US 20140262125A1

(19) United States

(12) Patent Application Publication

ERB et al.

(10) Pub. No.: US 2014/0262125 A1

(43) Pub. Date: Sep. 18, 2014

(54) ENERGY EXCHANGE ASSEMBLY WITH MICROPOROUS MEMBRANE

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(21) Appl. No.: 14/192,019

(22) Filed: Feb. 27, 2014

Related U.S. Application Data

(60) Provisional application No. 61/784,638, filed on Mar. 14, 2013.

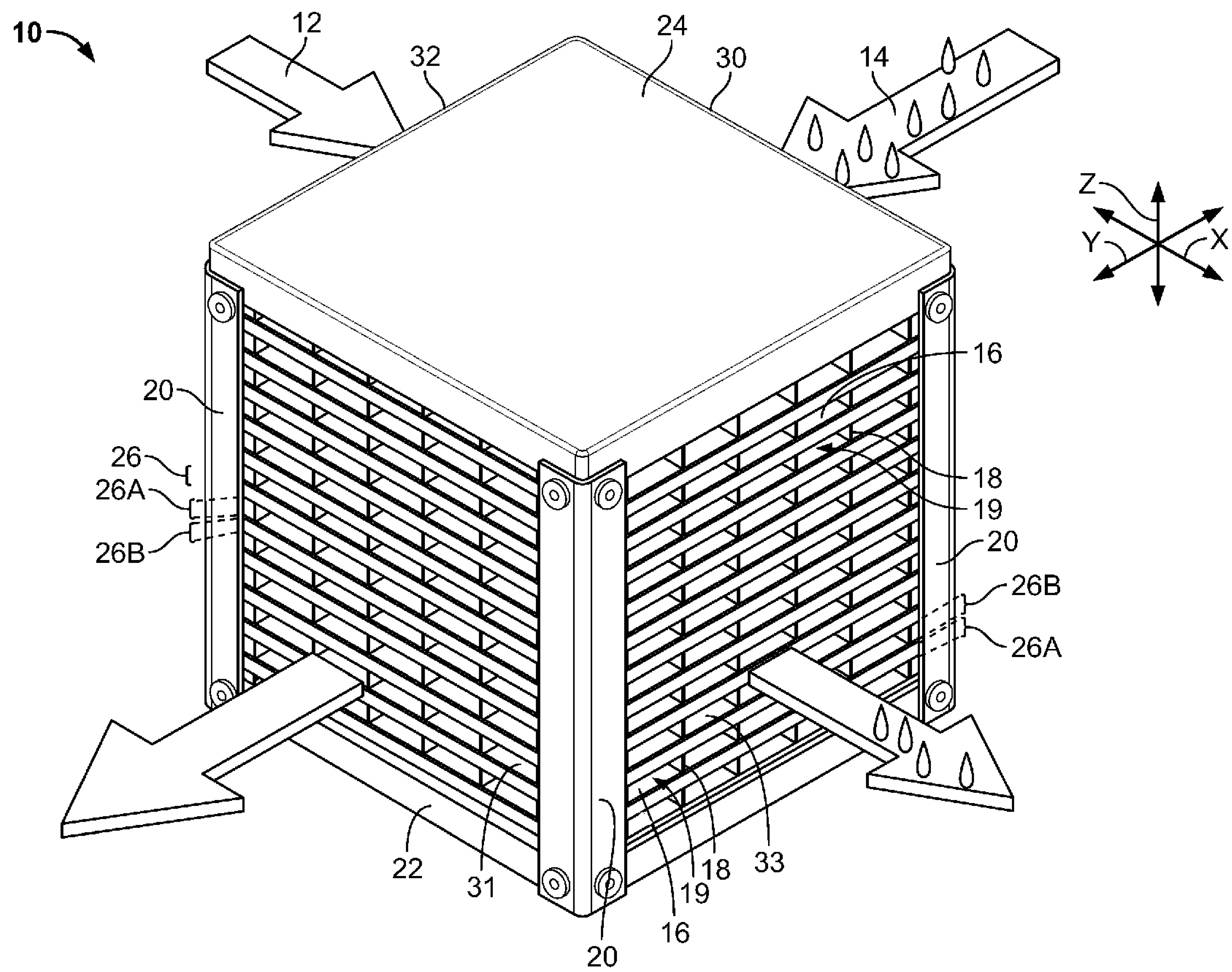
Publication Classification

(51) Int. Cl.
F28D 17/02 (2006.01)

(52) U.S. Cl.
CPC *F28D 17/02* (2013.01)
USPC 165/10

(57) ABSTRACT

An energy exchange assembly may include one or more membrane panels. The one or more membrane panels may include a microporous membrane that has a pore size between 0.02 and 0.3 micrometers (μm) and a porosity between 45% and 80%. Optionally, the energy exchange assembly may further include a plurality of spacers that define air channels. The air channels may be configured to receive air streams therethrough. Each of the one or more membrane panels may be disposed between two spacers. The one or more membrane panels may be configured to allow a transfer of sensible energy and latent energy across the one or more membrane panels between the air channels.



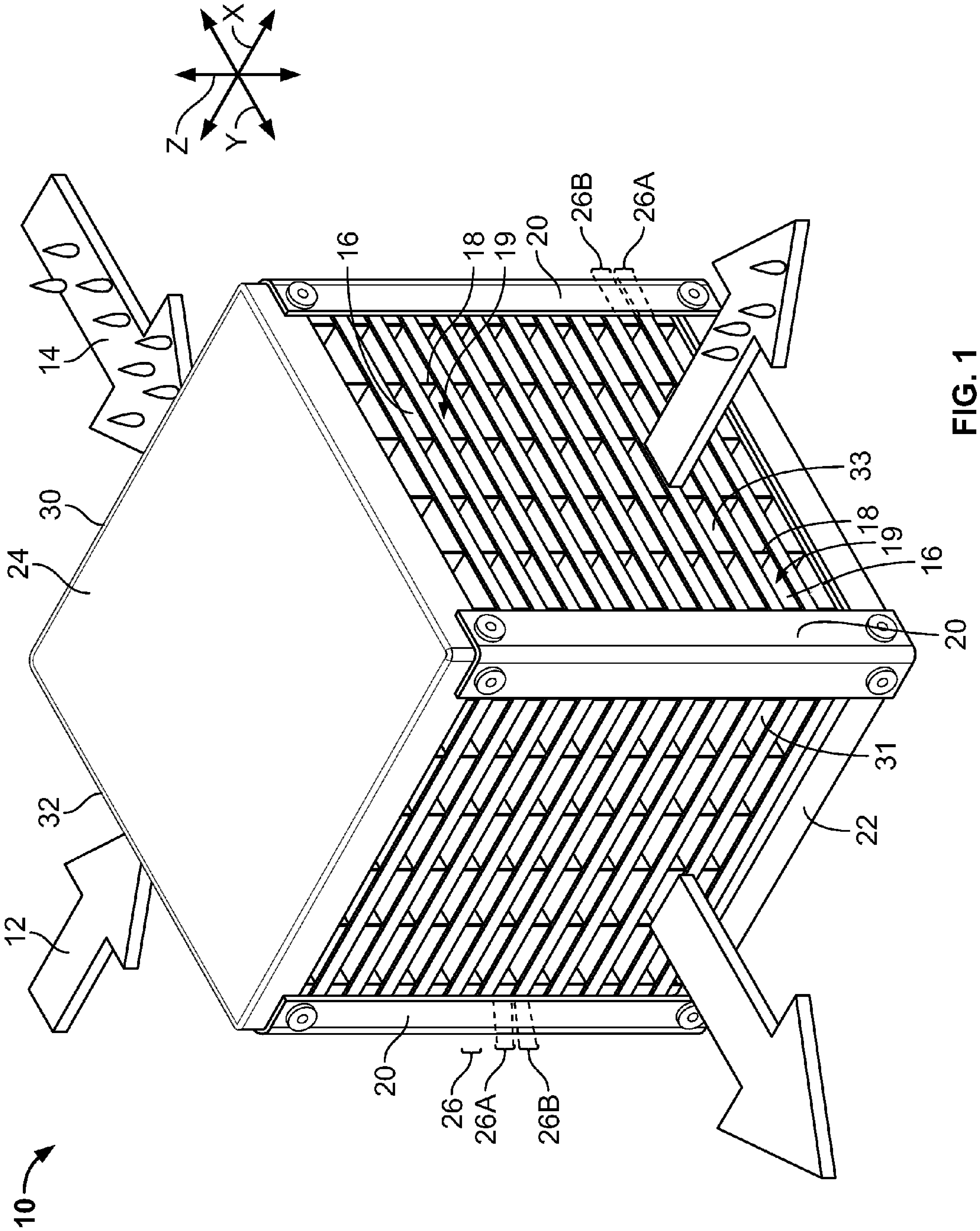
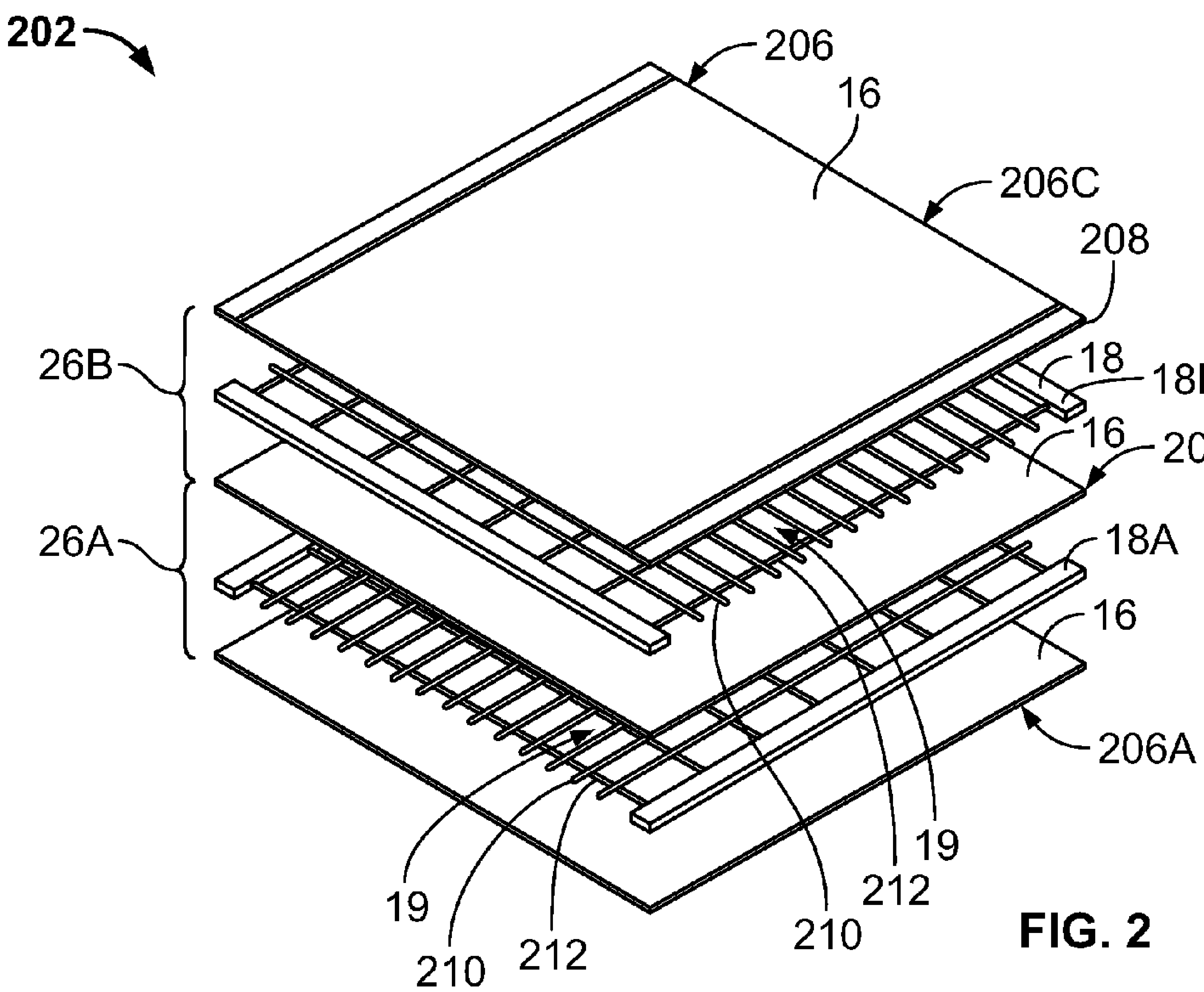


FIG. 1


202
206
16
206C
208
26B
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18B
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206B
26A
18A
16
206A
19
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212
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212
19

FIG. 2

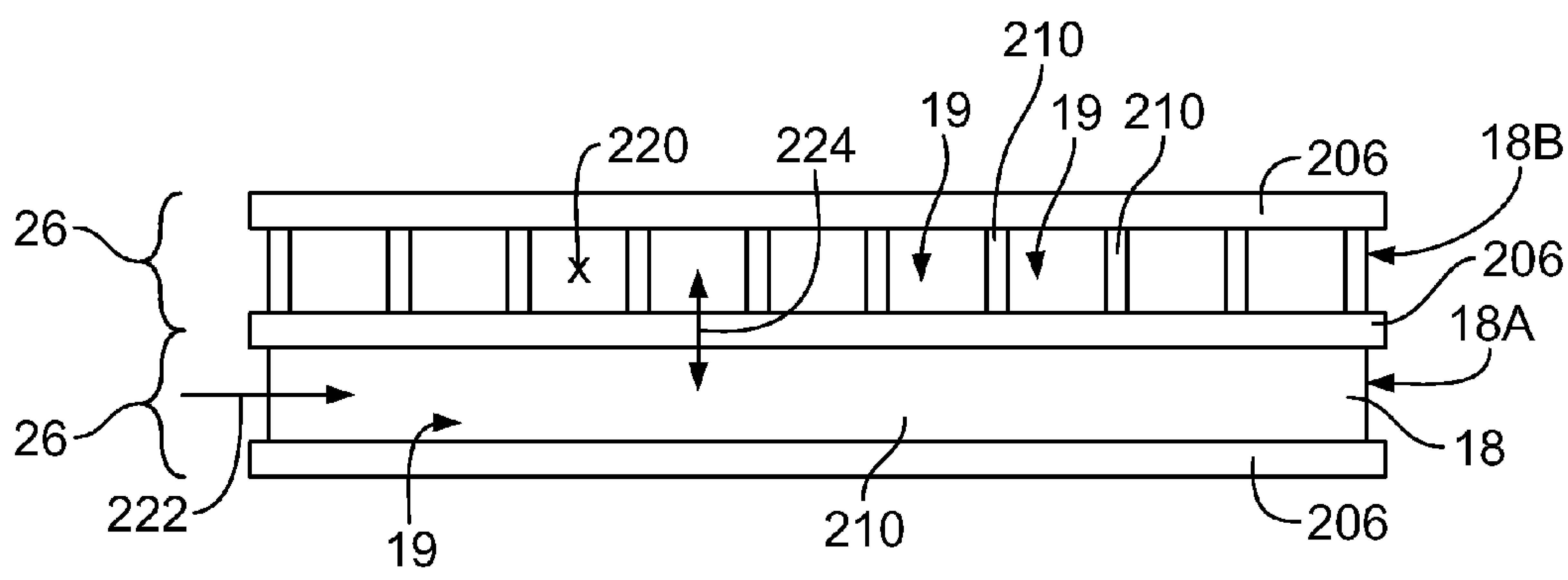
210
19
19
210
220
224
206
18B
26
206
18A
26
18
222
19
210
206

FIG. 3

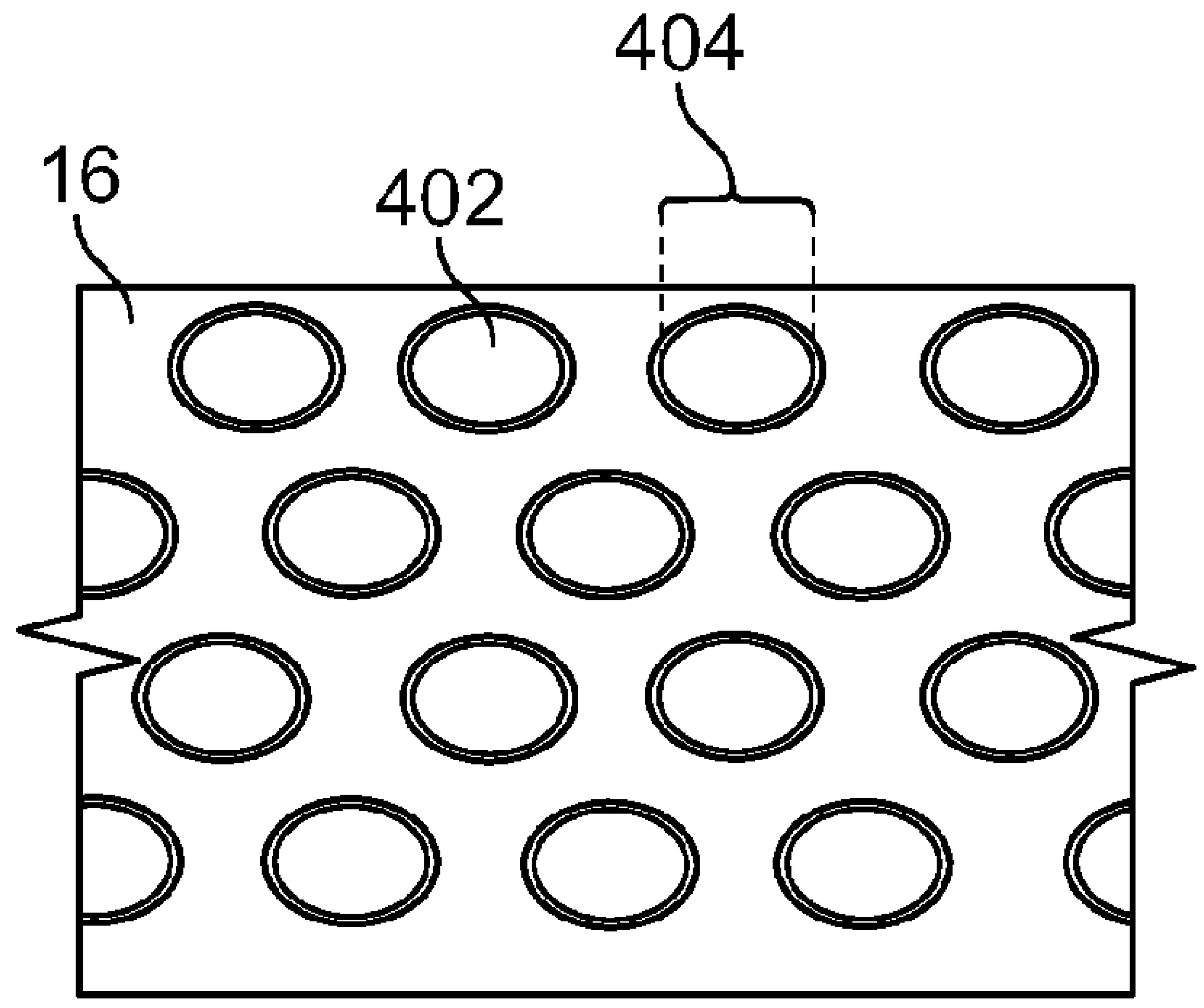
404
16
402

FIG. 4

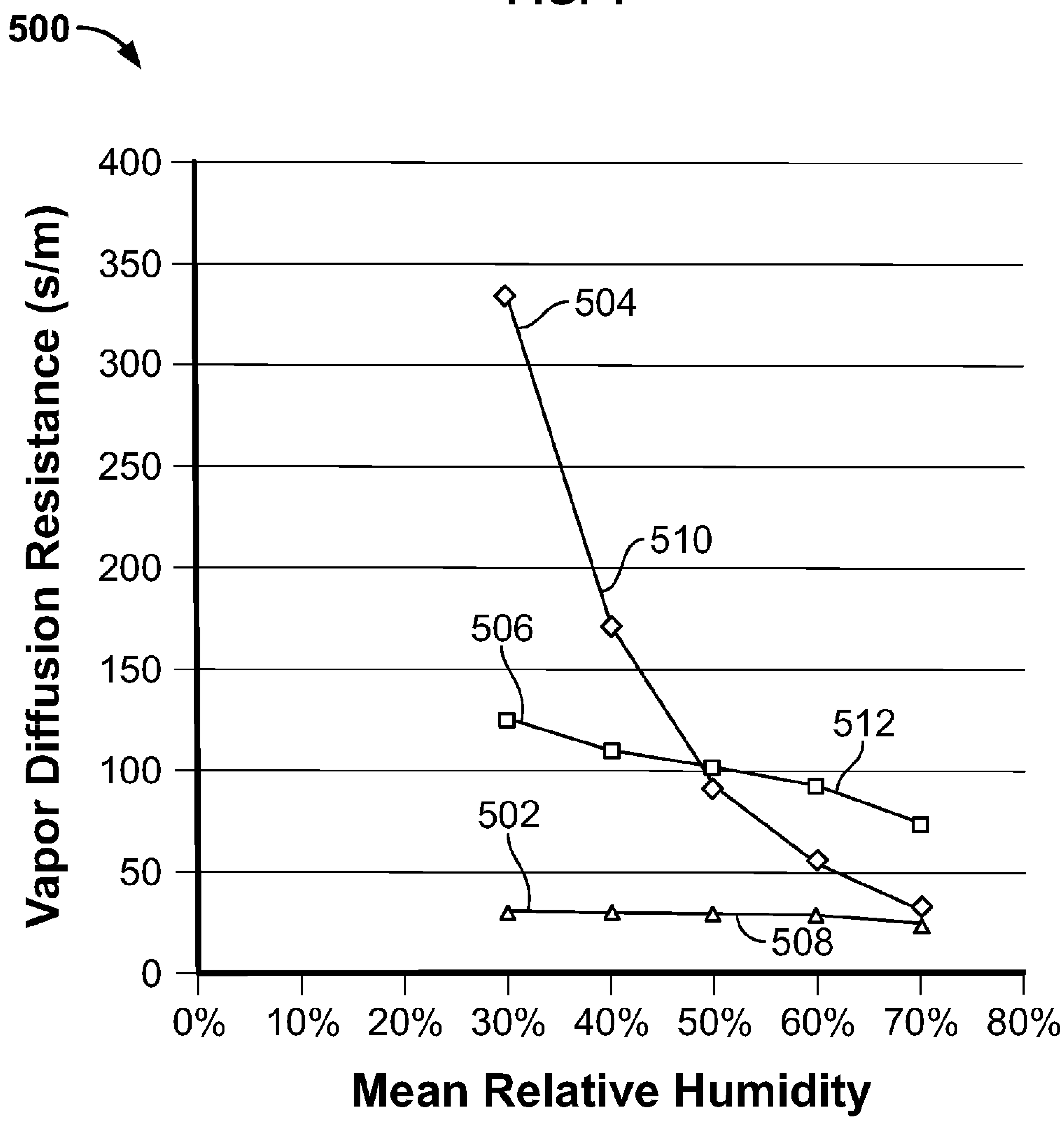
500
Vapor Diffusion Resistance (s/m)
400
350
300
250
200
150
100
50
0
504
510
506
512
502
508
0%
10%
20%
30%
40%
50%
60%
70%
80%
Mean Relative Humidity

FIG. 5

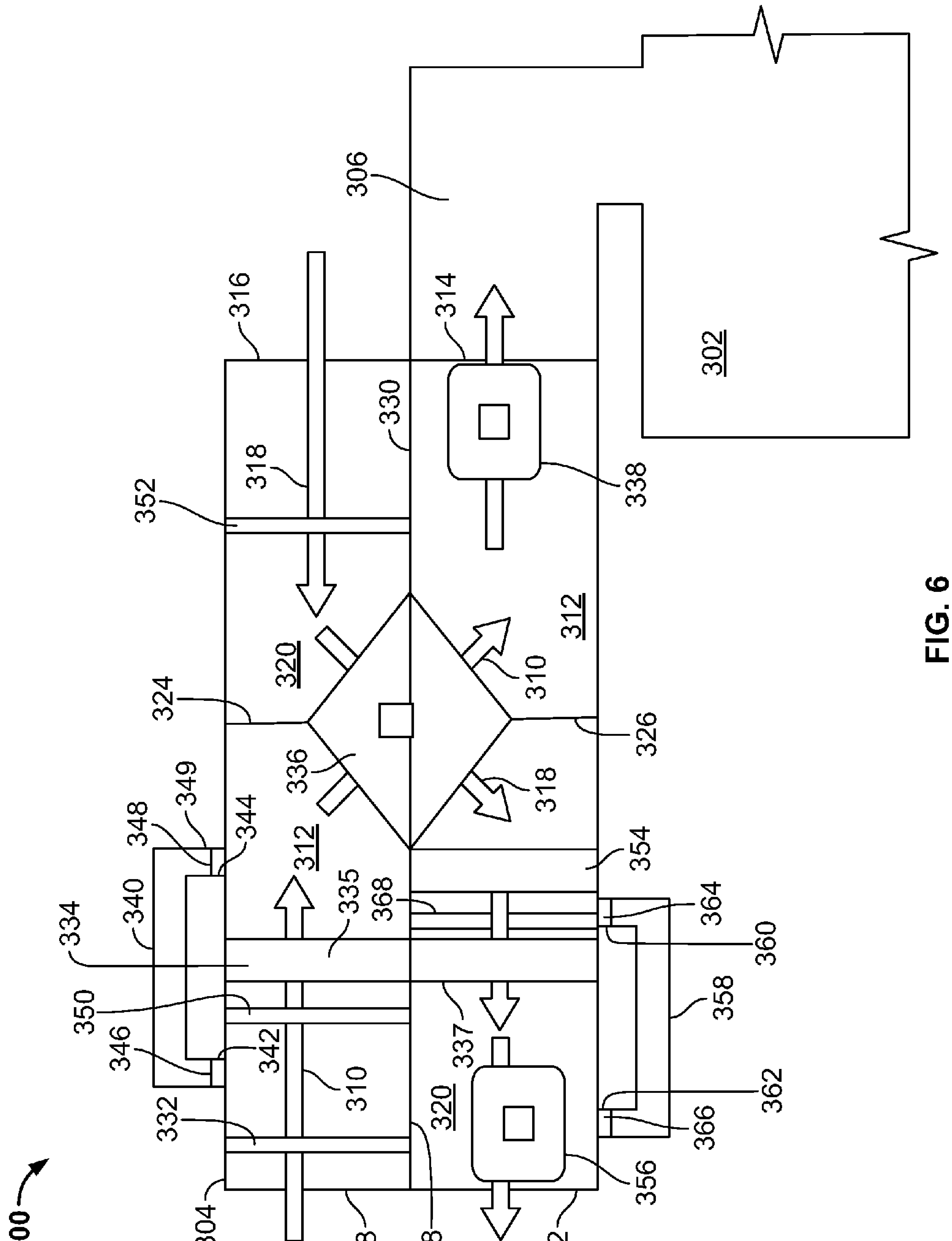
300
302
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FIG. 6

ENERGY EXCHANGE ASSEMBLY WITH MICROPOROUS MEMBRANE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application relates to and claims priority benefit from U.S. Provisional Patent Application No. 61/784,638, entitled "Air-To-Air Energy Recovery Core With Microporous Membrane," filed Mar. 14, 2013, which is hereby expressly incorporated by reference in its entirety.

BACKGROUND OF THE DISCLOSURE

[0002] Embodiments of the present disclosure generally relate to an energy exchange assembly, such as an energy recovery core, that incorporates a microporous membrane.

[0003] Energy exchange assemblies are used to transfer energy, such as sensible and/or latent energy, between fluid streams. For example, air-to-air energy recovery cores are used in heating, ventilation, and air conditioning (HVAC) applications to transfer heat (sensible energy) and moisture (latent energy) between two airstreams. A typical energy recovery core is configured to precondition outdoor air to a desired condition through the use of air that is exhausted out of the building. For example, outside or supply air is channeled through the energy recovery core in proximity to exhaust air. Energy between the supply and exhaust air streams is transferred therebetween. In the winter, for example, cool and dry outside air is warmed and humidified through energy transfer with the warm and moist exhaust air. As such, the sensible and latent energy of the outside air is increased, while the sensible and latent energy of the exhaust air is decreased. The energy recovery core typically reduces post-conditioning of the supply air before it enters the building, thereby reducing overall energy use of the system.

[0004] Air-to-air recovery cores may include a membrane through which heat and moisture are transferred between air streams. The membrane may be separated from adjacent membranes using a spacer. In an energy recovery core, the amount of heat transferred is generally determined by a temperature difference and convective heat transfer coefficient of the two air streams, as well as the material properties of the membrane. The amount of moisture transferred in the core is generally governed by a humidity difference and convective mass transfer coefficients of the two air streams, but also depends on the material properties of the membrane.

[0005] One known type of membrane used in an energy recovery core is a non-porous hygroscopic membrane. This membrane has a hygroscopic coating which is bonded to a resin or paper-like substrate material. The hygroscopic coating is used to drive moisture transfer through the membrane, while the substrate is used for an added layer of support. The hygroscopic coating may be configured to allow very little air transfer through the membrane at standard operating differential pressures. However, the ability for the membrane to transfer moisture typically depends on the relative humidity of the air. In a very humid environment, hygroscopic membranes have a low vapor diffusion resistance. In low humidity environments, however, hygroscopic membranes have a high vapor diffusion resistance. As such, an energy recovery core including such membranes generally exhibits a large change in latent effectiveness between heating and cooling conditions.

[0006] Another known type of membrane used in an energy recovery core is a composite polymer membrane. The composite polymer membrane has a thin vapor-promoting polymer film coated on a porous polymer substrate. The polymer film is used to drive moisture transfer through the membrane and prohibit airflow through the membrane at standard operating differential pressures. The porous polymer substrate may be used to reinforce the membrane while allowing the transfer of vapor therethrough. In adding and bonding multiple polymer layers together, however, the resistance to moisture transfer (i.e., the vapor diffusion resistance) through the membrane increases. Depending on the polymer film used in the composite membrane, the vapor diffusion resistance may be highly dependent on the relative humidity of the air streams.

SUMMARY OF THE DISCLOSURE

[0007] Certain embodiments of the present disclosure provide an energy exchange assembly that may include one or more membrane panels. The one or more membrane panels may include a microporous membrane that has a pore size between 0.02 and 0.3 micrometers (μm) and a porosity between 45% and 80%.

[0008] Optionally, the energy exchange assembly may further include a plurality of spacers that define air channels. The air channels may be configured to receive air streams therethrough. Each of the one or more membrane panels may be disposed between two spacers. The one or more membrane panels may be configured to allow a transfer of sensible energy and latent energy across the one or more membrane panels between the air channels. Optionally, the pore size of the microporous membrane may be between 0.04 and 0.2 μm. The porosity of the microporous membrane may be between 50% and 75%. The microporous membrane may have a vapor diffusion resistance below 40 seconds/meter (sec/m) and an air permeability below 0.06 $ft^3/min/ft^2$.

[0009] Certain embodiments of the present disclosure provide an energy exchange system that may include a supply air flow path configured to channel supply air to an enclosed structure, a regeneration air flow path configured to channel regeneration air from the enclosed structure to an outside environment, and an energy exchange assembly disposed within the supply air flow path and the regeneration air flow path. The energy exchange assembly may include a plurality of spacers and a plurality of membrane panels. Each membrane panel may include a microporous membrane that has a pore size between 0.02 and 0.3 micrometers (μm) and a porosity between 45% and 80%. Each of the spacers may be positioned between two of the membrane panels to define air channels through the spacer between the two membrane panels. The air channels may be configured to receive air streams therethrough. The membrane panels may be configured to allow a transfer of sensible energy and latent energy across the membrane panels between the air channels.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** illustrates a perspective top view of an energy exchange assembly, according to an embodiment of the present disclosure.

[0011] FIG. **2** illustrates a perspective exploded top view of two adjacent layers of the energy exchange assembly shown in FIG. **1**, according to an embodiment of the present disclosure.

[0012] FIG. **3** illustrates an end view of two adjacent layers of the energy exchange assembly shown in FIG. **1**, according to an embodiment of the present disclosure.

[0013] FIG. **4** illustrates a magnified microporous membrane of the energy exchange assembly shown in FIG. **1**, according to an embodiment of the present disclosure.

[0014] FIG. **5** illustrates a graph plotting vapor diffusion resistance versus mean relative humidity for comparison between three membranes.

[0015] FIG. **6** illustrates a simplified schematic view of an energy exchange system operatively connected to an enclosed structure, according to an embodiment of the present disclosure.

[0016] Before the embodiments are explained in detail, it is to be understood that the disclosure is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The disclosure is capable of other embodiments and of being practiced or being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein are for the purpose of description and should not be regarded as limiting. The use of "including" and "comprising" and variations thereof is meant to encompass the items listed thereafter and equivalents thereof as well as additional items and equivalents thereof.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0017] 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.

[0018] FIG. **1** illustrates a perspective top view of an energy exchange assembly **10**, according to an embodiment of the present disclosure. The energy exchange assembly **10** may be an energy recovery core, a plate heat exchanger, or the like configured to transfer energy between fluid streams, such as first and second air streams **12** and **14**. As such, the energy exchange assembly **10** may be an air-to-air energy recovery core assembly.

[0019] The energy exchange assembly **10** may include a plurality of microporous membranes **16** separated by spacers **18**. The membranes **16** may be formed of a microporous material that is configured to allow sensible and latent energy to pass therebetween. The membranes **16** may be designed with a pore size and a porosity that achieves a desired balance of air permeability and vapor permeability. For example, the characteristics of the microporous membranes **16** may be designed to enhance the transfer of vapor across the membranes **16** while also reducing the air transfer across the membranes **16**. By stacking the membranes **16** and the spacers **18**, channels **19** are formed that allow the first and second air streams **12** and **14** to pass through the energy exchange assembly **10**.

[0020] The energy exchange assembly **10** may be oriented so that the first air stream **12** may be outside air that is to be conditioned, while the second air stream **14** may be exhaust, return, or scavenger air that is used to condition the outside air before the outside air is supplied to downstream HVAC equipment and/or an enclosed space as supply air. Heat and moisture may be transferred between the first and second air streams **12** and **14** through the membranes **16** within the energy exchange assembly **10**.

[0021] The microporous membranes **16** and spacers **18** may be secured between outer upstanding brackets **20**, a base **22**, and a top wall **24**. As shown, the brackets **20** may generally be at the corners of the energy exchange assembly **10**. The base **22**, the top wall **24**, and the brackets **20** provide a main housing defining an internal chamber into which the membranes **16** and the spacers **18** are secured.

[0022] The energy exchange assembly **10** may include a plurality of layers or levels **26** which are vertically stacked along an elevation axis z. Each layer **26** may include a spacer **18** positioned between two microporous membranes **16**. One membrane **16** may be below the spacer **18**, while the other membrane **16** in the layer **26** is disposed above the spacer **18**. In an embodiment, the spacers **18** and membranes **16** are stacked in an alternating pattern such that only one membrane **16** separates adjacent spacers **18**. Thus, adjacent layers **26**A, **26**B may share one membrane **16**. The spacers **18** in adjacent layers **26**A, **26**B may be oriented orthogonally to each other such that the air channels **19** through the spacers **18** channel the air in different directions. For example, the air channels **19** in the layers **26**A may be oriented parallel to an axis y, while the air channels **19** in the layers **26**B may be oriented parallel to an axis x, which is perpendicular (or oriented at an acute angle) to the axis y. Thus, the levels **26**A may be oriented to receive the second air stream **14** at an inlet side **30** and direct the second air stream **14** to an outlet side **31**, while the levels **26**B may be oriented to receive the first air stream **12** at an inlet side **32**, which is perpendicular to the inlet side **30**, and direct the first air stream **12** to an outlet side **33**, which is perpendicular to the outlet side **31**. Therefore, the air stream **14**, passing through the levels **26**A, travels in a cross-flow direction with the air stream **12** passing through the levels **26**B. In this manner, sensible and/or latent energy may be exchanged between the levels **26**A and **26**B.

[0023] For example, as shown in FIG. **1**, the first air stream **12** may enter the inlet side **32** as cool, dry air. As the first air stream **12** passes through the energy exchange assembly **10**, the temperature and humidity of the first stream **12** are both increased through energy transfer with the second air stream **14** that enters the energy exchange assembly **10** through the inlet side **30** as warm, moist air. Accordingly, the first air stream **12** passes out of the outlet side **33** as warmer, moister air (as compared to the first air stream **12** before passing into the inlet side **32**), while the second air stream **14** passes out of the outlet side **31** as cooler, drier air (as compared to the second air stream **14** before passing into the inlet side **30**). In general, the temperature and humidity of the first and second air streams **12** and **14** passing through the levels **26**A and **26**B tends to at least partially equilibrate with one another. For example, warm, moist air within the levels **26**A is cooled and dried by heat exchange with the cooler, drier air in the levels **26**B. Cool, dry air within the levels **26**B is warmed and moistened by the warmer, cooler air within the levels **26**A. As a result, the second air stream **14** that passes through the levels **26**A may be cooler and drier after passing through the energy exchange assembly **10**. Conversely, the first air stream **12** that passes through the levels **26**B may be warmer and moister after passing through the energy exchange assembly **10**.

[0024] FIG. **2** illustrates a perspective exploded top view of two adjacent layers **26** of the energy exchange assembly **10** shown in FIG. **1**, according to an embodiment of the present disclosure. The layers **26** include alternating spacers **18** and microporous membranes **16**, which are stacked on top of each other in a layer stack **202**. The microporous membranes **16** may form a part of membrane panels **206**, which are alternatively stacked with the spacers **18**. The membrane panels **206** may each include a sheet of the microporous membrane **16** and an outer frame **208** to which the membrane **16** is attached, disposed, or integrated. The outer frame **208** may be a plastic or other polymer frame that retains the microporous membrane **16** in a stretched or at least tight configuration within an inner space (not shown) defined by the frame **208**. The frame **208** may engage the spacers **18** when assembling the layer stack **202**. In an alternative embodiment, the membrane panels **206** do not include an outer frame **208**.

[0025] The microporous membranes **16** may include thin, porous sheets composed of expanded polytetrafluoroethylene (ePTFE), polypropylene (PP), nylon, polyvinylidene fluoride (PVDF), polyethersulfone (PES), combinations thereof, or the like. The membranes **16** may be hydrophobic or hydrophilic (for example, if composed of nylon). The membranes **16** optionally may be manufactured by a dry stretch process, a wet stretch process, or another process. In at least one embodiment, the membrane panels **206** may include a backing layer (not shown in FIG. **2**) that is bonded to the microporous membrane **16** to provide structural support to the membrane **16**. The backing layer may be a spunbond non-woven or a non-woven mesh. The backing layer may be made from materials including polypropylene (PP), polyethylene (PE), polyester, nylon, fiberglass, and/or the like. The backing layer of the membrane panel **206** provides support to the microporous membrane **16**, making the membrane **16** stiffer and more durable. In at least one embodiment, each backing layer is bonded to a single sheet or layer of the microporous membrane **16** to form each membrane panel **206**.

[0026] The spacers **18** may be formed of plastic, metal, or the like. As shown in FIG. **2**, the spacers **18** include walls **210** that are aligned parallel to each other, and connecting cross-bars **212** that structurally support the walls **210**. The air channels **19** are formed between adjacent walls **210** and extend along the length of the walls **210**. For example, the walls **210** may engage the membrane panels **206** above and below the spacer **18**. The height of the walls **210** may define the height of the channels **19**. The cross-bars **212** may have a small height relative to the walls **210** to prohibit the cross-bars **212** from impeding the flow of air through the channels **19**. In alternative embodiments, the spacers **18** may have various other sizes and shapes. For example, the spacers may be corrugated with curved, undulating walls or saw tooth angled walls instead of upstanding walls.

[0027] During assembly of the layer stack **202**, a lower spacer **18**A is mounted on top of a lower membrane panel **206**A. A middle membrane panel **206**B is subsequently mounted on top of the spacer **18**A. An upper spacer **18**B is then mounted on the middle membrane panel **206**B, and an upper membrane panel **206**C is mounted on the upper spacer **18**B. As used herein, relative or spatial terms such as "top," "bottom," "upper," "lower," and "middle" are only used to distinguish the referenced elements and do not necessarily require particular positions or orientations in the energy exchange assembly **10** (shown in FIG. **10**) or in the surrounding environment of the energy exchange assembly **10**. The stacking pattern may continue to produce an energy exchange assembly **10** of a desired height. In an embodiment, the upper spacer **18**B is rotated 90° relative to the lower spacer **18**A. Consequently, the channels **19** through the spacer **18**A are orthogonal to the channels **19** through the spacer **18**B, so that air flows through the channels **19** of the adjacent layers **26**A, **26**B in a cross-flow direction. Alternatively, the membranes **16** and the spacers **18** may be arranged to support various other air flow orientations, such as counter-flow, concurrent flow, and the like.

[0028] FIG. **3** illustrates an end view of two adjacent layers **26** of the layer stack **202** (shown in FIG. **2**) according to an embodiment of the present disclosure. The two layers **26** include three membrane panels **206** and two spacers **18** that separate the panels **206**. The spacers **18** may each include upstanding parallel walls **210** that define air channels **19** therebetween. For example, the spacers **18** may be oriented orthogonally to each other such that the walls **210** of the upper spacer **18**B are oriented perpendicularly to the walls **210** of the lower spacer **18**A. Air flow is configured to flow in the directions **220** and **222** through the air channels **19** between the membrane panels **206**. Direction **220** is shown to extend into the page, and direction **222** is shown to extend towards the right. Optionally, the directions **220**, **222** may be reversed. The first air stream **12** (shown in FIG. **1**) may be configured to flow in the direction **222**, and the second air stream **14** (FIG. **1**) may be configured to flow in the direction **220**. Sensible and latent energy may be transferred to or from the air streams in the direction of arrows **224** through the membrane panels **206**. The membrane panels **206** include a microporous membrane (shown in FIG. **2**) that is designed to maximize the amount of vapor that transfers across the membrane panels **206** while minimizing the transfer of air across the panels **206**.

[0029] FIG. **4** illustrates a magnified microporous membrane **16** of the energy exchange assembly **10** shown in FIG. **1**, according to an embodiment. In order to balance the air permeability with vapor permeability (for example, vapor diffusion resistance), the microporous membrane **16** may have a specific range of characteristics. For example, the microporous membrane **16** may include various pores **402** that extend through the thin membranes **16**. The pores **402** may have a pore size or diameter **404** that is less than 0.5 micrometers (μm). In an embodiment, the pore size **404** of the pores **402** is between 0.01 and 0.4 μm. As used herein, the term "between" that introduces a range of values means "between and including" such that the range includes the listed end values. More specifically, the pore size **404** may be between 0.02 and 0.3 μm. More specifically, the pore size **404** may be between 0.04 and 0.2 μm, or more specifically between 0.06 and 0.1 μm. The pore size **404** and/or range of sizes is selected to reduce the vapor diffusion resistance of the membrane **16** to allow vapor transfer while also sufficiently reducing air permeability through the membrane **16**. In an embodiment, the shape of the pores **402** is not limited. For example, the pores **402** may be elliptical, as shown in FIG. **4**, or may be rectangular, circular, or the like.

[0030] The microporous membrane **16** may have a porosity between 40% and 80%. The porosity is the fraction or percentage of voids or empty spaces within a material. In an embodiment, the porosity of the microporous membrane **16** may be between 45% and 80%. More specifically, the porosity may be between 50% and 75%, or more specifically between 55% and 70%.

[0031] In an embodiment, the microporous membrane **16** may have a membrane vapor diffusion resistance below 50 second/meters (sec/m) (measured using the DMPC method with the inlet air streams set to 5% relative humidity (RH) and 95% RH) and an air permeability below 0.08 $ft^3/min/ft^2$ (0.041 $cm^3/sec/cm^2$) at 0.5 inches of water (inH_2O) (based on ASTM D737) (approximately 125 Pa). More specifically, the membrane vapor diffusion resistance may be below 40 sec/m and the air permeability below 0.06 $ft^3/min/ft^2$ (0.03 $cm^3/sec/cm^2$) at 0.5 inH_2O. For example, the membrane vapor diffusion resistance may be below 35 sec/m and the air permeability below 0.0574 $ft^3/min/ft^2$ (0.029 $cm^3/sec/cm^2$) at 0.5 inH_2O.

[0032] Referring now back to FIG. **2**, the thickness of the microporous membrane **16** also affects the rigidity and moisture vapor transfer rate (MVTR), which is directly related to the vapor diffusion resistance. For example, the rigidity of the membrane **16** increases by selecting a thicker material with the same pore size and porosity. However increasing the thickness of the membrane **16** reduces the MVTR. Therefore, the thickness may be selected to achieve a balance between rigidity and MVTR. The thickness of the membrane **16** may be reduced while preserving rigidity by laminating the membrane **16** onto the backing layer (not shown). For example, the thickness of the membrane **16** may be less than 50 μm, such as between 10 and 40 μm. More specifically, the thickness of the membrane **16** may be between 15 and 40 μm. When the membrane **16** is bonded to the backing layer, the thickness of the membrane panel **206** may be between 100 and 400 μm, such as between 200 and 300 μm. The backing layer may have higher pore sizes and porosities relative to the microporous membrane **16**, so the backing layer does not significantly affect (for example, has only a negligible impact on) vapor transmission and/or air transmission through the membrane panel **206**. In at least one embodiment, the backing layer and the membrane **16** have a combined stiffness (defined as the product of the modulus of elasticity and the material thickness) above 15 MPa·mm. More specifically, the stiffness may be above 25 MPa·mm.

[0033] As an example, a microporous membrane for use in an air-to-air energy recovery core may be made out of polypropylene, with a pore size of 0.06 μm, a porosity of 55%, and a thickness of 25 μm, and may be bonded it to a polyethylene mesh backing. The resulting membrane may have a vapor diffusion resistance of 28 sec/m, airflow permeability of 0.0146 $ft^3/min/ft^2$ (0.0074 $cm^3/sec/cm^2$) at 0.5 inches of water (inH_2O) (approximately 125 Pa), and a stiffness of 55 MPa·mm. When the resulting membrane is used in the membrane panels of an energy exchange core having a size of 21 in.×21 in.×18.625 in. (53.3 cm×53.3 cm×47.3 cm) and a channel thickness of 3.5 mm, the resulting performance of the energy exchange core is a total effectiveness of 55% and an Outdoor Air Correction Factor of 1.07 at a differential pressure of 5 inH_2O (based on ASHRAE Standard 84) (approximately 1.244 kPa).

[0034] As another example, a microporous membrane for use in an air-to-air energy recovery core may be formed of polypropylene, having a pore size of 0.1 μm, a porosity of 67%, and a thickness of 20 μm, and is bonded it to a 3.0 oz. (approximately 85 g) polypropylene spunbond non-woven backing. The resulting membrane has a vapor diffusion resistance of 17 sec/m, airflow permeability of 0.0382 $ft^3/min/ft^2$ (0.019 $cm^3/sec/cm^2$) at 0.5 inH_2O, and a stiffness of 27 MPa·mm. When the resulting membrane is used in the same energy exchange assembly of size 21 in.×21 in.×18.625 in. (53.3 cm×53.3 cm×47.3 cm) with a channel thickness of 3.5 mm, the resulting performance is a total effectiveness of 60% and an Outdoor Air Correction Factor of 1.07 at a differential pressure of 2 inH2O (based on ASHRAE Standard 84) (approximately 250 Pa).

[0035] FIG. **5** illustrates a graph **500** plotting vapor diffusion resistance versus mean relative humidity for comparison between three membranes. The graph **500** compares a microporous membrane **502**, as described herein, to other known membranes, including a non-porous hygroscopic membrane **504** and a composite polymer membrane **506**. As shown in FIG. **5**, the microporous membrane **502** may have less vapor diffusion resistance than both the non-porous hygroscopic membrane **504** and the composite polymer membrane **506**. In addition, the microporous membrane **502** may have a low (or even negligible) dependency on humidity, as shown by the relative lack of a slope **508** in the trend line for the microporous membrane **502**. The vapor diffusion resistance of the other two membranes **504**, **506** may be at least moderately dependent on humidity.

[0036] As seen in FIG. **5**, the disadvantage of the non-porous hygroscopic membrane **504** is that the ability for the membrane to transfer moisture is highly dependent on the relative humidity of the air. In a very humid environment, hygroscopic membranes have a low vapor diffusion resistance, while in a low humidity environment, the membranes have a high vapor diffusion resistance. This characteristic is shown by the drastic slope **510** in FIG. **5** as the humidity increases.

[0037] One of the primary disadvantages of the composite polymer membrane **506** is that by adding and bonding multiple polymer layers together, the resistance to moisture transfer through the membrane increases. Thus, as shown in FIG. **5**, the vapor diffusion resistance is significantly higher than that of the microporous membrane **502**. Depending on the polymer film used in the composite membrane **506**, the vapor diffusion resistance may also be at least moderately dependent on the relative humidity of the air, as seen in FIG. **5** by the negative slope **512** of the trend line for the composite membrane **506**.

[0038] In addition, although not shown in FIG. **5**, manufacturing the microporous membrane as a single layer membrane with a supporting backing layer may be cheaper to produce than typical multi-layer membranes. The typical multi-layer membranes either incorporate a hydrophobic or hydrophilic coating or an additional second membrane layer in order to achieve low water vapor diffusion resistance and low air permeability. In an exemplary embodiment, the microporous membrane does not include any additional coating or layer, excluding the support backing which does not affect vapor diffusion or air permeability.

[0039] FIG. **6** illustrates a simplified schematic view of an energy exchange system **300** operatively connected to an enclosed structure **302**, according to an embodiment of the present disclosure. The energy exchange system **300** may include a housing **304**, such as a self-contained module or unit that may be mobile (for example, the housing **304** may be moved among a plurality of enclosed structures), operatively connected to the enclosed structure **302**, such as through a connection line **306**, such as a duct, tube, pipe, conduit, plenum, or the like. The housing **304** may be configured to be removably connected to the enclosed structure **302**. Alternatively, the housing **304** may be permanently secured to the enclosed structure **302**. As an example, the housing **304** may be mounted to a roof, outer wall, or the like, of the enclosed structure **302**. The enclosed structure **302** may be a room of a building, a commodities storage structure, or the like.

[0040] The housing **304** includes a supply air inlet **308** that connects to a supply air flow path **310**. The supply air flow path **310** 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 **310** is configured to deliver supply air **312** to the enclosed structure **302** through a supply air outlet **314** that connects to the connection line **306**. The supply air **312** may be received in the supply air flow path **310** from the atmosphere (for example, an outside environment). Alternatively, the supply air **312** may be received from the enclosed structure **302** as return supply air.

[0041] The housing **304** also includes a regeneration air inlet **316** that connects to a regeneration air flow path **318**. The regeneration air flow path **318** may be formed by ducts, conduits, plenum, tubes, or the like, which may be formed by metal and/or plastic walls. The regeneration air flow path **318** is configured to channel regeneration air **320** received from the enclosed structure **302** to the atmosphere (for example, an outside environment) through an exhaust air outlet **322**. Alternatively, the regeneration air **320** may be received from the atmosphere and channeled back to the atmosphere through the exhaust air outlet **322**.

[0042] As shown in FIG. **6**, the supply air inlet **308** and the regeneration air inlet **316** may be longitudinally aligned. For example, the supply air inlet **308** and the regeneration air inlet **316** may be at opposite ends of a linear column or row of ductwork. A separating wall **324** may separate the supply air flow path **310** from the regeneration air flow path **318** within the column or row. Similarly, the supply air outlet **314** and the exhaust air outlet **322** may be longitudinally aligned. For example, the supply air outlet **314** and the exhaust air outlet **322** may be at opposite ends of a linear column or row of ductwork. A separating wall **326** may separate the supply air flow path **310** from the regeneration air flow path **318** within the column or row.

[0043] The supply air inlet **308** may be positioned above the exhaust air outlet **322**, and the supply air flow path **310** may be separated from the regeneration air flow path **318** by a partition **328**. Similarly, the regeneration air inlet **316** may be positioned above the supply air outlet **314**, and the supply air flow path **310** may be separated from the regeneration air flow path **318** by a partition **330**. Thus, the supply air flow path **310** and the regeneration air flow path **318** may cross one another proximate to a center of the housing **304**. While the supply air inlet **308** may be at the top and left of the housing **304**, the supply air outlet **314** may be at the bottom and right of the housing **304**. Further, while the regeneration air inlet **316** may be at the top and right of the housing **304**, the exhaust air outlet **322** may be at the bottom and left of the housing **304**.

[0044] Alternatively, the supply air flow path **310** and the regeneration air flow path **318** may be inverted and/or otherwise re-positioned. For example, the exhaust air outlet **322** may be positioned above the supply air inlet **308**. Additionally, alternatively, the supply air flow path **310** and the regeneration air flow path **318** may be separated from one another by more than the separating walls **324** and **326** and the partitions **328** and **330** within the housing **304**. For example, spaces, which may contain insulation, may also be positioned between segments of the supply air flow path **310** and the regeneration air flow path **318**. Also, alternatively, the supply air flow path **310** and the regeneration air flow path **318** may simply be straight, linear segments that do not cross one another. Further, instead of being stacked, the housing **304** may be shifted 90 degrees about a longitudinal axis aligned with the partitions **328** and **330**, such that that supply air flow path **310** and the regeneration air flow path **318** are side-by-side, instead of one on top of another.

[0045] An air filter **332** may be disposed within the supply air flow path **310** proximate to the supply air inlet **308**. The air filter **332** may be a standard HVAC filter configured to filter contaminants from the supply air **312**. Alternatively, the energy exchange system **300** may not include the air filter **332**.

[0046] An energy transfer device **334** may be positioned within the supply air flow path **310** downstream from the supply air inlet **308**. The energy transfer device **334** may span between the supply air flow path **310** and the regeneration air flow path **318**. For example, a supply portion or side **335** of the energy transfer device **334** may be within the supply air flow path **310**, while a regenerating portion or side **337** of the energy transfer device **334** may be within the regeneration air flow path **318**. In an alternative embodiment, the energy transfer device **334** or an additional energy transfer device may be disposed within the supply air flow path **310** downstream of the energy exchange assembly **336** and within the regeneration air flow path **318** upstream of the energy exchange assembly **336** in order to provide energy transfer between the supply air **312** and the regeneration air **320**. The energy transfer device **334** may be a desiccant wheel, a heat pipe, or a heat plate, for example. However, the energy transfer device **334** may be various other systems and assemblies, such as including liquid-to-air membrane energy exchangers (LAMEEs), as described below.

[0047] An energy exchange assembly **336**, which may be formed as described above with respect to FIGS. **5-16**, is disposed within the supply air flow path **310** downstream from the energy transfer device **334**. The energy exchange assembly **336** may be positioned at the junction of the separating walls **324**, **326** and the partitions **328**, **330**. The energy exchange assembly **336** may be positioned within both the supply air flow path **310** and the regeneration air flow path **318**. As such, the energy exchange assembly **336** is configured to transfer energy between the supply air **312** and the regeneration air **320**.

[0048] One or more fans **338** may be positioned within the supply air flow path **310** downstream from the energy exchange assembly **336**. The fan(s) **338** is configured to move the supply air **312** from the supply air inlet **308** and out through the supply air outlet **314** (and ultimately into the enclosed structure **302**). Alternatively, the fan(s) **338** may be located at various other areas of the supply air flow path **310**, such as proximate to the supply air inlet **308**. Also, alternatively, the energy exchange system **300** may not include the fan(s).

[0049] The energy exchange system **300** may also include a bypass duct **340** having an inlet end **342** upstream from the energy transfer device **334** within the supply air flow path **310**. The inlet end **342** connects to an outlet end **344** that is downstream from the energy transfer device **334** within the supply air flow path **310**. An inlet damper **346** may be positioned at the inlet end **342**, while an outlet damper **348** may be positioned at the outlet end **344**. The dampers **346** and **348** may be actuated between open and closed positions to provide a bypass line for the supply air **312** to bypass around the energy transfer device **334**. Further, a damper **350** may be disposed within the supply air flow path **310** downstream from the inlet end **342** and upstream from the energy transfer device **334**. The damper **350** may be closed in order to allow the supply air **312** to flow into the bypass duct **340** around the energy transfer device **334**. The dampers **346**, **348**, and **350** may be modulated between fully-open and fully-closed positions to allow a portion of the supply air **312** to pass through the energy transfer device **334** and a remaining portion of the supply air **312** to bypass the energy transfer device **334**. As such, the bypass dampers **346**, **348**, and **350** may be operated to control the temperature and humidity of the supply air **312** as it is delivered to the enclosed structure **302**. Examples of bypass ducts and dampers are further described in U.S. patent application Ser. No. 13/426,793, entitled "System and Method For Conditioning 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 **300** may not include the bypass duct **340** and dampers **346**, **348**, and **350**.

[0050] As shown in FIG. **6**, the supply air **312** enters the supply air flow path **310** through the supply air inlet **308**. The supply air **312** is then channeled through the energy transfer device **334**, which pre-conditions the supply air **312**. After passing through the energy transfer device **334**, the supply air **312** is pre-conditioned and passes through the energy exchange assembly **336**, which conditions the pre-conditioned supply air **312**. The fan(s) **338** may then move the supply air **312**, which has been conditioned by the energy exchange assembly **336**, through the energy exchange assembly **336** and into the enclosed structure **302** through the supply air outlet **314**.

[0051] With respect to the regeneration air flow path **318**, an air filter **352** may be disposed within the regeneration air flow path **318** proximate to the regeneration air inlet **316**. The air filter **352** may be a standard HVAC filter configured to filter contaminants from the regeneration air **320**. Alternatively, the energy exchange system **300** may not include the air filter **352**.

[0052] The energy exchange assembly **336** may be disposed within the regeneration air flow path **318** downstream from the air filter **352**. The energy exchange assembly **336** may be positioned within both the supply air flow path **310** and the regeneration air flow path **318**. As such, the energy exchange assembly **336** is configured to transfer sensible energy and latent energy between the regeneration air **320** and the supply air **312**.

[0053] A heater **354** may be disposed within the regeneration air flow path **318** downstream from the energy exchange assembly **336**. The heater **354** may be a natural gas, propane, or electric heater that is configured to heat the regeneration air **320** before it encounters the energy transfer device **334**. Optionally, the energy exchange system **300** may not include the heater **354**.

[0054] The energy transfer device **334** is positioned within the regeneration air flow path **318** downstream from the heater **354**. As noted, the energy transfer device **334** may span between the regeneration air flow path **318** and the supply air flow path **310**.

[0055] As shown in FIG. **6**, the supply side **335** of the energy transfer device **334** is disposed within the supply air flow path **310** proximate to the supply air inlet **308**, while the regeneration side **337** of the energy transfer device **334** is disposed within the regeneration air flow path **310** proximate to the exhaust air outlet **322**. Accordingly, the supply air **312** encounters the supply side **335** as the supply air **312** enters the supply air flow path **310** from the outside, while the regeneration air **320** encounters the regeneration side **337** just before the regeneration air **320** is exhausted out of the regeneration air flow path **318** through the exhaust air outlet **322**.

[0056] One or more fans **356** may be positioned within the regeneration air flow path **318** downstream from the energy transfer device **334**. The fan(s) **356** is configured to move the regeneration air **320** from the regeneration air inlet **316** and out through the exhaust air outlet **322** (and ultimately into the atmosphere). Alternatively, the fan(s) **356** may be located at various other areas of the regeneration air flow path **318**, such as proximate to the regeneration air inlet **316**. Also, alternatively, the energy exchange system **300** may not include the fan(s).

[0057] The energy exchange system **300** may also include a bypass duct **358** having an inlet end **360** upstream from the energy transfer device **334** within the regeneration air flow path **318**. The inlet end **360** connects to an outlet end **362** that is downstream from the energy transfer device **334** within the regeneration air flow path **318**. An inlet damper **364** may be positioned at the inlet end **360**, while an outlet damper **366** may be positioned at the outlet end **362**. The dampers **364** and **366** may be actuated between open and closed positions to provide a bypass line for the regeneration air **320** to flow around the energy transfer device **334**. Further, a damper **368** may be disposed within the regeneration air flow path **318** downstream from the heater **354** and upstream from the energy transfer device **334**. The damper **368** may be closed in order to allow the regeneration air to bypass into the bypass duct **358** around the energy transfer device **334**. The dampers **364**, **366**, and **368** may be modulated between fully-open and fully-closed positions to allow a portion of the regeneration air **320** to pass through the energy transfer device **334** and a remaining portion of the regeneration air **320** to bypass the energy transfer device **334**. Alternatively, the energy exchange system **300** may not include the bypass duct **358** and dampers **364** and **166**.

[0058] As shown in FIG. **6**, the regeneration air **320** enters the regeneration air flow path **318** through the regeneration air inlet **316**. The regeneration air **320** is then channeled through the energy exchange assembly **336**. After passing through the energy exchange assembly **336**, the regeneration air **320** passes through the heater **354**, where it is heated, before encountering the energy transfer device **334**. The fan(s) **356** may then move the regeneration air **320** through the energy transfer device **334** and into the atmosphere through the exhaust air outlet **322**.

[0059] As described above, the energy exchange assembly **336**, which may be formed according to any of the methods described above, may be used with respect to the energy exchange system **300**. Optionally, the energy exchange assembly **336** may be used with various other systems that are configured to condition outside air and supply the conditioned air as supply air to an enclosed structure, for example. The energy exchange assembly **336** may be positioned within a supply air flow path, such as the path **310**, and a regeneration or exhaust air flow path, such as the path **318**, of a housing, such as the housing **304**. The energy exchange system **300** may include only the energy exchange assembly **336** within the paths **310** and **318** of the housing **304**, or may alternatively include any of the additional components shown and described with respect to FIG. **6**.

[0060] Embodiments of the present disclosure provide an energy exchange assembly, such as an energy recovery core, that utilizes a microporous membrane in membrane panels to increase the latent effectiveness of the assembly. The membrane panels may not require a hydrophilic layer or multiple composite layers, other than a structural backing layer which may be added for support. The microporous membrane may not be significantly dependent on the relative humidity of the air, which allows the energy exchange assembly to have a similar effectiveness in a hot, humid climate and a cool, dry climate. The microporous membrane may include many pores, which allow water vapor through the membrane. The pore size of the pores may be designed to increase the water vapor transfer rate and reduce the vapor diffusion resistance. Some air may also pass through the pores across the membrane, but the amount of airflow may be maintained at an acceptable level by optimizing the properties of the membrane. For example, the properties of the microporous membrane, such as pore size and porosity, may be designed to achieve a balance between optimizing vapor transfer while maintaining acceptable air leakage.

[0061] 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, 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(f), unless and until such claim limitations expressly use the phrase "means for" followed by a statement of function void of further structure.

[0062] 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 assembly, comprising:

one or more membrane panels, wherein the one or more membrane panels include a microporous membrane that has a pore size between 0.02 and 0.3 micrometers (μm) and a porosity between 45% and 80%.

2. The energy exchange assembly of claim **1**, further comprising a plurality of spacers that define air channels configured to receive air streams therethrough, the one or more membrane panels each disposed between two spacers, the one or more membrane panels configured to allow a transfer of sensible energy and latent energy across the one or more membrane panels between the air channels.

3. The energy exchange assembly of claim **2**, wherein the plurality of spacers includes a first group of spacers and a second group of spacers, the first group of spacers is orthogonally oriented with respect to the second group of spacers.

4. The energy exchange assembly of claim **1**, wherein the microporous membrane is devoid of at least one of a hydrophilic or hydrophobic coating.

5. The energy exchange assembly of claim **1**, wherein the pore size of the microporous membrane is between 0.04 and 0.2 μm.

6. The energy exchange assembly of claim **1**, wherein the porosity of the microporous membrane is between 50% and 75%.

7. The energy exchange assembly of claim **1**, wherein the microporous membrane of the one or more membrane panels has a thickness between 15 and 30 μm.

8. The energy exchange assembly of claim **1**, wherein the microporous membrane has a vapor diffusion resistance below 40 seconds/meter (sec/m) and an air permeability below 0.06 $ft^3/min/ft^2$.

9. The energy exchange assembly of claim **1**, wherein the one or more membrane panels further include a backing layer bonded to the microporous membrane for support, the one or more membrane panels having a stiffness of at least 20 MPa·mm.

10. The energy exchange assembly of claim **8**, wherein the backing layer includes a non-woven mesh with a larger pore size and porosity than the microporous membrane, wherein the backing layer does not significantly affect the transmission of vapor or air through the one or more membrane panels.

11. The energy exchange assembly of claim **1**, wherein the microporous membrane is formed of at least one of expanded polytetrafluoroethylene (ePTFE), polypropylene (PP), nylon, polyvinylidene fluoride (PVDF), or polyethersulfone (PES).

12. An energy exchange system, comprising:

a supply air flow path configured to channel supply air to an enclosed structure;

a regeneration air flow path configured to channel regeneration air from the enclosed structure to an outside environment; and

an energy exchange assembly disposed within the supply air flow path and the regeneration air flow path, wherein the energy exchange assembly comprises:

a plurality of spacers; and

a plurality of membrane panels, each membrane panel including a microporous membrane that has a pore size between 0.02 and 0.3 micrometers (μm) and a porosity between 45% and 80%, wherein each of the spacers is positioned between two of the membrane panels to define air channels through the spacer between the two membrane panels, the air channels configured to receive air streams therethrough, the membrane panels configured to allow a transfer of sensible energy and latent energy across the membrane panels between the air channels.

13. The energy exchange system of claim **12**, wherein the microporous membrane is devoid of at least one of a hydrophilic or hydrophobic coating.

14. The energy exchange system of claim **12**, wherein the pore size of the microporous membrane is between 0.04 and 0.2 μm.

15. The energy exchange system of claim **12**, wherein the porosity of the microporous membrane is between 50% and 75%.

16. The energy exchange system of claim **12**, wherein the microporous membrane has a vapor diffusion resistance below 40 seconds/meter (sec/m) and an air permeability below 0.06 $ft^3/min/ft^2$.

17. The energy exchange system of claim **12**, wherein the plurality of spacers includes a first group of spacers and a second group of spacers, the first group of spacers is orthogonally oriented with respect to the second group of spacers.

18. The energy exchange system of claim **12**, wherein the membrane panels further include a backing layer bonded to the microporous membrane for support, the membrane panels having a stiffness of at least 20 MPa·mm.

19. The energy exchange system of claim **18**, wherein the backing layer includes a non-woven mesh with a larger pore size and porosity than the microporous membrane, wherein the backing layer does not significantly affect the transmission of vapor or air through the membrane panels.

20. The energy exchange system of claim **12**, wherein the microporous membrane is formed of at least one of expanded polytetrafluoroethylene (ePTFE), polypropylene (PP), nylon, polyvinylidene fluoride (PVDF), or polyethersulfone (PES).

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