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(12) **United States Patent**
Vandermeulen

(10) **Patent No.: US 9,709,285 B2**
(45) **Date of Patent: Jul. 18, 2017**

(54) **METHODS AND SYSTEMS FOR LIQUID DESICCANT AIR CONDITIONING SYSTEM RETROFIT**

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(73) Assignee: **7AC Technologies, Inc.**, Beverly, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 299 days.

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Related U.S. Application Data

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(51) **Int. Cl.**
F24F 3/14 (2006.01)

(52) **U.S. Cl.**
CPC ***F24F 3/1417*** (2013.01); *F24F 2003/1458* (2013.01); *F24F 2221/16* (2013.01)

(58) **Field of Classification Search**
CPC F24F 3/1411; F24F 3/1417; F24F 2003/1458; F24F 2221/16; E04D 13/17
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,791,086	A	2/1931	Sperr
2,221,787	A	11/1940	Downs et al.
2,235,322	A	3/1941	Martin
2,433,741	A	12/1947	Crawford
2,988,171	A	6/1961	Arnold et al.
3,718,181	A	2/1973	Reilly et al.
4,100,331	A	7/1978	Fletcher et al.
4,176,523	A	12/1979	Rousseau
4,205,529	A	6/1980	Ko
4,209,368	A	6/1980	Coker et al.
4,222,244	A	9/1980	Meckler
4,235,221	A	11/1980	Murphy

(Continued)

FOREIGN PATENT DOCUMENTS

CN	202229469	U	5/2012
EP	1120609	A1	8/2001

(Continued)

OTHER PUBLICATIONS

1—Open Absorption System for Cooling and Air Conditioning using Membrane Contactors—Annual Report 2005, Publication No. Publication 260097, Project: 101310—Open Absorption System for Cooling and Air Conditioning using Membrane Contactors, Date of publication: Jan. 31, 2006, Author: Manuel Conde-Petit, Robert Weber, Contractor: M. Conde Engineering.

(Continued)

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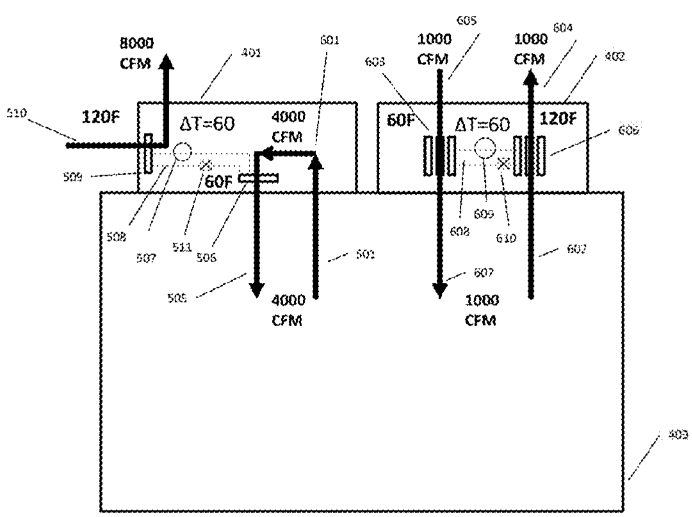
(74) *Attorney, Agent, or Firm* — Foley Hong LLP; Rajesh Vallabh

(57) **ABSTRACT**

Methods and systems are disclosed for utilizing liquid desiccant air conditioning systems in connection with existing HVAC equipment to achieve reductions in electricity consumption.

18 Claims, 12 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

4,239,507	A	12/1980	Benoit et al.	
4,259,849	A	4/1981	Griffiths	
4,324,947	A	4/1982	Dumbeck	
4,399,862	A *	8/1983	Hile	F24F 11/0009 165/253
4,429,545	A	2/1984	Steinberg	
4,435,339	A	3/1984	Kragh	
4,444,992	A	4/1984	Cox, III	
4,583,996	A	4/1986	Sakata et al.	
4,607,132	A	8/1986	Jarnagin	
4,612,019	A	9/1986	Langhorst	
4,649,899	A	3/1987	Moore	
4,691,530	A	9/1987	Meckler	
4,703,629	A	11/1987	Moore	
4,766,952	A	8/1988	Onodera	
4,786,301	A	11/1988	Rhodes	
4,832,115	A	5/1989	Albers et al.	
4,872,578	A	10/1989	Fuerschbach et al.	
4,882,907	A	11/1989	Brown, II	
4,887,438	A	12/1989	Meckler	
4,900,448	A	2/1990	Bonne et al.	
4,910,971	A	3/1990	McNab	
4,939,906	A	7/1990	Spatz et al.	
4,941,324	A	7/1990	Peterson et al.	
4,955,205	A	9/1990	Wilkinson	
4,976,313	A	12/1990	Dahlgren et al.	
4,979,965	A	12/1990	Sannholm	
4,984,434	A	1/1991	Peterson et al.	
4,987,750	A	1/1991	Meckler	
5,005,371	A	4/1991	Yonezawa et al.	
5,181,387	A	1/1993	Meckler	
5,182,921	A	2/1993	Yan	
5,186,903	A	2/1993	Cornwell	
5,191,771	A *	3/1993	Meckler	B01D 53/261 62/271
5,221,520	A	6/1993	Cornwell	
5,351,497	A	10/1994	Lowenstein	
5,375,429	A	12/1994	Tokizaki et al.	
5,462,113	A	10/1995	Wand	
5,471,852	A	12/1995	Meckler	
5,528,905	A	6/1996	Scarlatti	
5,534,186	A	7/1996	Walker et al.	
5,582,026	A *	12/1996	Barto, Sr.	F24F 1/0003 62/298
5,595,690	A	1/1997	Filburn et al.	
5,605,628	A	2/1997	Davidson et al.	
5,638,900	A	6/1997	Lowenstein et al.	
5,641,337	A	6/1997	Arrowsmith et al.	
5,661,983	A	9/1997	Groten et al.	
5,685,152	A	11/1997	Sterling	
5,685,485	A	11/1997	Mock et al.	
5,797,272	A	8/1998	James	
5,832,993	A	11/1998	Ohata et al.	
5,860,284	A	1/1999	Goland et al.	
5,860,285	A	1/1999	Tulpule	
5,928,808	A	7/1999	Eshraghi	
5,933,702	A	8/1999	Goswami	
6,018,954	A	2/2000	Assaf	
6,083,387	A	7/2000	LeBlanc et al.	
6,103,969	A	8/2000	Bussey	
6,156,102	A	12/2000	Conrad et al.	
6,171,374	B1	1/2001	Barton et al.	
6,216,483	B1	4/2001	Potnis et al.	
6,244,062	B1	6/2001	Prado	
6,247,604	B1	6/2001	Taskis et al.	
6,266,975	B1	7/2001	Assaf	
6,417,423	B1	7/2002	Koper et al.	
6,442,951	B1	9/2002	Maeda et al.	
6,463,750	B2	10/2002	Assaf	
6,487,872	B1	12/2002	Forkosh et al.	
6,488,900	B1	12/2002	Call et al.	
6,497,107	B2	12/2002	Maisotsenko et al.	
6,497,749	B2	12/2002	Kesten et al.	
6,502,807	B1	1/2003	Assaf et al.	
6,514,321	B1	2/2003	Lehto et al.	

6,539,731	B2	4/2003	Kesten et al.	
6,546,746	B2	4/2003	Forkosh et al.	
6,557,365	B2	5/2003	Dinnage et al.	
6,660,069	B2	12/2003	Sato et al.	
6,684,649	B1	2/2004	Thompson	
6,739,142	B2	5/2004	Korin	
6,745,826	B2	6/2004	Lowenstein et al.	
6,766,817	B2	7/2004	da Silva	
6,854,278	B2	2/2005	Maisotsenko et al.	
6,854,279	B1	2/2005	Digiovanni et al.	
6,918,404	B2	7/2005	Dias da Silva et al.	
6,938,434	B1	9/2005	Fair	
6,976,365	B2	12/2005	Forkosh et al.	
6,986,428	B2	1/2006	Hester et al.	
7,066,586	B2	6/2006	da Silva et al.	
RE39,288	E	9/2006	Assaf	
7,143,597	B2	12/2006	Hyland et al.	
7,191,821	B2	3/2007	Gronwall et al.	
7,197,887	B2	4/2007	Maisotsenko et al.	
7,269,966	B2	9/2007	Lowenstein et al.	
7,279,215	B2	10/2007	Hester et al.	
7,306,650	B2	12/2007	Slayzak et al.	
7,337,615	B2	3/2008	Reidy	
7,430,878	B2	10/2008	Assaf	
7,758,671	B2	7/2010	Kesten et al.	
7,938,888	B2	5/2011	Assaf	
8,337,590	B2	12/2012	Herencia et al.	
8,353,175	B2	1/2013	Wohlert	
8,496,732	B2	7/2013	Culp et al.	
8,500,960	B2	8/2013	Ehrenberg et al.	
8,623,210	B2	1/2014	Manabe et al.	
8,641,806	B2	2/2014	Claridge et al.	
8,648,209	B1	2/2014	Lastella	
8,695,363	B2	4/2014	Tang et al.	
8,696,805	B2	4/2014	Chang et al.	
8,769,971	B2	7/2014	Kozubal et al.	
8,790,454	B2	7/2014	Lee et al.	
8,800,308	B2	8/2014	Vandermeulen et al.	
8,876,943	B2	11/2014	Gottlieb et al.	
8,881,806	B2	11/2014	Xie et al.	
8,968,945	B2	3/2015	Fasold et al.	
2001/0015500	A1	8/2001	Shimanuki et al.	
2002/0023740	A1	2/2002	Lowenstein et al.	
2002/0026797	A1	3/2002	Sundhar	
2002/0098395	A1	7/2002	Shimanuki et al.	
2002/0104439	A1	8/2002	Komkova et al.	
2002/0139245	A1	10/2002	Kesten et al.	
2002/0139320	A1	10/2002	Shimanuki et al.	
2002/0148602	A1	10/2002	Nakamura	
2003/0000230	A1	1/2003	Kopko	
2003/0029185	A1	2/2003	Kopko	
2003/0033821	A1	2/2003	Maisotsenko et al.	
2003/0051498	A1	3/2003	Sanford	
2003/0106680	A1	6/2003	Serpico et al.	
2003/0121271	A1	7/2003	Dinnage et al.	
2003/0230092	A1	12/2003	Lowenstein et al.	
2004/0040697	A1	3/2004	Pierre et al.	
2004/0061245	A1	4/2004	Maisotsenko et al.	
2004/0109798	A1	6/2004	Chopard et al.	
2004/0118125	A1	6/2004	Potnis et al.	
2004/0134212	A1	7/2004	Lee et al.	
2004/0168462	A1	9/2004	Assaf	
2004/0194944	A1	10/2004	Hendricks et al.	
2004/0211207	A1*	10/2004	Forkosh	F24F 3/1417 62/271
2004/0231512	A1	11/2004	Slayzak et al.	
2005/0106021	A1	5/2005	Bunker et al.	
2005/0109052	A1	5/2005	Albers et al.	
2005/0133082	A1*	6/2005	Konold	H01L 31/0543 136/246
2005/0210907	A1	9/2005	Gillan et al.	
2005/0218535	A1	10/2005	Maisotsenko et al.	
2005/0257551	A1	11/2005	Landry	
2006/0042295	A1	3/2006	Assaf	
2006/0156750	A1	7/2006	Lowenstein et al.	
2006/0278089	A1	12/2006	Theilow	
2007/0169916	A1	7/2007	Wand et al.	
2007/0175234	A1	8/2007	Pruitt	
2007/0234743	A1	10/2007	Assaf	

(56) **References Cited**

U.S. PATENT DOCUMENTS

2008/0127965 A1	6/2008	Burton	
2008/0156471 A1	7/2008	Han et al.	
2008/0196758 A1	8/2008	McGuire	
2008/0203866 A1*	8/2008	Chamberlain	F24F 1/0007 312/236
2008/0302357 A1	12/2008	DeNault	
2008/0314567 A1	12/2008	Noren	
2009/0000732 A1	1/2009	Jacobine et al.	
2009/0056919 A1	3/2009	Hoffman et al.	
2009/0095162 A1	4/2009	Hargis et al.	
2009/0173096 A1*	7/2009	Wohlert	F25B 1/00 62/259.1
2009/0200022 A1	8/2009	Bravo et al.	
2009/0238685 A1	9/2009	Santa Ana	
2010/0000247 A1	1/2010	Bhatti et al.	
2010/0018322 A1	1/2010	Neitzke et al.	
2010/0051083 A1	3/2010	Boyk	
2010/0084120 A1	4/2010	Yin et al.	
2010/0170776 A1	7/2010	Ehrenberg et al.	
2010/0319370 A1*	12/2010	Kozubal	F24F 5/0035 62/92
2011/0100618 A1	5/2011	Carlson	
2011/0101117 A1*	5/2011	Miyauchi	B01D 53/1425 236/44 A
2011/0126885 A1	6/2011	Kokotov et al.	
2012/0052785 A1	3/2012	Nagamatsu et al.	
2012/0114527 A1	5/2012	Hoglund et al.	
2012/0118148 A1	5/2012	Culp et al.	
2012/0118155 A1	5/2012	Claridge et al.	
2012/0125020 A1*	5/2012	Vandermeulen	F24F 3/1417 62/94
2012/0125021 A1	5/2012	Vandermeulen et al.	
2012/0125031 A1	5/2012	Vandermeulen et al.	
2012/0131937 A1	5/2012	Vandermeulen et al.	
2012/0131939 A1	5/2012	Vandermeulen et al.	
2012/0132513 A1	5/2012	Vandermeulen et al.	
2012/0152318 A1	6/2012	Kee	
2013/0056177 A1	3/2013	Coutu et al.	
2013/0101909 A1	4/2013	Fasold et al.	
2013/0186121 A1	7/2013	Erb et al.	
2013/0199220 A1	8/2013	Ma et al.	
2013/0227982 A1	9/2013	Forkosh	
2013/0255287 A1	10/2013	Forkosh	
2013/0340449 A1	12/2013	Kozubal et al.	
2014/0054004 A1	2/2014	LePoudre et al.	
2014/0054013 A1	2/2014	LePoudre et al.	
2014/0150481 A1	6/2014	Vandermeulen	
2014/0150656 A1	6/2014	Vandermeulen	
2014/0150657 A1	6/2014	Vandermeulen et al.	
2014/0150662 A1	6/2014	Vandermeulen et al.	
2014/0223947 A1	8/2014	Ranjan et al.	
2014/0245769 A1	9/2014	Vandermeulen et al.	
2014/0250935 A1	9/2014	Prochaska et al.	
2014/0260367 A1	9/2014	Coutu et al.	
2014/0260369 A1	9/2014	LePoudre	
2014/0260371 A1	9/2014	Vandermeulen	
2014/0260398 A1	9/2014	Kozubal et al.	
2014/0260399 A1	9/2014	Vandermeulen	
2014/0262125 A1	9/2014	Erb et al.	
2014/0262144 A1	9/2014	Erb et al.	
2014/0264968 A1	9/2014	Erb et al.	
2014/0360373 A1	12/2014	Peacos et al.	
2014/0366567 A1	12/2014	Vandermeulen	
2015/0338140 A1	11/2015	Vandermeulen	

FOREIGN PATENT DOCUMENTS

EP	1563229	A1	8/2005
EP	1781995	A1	5/2007
EP	2256434	A2	12/2010
EP	2306100	A1	4/2011
JP	02306067	A	12/1990
JP	H08-105669	A	4/1996
JP	H11-351700	A	12/1999
JP	2002206834	A	7/2002
JP	2006-263508	A	10/2006
JP	2006-529022	A	12/2006
JP	04273555	B2	6/2009
JP	2009-293831	A	12/2009
JP	2010-247022	A	11/2010
JP	2011-163682	A	8/2011
KR	20040026242	A	3/2004
KR	10-0510774	B1	8/2005
KR	2014-0022785	A	2/2014
WO	9922180	A1	5/1999
WO	0011426	A1	3/2000
WO	0055546	A1	9/2000
WO	WO-02066901	A1	8/2002
WO	03004937	A1	1/2003
WO	2004046618	A1	6/2004
WO	2006006177	A1	1/2006
WO	2008037079	A1	4/2008
WO	2009094032	A1	7/2009
WO	2009144880	A1	12/2009
WO	2011062808	A1	5/2011
WO	2011161547	A2	12/2011
WO	2012082093	A1	6/2012

OTHER PUBLICATIONS

2—Open Absorption System for Cooling and Air Conditioning using Membrane Contactors—Annual, Report 2006, Publication No. Publication 260098, Project: 101310—Open Absorption System for Cooling and Air Conditioning using Membrane Contactors, Date of publication: Nov. 14, 2006, Author: Manuel Conde-Petit, Robert Weber, Contractor: M. Conde Engineering.

3—Open Absorption System for Cooling and Air Conditioning Using Membrane Contactors—Final Report, Publication No. Publication 280139, Project: 101310—Open Absorption System for Cooling and Air Conditioning using Membrane Contactors, Date of publication: Jul. 8, 2008, Author: Viktor Dorer, Manuel Conde-Petit, Robert Weber, Contractor: M. Conde Engineering.

4—Conde-Petit, M. 2007. Liquid Desiccant-Based Air-Conditioning Systems—LDACS, Proc. of the 1st European Conference on Polygeneration—Technologies and Applications, 217-234, A. Coronas, ed., Tarragona—Spain, Oct. 16-17, Published by CREVER—Universitat Rovira I Virgili, Tarragona, Spain.

5—Conde-Petit, M. 2008. Open Absorption Systems for Air-Conditioning using Membrane Contactors,Proceedings '15. Schweizerisches Status-Seminar <<Energie- und Umweltforschung im Bauwesen>>, Sep. 11-12—ETH Zurich, Switzerland. Published by BRENET—Eggwilstr. 16a, CH-9552 Bronschhofen—Switzerland (brenet@vogel-tech.ch).

6—Third Party Observations for PCT/US2011/037936, dated Sep. 24, 2012.

Ashrae, et al., "Desiccant Dehumidification and Pressue Drying Equipment," 2012 Ashrae Handbook—HVAC Systems and Equipment, Chapter 24, pp. 24.1-24.12.

Beccali, et al., "Energy and Economic Assessment of Desiccant Cooling," Solar Energy, Issue 83, pp. 1828-1846, Aug. 2009.

Fimbres-Weihs, et al., "Review of 3D CFD modeling of flow and mass transfer in narrow spacer-filled channels in membrane modules," Chemical Engineering and Processing 49 (2010) pp. 759-781.

Li, F. et al., "Novel spacers for mass transfer enhancement in membrane separations," Journal of Membrane Science, 253 (2005), pp. 1-12.

Li, Y., et al., "CFD simulation of fluid flow through spacer-filled membrane module: selecting suitable cell types for periodic boundary conditions," Desalination 233 (2008) pp. 351-358.

Liu, et al., "Research Progress in Liquid Desiccant Air Conditioning Devices and Systems," Frontiers of Energy and Power Engineering in China, vol. 4, Issue 1, pp. 55-65, Feb. 2010.

Lowenstein, "A Solar Liquid-Desiccant Air Conditioner," Solar 2003, Proceedings of the 32nd ASES Annual Conference, Austin, TX, Jul. 2003.

Mathioulakis, "Desalination by Using Alternative Energy," Desalination, Issue 203, pp. 346-365, 2007.

(56) **References Cited**

OTHER PUBLICATIONS

Russell, et al., "Optimization of Photovolatic Thermal Collector Heat Pump Systems," ISES International Solar Energy Conference, Atlanta, GA, vol. 3, pp. 1870-1874, May 1979.
Welty, "Liquid Desiccant Dehumidification," Engineered Systems, May 2010, vol. 27 Issue 5, p. 34.
International Search Report and Written Opinion for PCT/2014/028124, dated Aug. 22, 2014.
"Siphon." Encyclopedia Americana. Grolier Online, 2015. Web. Apr. 3, 2015. 1 page.
Perry "Perry's Chemical Engineers handbook" 1999 McGraw Hill p. 11-52, 11-53.
Korean Patent Application 10-2015-7025387, Office Action dated Aug. 26, 2016.
European Supplemental Search Report for EP14770288.0, dated Dec. 15, 2016.
Chinese Patent Application 201480015033.1, Office Action dated Mar. 21, 2017.
Korean Patent Application 10-2015-7025387, Office Action dated Apr. 27, 2017.

* cited by examiner

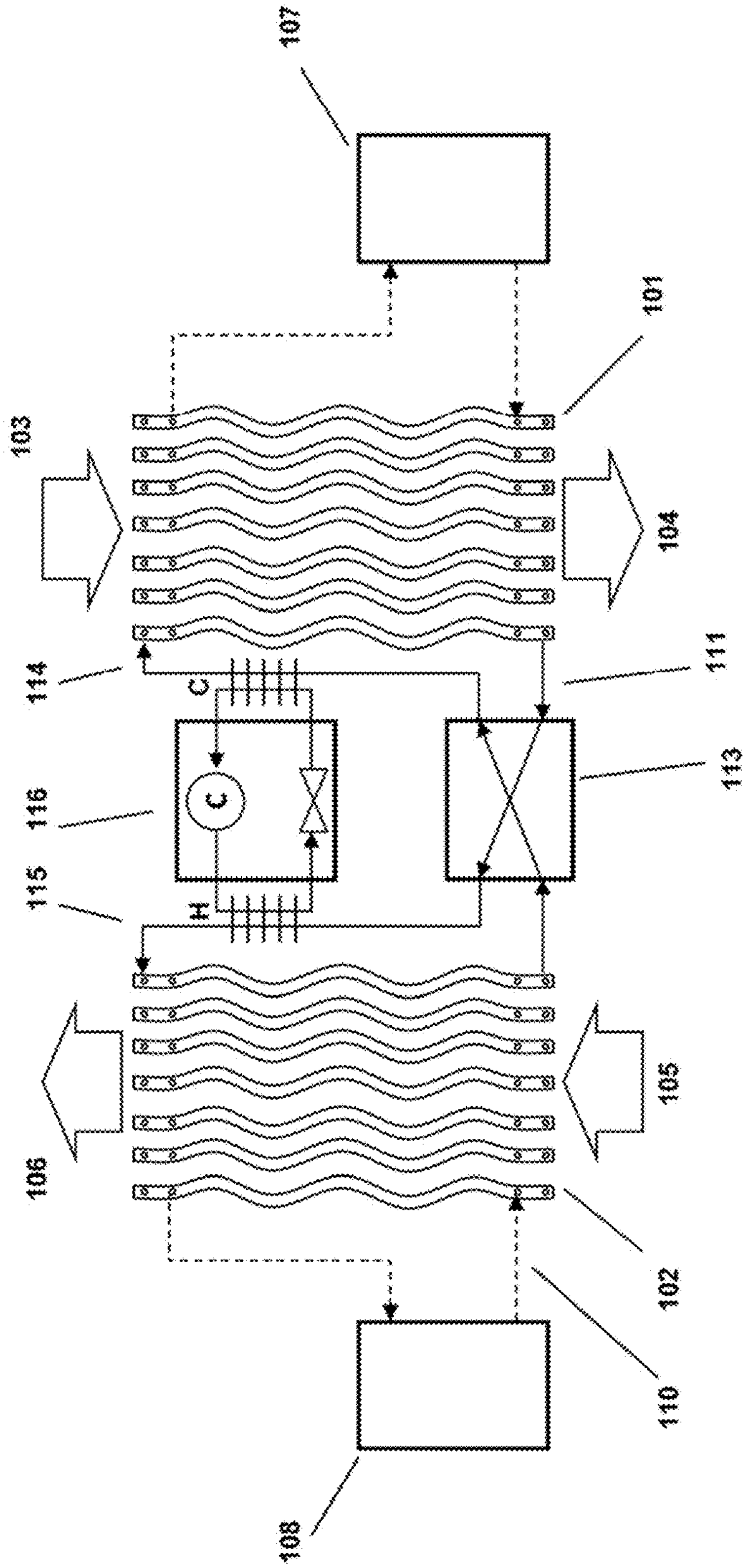


FIG. 1

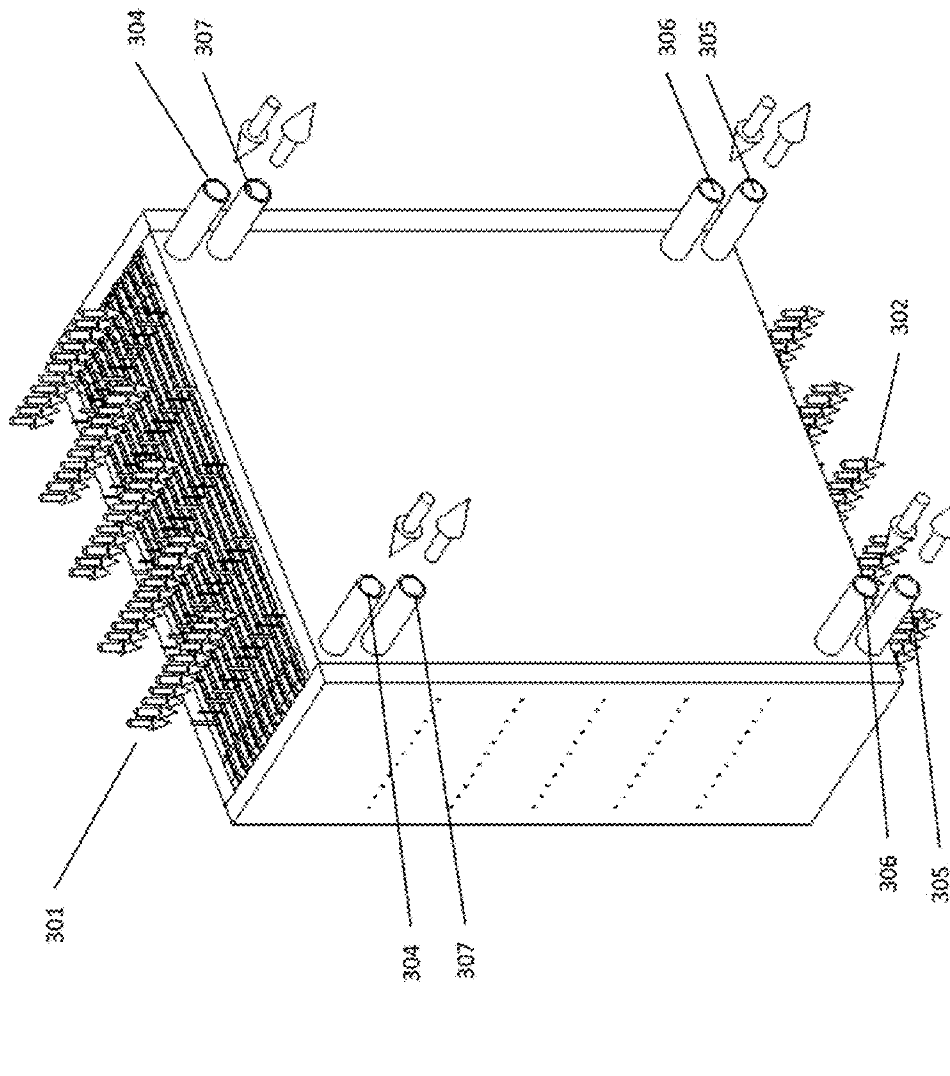


FIG. 2

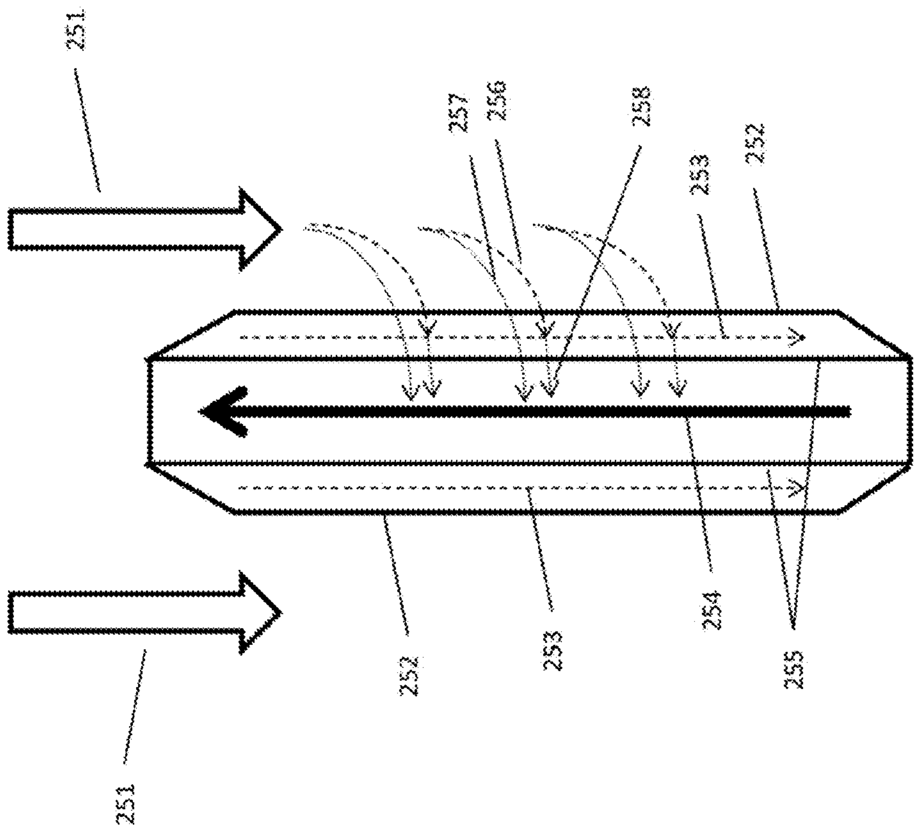
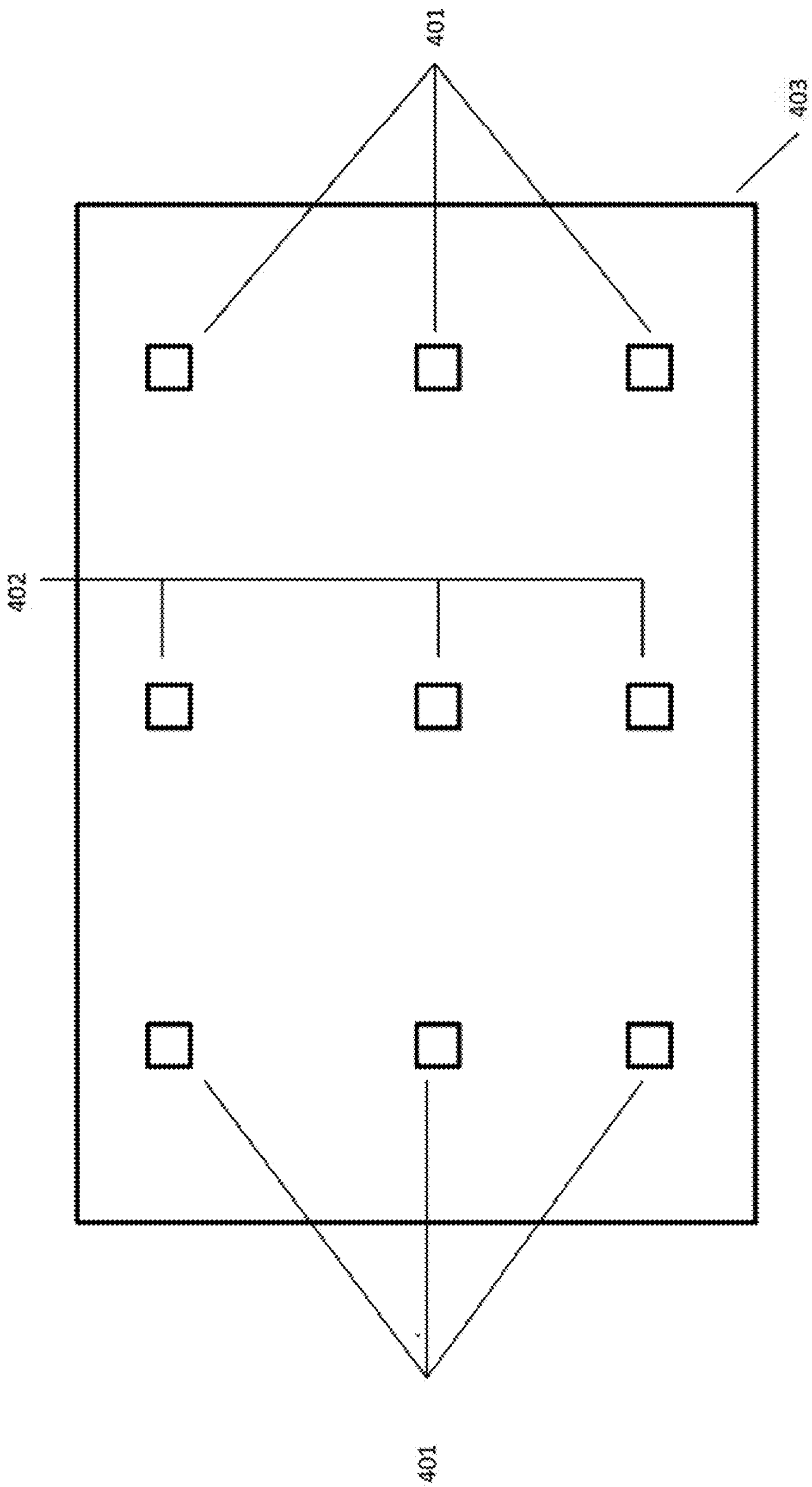


FIG. 3



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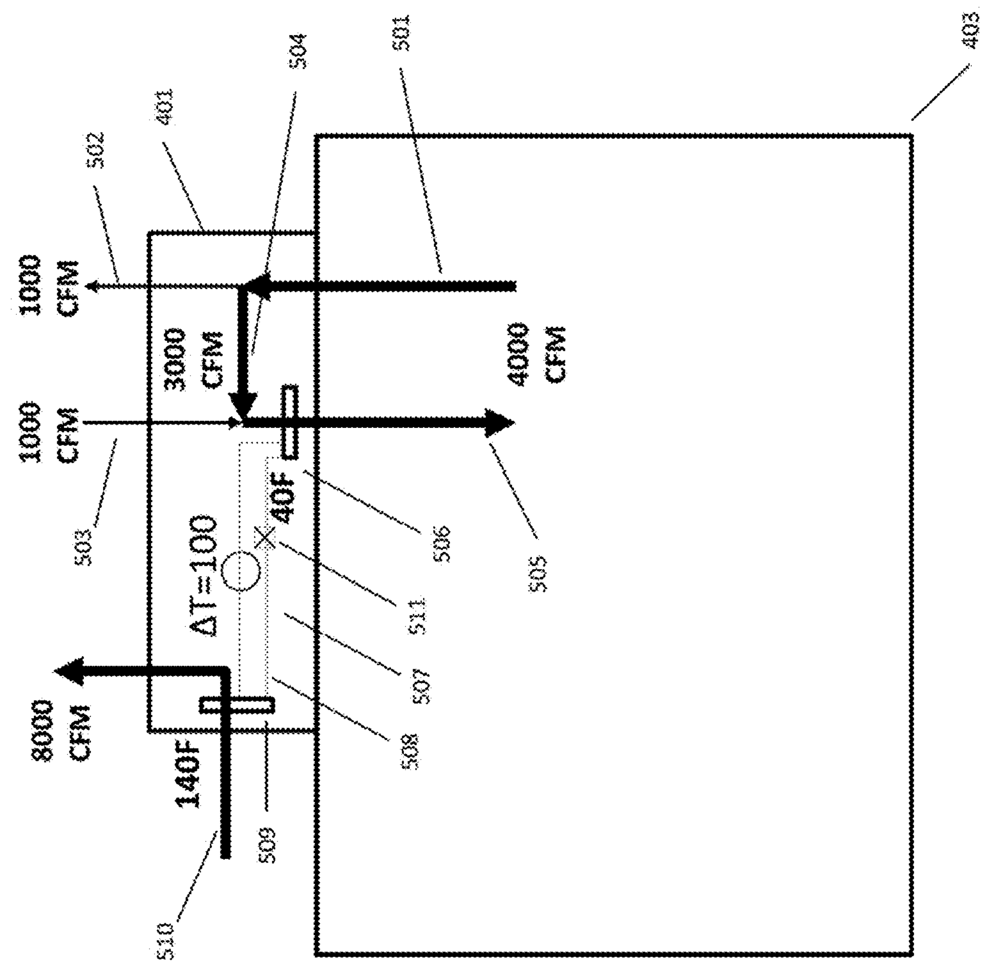
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FIG. 5

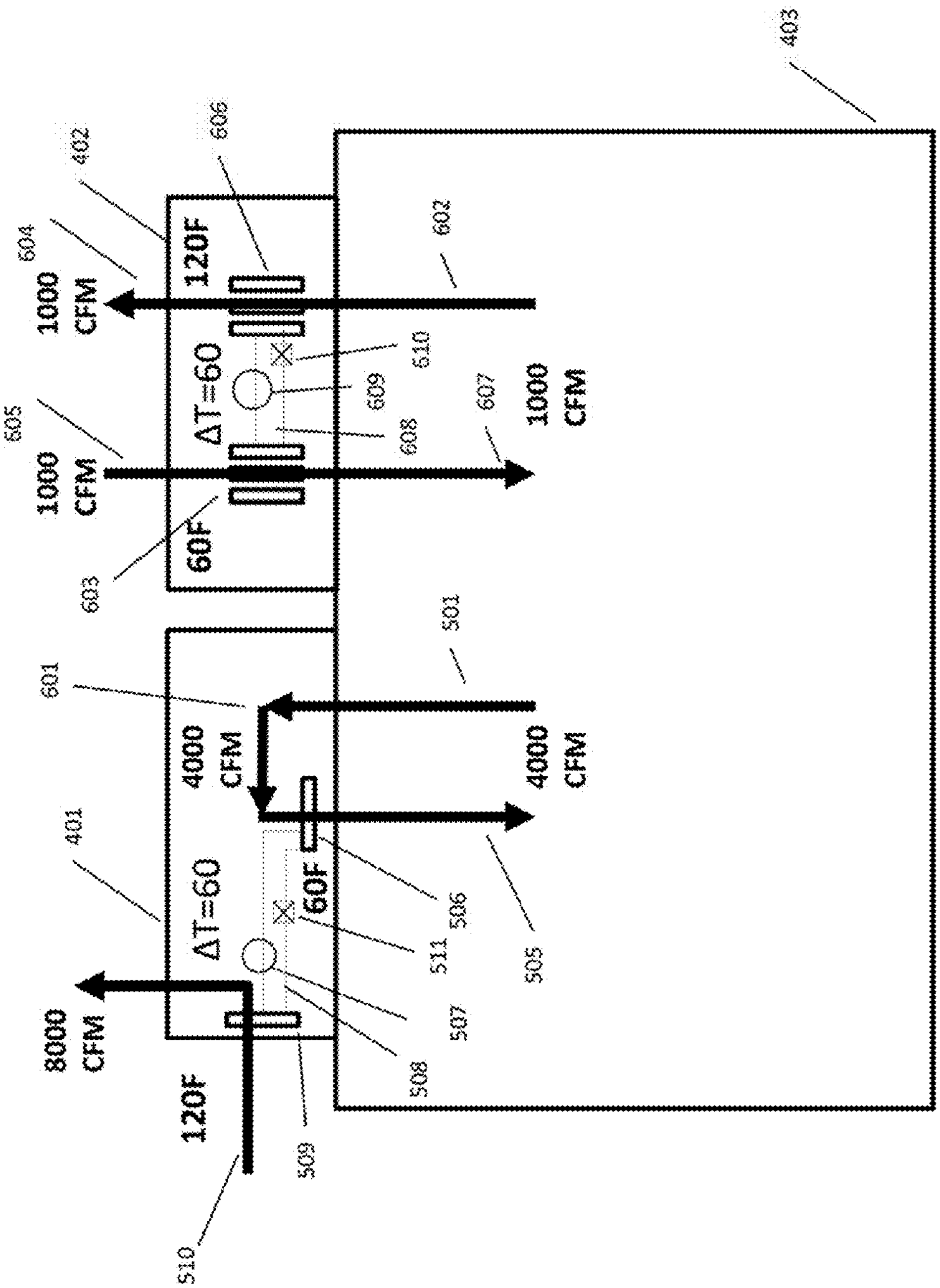
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FIG. 6

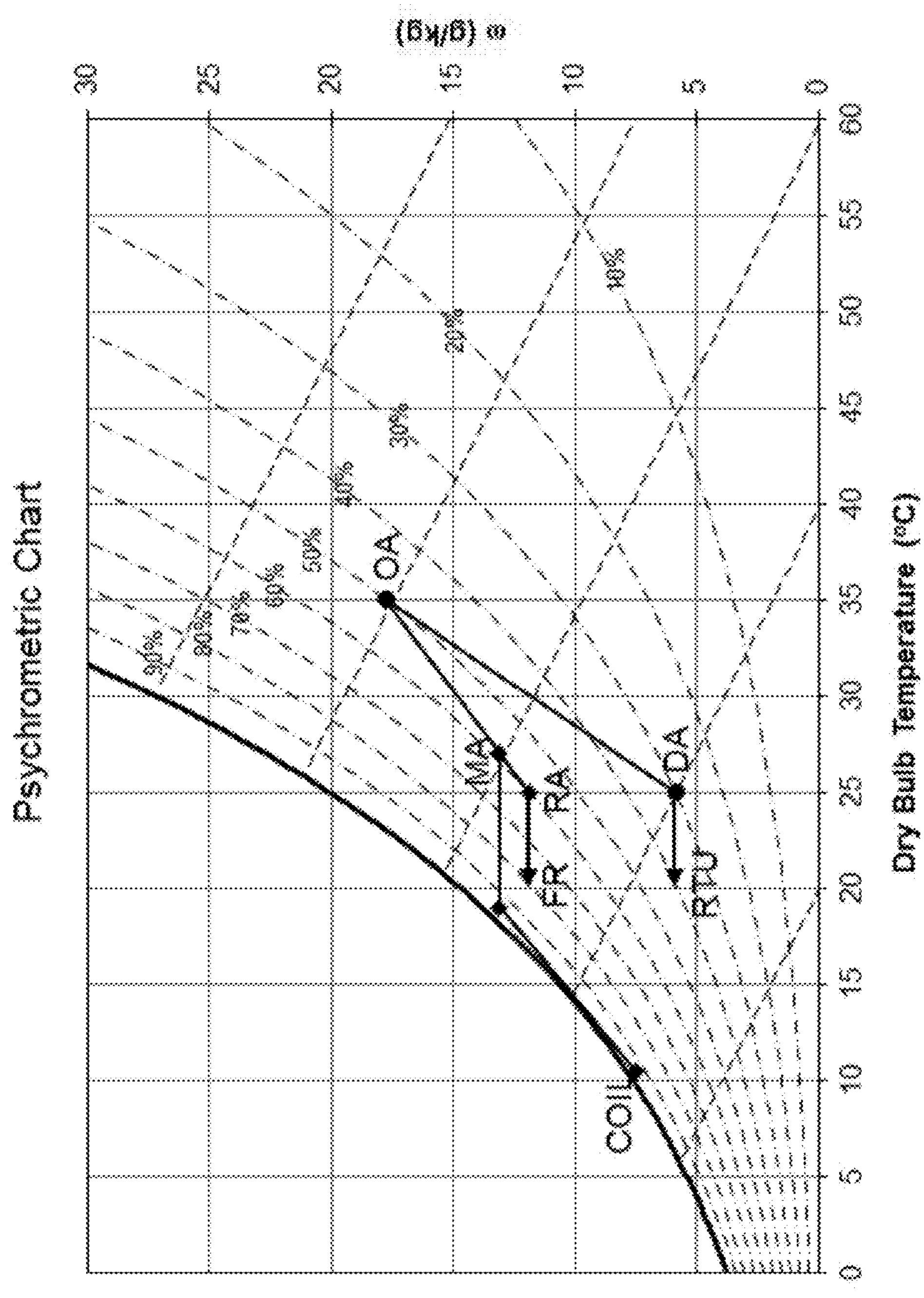
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FIG. 7

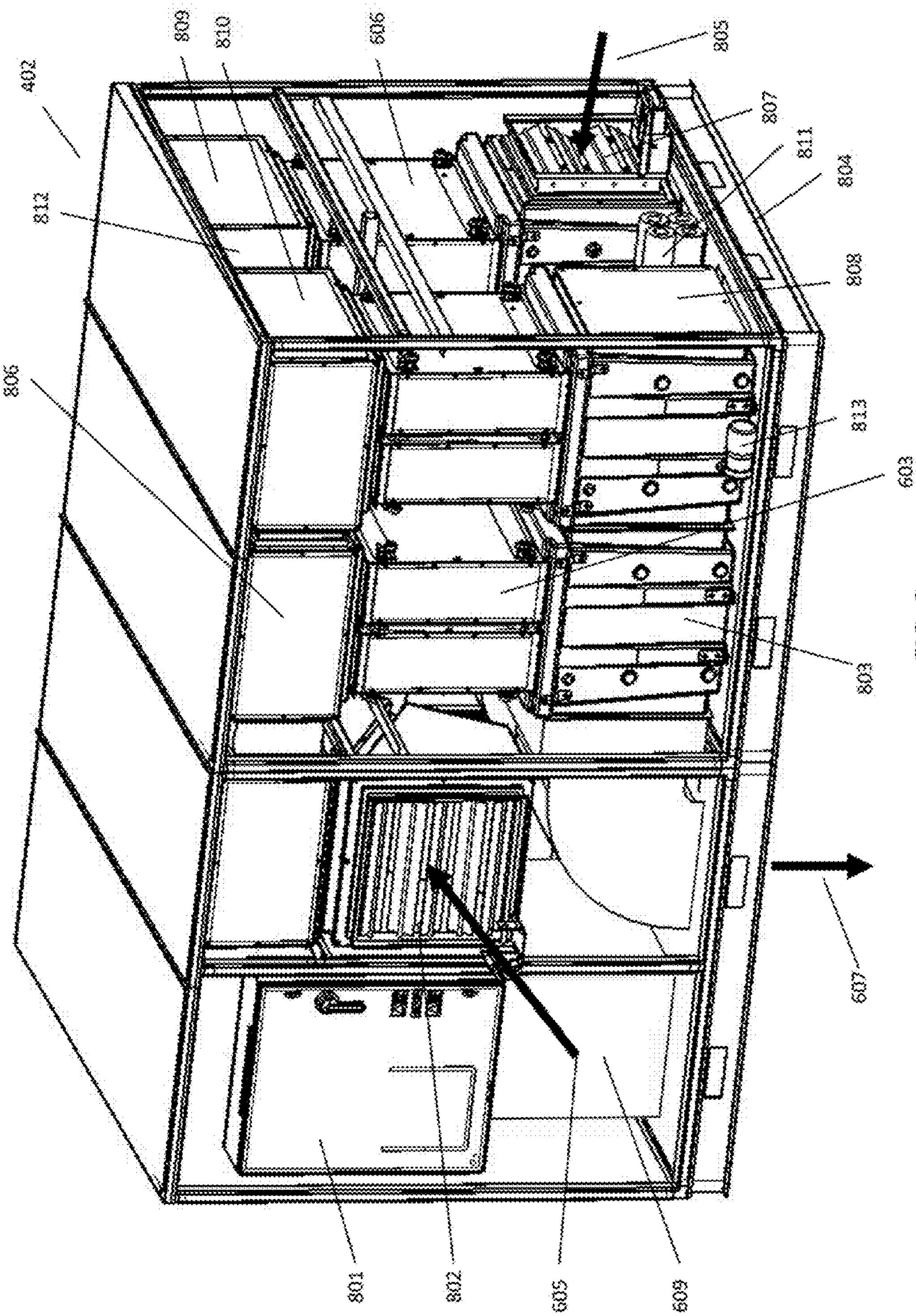
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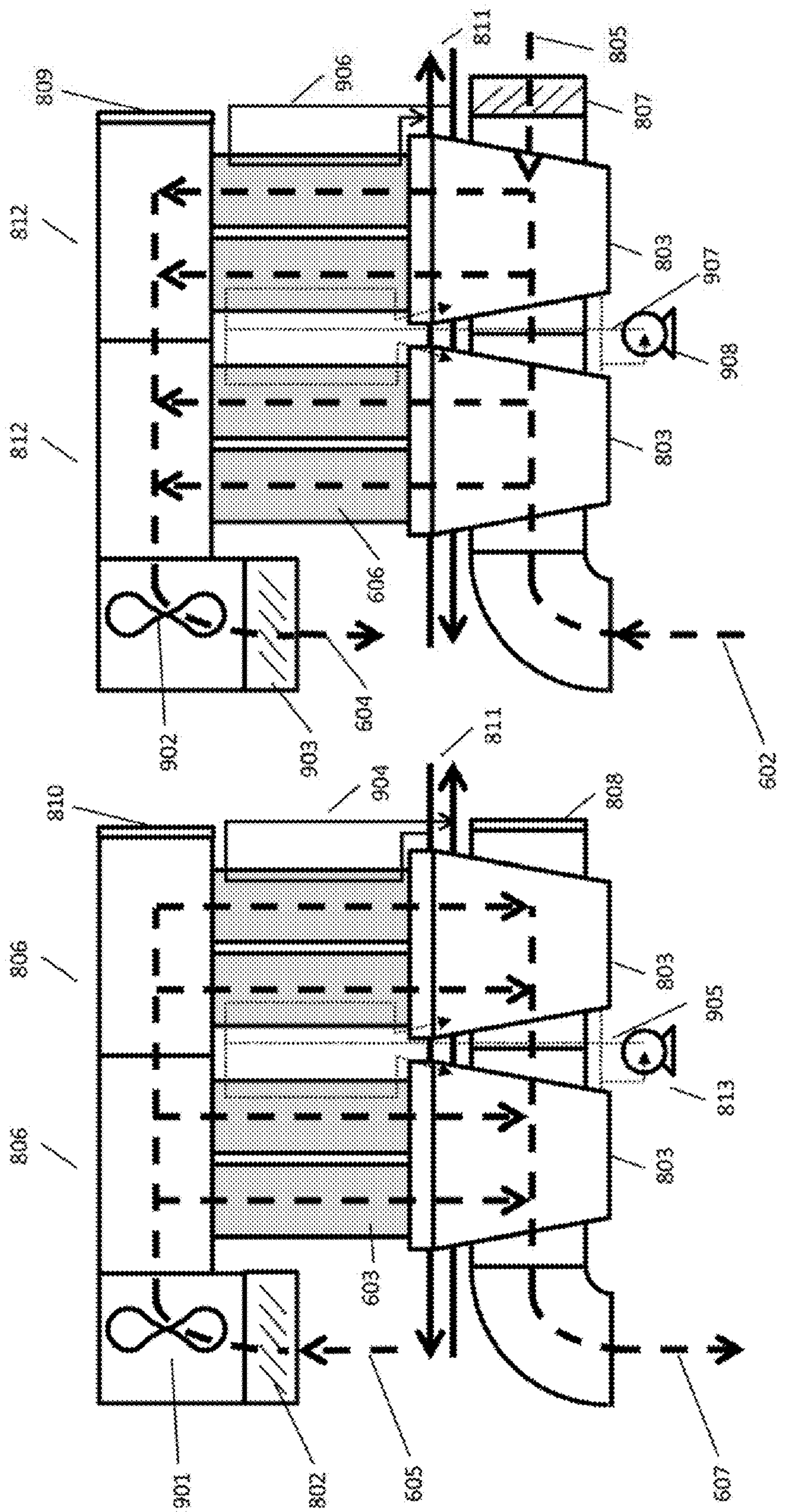
FIG. 8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807
812
812
803
907
908
803
606
902
903
604
602
810
904
811
808
806
806
803
905
813
803
603
901
802
605
607

FIG. 9B

FIG. 9A

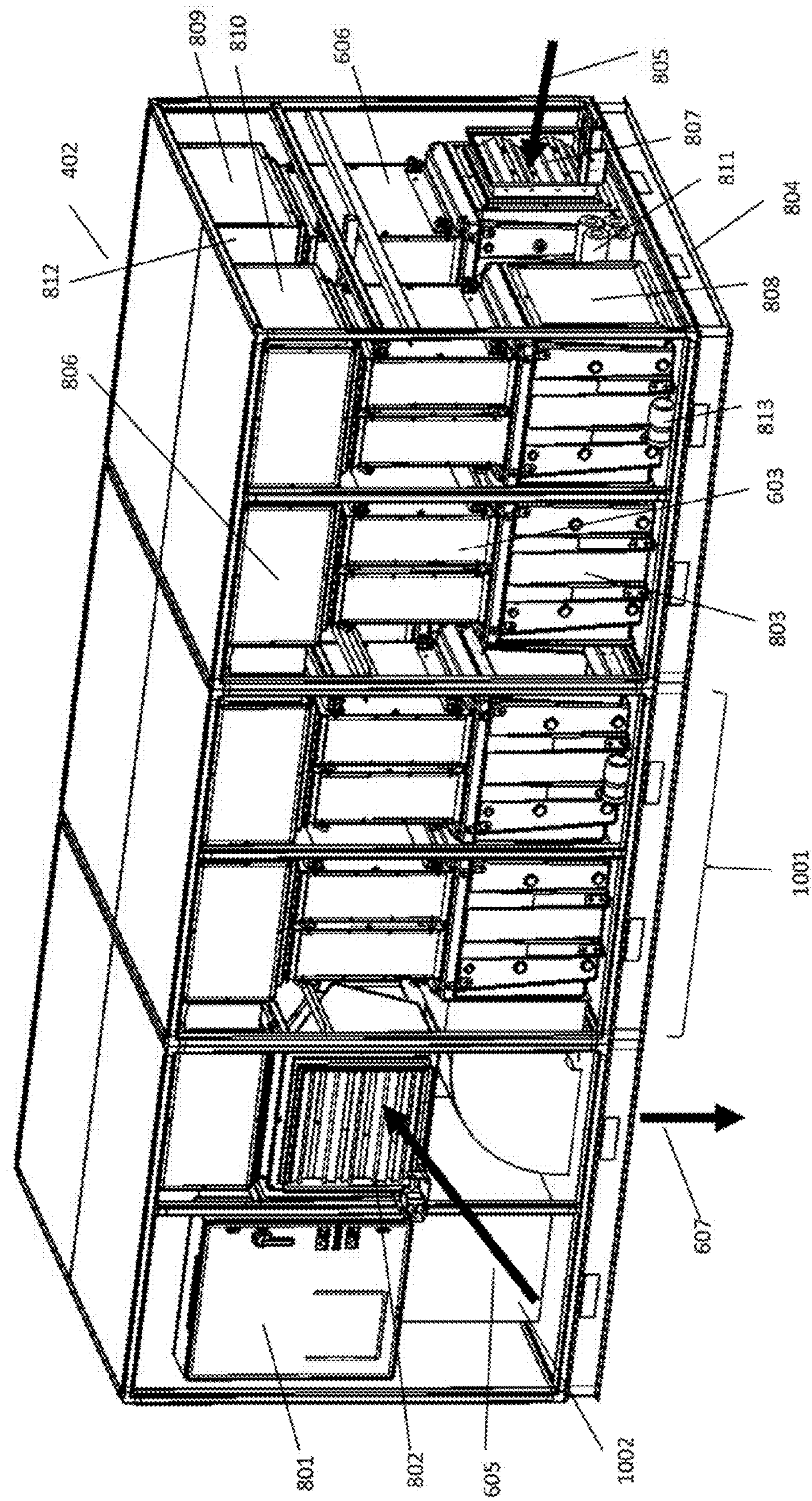
809
810
606
805
807
811
804
402
812
808
806
813
603
803
1001
607
801
802
605
1002

FIG. 10

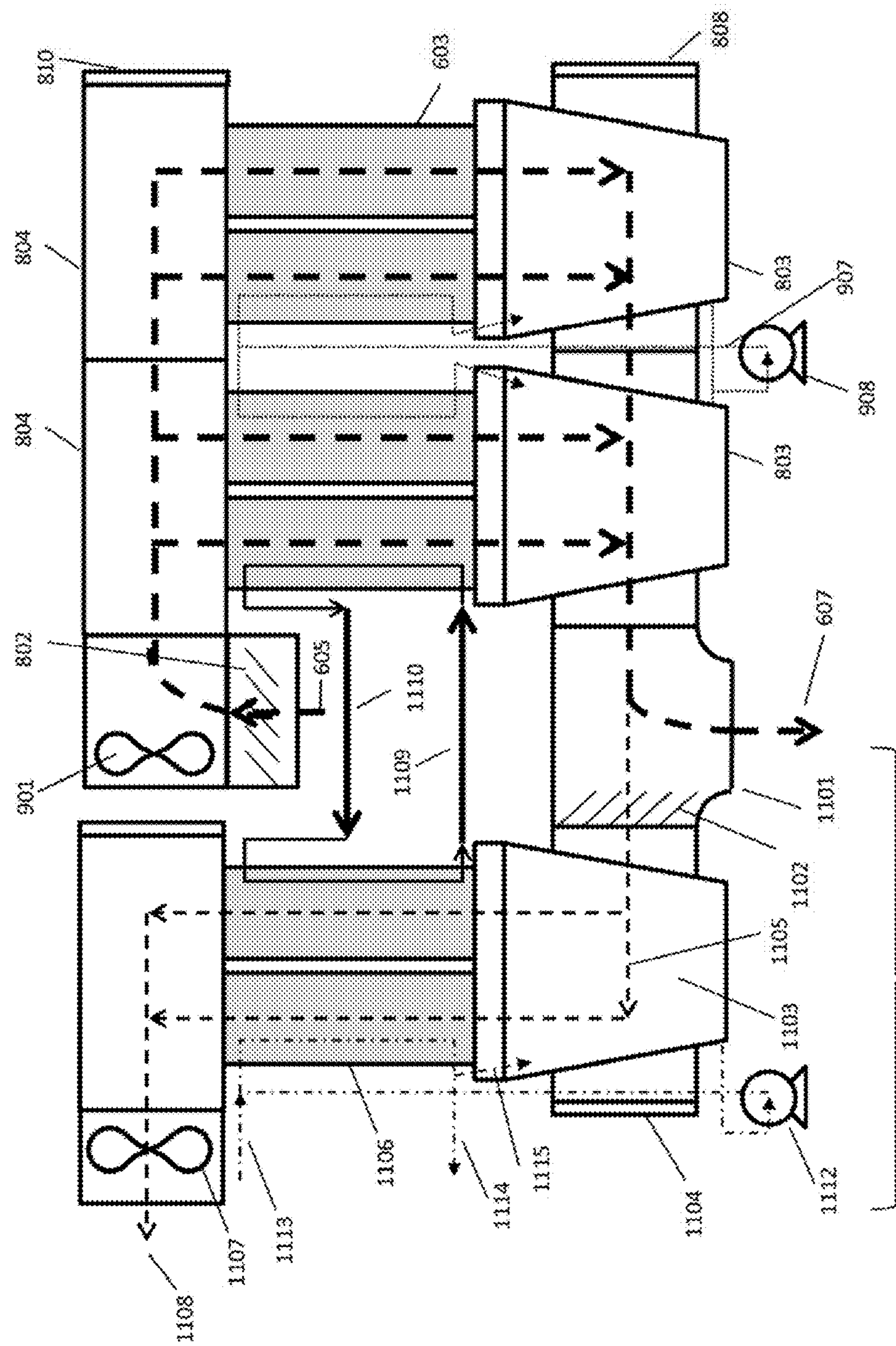
810
603
808
804
804
803
907
803
908
802
605
1110
1109
607
901
1101
1102
1105
1111
1103
1106
1114
1115
1104
1112
1107
1113
1108

FIG. 11

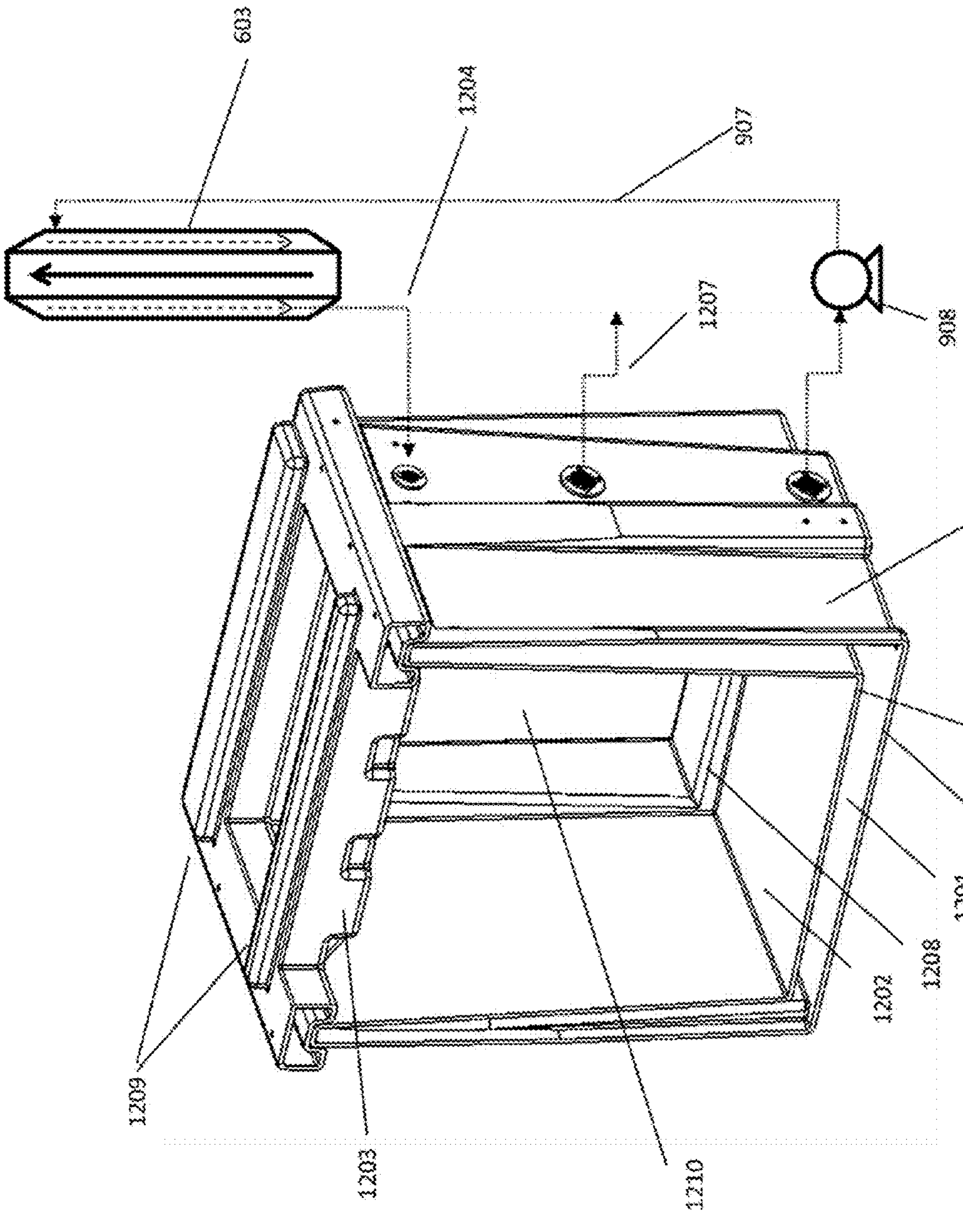
603
1204
907
1207
908
803
1205
1206
1201
1208
1202
1210
1203
1209

FIG. 12

METHODS AND SYSTEMS FOR LIQUID DESICCANT AIR CONDITIONING SYSTEM RETROFIT

CROSS REFERENCE TO RELATED APPLICATION

This application claims priority from U.S. Provisional Patent Application No. 61/782,579 filed on Mar. 14, 2013 entitled METHODS AND SYSTEMS FOR LIQUID DESICCANT AIR CONDITIONING SYSTEM RETROFIT, which is hereby incorporated by reference.

BACKGROUND

The present application relates generally to the use of liquid desiccants to dehumidify and cool, or heat and humidify an air stream entering a space. More specifically, the application relates to an optimized system configuration to retrofit 2- or 3-way liquid desiccant mass and heat exchangers that employ micro-porous membranes to separate the liquid desiccant from an air stream in large commercial and industrial buildings while at the same time modifying existing Heating Ventilation and Air Conditioning (HVAC) equipment to achieve a significant reduction in electricity consumption in the building.

Desiccant dehumidification systems—both liquid and solid desiccants—have been used parallel to conventional vapor compression HVAC equipment to help reduce humidity in spaces, particularly in spaces that require large amounts of outdoor air or that have large humidity loads inside the building space itself. (ASHRAE 2012 Handbook of HVAC Systems and Equipment, Chapter 24, p. 24.10). Humid climates, such as for example Miami, Fla. require a lot of energy to properly treat (dehumidify and cool) the fresh air that is required for a space's occupant comfort. Conventional vapor compression systems have only a limited ability to dehumidify and tend to overcool the air, oftentimes requiring energy intensive reheat systems, which significantly increase the overall energy costs, because reheat adds an additional heat-load to the cooling coil. Desiccant dehumidification systems—both solid and liquid—have been used for many years and are generally quite efficient at removing moisture from the air stream. However, liquid desiccant systems generally use concentrated salt solutions such as ionic solutions of LiCl, LiBr or $CaCl_2$ and water. Such brines are strongly corrosive, even in small quantities, so numerous attempts have been made over the years to prevent desiccant carry-over to the air stream that is to be treated. In recent years efforts have begun to eliminate the risk of desiccant carry-over by employing micro-porous membranes to contain the desiccant.

Liquid desiccant systems generally have two separate functions. The conditioning side of the system provides conditioning of air to the required conditions, which are typically set using thermostats or humidistats. The regeneration side of the system provides a reconditioning function of the liquid desiccant so that it can be re-used on the conditioning side. Liquid desiccant is typically pumped between the two sides. A control system is used to properly balance the liquid desiccant between the two sides as conditions necessitate and that excess heat and moisture are properly dealt with without leading to over-concentrating or under-concentrating the desiccant.

In large stores, supermarkets, commercial and industrial buildings, energy is wasted because the existing unitary HVAC units serving the building do not adequately dehumidify the ventilation air that they provide to the building. This excess humidity winds up being condensed out of the air with excess energy usage from refrigeration and freezer equipment inside the building, which creates a load on that equipment resulting in a higher than necessary energy consumption.

Older buildings typically have been designed with HVAC equipment that recirculates a large portion (80-90%) of the air from the space through its cooling coil. The equipment takes in approximately 10-20% of fresh outside air, which as discussed above requires dehumidification, which is not adequately done by this equipment. At time of construction and design, engineers will sometime add a desiccant system to create the necessary dehumidification, but such equipment is heavy, complex and expensive and is not retrofitable on buildings that were not originally designed to accommodate them.

There thus remains a need to provide a retrofitable cooling system for buildings with high humidity loads, wherein the dehumidification of outside air can be accommodated at low capital and energy costs.

BRIEF SUMMARY

Provided herein are methods and systems used for the efficient cooling and dehumidification of an air stream in a large commercial or industrial building using a liquid desiccant. In accordance with one or more embodiments, the liquid desiccant flows down the face of a support plate as a falling film. In accordance with one or more embodiments, the desiccant is contained by a microporous membrane, and the air stream is directed in a primarily vertical or primarily horizontal orientation over the surface of the membrane and whereby both latent and sensible heat are absorbed from the air stream into the liquid desiccant. In accordance with one or more embodiments, the support plate is filled with a heat transfer fluid that ideally flows in a direction counter to the air stream. In accordance with one or more embodiments, the system comprises a conditioner that removes latent and sensible heat through the liquid desiccant into the heat transfer fluid and a regenerator that rejects the latent and sensible heat from the heat transfer fluid to the environment. In accordance with one or more embodiments, the heat transfer fluid in the conditioner is cooled by a refrigerant compressor or an external source of cold heat transfer fluid. In accordance with one or more embodiments, the regenerator is heated by a refrigerant compressor or an external source of hot heat transfer fluid. In accordance with one or more embodiments, the refrigerant compressor is reversible to provide heated heat transfer fluid to the conditioner and cold heat transfer fluid to the regenerator, and the conditioned air is heated and humidified and the regenerated air is cooled and dehumidified.

In accordance with one or more embodiments, a liquid desiccant membrane system employs an indirect evaporator to generate a cold heat transfer fluid wherein the cold heat transfer fluid is used to cool a liquid desiccant conditioner. Furthermore in one or more embodiments, the indirect evaporator receives a portion of the air stream that was earlier treated by the conditioner. In accordance with one or more embodiments, the air stream between the conditioner and indirect evaporator is adjustable through some convenient means, for example through a set of adjustable louvers or through a fan with adjustable fan speed. In one or more embodiments, the water supplied to the indirect evaporator is seawater. In one or more embodiments, the water is waste water. In one or more embodiments, the indirect evaporator uses a membrane to inhibit or prevent carry-over of non-desirable elements from the seawater or waste water. In one or more embodiments, the water in the indirect evaporator is not cycled back to the top of the indirect evaporator such as would happen in a cooling tower, but between 20% and 80% of the water is evaporated and the remainder is discarded.

In accordance with one or more embodiments, the indirect evaporator is used to provide heated, humidified air to a supply air stream to a space while a conditioner is simultaneously used to provide heated, humidified air to the same space. This allows the system to provide heated, humidified air to a space in winter conditions. The conditioner is heated and is desorbing water vapor from a desiccant and the indirect evaporator can be heated as well and is desorbing water vapor from liquid water. In combination the indirect evaporator and conditioner provide heated humidified air to the building space for winter heating conditions.

In accordance with one or more embodiments, some number of Liquid Desiccant Air Conditioning systems (LDACs) is installed at existing large stores, supermarkets or other commercial or industrial buildings to replace a subset of the existing unitary heating ventilating and air conditioning (HVAC) recirculating rooftop units (RTUs) already present. In accordance with one or more embodiments, the new liquid desiccant air conditioning units are operated to provide heated or cooled 100% outside air ventilation to the conditioned space. In accordance with one or more embodiments, the remaining RTUs are modified in such a way that they no longer supply outside air to the space, but become 100% recirculating RTU's. In one or more embodiments, the modification is achieved by removing power to a damper motor. In one or more embodiments, the modification is achieved by removing a lever from a damper mechanism. In accordance with one or more embodiments, the remaining RTUs are modified to have a higher evaporator temperature so that moisture no longer condenses on the evaporator coils and the unit becomes more energy efficient. In one or more embodiments, the increase in evaporator temperature is achieved by replacing an expansion valve. In one or more embodiments, the increase in evaporator temperature is achieved by adding an APR valve such as the valve assembly supplied by Rawal Devices, Inc. of Woburn, Mass. In one or more embodiments, the increase in evaporator temperature is achieved by adding a hot-gas bypass system or some other convenient means of increasing the evaporator temperature.

In accordance with one or more embodiments, the new liquid desiccant air conditioning units provide all of the cooled, dehumidified outside air ventilation required by the building during the cooling season and warm humidified outside air ventilation during the heating season. The remaining existing unitary HVAC units have their outside air dampers shut so that they only provide heating or cooling of the indoor air. The benefit of this system retrofit that the new LDACs are more energy efficient and effective at dehumidifying the required ventilation air than the unitary HVAC units they replace. Another benefit of this system approach is that by the improved ability to reduce the space humidity in the building, the energy used by refrigeration and freezer units inside of the conditioned space is significantly reduced because they waste less energy having to condense humidity out of the air. Furthermore by modifying the remaining RTUs their energy consumption is also reduced. And lastly the advantage of replacing only a portion of the RTUs the cost of the upgrade is relatively minor since one can elect to replace mostly the oldest RTUs that are due for replacement anyway and payback periods are short because of the low upgrade cost and large energy savings.

In accordance with one or more embodiments, a liquid desiccant air conditioning system is constructed of repeatable membrane module elements and membrane module support tubs. In one or more embodiments, the scalable membrane modules are sized so as to fit through a standard access hatch for a roof with an opening of about 2.5 ft×2.5 ft. In one or more embodiments, the repeatable module support tubs are arranged in a linear fashion in such a way that the module support tubs form a support structure and an air duct simultaneously. In one or more embodiments, the module support tubs are hollow. In one or more embodiments, the module support tubs have double walls so that they can hold a liquid. In one or more embodiments, the liquid is a liquid desiccant. In one or more embodiments, the liquid desiccant is stratified with higher concentrations near the bottom and lower concentrations near the top of the tub. In one or more embodiments, the tub bottom is sloped so as the conduct any spilled liquid to a single corner of the tub. In one or more embodiments, the corner is equipped with a sensor or detector that can detect if any liquid has collected in the corner. In one or more embodiments, such a sensor is a conductivity sensor. In one or more embodiments, the module support tubs have openings on both ends. In one or more embodiments, the two ends are used to provide two different air streams into a series of support tubs. In one or more embodiments, the air streams are a return air stream and an outside air air-stream.

In accordance with one or more embodiments, a first series of membrane modules and module support tubs are arranged in a primarily linear fashion with a duct section that allows for a majority of air to be entered into a building and a portion of air to transported to a second series of membrane modules and module support tub sections. In one or more embodiments, the first series of modules and support tubs contain a membrane conditioner. In one or more embodiments, the membrane conditioner contains a desiccant behind the membrane. In one or more embodiments, the second series of modules contain a membrane conditioner. In one or more embodiments, the second conditioner contains water behind the membrane. In one or more embodiments, the water is seawater. In one or more embodiments, the water is waste water. In one or more embodiments, the water is potable water. In one or more embodiments, the air flow in the second series of membrane modules and module support tubs is reversible. In one or more embodiments, the first series of membrane modules receives a hot heat transfer fluid in winter mode from a heat source and receives a cold heat transfer fluid in summer mode. In one or more embodiments, the second series of membrane modules supplies the cold heat transfer fluid to the first series of membrane module in cooling mode and receives a hot heat transfer fluid from a heat source in winter mode. In one or more embodiments, the first series and second series of modules receive hot heat transfer fluid from the same heat source in winter mode.

In no way is the description of the applications intended to limit the disclosure to these applications. Many construction variations can be envisioned to combine the various elements mentioned above each with its own advantages and disadvantages. The present disclosure in no way is limited to a particular set or combination of such elements.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an exemplary 3-way liquid desiccant air conditioning system using a chiller or external heating or cooling sources.

FIG. **2** shows an exemplary flexibly configurable membrane module that incorporates 3-way liquid desiccant plates.

FIG. **3** illustrates an exemplary single membrane plate in the liquid desiccant membrane module of FIG. **2**.

FIG. **4** shows an exemplary building roof layout showing existing rooftop units (RTUs) and RTUs that would be replaced as part of a retrofit.

FIG. **5** shows a schematic aspect of an exemplary recirculating rooftop unit on a building space.

FIG. **6** shows a schematic aspect of an exemplary modified recirculating rooftop unit assisted by a liquid desiccant dedicated outdoor air system.

FIG. **7** depicts a psychrometric chart showing the processes of an exemplary recirculating rooftop unit as well as the liquid desiccant dedicated outdoor air system.

FIG. **8** shows an implementation of an exemplary scalable liquid desiccant dedicated outdoor air system.

FIG. **9**A shows a schematic diagram of the conditioner side of the system of FIG. **8**.

FIG. **9**B shows a schematic diagram of the regenerator side of the system of FIG. **8**.

FIG. **10** shows how the system of FIG. **8** can be expanded to increase the system's air flow and cooling capacity.

FIG. **11** shows an alternate embodiment of the system of FIG. **8** wherein the chiller has been replaced by an indirect evaporative cooling system.

FIG. **12** shows a detail of the membrane mass and heat exchanger tub support structure of FIG. **8**.

DETAILED DESCRIPTION

FIG. **1** depicts a new type of liquid desiccant system as described in more detail in U.S. Patent Application Publication No. US 20120125020, which is incorporated by reference herein. A conditioner **101** comprises a set of plate structures that are internally hollow. A cold heat transfer fluid is generated in cold source **107** and entered into the plates. Liquid desiccant solution at **114** is brought onto the outer surface of the plates and runs down the outer surface of each of the plates. The liquid desiccant runs behind a thin membrane that is located between the air flow and the surface of the plates. Outside air **103** is now blown through the set of wavy plates. The liquid desiccant on the surface of the plates attracts the water vapor in the air flow and the cooling water inside the plates helps to inhibit the air temperature from rising. The treated air **104** is put into a building space.

The liquid desiccant is collected at the bottom of the wavy plates at **111** and is transported through a heat exchanger **113** to the top of the regenerator **102** to point **115** where the liquid desiccant is distributed across the wavy plates of the regenerator. Return air or optionally outside air **105** is blown across the regenerator plate and water vapor is transported from the liquid desiccant into the leaving air stream **106**. An optional heat source **108** provides the driving force for the regeneration. The hot transfer fluid **110** from the heat source can be put inside the wavy plates of the regenerator similar to the cold heat transfer fluid on the conditioner. Again, the liquid desiccant is collected at the bottom of the wavy plates **102** without the need for either a collection pan or bath so that also on the regenerator the air flow can be horizontal or vertical. An optional heat pump **116** can be used to provide cooling and heating of the liquid desiccant. It is also possible to connect a heat pump between the cold source **107** and the hot source **108**, which is thus pumping heat from the cooling fluids rather than the desiccant.

FIG. **2** describes a 3-way heat exchanger as described in further detail in U.S. patent application Ser. No. 13/915,199 filed on Jun. 11, 2013, Ser. No. 13/915,222 filed on Jun. 11, 2013, and Ser. No. 13/915,262 filed on Jun. 11, 2013, which are all incorporated by reference herein. A liquid desiccant enters the structure through ports **304** and is directed behind a series of membranes as described in FIG. **1**. The liquid desiccant is collected and removed through ports **305**. A cooling or heating fluid is provided through ports **306** and runs counter to the air stream **301** inside the hollow plate structures, again as described in FIG. **1** and in more detail in FIG. **3**. The cooling or heating fluids exit through ports **307**. The treated air **302** is directed to a space in a building or is exhausted as the case may be.

FIG. **3** describes a 3-way heat exchanger as described in more detail in U.S. Provisional Patent Application Ser. No. 61/771,340 filed on Mar. 1, 2013, which is incorporated by reference herein. The air stream **251** flows counter to a cooling fluid stream **254**. Membranes **252** contain a liquid desiccant **253** that is falling along the wall **255** that contain a heat transfer fluid **254**. Water vapor **256** entrained in the air stream is able to transition the membrane **252** and is absorbed into the liquid desiccant **253**. The heat of condensation of water **258** that is released during the absorption is conducted through the wall **255** into the heat transfer fluid **254**. Sensible heat **257** from the air stream is also conducted through the membrane **252**, liquid desiccant **253** and wall **255** into the heat transfer fluid **254**.

FIG. **4** shows an example of a commercial or industrial building **403** rooftop. Some of the existing Roof Top Units (RTUs) **401** are kept in place and modified to provide only sensible cooling and are further modified to no longer accept outside air. A few (typically 1 in 3 to 1 in 5) of the unitary rooftop units **402** are to be replaced with new liquid desiccant air conditioning (LDAC) dedicated outdoor air units (DOAS). The replacement units **402** are chosen based on age of the equipment that they are replacing as well as based on the air distribution requirements to ensure that fresh air is distributed evenly in the space.

FIG. **5** shows a schematic diagram of a typical RTU **401** installed on a building **403**. The RTU will have between 10 and 25% outside air **503** and provide about 300-400 Cubic Feet per Minute (CFM) of total air flow per ton of cooling capacity. A typical 10 ton RTU will thus provide about 3,000 to 4,000 CFM of total air **505** with 300 to 1,000 CFM of outside air mixed in. It is well known that the outside ventilation air can represent more than 60% of the humidity load in grocery stores. (ASHRAE 2012 Handbook of HVAC Systems and Equipment, Chapter 24, p. 24.10). The air **505** supplied to the space is nearly 100% saturated unless some form of reheating is employed. Reheating however adds a significant heat load to the cooling coil since a lot of air **501** that is returned to the RTU **401** is internally directed **504** to the cooling coil and a small portion **502** is exhausted, typically about the same amount as the RTU took in. The evaporator coil **506** is providing the primary cooling function of the mixed air stream **503** and **504**. Compressor **507** is providing a refrigerant **508** and rejecting its heat to condenser **509**. A typical condenser will have some 800 CFM of outside air **510** per ton of cooling, or about 8,000 CFM for a 10 ton unit. An expansion valve **511** provides the cold liquid refrigerant to the evaporator coil **506**.

FIG. **6** shows how the RTU **401** of FIGS. **4** and **500** can be modified and supplemented by a liquid desiccant dedicated outdoor air system **402**. The RTU **401** has been modified to no longer provide or take in outside air. As a result only return air **501** from the building is recirculated

601 through the evaporator coil **506**. Alternatively, the RTU is modified to reduce the intake of outside air. The evaporator temperature has also been increased from a normal 40 F to about 50-60 F. There are several ways that this can be accomplished: one can replace the expansion valve **511** with a different valve **610** set for a higher evaporator temperature. Other ways to increase the evaporator temperature is for example to provide an APR bypass valve made by Rawal Devices, Inc., Woburn, Mass. 01888-0058. By increasing evaporator temperature the cooling load of the remaining RTU is reduced and the system operates more efficiently.

One of the RTUs is replaced with a liquid desiccant system **402** as discussed earlier. The main liquid desiccant system components are the conditioner **603**—which can be like component **101** in FIG. **1** and the regenerator **606**— which can be like component **102** in FIG. **1**. An optional compressor **609** pumps heat from the conditioner to the regenerator using refrigerant **608** and using expansion valve **610**. Outside air **605** is brought through the conditioner **606** and supplied **607** at a lower temperature and humidity than the space requires. Return air **602** enters the regenerator **606** where it picks up heat and moisture after which is exhausted **604**. (In case return air is unavailable for the liquid desiccant system **402**, the air stream **602** can comprise outside air.) The liquid desiccant system is sized in such a way that it provides all of the outside air as was previously provided by the recirculating RTU's **401**. Since the LDAC is providing dry, cool air, the space itself is much drier which will reduce the load on refrigeration equipment and freezers in the space.

FIG. **7** shows a psychrometric chart of the processes involved in the recirculating RTU and the liquid desiccant system. A conventional RTU takes in 10-25% of outside air ("OA") and mixes that air with return air from the building ("RA"). The resulting mixed air ("MA") point is determined by the amount of outside and return air that is combined. The cooling coil **506** subsequently takes the mixed air ("MA") and cools it to the saturation line where water vapor condenses out and ultimately supplies air to the space at low temperature but near saturation level ("COIL"). This air needs to be heated by the building somehow, which on hot sunny days can be naturally done, but on cloudy days or mid temperature days may not occur unless an additional reheat system is employed. In supermarkets, grocery stores and the like, the refrigeration cases and freezers can provide an additional cooling effect, indicated by the arrow ("FR") from the return air position ("RA"). As can be seen in the figure, the additional sensible cooling provided by the freezers and refrigerators and a lack of reheat, result in a space that is too cold and too humid, with relative humidity exceeding 70%. Furthermore, water sprayers in vegetable sections and short cycling of the RTU's make this situation even worse.

The liquid desiccant air conditioning system of FIG. **6** however, also takes in outside air ("OA") and produces cooler, dry air ("DA") to the space. The additional cooling by the remaining RTUs and freezers and refrigerators ("RTU") results in a much smaller increase in relative humidity which can be avoided by simply not operating the RTU's unless necessary.

FIG. **8** illustrates an embodiment of a liquid desiccant air conditioning system (LDAC) **402** that is able to provide cool, dry air to a space from 100% outside air. Several of the components in the system of FIG. **8** have been identified in FIG. **6**. The conditioner modules **603** (of which there are 4 in this example), contain the membrane plate structures as were shown in FIGS. **1-3**. Similarly the regenerator modules **606** (of which there are also **4** in this example) have similar construction to the conditioner modules. Outside air **605** is entering the conditioner section through louvers **802**. The outside air is then transported through optional internal ducts **806**, downward through the conditioner modules **603** and then through the tub modules **803** to exit the system as supply air **607**. The return air from the building (not shown) receives some additional outside air **805** through louvers **807**. This air is then transported through regenerator modules **606** and regenerator duct modules **812** and eventually exhausted out of the system (not shown). A power interface module **801** and an integral chiller/heat pump system **609** provide electrical facilities and hot and cold water for the regenerator and conditioner modules respectively. As shown in the figure, the system has 4 conditioner and 4 regenerator modules, mounted 2 at a time on tub supports **803**. The size of the modules was chosen such that they are able to fit through standard roof access hatches. As can be seen from the figure, it would be very easy to add additional tub modules **803** and membrane conditioner or regenerator modules **603** and **606**. The right side of the system of FIG. **10** is terminated by removable end plate **808** for the conditioner tub modules, removable end plate **810** for the conditioner duct **806**, and removable end plate **809** for the regenerator duct. Cold water supply and cold water return and hot water supply and hot water return are shown as item **811** in the figure. The louver **807** is mounted to the last tub module and is easily removed and mounted on a different tub module. Also shown is one of the desiccant pumps **813** which will be discussed in more detail under FIG. **9**A and FIG. **12**. The whole system is mounted on a modular support frame **804**.

FIG. **9**A illustrates the conditioner side of the system of FIG. **8**. As mentioned before, outside air **605** enters the system through louvers **802**. Fan **901** brings the air through ducts **806**. Conditioner membrane modules **603** cool and dehumidify the air stream which is transported through tubs **803** into the supply air stream **607**. End plates **808** and **810** terminate the system. Water lines for cold water supply and return **811** bring cold water to the individual conditioner modules **603**. For clarity only one of the water lines **904** is shown, the other modules **603** receive cooling water in a similar fashion. The desiccant pump **813** receives liquid desiccant from the tub modules **803**. The pump distributes the liquid desiccant to the conditioner modules **603** through supply lines **905**. For clarity the desiccant supply lines for two of the conditioner modules are shown in the figure and the remainder has been omitted. As can be seen in the figure, the desiccant drains out of the conditioner modules back into the tub modules **803**.

FIG. **9**B shows—similarly to FIG. **9**A—the main components of the regenerator side of the system of FIG. **8**. Return air **602** from the building is directed through the tub modules **803** and through the regenerator modules **606**. The regenerator ducts **812** conduct the air streams back through fan **902** and louver **903** where the hot, humid air **604** is exhausted. Since in buildings the amount of available return air can be less than the amount of air that is supplied to the building (supply air **607** is larger than return air **602**) and additional outside air stream **805** can be mixed in through louver **807**. This helps to ensure that the system has adequate air supply for the regenerator modules. Similar to the conditioner side, desiccant pump **908** provides liquid desiccant to the regenerator modules **606** through supply lines **907**. Hot water **906** is also supplied to the regenerator modules. For clarity only some of the water and desiccant lines have been shown.

It is also possible to reverse the direction of the chiller **609** in a winter operating mode so that the conditioner **603** receives hot heat transfer fluid and the regenerator **606** receives cold heat transfer fluid. In this mode the conditioner will desorb water vapor and humidify and heat the supply air stream **607** and the regenerator will absorb heat and water vapor from the return air stream **602** from the space. In effect the system will recover heat and moisture from the return air stream **602** in this mode.

FIG. **10** show the system of FIG. **8** with an additional section **1001** comprising 4 conditioner and 4 regenerator modules have been inserted in the system of FIG. **8**. The chiller **1002** as well as the fans and water pumps (not shown) now need to be sized to accommodate for the increase in air flow and cooling load of the system. It will be apparent that one can continue to increase the air flow and cooling capacity of the system by continuing to add membrane models and other components, at least until the air flow capacity of the ducts and tubs is exceeded.

FIG. **11** shows a schematic diagram of an alternate embodiment of the linkable system of FIG. **6**. The chiller section **609** from FIG. **6** and FIG. **8** has now been omitted in favor of an indirect evaporative cooling section **1111**. The supply air **607** is partially diverted (typically between 0 and 30%) as air stream **1105** into duct **1101** and louver **1102** to enter tub **1103**. The air stream now moves upward through membrane modules **1106**. But unlike the conditioner modules and regenerator modules, these evaporator membrane modules have water rather than desiccant behind their membranes. Since the air stream **1105** is very dry, a large cooling effect can be obtained in the membrane modules **1106** by evaporating the water behind the membranes. This in turn results in the heat transfer fluid **1109** becoming substantially cooled. This cold heat transfer fluid **1109** can then be used to remove heat from the original membrane modules **603**. The warmer heat transfer fluid **1110** is circulating back to the indirect evaporative cooling section **1111** from the conditioner modules **603**. Since the evaporator modules **1106** evaporate water, there needs to be a constant supply of water **1113**. This water can be clean drinking water, in which case the membranes on the evaporator modules **1106** are not absolutely necessary. In that case also, the remaining water can be drained **1115** from the membrane modules **1106** into the tub **1103** and removed from the tub by pump **1112** to be re-used at the top of the evaporative modules **1106**. Attention has to be paid to ensure that like a conventional cooling tower, there is no buildup of scale and other contaminants. There are several methods common in the industry that can be employed to deal with scale issues, for example blow-down systems or ultrasonic precipitation.

However, the use of membrane in evaporator modules **1106** also enables the use of seawater or waste water: the membranes will contain any salt particles or other contamination. In this case, the intent is to evaporate only a portion (typically around 50% or less) of the water supplied by supply **1113**. The concentrated remaining water is then drained through line **1114** and disposed of in an appropriate drainage system. The pump **1112** can now be omitted and no scaling or blow-down system is required. However membrane fouling may become an issue and can be dealt with using flushing and a proper pre-filtration system. The exhaust air stream **1108** leaving the evaporator modules **1106** is warm and near saturation and is pulled through the system by fan **1107**. It should be clear from the figure that when one adds additional conditioner modules **603** there should also be additional evaporator modules **1106**. This can be easily accomplished by removing cover **1104** and adding an additional section **1111**. Fan **1107** would also have to be sized larger and moved to the added section.

It is also possible to reverse the air stream **1105** while at the same time providing hot heat transfer fluid to the conditioner blocks **603**. In this winter heating mode, the conditioner will desorb water vapor into the air stream **1105** and the conditioners **603** will combine to supply warm, moist air to the space **607**.

FIG. **12** illustrates a detail cross section of the membrane module support tub **803** and part of the desiccant distribution system connected to it. The tub **803** is constructed as a hollow shell structure with walls **1205** and **1206**. The inner area **1201** functions as a liquid desiccant storage tank. This is beneficial since it eliminates the need for a separate tank and since the volume is located directly below the membrane modules, syphoning of desiccant into the tank structure is enhanced. Furthermore the tank structure allows for stratification of the desiccant wherein the higher concentration of desiccant can be found near the bottom of the tub and the lower concentration can be found near the top. The inner bottom **1202** of the tub **803** is slowed in such a way that any leaks from the membrane modules above will drain into a single corner where a detector or sensor can be located to indicate that a leak has occurred. Furthermore bottom has a lip **1208** constructed in such a way that the air stream cannot transport any droplets that may fall from the membrane modules. The membrane modules physically sit on the support plate **1203** which has designed in rail features **1209** to allow for a tight air seal between the membrane modules and the tub structure. Since the tub **803** contains the desiccant for the system, pump **908** pulls desiccant from the lower port on the tub, pumps it to the top of the membrane module **603** wherefrom it drains by gravity back through drain **1204** into the top port of the tub. A secondary port **1207** allows for dilute desiccant to be removed and pumped to the regenerator modules which are set up in a similar fashion except that the regenerator pumps from the top port to the top of membrane modules **606** and removes concentrated desiccant from the bottom port back to the conditioner. The air duct **1210** can also be seen in the figure.

Having thus described several illustrative embodiments, it is to be appreciated that various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to form a part of this disclosure, and are intended to be within the spirit and scope of this disclosure. While some examples presented herein involve specific combinations of functions or structural elements, it should be understood that those functions and elements may be combined in other ways according to the present disclosure to accomplish the same or different objectives. In particular, acts, elements, and features discussed in connection with one embodiment are not intended to be excluded from similar or other roles in other embodiments. Additionally, elements and components described herein may be further divided into additional components or joined together to form fewer components for performing the same functions. Accordingly, the foregoing description and attached drawings are by way of example only, and are not intended to be limiting.

The invention claimed is:

1. A method for increasing energy efficiency of an air conditioning system for a building, said air conditioning system comprising a plurality of existing air conditioning units mounted on a rooftop of the building, the method comprising:

(a) removing some, but not all, of the plurality of air conditioning units from the rooftop;

(b) installing a liquid desiccant air-conditioning unit on the rooftop in place of each removed air conditioning unit, said liquid desiccant air-conditioning unit being switchable between operating in a warm weather operation mode and in a cold weather operation mode, each liquid desiccant air-conditioning unit comprising:

a conditioner configured to expose a ventilation air stream entering the building from outside the building to a liquid desiccant such that the liquid desiccant dehumidifies the ventilation air stream in the warm weather operation mode and humidifies the ventilation air stream in the cold weather operation mode; and

a regenerator connected to the conditioner and configured to expose an air stream to the liquid desiccant such that the liquid desiccant humidifies the air stream in the warm weather operation mode and dehumidifies the air stream in the cold weather operation mode; and

(c) completely transferring a ventilation air stream treatment load from the one or more air conditioning units remaining on the rooftop to each liquid desiccant air-conditioning unit by reconfiguring the one or more air conditioning units remaining on the rooftop such that any intake of a ventilation air stream for the building in said one or more air conditioning units is eliminated by removing power to a damper motor of the one or more air-conditioning units remaining on the rooftop or removing a lever from a damper mechanism of the one or more air-conditioning units remaining on the rooftop.

2. The method of claim **1**, wherein the conditioner includes a plurality of structures arranged in a vertical orientation, each structure having at least one surface across which the liquid desiccant can flow, wherein the ventilation air stream flows between the structures, and wherein the regenerator includes a plurality of structures arranged in a vertical orientation, each structure having at least one surface across which the liquid desiccant can flow, wherein a return air stream flows between the structures.

3. The method of claim **2**, wherein each of the plurality of structures in the regenerator and conditioner includes an internal passage through which a heat transfer fluid can flow for transfer of heat between the heat transfer fluid and the liquid desiccant or the ventilation air stream or the return air stream.

4. The method of claim **3**, wherein each of the plurality of structures in the regenerator and conditioner includes a sheet of material positioned proximate to the outer surface of each structure between the liquid desiccant and an air stream, said sheet of material permitting transfer of water vapor between the liquid desiccant and the ventilation air stream or the return air stream.

5. The method of claim **4**, wherein the sheet of material comprises a membrane.

6. The method of claim **2**, wherein said plurality of structures in the regenerator and conditioner comprise a plurality of plate assemblies arranged in a vertical orientation and spaced apart to permit flow of the air stream between adjacent plate assemblies.

7. The method of claim **1**, wherein the ventilation air stream entering the building flows in a vertical direction through the conditioner and the air stream flowing in the regenerator flows in a vertical direction.

8. The method of claim **1**, wherein the ventilation air stream entering the building flows in a generally horizontal direction through the conditioner and the air stream flowing in the regenerator flows in a generally horizontal direction.

9. The method of claim **1**, wherein each liquid desiccant air-conditioning unit further comprises a heat pump for pumping heat from the conditioner to the regenerator in the warm weather operation mode and pumping heat from the regenerator to the conditioner in the cold weather operation mode.

10. The method of claim **9**, wherein the heat pump pumps heat from the liquid desiccant flowing in the conditioner to the liquid desiccant flowing in the regenerator in the warm weather operation mode, and wherein the heat pump pumps heat from the liquid desiccant flowing in the regenerator to the liquid desiccant flowing in the conditioner in the cold weather operation mode.

11. The method of claim **9**, wherein the heat pump pumps heat from a heat transfer fluid flowing in the conditioner to a heat transfer fluid flowing in the regenerator in the warm weather operation mode, and wherein the heat pump pumps heat from the heat transfer fluid flowing in the regenerator to the heat transfer fluid flowing in the conditioner in the cold weather operation mode.

12. The method of claim **1**, wherein each liquid desiccant air-conditioning unit further comprises a heat exchanger connected between the conditioner and the regenerator for transferring heat from the liquid desiccant flowing from one of the regenerator and the conditioner to the liquid desiccant flowing from the other of the regenerator and conditioner.

13. The method of claim **1**, wherein every one out of three to one out of five of the removed air conditioning units is replaced by a liquid desiccant air-conditioning unit.

14. The method of claim **1**, wherein reconfiguring the one or more air conditioning units comprises recirculating a return air stream from the building through a coil of an evaporator of each of said one or more air conditioning units, and increasing the operating temperature of the evaporator.

15. The method of claim **1**, reconfiguring the one or more air conditioning units remaining on the rooftop comprises closing a damper therein to reduce or eliminate intake of a ventilation air stream.

16. The method of claim **1**, wherein step (c) further comprises changing an evaporator temperature setting of the one or more air conditioning units remaining on the rooftop to a higher temperature setting.

17. The method of claim **16**, wherein the higher temperature setting increases the evaporator temperature such that substantially no condensation forms on the evaporator.

18. The method of claim **16**, wherein the higher temperature setting is 50-60° F.

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