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(54) Air conditioning and dehumidification integrated system

(57) The present invention relates to an air conditioning and dehumidification integrated system (1, 1'), comprising a thermal source, a conditioning/dehumidification unit (20), for cooling and dehumidificating air by means of a desiccant solution, refrigerant means (40), connected with said conditioning/dehumidification unit (20), suitable for cooling said desiccant solution to a set beforehand temperature by controlling its temperature, to introduce said desiccant solution again into said conditioning/dehumidification unit (20), a tank (30), loop circuit connected with said conditioning/dehumidification unit (20) and with said refrigerant means (40), wherein a reserve of said desiccant solution from said conditioning/dehumidification unit (20) is collected, and means (60; 70) for regenerating said desiccant solution connected with said tank (30), said regeneration means (60; 70) being capable to re-concentrate said desiccant solution diluted that comes from said conditioning/dehumidification unit (20), extracting water therefrom using thermal energy obtained by said thermal source, in order to return said desiccant solution to said tank (30), characterized in that said regeneration means (60; 70) comprise a membrane distiller (61; 71) of the liquid/liquid type.

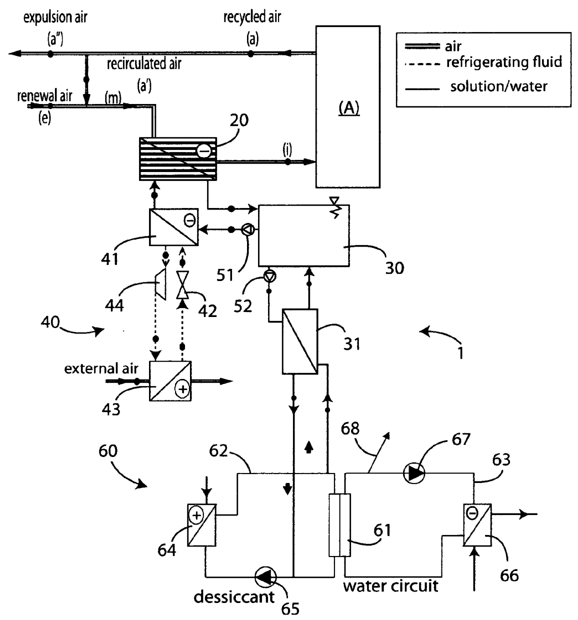

Fig. 1

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Description

[0001] The present invention relates to an air conditioning and dehumidification integrated system.

[0002] More specifically, the invention relates to an air conditioning and dehumidification system to be used in civil and industrial fields, for air conditioning of transportation means, for hygrometric control of limited spaces, suitable to be used in refrigerated transportation field and in refrigeration field. System suggested according o the invention is very compact, so as to be possible installing the same also in small spaces, at the same time permitting remarkable energy savings with respect to traditional techniques.

[0003] As it is well known, at present dehumidification of air can be also carried out "chemically", by using solid or liquid desiccating substances (e.g. LiCl, $CaCl_2$, ecc. aqueous solutions). It is known that the above solution permits controlling specific humidity regardless the temperature, while more traditional technology employs a frigorific cycle to dehumidificate air, cooling the same under the dew point. Therefore, it is possible obtaining remarkable energy savings with respect to the traditional process mainly when high latent loads are involved and at the same time a thermal energy source is available to regenerate the desiccant substance.

[0004] Generally speaking, this kind of system is mainly used in the industrial field for dehumidification of air within devices providing direct air

- desiccant solution contact both in absorption phase and in regeneration phase.

[0005] Under regime operation conditions, it is required a continuous regeneration of the desiccant solution in order to remove absorbed water, that would otherwise gradually dilute desiccant solution, weakening the dehumificating action.

[0006] Usually, regeneration is carried out thermally, either making desiccant boiling at atmospheric temperature, and using different air - solution contact systems. In the first case, to be able to actuate an efficient regeneration, it is necessary having thermal energy at temperature higher than 130° - 140° C. in the second case, the following drawbacks are present:

(a) noticeable dimensions of the regeneration system since it comprises, besides the real regenerator, inlet and outlet ducts for regeneration air and a fan for moving the same;
(b) dragging of desiccant droplets with treated air;
(c) reduced possibility of independently varying air and desiccant flow rate;
(d) progressive pollution of the solution by atmospheric powders.

[0007] Besides that, said systems can be much more easily used on transportation means which are subjected to acceleration/deceleration.

[0008] Air conditioning systems are further known, integrating direct contact dehumidification systems with vapor compression frigorific cycle. In the above systems, frigorific machine can operate at an evaporation temperature higher than a traditional system, with higher operative coefficients (COP). Regeneration is carried out exploiting thermal energy yield to condenser of frigorific cycle and therefore these systems do not require further thermal energy. Total energetic saving with respect to traditional air conditioning systems employing frigorific cycles can reach 30 - 35%, with further improvements when high latent loads are present. Obviously, hybrid systems too have the same above drawbacks due to direct contact.

[0009] Technical development have been recently suggested for air conditioning and dehumidification systems with liquid desiccating (traditional and hybrid systems) preventing direct air - desiccant contact, inserting between the two phases a thin hydrophobic membrane, which is waterproof to the liquid phase, and permeable to vapor through which energy and mass exchange are realized, both for realizing vapor absorption (i.e. air dehumidification) and its desorption, i.e. regeneration of desiccant solution. To this end, it is possible using components, known as *"membrane contactors",* provided with well known hydrophobic membranes, e.g. micropore membranes comprised of polymeric materials (polytetrafluoroethylene PTFE, polyvinyliden fluoride PVDF, polypropylene PP, ecc,). Search and development activity to increase membranes and contactors performances in many sectors is always more developed all over the world.

[0010] Present membrane contactors (plane symmetry contactors, spiral contactors of hollow fiber contactors) permit having large exchange surfaces for each volume unit, with reduced load losses both on air side and on solution side, and can be used on transportation means.

[0011] It has also been noted that hybrid systems using membrane contactors have some limits. For example, air - desiccant solution contactors can have problems connected with their reliability, mainly when they operate under the regeneration phase, i.e. higher temperatures. Further, dimensions of regeneration system are still large both due to the fact that regeneration system must be sized to dispose of all sensible and latent load of the system toward outside air, and due to presence of inlet and outlet ducts for regeneration air and of fan for moving the latter. The above jeopardize reduced dimensions of the whole system (which is highly relevant, mainly in the transportation field, such as car, buses, trucks, train cars and like).

[0012] These and other technical aspects are solved by an air conditioning and dehumidification system providing combination of frigorific means with a cycle employing desiccating liquids, still using, to conditioning and dehumificating air, an air - desiccant membrane contactor, providing regeneration means for desiccant solution, provided with a liquid/liquid membrane distillatory.

[0013] It is therefore object of the present invention that of providing an air conditioning and dehumidification integrated system which is energetically more efficient with respect to traditional process, which is only based on frigorific cycle.

[0014] Another object of the present invention is that of providing an air conditioning and dehumidification integrated system with reduced dimensions.

[0015] Further object of the present invention is that of providing a system that can condition air, cooling and dehumidificating the same, or only dehumidificating air.

[0016] It is therefore specific object of the present invention an air conditioning and dehumidification integrated system, comprising a thermal source, a conditioning/dehumidification unit, for cooling and dehumidificating air by means of a desiccant solution, refrigerant means, connected with said conditioning/dehumidification unit, suitable for cooling said desiccant solution to a set beforehand temperature by controlling its temperature, to introduce said desiccant solution again into said conditioning/dehumidification unit, a tank, loop circuit connected with said conditioning/dehumidification unit and with said refrigerant means, wherein a reserve of said desiccant solution from said conditioning/dehumidification unit is collected, and means for regenerating said desiccant solution connected with said tank, said regeneration means being capable to re-concentrate said desiccant solution diluted that comes from said conditioning/dehumidification unit, extracting water there from using thermal energy obtained by said thermal source, in order to return said desiccant solution to said tank, characterized in that said regeneration means comprise a membrane distiller of the liquid/liquid type.

[0017] Always according to the invention, said membrane distiller is of the Direct Contact Membrane Distillation - DCMD type and is interposed between a first desiccant regeneration circuit, wherein a first heat exchanger is series-connected with said thermal source for heating said desiccant solution, a pump, and a second collected water circulation circuit, wherein means for cooling said water is series-connected with a further pump, said means for cooling said collected water circulation circuit being further provided with a waste pipe of the collected distilled water.

[0018] Still according to the invention, said cooling means comprise a second heat exchanger for cooling said water or a water-air hydrophobic membrane contactor capable of exchange, with the room air, not only thermal energy but even water steam, so as to cool the water below the temperature of the external air. In the latter case, to keep the circuit always filled in with water, it will be necessary reintegrating water from outside.

[0019] Advantageously, according to the invention, said membrane distiller can be an *Air-Gap Membrane Distiller* - AGMD with thermal recovery, and it comprises a heat exchanger with said thermal source, connected with said membrane distiller, and a waste pipe of the distilled water.

[0020] Furthermore, according to the invention, said refrigerant means comprise an evaporator, a thermal expansion valve, a condenser and a compressor.

[0021] Preferably, according to the invention, said thermal source is said condenser.

[0022] Always according to the invention, said system comprises a sensor for detecting the concentration of the solution and/or the level of the solution contained within the tank, said sensor being suitable to activate the operation of said regeneration means when the dilution of the solution has exceeded the set threshold.

[0023] Still according to the invention, said tank is connected with said refrigerant means by a first pump and it is connected with said regeneration means by a first delivery pipe, wherein a second pump is provided, and by a return pipe.

[0024] Furthermore, according to the invention, said regeneration means are connected, preferably interposed, with said tank and said refrigerant means.

[0025] Advantageously, according to the invention, said system comprises an economizer interposed between said tank and said refrigerant means.

[0026] Present invention will be now described for illustrative, but not limitative, purposes, according to its preferred embodiments, with particular reference to the enclosed drawings, wherein:

figure 1 shows architecture of conditioning/dehumidification system using a first embodiment of an air conditioning and dehumidification integrated system according to the present invention;

figure 2 shows an architecture of conditioning/dehumidification system using a first embodiment of an air conditioning and dehumidification integrated system according to the present invention; and

figure 3 shows on psychometric diagram (Ashrae diagram) transformation of process air occurring in system of figures 1 and 2.

[0027] In the various figures, similar parts will be indicated by the same reference numbers.

[0028] Making reference to figure 1, it is observed an integrated system 1 for conditioning and dehumidification of air within an environment A, such as a vehicle passenger compartment, such as car, buses, trucks, train cars and like.

[0029] Air at the thermodynamic state (m), from mixing of fresh air (e) and recirculation air (a') is cooled and dehumidificated by integrated system 1 according to the present invention up to admission conditions (i) within conditioned environment (A).

[0030] System 1 comprises a conditioning/dehumidification unit 20 by which fresh air (e) and recirculation air (a') are cooled and dehumidificated, and a tank 30 connected to said unit 20 for collection of desiccant solution.

[0031] System 1 further comprises refrigerant means

40, provided with an evaporator 41, an evaporator 41, a thermal expansion valve 42, a condenser 43 and a compressor 44. Said evaporator 41 is connected to said tank 30 by a first pump 51.

[0032] System 1 also comprises an economizer 31, connected by a pair of inlet and return ducts, wherein circulation is eased by a second pump 52. Said economizer 31 can be also connected by a loop between tank 30 and evaporator 41. Further, regeneration means 60 are connected with said economizer, said means 60 comprising a membrane distiller 61, provided between desiccant regeneration circuit 62 and distilled water circulation circuit.

[0033] Regeneration means 60 are suitable to re-concentrate said diluted desiccant solution arriving from said conditioning/dehumidification units 20, extracting water by thermal energy obtained from a thermal source, to send it back to said tank 30.

[0034] In preferred embodiment, said thermal source is a waste thermal source or it can be the same condenser 43. In the latter case, the system has the advantage of not requiring inputting thermal energy from outside.

[0035] Further, a first heat exchanger 64 and a pump 65 are connected in series to said circuit 62. Collection water circulation circuit 63 provides, in series, a second heat exchanger 66 and a further pump 67. Said collection water circulation circuit 63 also has a water discharge 68.

[0036] Advantageously according to the invention, heat exchanger 66 can be replaced by a water/air hydrophobic membrane contactor 20 that can exchange with environment air not only thermal energy, but also steam, thus obtaining a higher flow of distillate substance per membrane area unit or, with the same area, realising the process with a lower temperature from said second heat source 66.

[0037] As it can be observed, said membrane distillatory 61 is of the liquid/liquid type, and particularly a direct contact membrane or DCMD (Direct Contact membrane Distillation).

[0038] This kind of condenser is presently applied for de-salinisation of sea water to produce drinkable water and for concentration of aqueous solutions. Said direct contact membrane distillers DCMD carry out a distillation making sea water passing at a higher temperature on one side of membrane and water at a lower temperature on the other side, thus realising distillation process, preventing mixing of phases.

[0039] Reason of transportation process through membrane is difference of partial pressure of vapour on two sides of the same, which is caused by temperature difference. Thus, distillation is carried out at room pressure using thermal sources at low temperature (maximum 90 - 95°C).

[0040] Said processes are an alternative sector with respect to known desalinization processes such as traditional distillation and reverse osmosis.

[0041] Operation is as follows. In conditioning/dehumidification unit 20 (e.g. also dehumidification contactor) it is made at the same time a thermal exchange and a mass exchange, so that cooled and concentrate hygroscopic solution, entering within component 20 (conditioning/dehumidification unit) exits warmer and diluted. In view of the above, solution must be cooled and regenerated to maintain uniform temperature and concentration at the inlet of the same conditioning/dehumidification unit 20. Control of temperature (cooling) of absorbing solution is realised by frigorific cycle of said refrigerant means, while restore of concentration occurs by said regeneration means 80. Circuit of the solution can be considered as comprised of two parts between two different temperature and concentration levels: absorption circuit (dehumidification), wherein solution is maintained cool and at the desired concentration, and regeneration circuit, comprised of said regeneration means 60, wherein said solution is maintained hot and at a higher concentration.

[0042] Heat economizer 31 operates between two circuits so as to preheat solution pumped by said pump 52, deviated toward regeneration circuit, and pre-cooling solution coming back from said desiccant regeneration circuit 2. By membrane distiller 61 it is realised vapour distillation process from solution at the highest temperature toward water circulating within distilled water circulation circuit 63, which is at a lower temperature with respect to regeneration circuit 62. Particularly, water evaporates from solution on membrane warm side of distillatory 61, passes as vapour phase through membrane and condensate within water at a lower temperature on the other side of the same membrane. Thermal energy necessary for distillation process is provided to the solution by said first heat exchanger 64. Water is cooled within circuit 63 by an exchange battery (i.e. second heat exchanger 66) operating by outer air or by sink water. Volumetric excess of condensate water is conveyed outside through discharge 68. Regeneration process can operate continuously in parallel with respect to absorption circuit or it can be slaved to the signal of a sensor depending on solution concentration, or on level of solution within tank 30.

[0043] System permits reaching a remarkable energy saving since, as already noted, it permits to frigorific cycle of said refrigerant means 40 to operate thermodynamically more advantageously. In fact, by a higher evaporation temperature, cycle realises more favourable performance coefficients (COP) with reduced requests of mechanical energy to compressor 44. The latter feature is even more evident in case it is taken as comparison a standard hydronic conditioning system rather than a direct expansion system (i.e. comprising, for medium-large systems, an intermediate circuit of water refrigerated by refrigerant evaporator supplying battery, passing through which air is cooled and dehumidificated).

[0044] System according to the invention also permits preventing post-heating of air, which is necessary in standard systems in order to control inner hygrometric conditions.

[0045] Figure 2 shows a second embodiment of the system 1' according to the present invention, which is different with respect to the previous embodiment since economizer 31 is not provided and because regeneration means 70 comprise a liquid/liquid membrane distillatory 71, but of the air gap membrane type (Air-Gap membrane Distillation), connected with a single heat exchanger 72, said membrane distillatory 71 being provided with a water discharge 73.

[0046] Also air-gap membrane distillers or AGMD are presently applied in the sea water conditioning sector. In this case, sea water is passed on one side of membrane at a higher temperature, while on the other side it is present a thin air gap which contacts a wet waterproof sheet, on the other side by sea water at a lower temperature. Vapour passing through membrane condensate on waterproof sheet. With respect to the DCMD distiller of the previous embodiment, a remarkable thermal recovery is obtained by inner exchange between the two sea water flows and a higher compactness.

[0047] Above system 1', therefore, has a simplified regeneration circuit, making the system much more compact, thanks to the thermal recovery membrane distiller 71.

[0048] An advantage obtained by the thermal recovery within membrane distillatory 71 is that of remarkably reducing request of thermal energy for regeneration and thus also the heat exchanger 72 can be very compact. On the other end, mass flows realised in AGMD modules are lower than DCMD, and their structure is more complicated. For example, DCMD processes permit having vapour flow density through membrane in the order of 20 - 40 kg/hm^2, while for AGMD flows, although still quite high, they are lower 2-5 kg/hm^2.

[0049] Process air transformation in both systems according to embodiments of figures 1 and 2 are not different each other and are shown in Ashrae psychometric diagram of figure 3.

[0050] Main technical advantages of systems according to the present invention, when recovery thermal energy is available, are the following:

- they can be easily integrated/used in existing systems (e.g.
  direct contact systems);
- differently from hybrid systems regenerating solution using all the heat delivered to refrigerant condenser, inventive system can also make regeneration regardless absorption circuit, e.g., using waste heat (motor on vehicles), i.e. it can concentrate solution also when it is not intervened on refrigerant. In other words, system according to the invention can operate under dehumification mode or under dehumidification and cooling mode;
- during summer, they permit remarkable savings of mechanical/electrical energy (30 - 40%) with respect to traditional vapour compression systems;
- during intermediate seasons, it is possible dehumidificating air without being it necessary cooling it under dew temperature, thus saving mechanical/electrical energy;
- permit realising compact systems characterised by dimensions of the same order of the traditional ones, thanks to the high efficiency of energy and mass exchange permitted by modern technology of membrane components.

[0051] Moreover, it is to be said that system according to the invention permits reaching remarkable commercial advantages both in civil sector and in transportation sector. For example, it can be observed that request of power for air conditioning in new vehicles is now a relevant portion of the fuel consumption, as a consequence of higher efficiency of engines and of larger glasses of modern vehicles (higher solar loads). In principle, a vehicle having an engine with maximum power of 70-80 kw can absorb a mechanical power of about 4-5 kW for summer conditioning. Said request has a percentage meaningful relevance if it is considered that, under the standard use conditions, power delivered by engine is much lower (about 18 kW). It can be still noted that in intermediate seasons or during rainy days, often, to prevent glass steaming up problems it is necessary only air dehumidification and not also its cooling, and system according to invention permits excluding operation of refrigerant means.

[0052] Present invention has been described for illustrative but not limitative purposes, according to its preferred embodiments, but it is to be understood that variations and/or modifications can be introduced by those skilled in the art without departing from the relevant scope as defined in the enclosed claims.

Claims

1. Air conditioning and dehumidification integrated system (1, 1'), comprising
a thermal source,
a conditioning/dehumidification unit (20), for cooling and dehumidificating air by means of a desiccant solution,
refrigerant means (40), connected with said conditioning/dehumidification unit (20), suitable for cooling said desiccant solution to a set beforehand temperature by controlling its temperature, to introduce said desiccant solution again into said conditioning/dehumidification unit (20),
a tank (30), loop circuit connected with said conditioning/dehumidification unit (20) and with said refrigerant means (40), wherein a reserve of said desiccant solution from said conditioning/dehumidification unit (20) is collected, and
means (60; 70) for regenerating said desiccant solution connected with said tank (30), said regeneration means (60; 70) being capable to re-concentrate said desiccant solution diluted that comes from said conditioning/dehumidification unit (20), extracting

water therefrom using thermal energy obtained by said thermal source, in order to return said desiccant solution to said tank (30),
characterized in that said regeneration means (60; 70) comprise a membrane distiller (61; 71) of the liquid/liquid type.

2. Integrated system (1, 1') according to claim 1, **characterized in that** said membrane distiller (61) is of the Direct Contact Membrane Distillation - DCMD type and is interposed between
a first desiccant regeneration circuit (62), wherein a first heat exchanger (64) is series-connected with said thermal source for heating said desiccant solution, a pump (65), and
a second collected water circulation circuit (63), wherein means (66) for cooling said water is series-connected with a further pump (67), said means for cooling said collected water circulation circuit (63) being further provided with a waste pipe of the collected distilled water.

3. Integrated system (1, 1') according to claim 2, **characterized in that** said cooling means comprise a second heat exchanger (66) for cooling said water or a water-air hydrophobic membrane contactor capable of exchange, with the room air, not only thermal energy but even water steam, so as to cool the water below the temperature of the external air.

4. Integrated system (1, 1') according to claim 1, **characterized in that** said membrane distiller (71) is an Air-Gap Membrane Distiller - AGMD with thermal recovery, and **in that** it comprises a heat exchanger (72) with said thermal source, connected with said membrane distiller (71), and a waste pipe of the distilled water (73).

5. Integrated system (1, 1') according to anyone of the preceding claims, **characterized in that** said refrigerant means (40) comprise an evaporator (41), a thermal expansion valve (42), a condenser (43) and a compressor (44).

6. Integrated system (1, 1') according to claim 5, **characterized in that** said thermal source is said condenser (43).

7. Integrated system (1, 1') according to anyone of the preceding claims, **characterized in that** it comprises a sensor for detecting the concentration of the solution and/or the level of the solution contained within the tank (30), said sensor being suitable to activate the operation of said regeneration means (60; 70) when the dilution of the solution has exceeded the set threshold.

8. Integrated system (1, 1') according to anyone of the preceding claims, **characterized in that** said tank (30) it is connected with said refrigerant means (40) by a first pump (51) and it is connected with said regeneration means (60; 70) by a first delivery pipe, wherein a second pump is provided, and by a return pipe.

9. Integrated system (1, 1') according to claims 1 - 7, **characterized in that** said regeneration means (60; 70) are connected, preferably interposed, with said tank (30) and said refrigerant means (40).

10. Integrated system (1, 1') according to anyone of the preceding claims, **characterized in that** it comprises an economizer (31) interposed between said tank (30) and said refrigerant means (40).

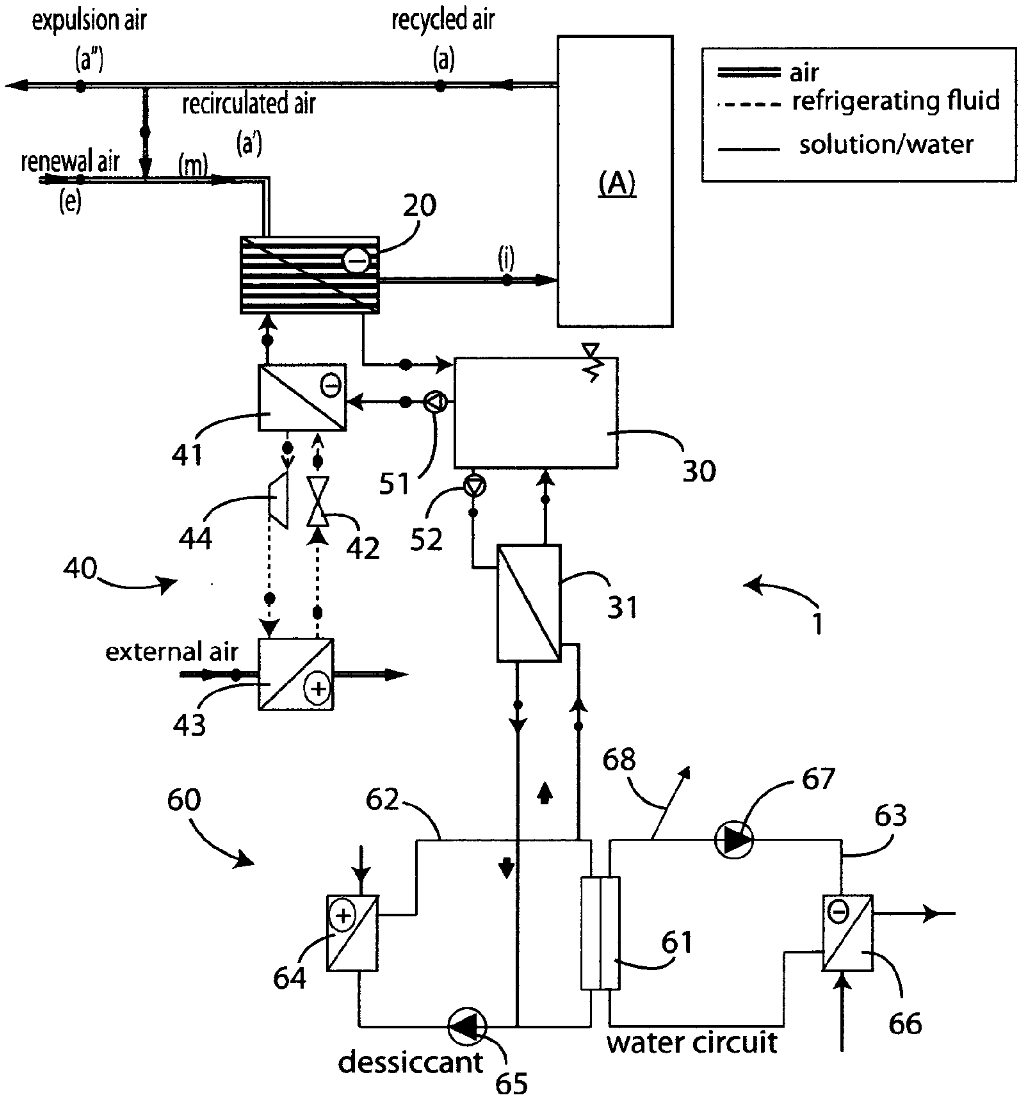
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Fig. 1

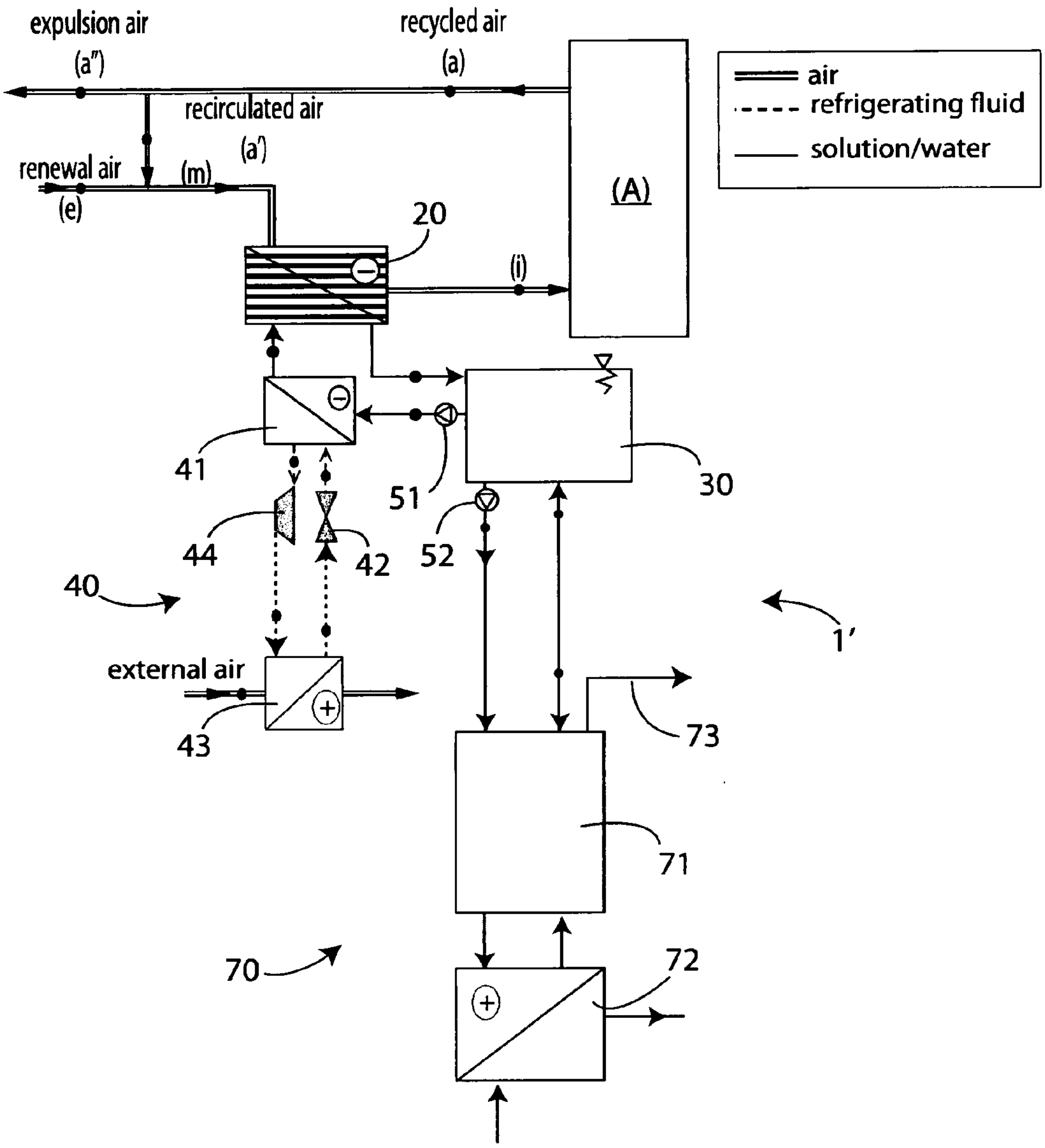
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Fig. 2

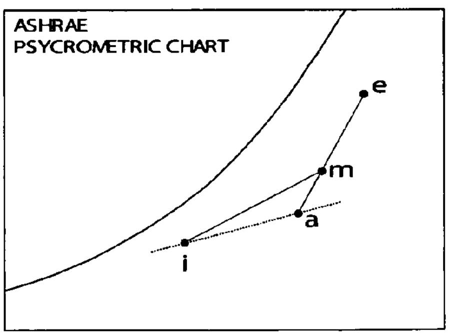
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Fig. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 10 42 5383

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TECHNICAL FIELDS SEARCHED (IPC)

F24F

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	4 April 2011	Valenza, Davide

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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