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A device for closed loop hollow fiber membrane dehumidification for high performance air cooling.

Prior art/background:

A conventional cooling system lowers the temperature of the air stream as the air passes over a cooling coil. Heat is removed from the air in the form of sensible cooling and latent cooling. Sensible cooling is simply the reduction of the dry bulb temperature of the air. Latent cooling is the removal of moisture from the air or dehumidification. Latent cooling takes place when the air is cooled below the air dew point followed by heating of the dehumidified air to a desired temperature, an undoubtedly it is an energy-intensive process

Cooling below the dew point requires higher energy for highly moist air than dry air. If the humidity of the air is decreased by any other energy efficient way such as using membrane contactors, the energy requirements for cooling can be decreased substantially.

Evaporative coolers offer an energy efficient alternative because cooling air is achieved by the simple evaporation of air. However, as the humidity of the incoming air to be cooled increases, the ability for it to be cooled effectively decreases. Therefore, their use has been limited to climates where the air is hot and dry.

There is a current need for energy efficient air conditioning systems that are able to provide good temperature and humidity control of air. Liquid

desiccant air conditioning (LDAC) is a promising new technology that is potentially capable of filling that niche. LDAC systems utilize desiccant solution such as lithium chloride (LiCl), lithium bromide (LiBr) and calcium chloride ($CaCl_2$) to absorb water vapor from the incoming air, effectively dehumidifying the air. The cooling of air in such systems can be based on vapour compression or evaporative cooling. WO 2012/042553 A1 and EP 2339252 A1 describe integrated air cooling and dehumidification LDAC systems based on vapour compression refrigeration.

LDAC systems based on evaporative cooling are typically more energy efficient and also more environmentally friendly because it is free of ozone-depleting refrigerants. US Pat. No. US2010/0319370 A1 describes an integrated system for air cooling and dehumidification based on indirect evaporative cooling. Flat sheet membranes used for mass and heat transfer between the supply air stream and liquid desiccant stream. Regeneration of the liquid desiccant is performed thermally by passing the spent liquid desiccant to a boiler. Other than requiring corrosion-resistant metal for the boiler material, such boiler systems also require considerable amount of heat energy for the evaporation of water vapour from the spent liquid desiccant. The use of membrane contactors may lower the heat energy required for desiccant regeneration. US Pat. No. US 2012/0125021 A1 describes a desiccant air conditioning system based on evaporative cooling that consists of a conditioner, an air treatment unit and a regenerator. The conditioning of air and regeneration of liquid desiccant occurs at wavy plate structures made of specialty corrosion resistant and thermally conductive materials. Thin flat sheet membranes are positioned between the liquid desiccant, which flows on the surface of wavy plate

structures and the air flow. However, such systems are not compact and may not be feasible for certain smaller scale applications. WO 2004/081462 discloses another type of LDAC based on evaporative cooling in which the liquid desiccant and air contact occurs directly in rotating contacting discs.

The application of membranes as contactors between air and desiccant offers advantages over direct air-desiccant contact in the vapour absorption and desiccant regeneration phases. Because systems utilizing membranes contactors have well-defined contact areas, huge evaporative surface area and the air and liquid desiccant phase is operated independently, it tends to be more stable, predictable and controllable than direct contact systems. Additionally, the selectively permeable hydrophobic membranes ensures that only water vapour is transported across the membranes during air dehumidification and liquid desiccant regeneration, thus minimizing carry over /contamination of the corrosive liquid desiccant droplets in the treated air. For liquid desiccant regeneration, less heat energy is required in systems utilizing membranes as compared to thermal regeneration of the spent desiccant by using boilers. Apart from requiring large amounts of corrosion resistant boiler material, the liquid desiccant is conventionally heated to its boiling temperature of about 130 to 140 °C to regenerate the spent desiccant, resulting in higher capital and operational costs. The use of membranes contactors will allow for less energy-intensive sources of heating such as solar heat or waste energy from other waste heat streams.

The abovementioned evaporative cooling based air conditioners (US Pat. No. US2010/0319370 A1 and US Pat. No. US 2012/0125021 A1)

utilized flat sheet membrane contactors for air dehumidification and desiccant regeneration within a same housing.

The application of hollow fiber membranes in contactors will allow for more efficient and compact systems due to its relatively larger surface area per unit volume and higher packing densities. Unlike flat sheet membranes which typically require spacers and other supports, hollow fiber membranes are self-supporting and hence these markedly simplify the hardware for fabrication of membrane permeator. These advantages are vital for its application in residential and commercial buildings as the air conditioning system must fit in an acceptable space. Hollow fiber membranes have been utilized in many air dehumidification / drying based applications for industrial manufacturing processes or air conditioning/ventilation systems. However, its use in integrated air cooling/dehumidification systems, particularly based on evaporative cooling, has been rather limited thus far.

This innovative work thus clearing all the limitations in evaporative cooling by integration and closed loop system of dehumidification of supply air by hollow fiber contactor with hygroscopic liquid system and regeneration of desiccant using membrane contactor by heating the hygroscopic liquid with help of waste heat produced from the air cooler condenser units. The innovative closed loop offers an energy efficient, high performing and environmental friendly alternative to conventional air conditioning systems used today.

According to an aspect of the present invention, a process/device is provided for air cooling/dehumidification that includes steps of: a) a sub-

segment for the conditioning/dehumidification of air, b) a sub-segment for the regeneration of hygroscopic liquid.

Summary of the Invention:

As discussed in further detail below, various embodiments disclosed herein are directed to methods and systems for air dehumidification and conditioning, usage of membrane contactors, Forward osmosis device and membrane distillation devices.

In accordance with one or more embodiment, the hollow fiber module housing is made by providing inlet and out let channels and membrane compartment that holds bundles of the hollow fiber membrane. Both ends of the fiber bundles are ceased with both ends of the membrane housing by potting materials. The membrane housing is made in the shape of either cuboidal or cubical shape. The two sides of membrane housing are covered with plastic plates which fasten both ends of the membrane housing. Fluid channel is made on both top and bottom ends of the module which connects the inlet and outlet of the module. The fluid channel distributes the liquid to the lumen of the hollow fiber membranes. A conduit is connected to front and to back side of the membrane housing, which provide inlet and outlet for air to flow. The air flow is made across the membrane compartment of the membrane housing.

In accordance with one or more embodiments, the hygroscopic fluid is flow through the fluid channel which connects to the lumen of the hollow fiber membrane from bottom of the module and collected at the top outlet of the module. Fresh air from atmosphere is passed across the module from air inlet. Water vapour from air diffused through the membrane pores and it

is absorbed by the hygroscopic liquid. The dehumidified dry air collected at the back end of the module. Water vapour is diffused from the phase (moist air) or as long as its vapour pressure is higher than the other phase (concentrated hygroscopic liquid) it is in contact with. These processes are facilitated by membranes, specifically hollow fiber membrane made of hydrophobic polymeric materials such as polypropylene, polyethylene, Polytetrafluoroethylene (PTFE), polyvinylidene Fluoride (PVDF) and it can be utilized to provide heat and mass transfer. PVDF is the preferred material type for this invention. With respect to the hygroscopic liquids, preferred liquids are $CaCl_2$ due to its low cost, strong affinity for water, and relative ease of regeneration. Other candidates for hygroscopic liquid include halogenated metallic salts, hydroxylated compounds that have high affinity towards the water molecules

In accordance with one or more embodiments, this invention provides a means of efficient regeneration of the spent diluted hygroscopic liquid using membrane contactors and waste heat. Water vapour is removed from the spent diluted hygroscopic liquid when it passes through a membrane contactor module through the lumen of the hollow fiber. The tapped heat from the condenser of the mechanical air coolers is used to heat the fresh air by passing it through the heating coil. The hot air is passed through the membrane module from the front side, as long as its vapour pressure is lower than the spent (diluted) hygroscopic liquid, the water vapour diffuse from spent diluted hygroscopic liquid to the air. These processes are facilitated by membranes, specifically hollow fiber membrane made of hydrophobic polymeric materials such as polypropylene, polyethylene, Polytetrafluoroethylene (PTFE),

polyvinylidene (PVDF) can be utilized to provide heat and mass transfer. PVDF is the preferred material type for this invention.

The use of membranes contactors, specifically hollow fiber membranes not only increases the contact area for heat and mass transfer but also results in overall lower energy requirement for hygroscopic regeneration and air cooling.

In accordance with one or more embodiments, the concentrated hot hydroscopic liquid is cooled by membrane heat exchanger before it is stored and it is recycled in the membrane dehumidifiers. By this step, the hygroscopic liquid closes the loop of humidification and dehumidification cycles and removes moisture from the air, enhance the efficiency of air cooling unit and reduce the heat release to the atmosphere.

In accordance with one or more embodiment, the dehumidified air is passed to mechanical air cooler to cool the air to desired temperature. Decoupling the dehumidification and cooling of the air increase energy efficiency of the air conditioning.

In accordance with one or more embodiments, another inventive step involved in the regeneration of the spent diluted hygroscopic fluid. The content in technology is used in the sub-segment of (b) in this innovation is to explore the removal of water molecules from the spent hygroscopic liquid using forwards osmosis and membrane distillation systems. Forward osmosis is a membrane process in which a net water movement occurs through a semi-permeable membrane from a low concentration solution to a high concentration solution under the osmotic pressure gradient across the membrane which is highly energy efficient. In this inventive step, the

spent diluted hygroscopic liquid is concentrated by forward osmosis process.

In accordance with one or more embodiments, forward osmosis membrane module contains an inlet and an outlet for draw solution which has higher concentration and osmotic pressure of the feed. The forward osmosis membrane module has inlet and outlet for feed solution which need to be concentrated by this process. The membrane module contains a specially coated membrane and it can be in hollow fiber, flat sheet or tubular configurations. The membrane pore sizes are in the range of 1 to10 ^{o}A.

In accordance with one or more embodiments, the spent diluted hygroscopic liquid from the membrane dehumidification unit is passed into the forward osmosis system at the feed inlet and it is collected at the feed outlet of the module. The draw solution is passed at another side of the membrane through the draw solution inlet and collected outlet of the draw solution.

Water is transported from spent dilute hygroscopic liquid to high draw solution which possesses higher osmotic pressure and thus concentrating the hygroscopic liquid and dilutes the draw solution. Since no heating is involved in forward osmosis concentration process, the concentrated hygroscopic liquid is directly used in membrane dehumidification unit without cooling.

In accordance with one or more embodiments, the diluted draw solution is concentrated by membrane distillation devices. Membrane distillation is the combination thermal distillation and membrane process. In

this process, the liquid is heated to a temperature lower than its boiling range. It is passed through a hydrophobic hollow fiber membrane with pore size range from 0.1 to 0.01 micron; the vapour from the hot feed stream is passed through the hydrophobic membrane pores which are continuously evacuated by applied vacuum in other side of the membrane.

In accordance with one or more embodiments, the diluted draw solution is concentrated by Membrane distillation process; the driving force for this process is vapour pressure difference across the membrane. Since the process is independent of concentration of solution, draw solution can be concentrated to its solubility limit. The diluted draw solution is heated and concentrated through the membrane distillation unit. Membrane distillation device contains several membrane modules with feed pumps, vacuum pumps and heat recovery units. The membrane module has cylindrical housing which has inlet and outlet ports at both ends. They are connected to the lumens of the bundles of hollow fiber membranes. The hollow fiber bundles are potted at both ends in order to fasten the fibers in the housing and separate outside surface to the inside surface of the membrane. The outside of the fibers space is connected to vacuum pump by the vacuum port attached inside of membrane housing.

In accordance with one or more embodiments, the diluted draw solution from the forward osmosis unit is heated to 35-90 deg C preferably 60 deg C and passed to the inlet of the membrane distillation device. Water vapour is diffused through the membrane pores and it is evacuated from the membrane module by vacuum at the other side of the membrane. The

concentrated draw solution looped between forward osmosis and membrane distillation. The permeated water vapour is condensed at the heat exchanger surface. Heat of condensation is exchanged to warm up the dilute draw solution prior to heating to suit as feed solution to membrane distillation system.

At the end of membrane distillation process, the draw solution is concentrated and still holds the temperature of about 60 ^{0}C. The higher temperature of the draw solution and higher its osmotic pressure and thus increase the efficiency of the forward osmosis process.

The integration Forward osmosis and Membrane distillation in the membrane dehumidification and cooling device offers four major advantages over other systems, 1) No heating of hygroscopic liquid during regeneration, 2) No pre-cooling of regenerated hygroscopic liquid before it is subject to membrane dehumidification unit, 3) Effective concentration of spent hygroscopic liquid, 4) Hot draw solution from Membrane distillation unit has higher osmotic pressure which can effectively increase the efficiency of forward osmosis process.

Brief Description of detailed Drawings

Fig: 1, Schematic representation of membrane contactor.

Fig-2, Schematic representation of the hygroscopic liquid-membrane dehumidifier combined with mechanical air cooler and hydroscopic liquid regeneration system by membrane contactor for air conditioning of user space.

Fig:3, Schematic representation of the hygroscopic liquid-membrane dehumidifier combined and hydroscopic liquid regeneration system by membrane contactor for dehumidification of user space.

Fig: 4, schematic representation of the Hygroscopic liquid-membrane dehumidifier combined with mechanical air cooler and hydroscopic liquid regeneration system by combined Forward osmosis and Membrane distillation membrane systems for air conditioning of user space.

Fig: 5, schematic representation of the Hygroscopic liquid-membrane dehumidifier combined and hydroscopic liquid regeneration system by combined Forward osmosis and Membrane distillation membrane systems for dehumidification of user space.

Detailed Description of the drawings:

The following provides detailed description of the exemplary drawings of closed loop hygroscopic liquid-membrane dehumidification system with regeneration of hygroscopic liquid. The hollow fiber membranes are packed in the form of module. The schematic representation of module is depicted in Fig 1. The module is uniquely designed to meet the requirements of this application. The membrane modules are made in such a way the hollow fiber membranes are exposed air. The both ends of the fiber membranes are held by potting materials and have channels for the air passage. The hygroscopic liquid passed through the lumen of the Hollow fiber membranes.

The membrane module is made in the shape of cube or cuboidal box. The bundles of hollow fiber membranes held between the top and bottom sides of the box by potting the bundles with glue materials. These both ends are slotted into the channels which has path for fluid to pass through the lumen of the capillary membrane. The inlet and outlet ports for hygroscopic liquid are attached in the bottom and top portions of the module facing opposite to each other. Both sides of the modules are covered with plastic plates and fasten to the top and bottom side so that front side of the membrane module is open for air inlet and the backside of the module is used to channel the dehumidified air. Conduits are made at front and back side of the module to connect to an air duct. The hygroscopic liquid is passed through the inlet port and it passed through the lumen of capillary membrane. It is collected on the other end of the module by outlet port. The fresh air from atmosphere is flow through a front side of the module and it is collected at the back end of the module.

The schematic representation of segment (A) and segment (B) is illustrated in Fig 2, Segment (A) describes the dehumidification and air cooling section of the device and Segment B describes the regeneration of hygroscopic liquid using membrane contactors. Fresh air (101) from the atmosphere is flow in through the air channel of the open exposed capillary membrane. The hygroscopic fluid (115) is passed through the lumen of the hollow fiber membrane in the uniquely designed membrane dehumidification unit (102). The membrane is made up of the highly hydrophobic material, so that the hygroscopic liquid from the lumen of the membrane pore will not pass through where as only the water vapour from air will be diffuse through it and the permeated water vapour is absorbed by

the flowing hygroscopic liquid in the lumen and thus dehumidify the air. The permeated water vapour condenses in the hygroscopic liquid and dilutes the concentration of the hygroscopic liquid. The dehumidified air from the membrane humidifier (102) is channeled to mechanical air cooler via an air duct (104).

The air cooler cools the dry air (103) and it ducted (105) to user space (106). The user space can be a single large space or divided into many compartments. It can be an office space, residential building, commercial buildings, closed space, hotels and other confined spaces.

The 80-90% of the exhaust air from the user space (107) re-circulated (109) to the membrane dehumidification unit and the remaining 10-20% of the exhaust air (108) is return to the atmosphere.

The diluted spent hygroscopic liquid (116) is regenerated using another membrane contactor unit (120). This membrane contactor (120) is consisting of similar type of membrane modules (102) used in the membrane dehumidification chamber. In membrane contactor (120), membrane is used to diffuse water from spent hygroscopic liquid to hot air. It works exactly in reverse function of the dehumidification process. The air from atmosphere (122) is heated by passing it through a hot coil (118). The heat harvested (117) from the condenser unit of the mechanical air cooler (104) is used to heat the heating the coil (118). The hot air (119) is passed through the membrane channel of the module (120). The spent hygroscopic liquid (116) is passed through the lumen of the capillary

membrane in the module (120). The water vapour from the spent hygroscopic liquid is diffused through the pores of the membrane and carried away by the flowing hot air (121). The spent hygroscopic liquid is thus concentrated to the desired level (110) and subsequently cooled by membrane cooler (111). The cooled hygroscopic fluid (112) is stored in the tank (113) and used again (115) in the membrane dehumidifier. A centrifugal pump (114) is used for circulation hygroscopic liquid to close the loop between segment (A) and segment (B).

This inventive method describes the usage of hollow fiber membrane in humidification and de-humidification decreases the energy consumption substantially and highly suitable for regions where it is situated at highly hot and humid environment.

The innovative process can be used for de-humidification of user space without cooling the air. Fig-3 illustrates the process of dehumidification of the user space using closed loop membrane de-humidification units. In this process, the process conditions are similar to Fig 2 without mechanical air cooler. The air from the membrane dehumidifier (103) is directly ducted to user space (206). 70-90% of exhaust air from the user space (207) re-circulated (209) to the membrane dehumidification unit and the remaining 10-30% (208) is return to the atmosphere. Regeneration of spent hygroscopic liquid system is similar to the description in Fig 2.

Since waste heat from the mechanical air cooler is not available, the heat source for heating air in segment (B) is tapped from solar system (319) or any other source to heat the heating coil (118).

A membrane contactor is efficient in regeneration of the spent hygroscopic liquid. Another inventive method has been developed to regenerate spent hygroscopic liquid in combined forward osmosis and membrane distillation process in segment (B). In this process, the heating of air and cooling of the regenerated hygroscopic liquid as described in Fig 2 and Fig 3 can be eliminated. This method consists of two membrane processes to concentrate the spent hygroscopic liquid. Forward osmosis is a membrane process in which water is transported from dilute solution to concentrated solution through a semi permeable membrane. The osmotic pressure difference in the solutions acts as a driving force for this transport of the water through the semi-permeable membrane. This process is depicted in the Fig 4. When spent hygroscopic liquid is flow through one side of the forward osmosis membrane and the draw solution having higher concentration (higher osmotic pressure) is passed through the other side of the membrane, transport of water from the spent hygroscopic liquid to the draw solution is observed. The transportation of water continues until it reaches to the equilibrium in osmotic pressure.

Diluted draw solution from forward osmosis system is subsequently concentrated by another membrane process called membrane distillation. The diluted draw solution is heated to 40 – 99 °C, preferably 60 °C and passed to the lumen of hydrophobic hollow fiber membrane distillation module. The hydrophobic membrane having pore size of 0.01 -10 micron, preferably 0.1 micron is used for this process. The water vapour from the diluted draw solution is permeated through the pores of membrane distillation unit and it evacuated by applied vacuum on the other side of the membrane. Membrane distillation process is similar to membrane contactor

unit used in regeneration of hygroscopic liquid, the difference between in these process is dilute draw solution is heated in the membrane distillation where as air is heated in membrane contactor regeneration system.

Fig 4 illustrates the combined forward osmosis and membrane distillation system for regeneration of the hygroscopic liquid. The air dehumidification and air cooling methods are similar to described in fig 2. The focus is given in the segment (B), regeneration of the diluted spent hygroscopic liquid using forward osmosis and membrane distillation systems.

The diluted spent hygroscopic liquid (116) from membrane dehumidification chamber is regenerated using Forward Osmosis unit (405). Forward osmosis unit consists of the membrane modules and a stream of spent hygroscopic liquid (116) is passed in one side of the membrane and draw solution (404) is passed on the other side of the membrane with help of centrifugal pumps. The selected draw solution has more osmotic pressure then the spent hygroscopic liquid. This induces the water transport from hygroscopic liquid through the membrane pores to draw solution and concentrates the spent hygroscopic liquid. The concentrated spent hydroscopic liquid is transferred to storage tank and recycled back to membrane dehumidifier. The draw solution is diluted by this process is subsequently concentrated by membrane distillation device (403).

Membrane distillation process is the combination of membrane separation and distillation processes. In this process vapour is formed due

to difference vapour pressure of two fluid placed between the membrane. The huge surface area available in membrane system aid to increase the efficiency of vaporization of liquids, To maintain high vapour pressure difference, the transported vapour has to be continuously evacuated which can be achieved by different ways including direct condensation of vapour with water by passes water on the other side of the membrane, apply either air sweep and vacuum on the other side of the membrane.

The diluted draw solution (401) from forward osmosis system is heated by passing it through a hot coil (418). The coil is heated by the harvested heat (117) from the condenser unit of the mechanical air cooler (104). The hot diluted draw solution (402) is passed through the membrane distillation modules. Vacuum (406) is applied on the other side of the membrane.

The water vapour from the diluted draw solution is transported and evacuated by vacuum thus concentrating the draw solution. The hot concentrated hot solution (404) is re-cycled in forward osmosis device to close the loop. Since the osmotic pressure is directly proportional to the temperature, hot draw solution is more efficient in the forward osmosis process.

Fig 5 illustrates the using membrane dehumidification system to supply dry air to user space and regeneration of the hygroscopic liquid is achieved by integrated forward osmosis and membrane distillation system.

In this process, the process conditions are similar to Fig 4 without mechanical air cooler. The air from the membrane dehumidifier (103) is directly ducted to user space (206). 70-90 % of exhaust air from the user

space (207) re-circulated (209) to the membrane dehumidification unit and the remaining 10-30% of the exhaust air (208) is return to the atmosphere. Regeneration of spent hygroscopic liquid system is similar to the description in Fig 4 of segment B. To heat for heating coil (418) is harvested from solar system (319) or from any other sources.

Examples 1:

The method of example 1 illustrated in Fig 2, The hygroscopic liquid used in the process having concentration of 40-60% of calcium chloride solution which is pumped at the rate of 10 liters per minute into the membrane dehumidification device. It contains 10 units of box membrane modules. The pressure of the system is maintained at 0.5 to 0.8 bar. The fresh air from atmospheric having temperature of 28-30 °C and relative humidity of 70-75% is blew across the outside of membrane in the module. It was observed that the decrease of more than 10-20% in relative humidity of air at the outlet of the membrane module. The spent $CaCl_2$ solution is diluted to 30-50%. The diluted spent hygroscopic liquid is passed to the membrane contactor unit consists of 3 box units. Atmospheric air is passed to the condenser unit of mechanical air cooler and it is heated to 45-50 °C then it is passed to membrane module at the outside of the hollow fiber membrane. The water vapour diffused through the membrane is carried away by air. The diluted $CaCl_2$ solution is concentrated is to 50-60%. The warm calcium chloride solution is cooled and recycled back to membrane dehumidifier.

The methods of example 2 illustrated in Fig 4, the hygroscopic liquid is 40-60% of calcium chloride solution which is pumped at the rate of 10 liters per minute into the membrane dehumidification device. It contains 10 units of box membrane modules. The pressure of the system is maintained at 0.5 to 0.8 bar. Fresh atmospheric air is blown across the membrane at 28-30 °C of temperature and relative humidity of 70-75% . It was observed that

more than 10-20% in relative humidity of air decreased at the outlet of the membrane and dilutions of calcium chloride solution to 30-50%.

The 10 L diluted $CaCl_2$ solution is collected from the dehumidification system and it is circulated in to the forward osmosis module. The forward osmosis module consists of 0.01 m^2 membrane area. The 10 L of the concentrated draw solution consisted of 60-70% of metal halide solution is circulated on the other side of the membrane. The flow rate and pressure for both the solutions are maintained at 2 liters per hour and 0.5 bar respectively. The water is transported through the membrane at permeation rate 4-8 liters/m^2/hr and the concentration of $CaCl_2$ solution up to 60% is observed.

The 10 L of draw solution is heated to 55-60 °C and circulated through membrane distillation membrane at the flow rate 2 liters per hour. Vacuum of negative pressure of 10 psi is applied on the other side of the membrane. The membrane area of the module is 0.2 m^2. The water vapor from the draw solution is diffused through the membrane at the rate of 3-7 liter per m^2 per hour. The draw solution is concentrated to 60-70% and used again in the forward osmosis process.

Claims:

1) A device consists of two sub segments (A) and (B). These segments are mainly consists of hollow fiber membrane modules for dehumidification of air and Regeneration of hygroscopic liquids. Segment (A) and (B) are looped with hygroscopic liquid. Dehumidification and /or cooling of air is carried out through passing moist air at the one side of highly hydrophobic hollow fiber membrane and flow the hygroscopic liquid lumen as in Segment A. The regeneration of diluted hygroscopic liquid is carried out segment (B). The regeneration of hygroscopic liquid is carried out two different methods,
    a. Membrane contactor is used to concentrate the liquid.
    b. Forward osmosis and/or membrane distillation used to concentrate the liquid.

2) The said devices/systems in claim 1, segment (A) uses hollow fiber membrane made up of hydrophobic polymeric materials such as polypropylene, PTFE and PVDF, preferably PVDF type material and modified polymeric materials.

3) The membrane said in claim 2 is having pore size of in the range of 1-0.001 micron.

4) The membrane said in claim 2 is having the internal diameter of 0.2 mm to 2 mm and outside diameter of 0.3 mm to 3 mm.

5) The membrane said in claim 2 is bundled and made in the form of module.

6) The modules said in claim 5 contains several number of bundles of membrane and are potted the both ends. A layer from the end of potting is sliced to have lumens of the fibers are open at the both

ends. The both ends are capped with a port which is used as hygroscopic liquid incoming and outgoing ports. The air is passed through the outside of the capillary membrane.

7) The module said in claim 5 made in the shape of cuboids, cube, cylindrical. The body of the module is open to expose hollow fibers.

8) The segment (A) the device mentioned in claim 1 is constructed using several modules said in claim 7 and are connected in parallel with necessary pumps, valves and pipes to convey air and hygroscopic liquid into the membrane modules.

9) The hygroscopic liquid used in the claim 1 is solution of pure or mixture of halogenated, hydroxylated metallic salt compounds that have high affinity towards the water molecules such as LiCl, LiBr and $CaCl_2$. Preferably $CaCl_2$.

10) The hygroscopic liquid said in claim 9, is having the concentration in the range of 10% to 60%.

11) The hygroscopic liquid said in claim 9 is flow through lumen side of the hollow fiber membrane and the moist air from atmosphere mixed with exhaust air from the user space is flow through the open shell side of the hollow fiber membranes in the module.

12) Membrane module said in the claim 11 act as a vapour transporter from moist air to hygroscopic liquid, where the transported vapour is absorbed in the hygroscopic liquid. This process is driven by vapour pressure difference of water between air and hygroscopic liquid.

13) The dehumidified air from the process said in claim 12 is passed through cooling device to cool the air. The air is cooled to required temperature and circulated in the segregated user space.

14) The absorbed water vapour in the hygroscopic liquid (a diluted hygroscopic liquid) said in claim 12 is carried to another similar membrane system regeneration segment of the device as said in claim 1a segment (B).

15) In the segment mentioned in the claim 14, the atmospheric air liquid is heated to 25° C to 90° C. Heating source can be solar energy, exhausting heat from compressor fans and other type of waste heat.

16) The hot air mentioned in claim 15 is flow through the outer side of the membrane where as diluted hygroscopic liquid said in claim 14 is flow through the lumen side of membrane in the module.

17) Water vapour is transported in the process mentioned in claim 16 from diluted hygroscopic liquid to the air through the membrane pores due to difference vapour pressure of water between hot air and diluted spent hygroscopic liquid.

18) The air leaving the membrane module as said in claim 16 is humidified with water vapour and hygroscopic liquid at the lumen side of the membrane is concentrated to its original concentration of 40-60%. The concentrated hygroscopic liquid can be used in the process which is mentioned in claim 11. In this way hygroscopic liquid closes the loop of humidification and dehumidification cycles and remove moisture from the air, enhance air cooling unit efficiency and reduce the heat released to atmosphere.

19) The hygroscopic liquid said in claim 12 is concentrated using combined forward osmosis and membrane distillation devices.

20) The forward osmosis system said in claim 19 is consists of a membrane in the configuration of hollow fiber, flat sheet, tubular types.

21) The forward osmosis membrane said in claim 20 is having special coatings of polymer include a layer of polyamide, polyethyleneimide, modified polymers of polysulfone etc.,

22) The system said in claim 19, uses the feed liquid and draw solution. The draw solution is to create a driving force to induce water transport from the feed liquid to draw solutions.

23) The draw solution said in claim 22 consists of organic and/or inorganic salts in aqueous or suspended forms. The chemical compounds include halides of metals, hydroxy, amino, keto, aldehehyde, sulfate compounds and/or combination of these compounds.

24) The forward osmosis system said in claim 19 has membrane module (s), circulation devices and pressure, temperature and flow measuring devices.

25) The forward osmosis system said in claim 19, the draw solution and feed liquid separated by the forward osmosis membrane. The selected draw solution is having higher osmotic pressure than the feed liquid (spent dilute hygroscopic liquid)

26) The forward osmosis system said in claim 24, the water is transferred from the spent dilute hygroscopic to the draw solution due to osmotic pressure difference. It concentrates the spent hygroscopic liquid and dilutes the draw solution.

27) The membrane distillation system said in claim 19, concentrates the diluted draw solution said in claim 26.

28) The membrane distillation system said in claim 19 consists of a membrane in hollow fiber, flat sheet, and tubular configurations.

29) The membrane said in claim 28 is having pore size of 0.01 to 10 micron, preferably 0.4 to 1 micron.

30) The membrane said in claim 29 is made up of polymers have highly hydrophobic characters and creates the hydrophobic membrane surface.

31) The membrane distillation system said in claim 19 has membrane module (s), circulation devices and pressure, temperature and flow measuring devices, energy recovery devices.

32) The membrane distillation system said in claim 19, uses the hot solution on the one side of the membrane and vacuum on the another side of the membrane.

33) The draw solution said in claim said in claim 26 is heated to 35 to 90 °C preferably 50 to 70 ° C and passed in to the membrane module. Vapour pressure difference between the membranes create a driving force to induce water transport from the Draw solution and concentrate the draw solution.

34) The membrane distillation said in claim 19, the vapour is condensed in the heat exchanger and condensation heat is used raise the temperature of draw solution.

35) The concentrated solution said in claim 33 is used again in the Forward osmosis system said in claim 19.