The exchanger may include alternating layers of plates that are separated and sealed. Because the plates are generally solid and non-permeable, only sensible energy is transferred. Optionally, the plates may be made from a selectively permeable material that allows for both sensible and latent energy transfer.

[0059] Also, the energy transfer device 212 may be a heat exchanger, such as shown and described in U.S. application Ser. No. 12/910,464 entitled “Heat Exchanger for an Equipment Rack,” filed Oct. 22, 2010, which is hereby incorporated by reference in its entirety.

[0060] Additionally, the energy transfer device 212 may be a run-around loop or coil. A run-around loop or coil includes two or more multi-row finned tube coils connected to each other by a pumped pipe network. The pipework is charged with a heat exchange fluid, typically water or glycol, which picks up heat from a conditioning coil and transfers the heat to a supply coil before returning again. Thus, heat from an exhaust air stream is transferred through the pipe network to the circulating fluid, and then from the fluid through the pipework to the supply air stream.

[0061] Also, alternatively, the energy transfer device 212 may be a heat pipe. A heat pipe is a thermal transfer device that includes one or more sealed pipes or tubes made of a material with a high thermal conductivity such as copper or aluminum at both hot and cold ends. A vacuum pump is used to remove all air from the empty heat pipe, and then the pipe is filled with a fraction of a percent by volume of a vaporizable liquid or refrigerant, such as water, ethanol, HFC, R134a, R-22, R407C, R410a, etc. Heat pipes contain no mechanical moving parts. Heat pipes transfer thermal energy from one point to another by the evaporation and condensation of a working fluid, vaporizable liquid, or coolant.

[0062] FIG. 3 illustrates a perspective view of a damper 340, according to an embodiment of the present disclosure. Any of the dampers shown and described with respect to FIG. 1 may be configured as the damper 340. The damper 340 includes a plurality of plates 342. Each plate 342 is positioned on a pivot (not shown) that allows the plates 342 to be moved between open and closed positions. As shown in FIG. 3, the plates 342 are in fully-closed positions. When the damper 340 is to be opened, the plates 342 swing open in the direction of arc A.

[0063] Alternatively, the damper 340 may include a single sliding plate that slides between open and closed positions in directions denoted by arrow B. Indeed, the damper 340 may take any form that allows selective movement between open and closed positions.

[0064] FIG. 4 illustrates a simplified perspective view of a plate heat exchanger 414, according to an embodiment of the present disclosure. The heat exchanger 136 shown in FIG. 1 may be configured as the plate heat exchanger 414. The plate heat exchanger 414 includes a plurality of parallel plates 444, which may be formed of aluminum and/or polyester, for example. The plates 444 are integrally connected with side walls 446. As shown, the side walls 446 alternate between levels 448 and 450. The levels 448 are oriented parallel with an axis x, while the levels 450 are oriented parallel with an axis y, which is perpendicular to the axis x. Thus, levels 448 are oriented to receive and direct supply air 408 within a supply air flow path 418, while the levels 450 are oriented to receive regeneration air 409 from a regeneration air flow path 426. Therefore, air passing in the levels 448 cross-flows with the air in the levels 450. In this manner, sensible energy is exchanged between levels 448 and 450. The temperature of the warm air within the levels 448 is cooled by the cooler air cross-flowing through the levels 450. Therefore, the temperature of the air within the levels 448 and 450 tends to equilibrate with one another. That is, the warm air within the levels 448 is cooled by heat exchange with the cooler air in the levels 450, and the cooler air within the levels 450 is warmed by the warmer air within the levels 448. Air that passes into the levels 448 is cooler after passing through the plate heat exchanger 414. Conversely, air that passes into the levels 450 is warmer after passing through the plate heat exchanger 414.

[0065] FIG. 5 illustrates a psychrometric chart with respect to the energy exchange system 100 (shown in FIG. 1), according to an embodiment of the present disclosure. Referring to FIGS. 1 and 5, the dampers 150 and 168 are fully-opened, while the dampers 146 and 164 are fully-closed. However, the dampers 150, 168, 146, and 164 may be modulated between open and closed positions to control the temperature and humidity of both the supply air 112 and the regeneration air 120.

[0066] Outside air passes into the supply air flow path 110 through the supply air inlet 108. The supply air 112 may be filtered of contaminants, allergens, and the like, by the filter 132. The supply air 112 has a particular temperature and humidity at area 170 within the supply air flow path 110, upstream from the energy transfer device 134. At area 170, the supply air 112 generally has the same temperature and humidity of the outside air. For example, at area 170, outdoor air enters the supply air inlet 108 having a temperature of 60°F and a humidity ratio of about 60 grains/lb.

[0067] Similarly, outside air passes into the regeneration air flow path 118 through the regeneration air inlet 116. The regeneration air 120 may be filtered of contaminants, allergens, and the like, by the filter 152. The regeneration air 120 has a particular temperature and humidity at area 172 within the regeneration air flow path 118, upstream from the heat exchanger 136. At area 172, the regeneration air 120 generally has the same temperature and humidity of the outside air. For example, outdoor air enters the regeneration air flow path 118 and has a temperature and a humidity of about 60°F and a humidity ratio of about 60 grains/lb.

[0068] The supply air 112 is moved from the area 170 through the supply side 135 of the energy transfer device 134. The energy transfer device 134 increases the temperature of the supply air 112, while decreasing its humidity. Thus, at area 174 within the supply air flow path 110, the supply air 112 has a higher temperature and lower humidity than at area 170. For example, after the supply air 112 is moved through
the energy transfer device 134, its temperature is increased to about 117° F., while its humidity ratio is lowered to about 18 grains/lb. at area 174. Thus, the humidity level of the supply air 112 has been decreased, thereby allowing for more efficient drying of material within the enclosed structure 102, such as a commodities storage or depository structure. However, the temperature of the pre-conditioned supply air 112 at area 174 may be high enough to adversely affect the material within the enclosed structure (for example, by cooking protein within grain). Therefore, the system 100 is also configured to cool the temperature of the pre-conditioned supply air 112 by passing the pre-conditioned supply air 112 at area 174 through the heat exchanger 136.

[0069] The pre-conditioned supply air 112 at area 174 having increased temperature and decreased humidity is then passed into the heat exchanger 136, where it exchanges sensible energy with the regeneration air 120 within the regeneration air flow path 118. Because the regeneration air 120 has a lower temperature than the supply air 112 within the heat exchanger 136, the temperature of the supply air 112 is decreased, while the temperature of the regeneration air 120 is increased. Thus, at area 176 within the supply air flow path 110, which is downstream from the heat exchanger 136, the temperature of the supply air 112 is lower than at area 174, although its humidity is unaltered. For example, after moving through the heat exchanger 136, the temperature of the supply air 112 is lowered to about 89° F., while its humidity ratio remains at about 18 grains/lb. at area 176. The low humidity supply air at area 176 is then supplied to the enclosed structure 102. Notably, the temperature of the conditioned supply air 112 at area 176 has been lowered to a point where it does not adversely affect material within the enclosed structure. At the same time, the humidity level has been decreased through the energy transfer device 134 (and unaltered by the heat exchanger 136), thereby allowing conditioned supply air 112 at area 176 to be delivered to the enclosed structure 102. The conditioned supply air 112 having a reduced humidity is able to dry contents within the enclosed structure, but the temperature of the conditioned supply air 112 does not adversely affect contents within the enclosed structure 102.

[0070] The supply air 112 at area 176, having an increased temperature and lower humidity than outside air, is then delivered to the enclosed structure 102, which may be a commodities storage or depository structure, such as a grain silo or bin, for example. The warm, dry conditioned supply air 112 supplied to the enclosed structure 102 may dry material within the enclosed structure, such as grain. Because the temperature of the supply air 112 has been decreased as it moves through the heat exchanger 136, the temperature of the supply air 112 supplied to the enclosed structure does not overly heat material, such as grain, within the enclosed structure. Instead, the dry air supplied to the enclosed structure is configured to quickly and efficiently dry material, such as grain, with the enclosed structure 102, which may be a grain bin or silo.

[0071] Returning to the regeneration air 120, the temperature of the regeneration air 120 at area 178 within the regeneration air flow path 118 downstream from the heat exchanger 136 is higher than at area 172, although its humidity remains unaltered. After the regeneration air 120 passes through the heat exchanger 136, the temperature of the regeneration air 120 is increased through heat exchange with the supply air 112. For example, at area 178, the temperature of the regeneration air 120 is about 90° F. with a humidity ratio that remains at about 60 grains/lb.

[0072] The temperature of the regeneration air 120 is further increased by the heater 154, so that its temperature at area 180 is higher than at area 178. For example, after passing through the heater 154, the temperature of the regeneration air 120 is raised to over 280° F., while its humidity ratio remains at about 60 grains/lb. at area 180. Because the temperature of the regeneration air 120 is heated by the heater 154, the energy transfer device 134 operates more efficiently, in that the regeneration side 137 is able to transfer more heat energy to the supply side 135. The regeneration air 120 at area 180 regenerates the energy transfer device 134. The increased temperature of the regeneration side 137 transfers heat to the supply side 135, which is then transferred to the supply air 112. Moreover, humidity is transferred from the supply air 112 to the supply side 135, and to the regeneration side 137, thereby reducing the humidity of the supply air 112.

[0073] Accordingly, the temperature of the regeneration air 120 at area 182 in the regeneration air flow path 118 (downstream from the regeneration side 137 of the energy transfer device 134) is higher than at area 180, while the temperature of the regeneration air 120 at area 182 is decreased. For example, after moving through the regeneration side 137 of the energy transfer device 134, the temperature of the regeneration air 120 is lowered to about 125° F., while its humidity ratio increases to almost 200 grains/lb. at area 182. The warm, humid regeneration air at area 182 is exhausted from the energy exchange system 100 into the atmosphere through the exhaust air outlet 122. Alternatively, at least a portion of the regeneration air 120 at area 182 may be re-directed through a bypass duct, for example, to preheat the regeneration air at either area 172 or 178.

[0074] Through the energy transfer device 134, sensible energy (heat) is transferred from the regeneration air 120 to the supply air 112, thereby increasing the temperature of the supply air 112 (and reducing the temperature of the regeneration air 120). At the same time, latent energy (humidity) is transferred from the supply air 112 to the regeneration air 120, thereby decreasing the moisture content of the supply air 112 (while increasing the moisture content of the regeneration air 120).

[0075] The dampers 146, 148, 150, 164, 166, and 168 may be operated to control the amount of supply and regeneration air that passes through the energy transfer device 134. For example, a portion of the supply air 112 may be re-directed around the energy transfer device 134. In this manner, an operator may control humidity and temperature levels of the supply air 112 that is delivered to the enclosed structure 102. The temperature and humidity levels of the supply air 112 that is delivered to the enclosed structure 102 may be controlled depending on the nature of the contents within the enclosed structure 102. For example, one type of commodity, such as wheat, may be efficiently dried with supply air at particular humidity and temperature levels that differ from another type of commodity, such as rice. The dampers may be controlled to allow for the amount of supply air and the regeneration air to pass through the energy transfer device 134, through control of the amount of air that passes through the bypass ducts 140 and 158, in order to control humidity and temperature levels of the supply air 112 that is supplied to the enclosed structure 102.

[0076] FIG. 6 illustrates a simplified schematic view of an energy exchange system 600 connected to an enclosed structure 602, according to an embodiment of the present disclosure. The energy exchange system 600 is similar to the energy exchange system 100, except that an energy transfer device
604 extends between areas proximate to a supply air inlet 606 and a regeneration air inlet 608.

[0077] The energy exchanger system 600 may include a supply liquid-to-air membrane energy exchanger (LAMEE) 610 disposed within a supply air flow path 612 proximate to the supply air inlet 606. An air filter 614 may be disposed within the supply air flow path 612 between the supply air inlet 606 and the supply LAMEE 610. Optionally, the system 600 may not include the air filter 614.

[0078] A regeneration LAMEE 616 may be disposed within a regeneration air flow path 618 proximate to the regeneration air inlet 608. An air filter 620 may be disposed within the regeneration air flow path 618 between the regeneration LAMEE 616 and the regeneration air inlet 608. Optionally, the system 600 may not include the air filter 620.

[0079] The supply LAMEE 610 may connect to a heating source 622 through a fluid inlet conduit 624 and a fluid outlet conduit 626. The heating source 622 may be a heat pump, solar heating system, waste heat recovery system, geothermal heating system, or the like. Similarly, the regeneration LAMEE 616 connects to the heating source 622 through a fluid inlet conduit 628 and a fluid outlet conduit 630. The fluid inlet and outlet conduits 624, 628 and 626, 630, respectively, are configured to transfer an energy transfer fluid, such as a refrigerant, desiccant, or the like, between the supply LAMEE 610 and the regeneration LAMEE 616. The heating source 622 is configured to heat at least a portion of energy transfer fluid, such as liquid desiccant, circulated between the regeneration LAMEE 616 and the supply LAMEE 610. The energy transfer device 604 may include one or more fluid pumps to pump the energy transfer fluid between the supply and regeneration LAMEEs 610 and 616.

[0080] In operation, heat from the energy transfer fluid within the regeneration LAMEE 616 may be transferred to regeneration air 632 with the regeneration air flow path 618 passing through the regeneration LAMEE 616. At the same time, moisture from the energy transfer fluid within the regeneration LAMEE 616 is transferred to the regeneration air 632. According, the temperature of the regeneration air passing through the regeneration LAMEE 616 may increase, while its moisture content also increases.

[0081] The energy transfer fluid, now having a decreased temperature and decreased moisture content, is then passed into the heating source 622 through the fluid outlet conduit 630. The energy transfer fluid may be further heated within the heating source 622, and then passed to the supply LAMEE 610 by way of the fluid inlet conduit 624. Heat within the supply air 634 passing through the supply LAMEE 610 is then transferred to the energy transfer fluid within the supply LAMEE 610. At the same time, moisture from the supply air 634 passing through the supply LAMEE 610 is transferred to the energy transfer fluid, thereby increasing the moisture content of the energy transfer fluid and decreasing the moisture content of the supply air 634. The energy transfer fluid is then pumped through the fluid outlet 626 to the heating source 622, and back to the regeneration LAMEE 616, and the process repeats. While the energy transfer device 604 is shown having the heating source 622, the energy transfer device 604 may alternatively include the heat source 622.

[0082] As outside air enters the supply air inlet 606, the supply air 634 has an initial temperature and humidity at area 640 within the supply air flow path 612, upstream from the supply LAMEE 610. Similarly, as outside air enters the regeneration air inlet 608, the regeneration air 632 has an initial temperature and humidity at area 642 within the regeneration air flow path 618 upstream from the regeneration LAMEE 616.

[0083] As the regeneration air 632 passes through the regeneration LAMEE 616, the temperature of the regeneration air 632 may be increased, while its moisture content is also increased. Thus, the temperature of the regeneration air 632 at area 644 may be greater than at area 642, while its moisture content may also be greater than at area 642.

[0084] Conversely, as the supply air 634 passes through the supply LAMEE 610, the temperature of the supply air 634 may be reduced, while its humidity content is also reduced. Thus, the temperature of the supply air 634 at area 646 may be less than at area 640, while its moisture content may also be less than at area 640.

[0085] The supply air 634 then passes from area 646 within the supply air flow path 612 into a heat exchanger 650, as described above. Similarly, the regeneration air 632 passes from area 644 within the regeneration air flow path 618 into the heat exchanger 650. Within the heat exchanger 650, sensible energy is transferred between the supply air 634 and the regeneration air 632. Accordingly, the temperature of the supply air 634 that passes out of the heat exchanger 650 increases, while the temperature of the regeneration air that passes out of the heat exchanger 650 decreases. At area 652 within the supply air flow path 612, the temperature of the supply air 634 is greater than at area 646, while its moisture content remains the same. At area 654 within the regeneration air flow path 618, the temperature of the regeneration air 632 is less than at area 644, while its moisture content remains the same. The regeneration air 632 at area 654 within the regeneration air flow path 618 is then exhausted to atmosphere through an exhaust air outlet 656. One or more fans 658 may be disposed within the regeneration air flow path 618 to move the regeneration air 632 therethrough.

[0086] A heater 660, such as an electric, propane, natural gas, or the like, heater may be disposed within the supply air flow path 612 downstream from the heat exchanger 650. The heater 660 may further increase the temperature of the supply air 634 before it is supplied to the enclosed structure 602. Thus, the temperature of the supply air 634 at area 642 within the supply air flow path 612 may be greater than at area 652, while its moisture content remains the same. Alternatively, the system 600 may not include the heater 660. One or more fans 664 may be disposed within the supply air flow path 612 to move the supply air 634 therethrough.

[0087] While not shown, the energy exchange system 600 may also include bypass ducts and dampers that are configured to allow air streams to bypass the energy transfer device 604, as described above. The dampers may be modulated in order to control the temperature and humidity of the air streams.

[0088] FIG. 7 illustrates a side perspective view of a LAMEE 700, according to an embodiment of the present disclosure. The LAMEE 700 may be a LAMEE as described in WO 2011/161547, entitled “Liquid-To-Air Membrane Energy Exchanger,” filed Jun. 22, 2011, which is hereby incorporated by reference in its entirety. The LAMEE 700 may be used as the supply LAMEE 610 and/or the regeneration LAMEE 616 (shown in FIG. 6). The LAMEE 700 includes a housing 702 having a body 704. The body 704 includes an air inlet end 706 and an air outlet end 708. A top 710 extends between the air inlet end 706 and the air outlet end 708. A stepped-down top 712 may be positioned at the air.
inlet end 706. The stepped-down top 712 may be stepped a distance 714 from the top 710. A bottom 716 extends between the air inlet end 706 and the air outlet end 708. A stepped-up bottom 718 may be positioned at the air outlet end 708. The stepped-up bottom 718 may be stepped a distance 720 from the bottom 716. In certain embodiments, the stepped-up bottom 718 or stepped-down top 712 sections may have different sizes of steps or no step at all.

[0089] An air inlet 722 is positioned at the air inlet end 706. An air outlet 724 is positioned at the air outlet end 708. Sides 726 extend between the air inlet 722 and the air outlet 724.

[0090] An energy exchange cavity 730 extends through the housing 702 of the LAMEE 700. The energy exchange cavity 730 extends from the air inlet end 706 to the air outlet end 708. An air stream 732 is received in the air inlet 722 and flows through the energy exchange cavity 730. The air stream 732 is discharged from the energy exchange cavity 730 at the air outlet 724. The energy exchange cavity 730 includes a plurality of panels 734.

[0091] A desiccant inlet reservoir 738 may be positioned on the stepped-up bottom 718. The desiccant inlet reservoir 738 may have a height 740 equal to the distance 720 between the bottom 716 and the stepped-up bottom 718. Alternatively, the liquid desiccant inlet reservoir 738 may have any height that meets a desired performance of the LAMEE 700. The desiccant inlet reservoir 738 extends a length 739 of the LAMEE body 704. The length 739 is configured to meet a desired performance of the LAMEE 700. In an embodiment, the desiccant inlet reservoir 738 may extend no more than one fourth of the length 727 of the LAMEE body 704. Alternatively, the desiccant inlet reservoir 738 may extend along one fifth, for example, of the length 727 of the LAMEE body 704.

[0092] The liquid desiccant inlet reservoir 738 is configured to receive desiccant 741 from a storage tank (such as within the heat source 622 of FIG. 6). The desiccant inlet reservoir 738 includes an inlet 742 in flow communication with the storage tank. The desiccant 741 is received through the inlet 742. The desiccant inlet reservoir 738 includes an outlet that is in fluid communication with desiccant channels 776 in the energy exchange cavity 730. The liquid desiccant 741 flows through the outlet into the desiccant channels 776. The desiccant 741 flows along the panels 734 through the desiccant channels 776 to a desiccant outlet reservoir 746.

[0093] The desiccant outlet reservoir 746 may be positioned on the stepped-down top 712 of the housing 702. Alternatively, the desiccant outlet reservoir 746 may be positioned at any location along the top 712 of the LAMEE housing 702 or alternatively on the side of the reservoir with a flow path connected to all the panels. The desiccant outlet reservoir 746 has a height 748 that may be equal to the distance 714 between the top 710 and the stepped-down top 712. The desiccant outlet reservoir 746 extends along the top 712 of the LAMEE housing 702 for a length 750. In an embodiment, the length 750 may be no more than one fourth the length 727 of the flow panel exchange area length. In another embodiment, the length 750 may be one fifth, for example, the length 727 of the panel exchange area length.

[0094] The desiccant outlet reservoir 746 is configured to receive desiccant 741 from the desiccant channels 776 in the energy exchange cavity 730. The desiccant outlet reservoir 746 includes an inlet 752 in flow communication with the desiccant channels 776. The desiccant 741 is received from the desiccant channels 776 through the inlet 752. The desiccant outlet reservoir 746 includes an outlet 754 that is in fluid communication with a storage tank. The desiccant 741 flows through the outlet 754 to the storage tank where the desiccant 741 is stored. In an alternative embodiment, the desiccant outlet reservoir 746 may be positioned along the bottom 718 of the LAMEE housing 702 and the desiccant inlet reservoir 738 may be positioned along the top 710 of the housing 702.

[0095] As shown in FIG. 7, the LAMEE 700 includes one liquid desiccant outlet reservoir 746 and one liquid desiccant inlet reservoir 738. Alternatively, the LAMEE 700 may include liquid desiccant outlet reservoirs 746 and liquid desiccant inlet reservoirs 738 on the top and bottom of each of each end of a LAMEE 700. A liquid flow controller may direct the liquid flow to either the top or bottom.

[0096] FIG. 8 illustrates a front view of the panels 734 within the energy exchange cavity 700 of the LAMEE 700, according to an embodiment of the present disclosure. The liquid flow panels 734 form a liquid desiccant channel 776 that may be confined by semi-permeable membranes 778 on either side and are configured to carry desiccant therethrough. The semi-permeable membranes 778 are arranged in parallel to form air channels 736 with an average flow channel width of 737 and liquid desiccant channels 776 with an average flow channel width of 777. In an embodiment, the semi-permeable membranes 778 are spaced to form uniform air channels 736 and liquid desiccant channels 776. The air stream 732 (shown in FIG. 7) travels through the air channels 736 between the semi-permeable membranes 778. The desiccant in each desiccant channel 776 exchanges heat and moisture with the air stream 732 in the air channels 736 through the semi-permeable membranes 778. The air channels 736 alternate with the liquid desiccant channels 776. Except for the two side panels of the energy exchange cavity, each air channel 736 may be positioned between adjacent liquid desiccant channels 776.

[0097] In order to minimize or otherwise eliminate the liquid desiccant channels 776 from outwardly bulging or bowing, membrane support assemblies may be positioned within the air channels 736. The membrane support assemblies are configured to support the membranes, as well as promote turbulent air flow between the air channels 736 and the membranes 778. The membrane support assemblies are further described in U.S. application Ser. No. ____ , entitled “Membrane Support Assembly for an Energy Exchanger,” filed, which claims priority to U.S. Provisional Application Ser. No. 61/692,793 filed Aug. 24, 2012, entitled “Membrane Support Assembly for an Energy Exchanger,” both of which are hereby expressly incorporated by reference in their entirety. Liquid panel assemblies that may be used in the LAMEE 700 are described and shown in U.S. application Ser. No. ____ , entitled “Liquid Panel Assembly,” filed ____ , which claims priority to U.S. Provisional Application No. 61/692,798, entitled “Liquid Panel Assembly,” filed Aug. 24, 2012, both of which are also incorporated by reference in their entirety.

[0098] FIG. 9 illustrates a psychrometric chart with respect to the energy exchange system 600 (shown in FIG. 6), according to an embodiment of the present disclosure. Referring to FIGS. 6 and 9, as outdoor air enters the supply air inlet 606, it has an initial temperature of about 60°F and a humidity ratio of about 60 grains/lb. at area 640 within the supply air flow path 612. After moving through the supply LAMEE 610, the temperature of the supply air 634 may be reduced to about 40°F and its humidity ratio reduced to about 16 grains/lb. at area 646, which is just downstream of the supply LAMEE 610 within the supply air flow path 612. After passing through the
heat exchanger 650, sensible energy is transferred between the supply air 634 and the regeneration air 632 such that the temperature of the supply air 634 is increased to about 50° F. (while its humidity ratio stays the same) at area 652 within the supply air flow path 612, which is between the heat exchanger 650 and the heater 660. The heater 660 then increases the temperature of the supply air 634 to about 100° F at area 662 before it is delivered to the enclosed structure 602. Accordingly, the system 600 provides dry air, which may be warm or hot, to the enclosed structure 602.

Conversely, as outdoor air enters the regeneration air inlet 608, it has an initial temperature of about 60° F and a humidity ratio of about 60 grains/lb. at area 642 within the regeneration air flow path 618. After moving through the regeneration LAMEE 616, the temperature of the regeneration air 632 may be increased to about 80° F. and its humidity ratio increased to about 110 grains/lb. at area 644, which is just downstream of the regeneration LAMEE 616 within the regeneration air flow path 618. After passing through the heat exchanger 650, sensible energy is transferred between the supply air 634 and the regeneration air 632 such that the temperature of the regeneration air 634 is decreased to about 70° F. (while its humidity ratio stays the same) at area 654 within the regeneration air flow path 618, which is downstream from the heat exchanger 650. The moist air is then exhausted to atmosphere through the exhaust air outlet 656.

FIG. 10 illustrates a lateral view of an energy exchange system 1000 operatively connected to a grain bin 1002, according to an embodiment of the present disclosure. The energy exchange system 1000 includes a housing 1004 supported by a base 1006, which may include wheels 1008. As such, the energy exchange system 1000 may be hitched to a vehicle and moved between locations, such as the grain bin 1002. In this manner, the energy exchange system 1000 may be a mobile system. The energy exchange system 1000 may be similar to any of the systems described above, such as systems 100 (shown in FIG. 1) and 600 (shown in FIG. 6). As described above, the housing 1004 includes a supply air inlet 1010, a regeneration air inlet 1012, an exhaust air outlet 1014, and a supply air outlet 1016. The supply air outlet 1016 may be operatively connected to an air plenum 1018 of the grain bin 1002 through an air delivery member 1020, such as a conduit, duct, or the like, that connects the supply air outlet 1016 to the air plenum 1018.

The grain bin 1002 may include a base 1022 integrally connected to cylindrical walls 1024, which, in turn, integrally connect to a cone-shaped roof 1026 having a central air outlet 1028. The air plenum 1018 may be defined between an interior surface 1030 of the base 1022 and a vented support floor 1032. A grain retention chamber 1034 is defined between the vented support floor 1032, the cylindrical walls 1024, and the roof 1026. Grains 1036, such as wheat, rice, corn, or the like, is retained within the grain retention chamber 1034. While the grain bin 1002 is shown as being a silo-like structure having cylindrical walls and a cone-shaped roof, the grain bin 1002 may be various other shapes and sizes, such as rectangular or block shaped.

In operation, the energy exchange system 1000 provides supply air having low humidity to the air plenum 1018 within the grain bin 1002. The dry supply air may also have a relatively high temperature, as compared to outside air. The dry air supplied to the grain bin 1002 passes through the grain 1036 toward the air outlet 1028. The dry supply air 1040 dries the grain 1036 and removes moisture therefrom. As the supply air 1040 rises through the grain retention chamber 1034, its temperature may decrease and its humidity may increase. As heat from the supply air 1040 is transferred to the grain 1036, and moisture from the grain 1036 is transferred to the supply air 1040. The cooler air 1050 having increased moisture may then vent to the atmosphere through the air outlet 1028.

In an embodiment, a duct 1060 may connect the air outlet 1028 to the regeneration air inlet 1012. Accordingly, the cooler air 1050 may be channeled from the air outlet 1028 to the regeneration air inlet 1012. As such, instead of outside air, the regeneration air may be supplied from return air from an enclosed structure, such as the grain bin 1002. While the return air from the grain bin 1002 may be cooler and more humid than the air supplied from the energy exchange system 1000, the return air may still be warmer and less humid than outside air. Therefore, the duct 1060 connecting the air outlet 1028 to the regeneration air inlet 1012 may lead to a more efficient energy exchange system 1000.

FIG. 11 illustrates a simplified schematic view of an energy exchange system 1100 connected to an enclosed structure 1102, according to an embodiment of the present disclosure. The energy exchange system 1100 is similar to the system 100 (shown in FIG. 1), except that an additional heat exchanger 1104 is positioned between a regeneration air flow path 1106 downstream from a heat exchanger 1108 and upstream from a heater 1110. A portion of the heat exchanger 1104 may be within the regeneration air flow path 1106, while another portion may be disposed within a return air duct or path 1112. The return air path 1112 channels return air from the enclosed structure 1102 to the heat exchanger 1104, so that sensible energy is exchanged between regeneration air 1114 within the regeneration air flow path 1114 and return air 1116 with the return air path 1112. After passing through the heat exchanger 1104, the return air 1116 may be exhausted to the atmosphere. The heat exchanger 1104 may be any of the heat exchangers described above, such as a flat plate, a sensible wheel, a heat pipe, a run-around glycol loop, and/or the like. Alternatively, at least a portion of air from area 1146 may be diverted into the air path 1112.

In operation, outdoor air enters a supply air flow path 1120 through a supply air inlet 1122. The supply air 1124 has an initial temperature and humidity at area 1126. The supply air 1124 then passes through a supply side 1128 of an energy transfer device 1130, such as a desiccant wheel. The energy transfer device 1130 may increase the temperature of the supply air 1124 and reduce its humidity. Therefore, the supply air 1124 at area 1132 may have a higher temperature and a lower humidity ratio than the supply air 1124 at area 1126. The supply air 1124 then passes through the heat exchanger 1108, which may reduce its temperature. After passing through the heat exchanger 1108, the temperature of the supply air 1124 at area 1134 is reduced, but its humidity ratio remains the same as compared to area 1132. The supply air 1124 at area 1134 is then supplied to the enclosed structure 1102.

Outside air (and/or return air) enters the regeneration air flow path 1106 through a regeneration air inlet 1136. At area 1138 within the regeneration air flow path 1106, which is upstream from the heat exchanger 1108, the regeneration air 1114 has an initial temperature and humidity. After passing through the heat exchanger 1108, the temperature of regeneration air is decreased, while its humidity ratio remains the same. Thus, at area 1140 within the regeneration air flow
path 1106, which is downstream from the heat exchanger 1108, but upstream from the heat exchanger 1104, the temperature of regeneration air 1114 is reduced as compared to the area 1138, while the humidity ratio of the regeneration air 1114 is the same. As the regeneration air 1114 passes from the area 1140 through the heat exchanger 1104, the temperature of the regeneration air 1114 is increased. The sensible energy from the higher temperature return air 1116 is transferred to the regeneration air 1114, thereby increasing the temperature of the regeneration air 1114. Thus, the temperature of the regeneration air 1114 at area 1142 is higher than at area 1140, while the humidity ratio remains the same.

[0107] The heater 1110 may be used to further increase the temperature of the regeneration air 1114. At area 1144, the temperature of the regeneration air 1114 is higher than at area 1142, while the humidity ratio remains the same. The regeneration air 1114 at area 1144 is then used to regenerate the energy transfer device 1128. Accordingly, at area 1146 within the regeneration air flow path 1106 downstream from the regeneration side 1148 of the energy transfer device 1130, the temperature of the regeneration air 1114 is reduced, while its humidity ratio is increased. The regeneration air 1114 at area 1146 is then exhausted to atmosphere.

[0108] The heat exchanger 1104 and return air path 1116 may be used with any of the embodiments discussed above. For example, instead of the energy transfer device being a desiccant wheel, the energy transfer device may be one or more LAMEEs, as described above.

[0109] FIG. 12 illustrates a psychrometric chart with respect to the energy exchange system 1100 (shown in FIG. 11), according to an embodiment of the present disclosure. Referring to FIGS. 11 and 12, supply air 1124 at area 1126 has a temperature of about 60° F. and a humidity ratio of about 60 grains/lb. After passing through the supply side 1128 of the energy transfer device 1130, the temperature of the supply air 1124 is increased, while its humidity ratio is decreased. At area 1132, the temperature of the supply air 1124 is about 115° F., while its humidity ratio is about 17 grains/lb. After passing through the heat exchanger, the temperature of the supply air 1124 may be lowered to about 80° F., while its humidity ratio remains at about 17 grains/lb. at area 1134.

[0110] Turning now to the regeneration air 1114, at area 1136, the temperature and humidity ratio of the regeneration air 1114 are generally the same as the supply air 1124 at area 1126. At area 1136, the temperature of the regeneration air 1114 may be about 60° F., with a humidity ratio of about 60 grains/lb. After the regeneration air 1114 is passed through the heat exchanger 1108, the temperature of the regeneration air 1114 may be increased as it exchanges sensible energy with the supply air 1124 passing through the heat exchanger 1108. At area 1140, the regeneration air may have a temperature of about 92° F., with a humidity ratio remaining at about 60 grains/lb. After passing through the heat exchanger 1104, which is downstream from the heat exchanger 1108, the regeneration air 1114 exchanges sensible energy with the return air 1116 within the return path 1112. At area 1142, the temperature of the regeneration air 1114 may be about 119° F., with a humidity ratio remaining at about 60 grains/lb. The heater 1110 increases the temperature of the regeneration air 1114 before the regeneration air 1114 encounters the regeneration side 1148 of the energy transfer device 1130. At area 1144, the temperature of the regeneration air 1114 has been increased to about 290° F., while its humidity ratio remains at about 60 grains/lb. After the regeneration air 1114 passes through the regeneration side 1148 of the energy transfer device 1130, thereby regenerating the energy transfer device 1130, the temperature of the regeneration air 1114 is lowered, while its humidity ratio increases. At area 1146, the temperature of the regeneration air has been lowered to about 130° F., while its humidity ratio has been increased to about 195 grains/lb. The regeneration air 1114 at area 1146 is then exhausted to the atmosphere.

[0111] FIG. 13 illustrate a simplified overhead view of an energy exchange system 1300 operatively connected to a plurality of enclosures 1302a, 1302b, and 1302c, according to an embodiment of the present disclosure. The energy exchange system 1300 may be any of those described above. Each enclosure 1302a, 1302b, and 1302c may be a grain bin, room, barn, or various other enclosures. The energy exchange system 1300 may be operatively connected to more or less enclosures than shown in FIG. 13.

[0112] A supply air outlet 1304 of the energy exchange system 1300 is operatively connected to a conduit 1306 that branches off to air inlets 1308 of each enclosure 1302a, 1302b, and 1302c. As such, the energy exchange system 1300 may provide relatively dry supply air to each of the enclosures 1302a, 1302b, and 1302c.

[0113] FIG. 14 illustrates a flow chart of a method of providing conditioned air to an enclosed structure, according to an embodiment of the present disclosure. At 1400, a humidity level of supply air is reduced by passing the supply air through an energy transfer device, such as a desiccant wheel or supply LAMEE. Then, at 1402, sensible energy is transferred between the supply air and regeneration air through the use of a heat exchanger. At 1404, the reduced-humidity supply air is supplied to an enclosed structure. At 1406, which may occur simultaneously with 1404, the energy transfer device is regenerated through the regeneration air, after it has passed through the heat exchanger. After 1406, the regeneration air is exhausted to atmosphere at 1408.

[0114] Referring to FIGS. 1-14, embodiments of the present disclosure provide energy exchange systems that receive outdoor air, return air, or a combination of both, and dry the air before supplying it to an enclosed structure, such as a commodities storage or depository structure. The air may be conditioned to a desired temperature through one or more heaters, heat exchangers, and/or the like. Accordingly, embodiments of the present disclosure provide quick, efficient, and inexpensive systems and methods for providing dry air to an enclosed structure. The dry air may be used to quickly and efficiently dry material, such as grain, within the enclosed structure. Unlike grain tower drying systems, there is no need to move grain between a grain bin and a tower. It has been found that embodiments of the present disclosure provide systems and methods for drying grain that are quicker and more efficient than traditional blower systems and methods. Additionally, embodiments of the present disclosure provide systems and methods for drying grain, for example, that are safer than conventional systems and methods. For example, embodiments of the present disclosure allow for the temperature of the supply air to be controlled in order to ensure that the grain is not overheated. Further, the energy exchange systems described above may be operatively connected to any enclosed structure, such as a grain bin, in contrast to a tower drying system, in which grain from a bin is hauled in batches to a tower.
the like may be used to describe embodiments of the present disclosure, it is understood that such terms are merely used with respect to the orientations shown in the drawings. The orientations may be inverted, rotated, or otherwise changed, such that an upper portion is a lower portion, and vice versa, horizontal becomes vertical, and the like.

[0116] It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments (and/or aspects thereof) may be used in combination with each other. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the various embodiments of the disclosure without departing from their scope. While the dimensions and types of materials described herein are intended to define the parameters of the various embodiments of the disclosure, the embodiments are by no means limiting and are exemplary embodiments. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the various embodiments of the disclosure should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms “including” and “in which” are used as the plain-English equivalents of the respective terms “comprising” and “wherein.” Moreover, in the following claims, the terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to impose numerical requirements on their objects. Further, the limitations of the following claims are not written in means-plus-function format and are not intended to be interpreted based on 35 U.S.C. §112, sixth paragraph, unless and until such claim limitations expressly use the phrase “means for” followed by a statement of function void of further structure.

[0117] This written description uses examples to disclose the various embodiments of the disclosure, including the best mode, and also to enable any person skilled in the art to practice the various embodiments of the disclosure, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the various embodiments of the disclosure is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if the examples have structural elements that do not differ from the literal language of the claims, or if the examples include equivalent structural elements with insubstantial differences from the literal languages of the claims.

What is claimed is:

1. An energy exchange system configured to provide supply air to an enclosed structure, the system comprising:
   an energy transfer device having a first portion configured to be disposed within a supply air flow path and a second portion configured to be disposed within a regeneration air flow path, the energy transfer device being configured to decrease a humidity level of the supply air, and wherein the energy transfer device is configured to be regenerated with regeneration air; and
   a first heat exchanger configured to be disposed within the supply air flow path downstream from the energy transfer device and within the regeneration air flow path upstream from the second portion of the energy transfer device, the first heat exchanger configured to transfer sensible energy between the supply air and the regeneration air, wherein the energy exchange system is configured to supply the supply air to the enclosed structure after the supply air passes through the energy transfer device and the first heat exchanger.

2. The energy exchange system of claim 1, wherein the enclosed structure comprises a grain bin for retaining grain, and wherein the energy exchange system is configured to supply the supply air to the grain bin in order to dry grain.

3. The energy exchange system of claim 1, further comprising one or more bypass ducts configured to be disposed within one or both of the supply air flow path or the regeneration air flow path, wherein the one or more bypass ducts are configured to bypass at least a portion of one or both of the supply air and the regeneration air around the energy transfer device.

4. The energy exchange system of claim 1, further comprising a heater configured to be disposed within a portion of regeneration air flow path upstream from the energy exchange device.

5. The energy exchange system of claim 1, wherein the energy transfer device comprises a desiccant wheel.

6. The energy exchange system of claim 1, wherein the energy transfer device comprises a supply liquid-to-air membrane energy exchanger (LAMEE) configured to be positioned within the supply air flow path, and a regeneration LAMEE configured to be positioned within the regeneration air flow path.

7. The energy exchange system of claim 1, further comprising a heater configured to be positioned within the supply air flow path downstream from the first heat exchanger.

8. The energy exchange system of claim 1, further comprising a housing that contains the energy transfer device and the first heat exchanger.

9. The energy exchange system of claim 8, further comprising a wheeled base connected to the housing, wherein the wheeled base is configured to provide a mobile energy exchange system.

10. The energy exchange system of claim 8, wherein the housing is configured to be operatively connected to a plurality of enclosed structures.

11. The energy exchange system of claim 1, further comprising a duct configured to connect a regeneration air inlet of the regeneration air flow path to an air outlet of the enclosed structure.

12. The energy exchange system of claim 1, further comprising a second heat exchanger having a first portion that is configured to be disposed within the regeneration air flow path downstream from the first heat exchanger and a second portion that is configured to be disposed within a return air path.

13. A method of providing supply air to an enclosed structure, the method comprising:
   decreasing a humidity level of supply air with an energy transfer device having a first portion disposed within a supply air flow path and a second portion disposed within a regeneration air flow path; transferring sensible energy between the supply air and regeneration air with a first heat exchanger that is within the supply air flow path downstream from the energy transfer device and within the regeneration air flow path upstream from the second portion of the energy transfer device;
   regenerating the energy transfer device with the regeneration air that passes through the second portion of the energy transfer device disposed within the regeneration air flow path; and
supplying the supply air to the enclosed structure after the decreasing and transferring operations.

14. The method of claim 13, wherein the enclosed structure comprises a grain bin that retains grain, and further comprising drying the grain within the grain bin with the supply air that is supplied to the grain bin.

15. The method of claim 13, further comprising bypassing at least a portion of one or both the supply air or the regeneration air around the energy transfer device.

16. The method of claim 13, further comprising heating the regeneration air after the transferring operation and before the regenerating operation.

17. The method of claim 13, wherein the energy transfer device comprises a desiccant wheel.

18. The method of claim 13, wherein the energy transfer device comprises a supply liquid-to-air membrane energy exchanger (LAMEE) configured to be positioned within the supply air flow path, and a regeneration LAMEE configured to be positioned within the regeneration air flow path.

19. The method of claim 13, further comprising heating the supply air after the transferring operation.

20. The method of claim 13, further comprising containing the energy transfer device and the first heat exchanger within a housing.

21. The method of claim 20, further comprising connecting a wheeled base to the housing.

22. The method of claim 20, further comprising operatively connecting the housing to a plurality of enclosed structures.

23. The method of claim 13, further comprising connecting a regeneration air inlet of the regeneration air flow path to an air outlet of the enclosed structure with a duct.

24. The method of claim 13, further comprising transferring sensible energy between the regeneration air and return air with a second heat exchanger having a first portion disposed within the regeneration air flow path downstream from the first heat exchanger and a second portion disposed within a return air path.

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