CLAIMS

1. A membrane unit comprising

a support structure comprising open space within the support structure for removal of water vapor; and

at least one membrane disposed on at least one surface of the support structure, wherein the membrane is water permeable and water selective,

wherein the membrane unit is configured such that when a vacuum is applied to the open space of the support structure, water vapor is drawn across the membrane and through the support structure along an axis parallel to an interface between the support structure and the membrane.

2. The membrane unit of claim 1, wherein the open space comprises either:

(i) pores within the support structure, and optionally

wherein the geometry of the pores varies spatially, and further optionally

the geometry of the pores varies in an axis parallel or perpendicular to the interface between the support structure and the membrane; or

(ii) channels within the support structure, and optionally

wherein the geometry of the channels varies spatially, and further optionally

wherein the geometry of the channels varies in an axis parallel or perpendicular to the interface between the support structure and the membrane.

3. The membrane unit of claim 1 or claim 2, wherein the chemistry of the support structure varies spatially, and optionally

wherein the chemistry of the support structure varies in an axis parallel or perpendicular to the interface between the support structure and the membrane.

4. The membrane unit of any preceding claim, wherein the geometry or the chemistry of the membrane varies spatially, and optionally one or both selected from the group consisting of:

wherein the geometry of the membrane varies in an axis parallel or perpendicular to the interface between the support structure and the membrane; and

wherein the chemistry of the membrane varies in an axis parallel or perpendicular to the interface between the support structure and the membrane.

5. The membrane unit of any preceding claim, wherein the membrane unit has one or more selected from the group consisting of:

a planar or non-planar geometry;

a water vapor permeability of at least 0.01 g $H_2O/m^2/s$; and

a water vapor selectivity H_2O/N_2 of at least 1000 H_2O/N_2.

6. The membrane unit of any preceding claim, wherein the membrane comprises pores with one or both selected from the group consisting of:

diameters of less than about 10 nm; and

diameters of about 100 μm to about 1 cm.

7. The membrane unit of any preceding claim, further comprising a membrane support substrate disposed between the membrane and the support structure, and optionally

the membrane support substrate comprises pores with diameters of about 100 nm to about 10 mm.

8. The membrane unit of any preceding claim, further comprising one or more selected from the group consisting of:

an inlet in fluid communication with the open space of the support structure for application of a vacuum;

an outlet in fluid communication with the open space of the support structure for removal of water vapor; and

a non-porous frame.

9. The membrane unit of any preceding claim, wherein one or both selected from the group consisting of:

the membrane unit allows passage of visible light; and

the membrane unit blocks passage of infrared light.

10. The membrane unit of any preceding claim, further comprising a membrane overlay disposed on the membrane, and optionally one or more selected from the group consisting of:

(i) wherein the membrane overlay comprises pores, and optionally

wherein the membrane overlay comprises pores with diameter greater than 10 μm;

(ii) wherein the membrane overlay is chemically functionalized, and optionally

wherein the membrane overlay has one or more of anti-fouling, dirt repelling, wetting, antimicrobial, or filtration characteristics;

(iii) wherein the membrane overlay comprises a photocatalytic compound, and optionally

wherein the photocatalytic compound includes titanium dioxide;

(iv) wherein the membrane overlay comprises at least one of high surface area particles or high molecular structures, and optionally

wherein the at least one of high surface area particles or high molecular structures includes activated carbon, metal organic frameworks, zeolites, or a combination thereof;

(v) wherein the membrane overlay comprises a biocidal compound, and optionally

wherein the biocidal compound includes silver ions, copper ions, silver nanoparticles, copper nanoparticles, quaternary ammonium compounds, or a combination thereof; and

(vi) wherein the membrane overlay causes a turbulent mixing or reduces a concentration polarization of a non-water gas species at an interface of the membrane.

11. The membrane unit of any preceding claim, further comprising at least one non-permeable barrier disposed on at least another surface of the support structure, and optionally

further comprising a sensible cooling layer disposed on a surface of the non-permeable barrier, and further optionally comprising one or more selected from the group consisting of:

(i) wherein the sensible cooling layer comprises a wettable evaporative media, and optionally

wherein the wettable evaporative media comprises a heat transfer fluid;

(ii) wherein the sensible cooling layer comprises a radiant cooler, a reflective barrier, or combination thereof;

(iii) wherein the sensible cooling layer comprises pores; and

(iv) wherein the sensible cooling layer is hydrophilic.

12. The membrane unit of claim 11, one or more selected from the group consisting of:

wherein the non-permeable barrier is non-permeable to water vapor;

wherein the non-permeable barrier is non-permeable to gas molecules;

wherein the non-permeable barrier is non-porous;

wherein the non-permeable barrier comprises a structural support layer;

wherein the non-permeable barrier comprises a metal, an alloy, or a combination thereof;

wherein the non-permeable barrier comprises a polymer;

wherein the non-permeable barrier has a thermal conductivity in the range of 0.1-0.5 W/m-K;

wherein the non-permeable barrier has a thermal conductivity in the range of 0.5-10 W/m-K;

wherein the non-permeable barrier has a thermal conductivity in the range of 10-500 W/m-K; and

wherein the non-permeable barrier is hydrophobic.

13. A system comprising

one or more membrane units of any preceding claim;

a vacuum pump configured to apply a vacuum to the open spaces of the support structure of the one or more membrane units; and

one or more inlets configured to deliver humid feed air to each membrane of the one or more membrane units along an axis parallel to an interface between the support structure and the membrane, and optionally

comprising a plurality of membrane units, and further optionally one or more selected from the group consisting of:

wherein the plurality of membrane units are arranged parallel to each other;

wherein at least one membrane unit is arranged perpendicular to another membrane unit;

wherein at least one membrane unit is arranged counter-parallel to another membrane unit; and

wherein the inlets are configured to deliver humid feed air to one or more spaces between the plurality of membrane units.

14. The system of claim 13, further comprising one or more selected from the group consisting of:

a vacuum manifold system;

a vacuum reservoir;

a plurality of vacuum pumps;

a gas-to-liquid heat exchanger;

a water circuit;

a water pump;

a plurality of vacuum gates or valves; and

a vapor compressor.

15. The system of claim 13, comprising a plurality of membrane units, wherein at least one membrane unit comprises at least one non-permeable barrier disposed on at least another surface of the support structure of the at least one membrane unit, and optionally

further comprising one or more first inlets configured to deliver working air adjacent to a surface of each non-permeable barrier of the one or more membrane units along an axis parallel to an interface between the support structure and the non-permeable barrier, and further optionally one or more selected from the group consisting of:

wherein the working air comprises dehumidified feed air;

further comprising a water mister for distributing water to the working air; and

wherein the first inlets are configured to deliver working air to one or more spaces between the plurality of membrane units.