

DEDICATED OUTDOOR AIR SYSTEM WITH ENERGY RECOVERY VENTILATOR

This patent application claims priority benefit of US provisional patent application 63/431,660, filed on December 9, 2022.

FIELD OF THE INVENTION

[0001] The present disclosure relates generally to air conditioning systems, and more specifically, to a dedicated outdoor air system (DOAS) and method to recover energy from exhaust air which is then used to treat outdoor air for a building.

BACKGROUND OF THE INVENTION

[0002] Air conditioning systems play an integral role in modern settings. Typical air conditioning units use vapor compression systems to provide the necessary cooling to surroundings by increasing the temperature and humidity levels ideal for thermal comfort. Although these conventional vapor compression systems are widely used, there has been an emphasis on cooling technologies which reduce operational costs associated with intensive energy consumption. As such, a variety of emerging technologies such as liquid cooling technology, solar based cooling and desiccant technology have been established to address these challenges.

[0003] Evaporative cooling, otherwise known as adiabatic cooling, is a form of liquid cooling technology that is becoming more widely adopted due to its high energy efficiency and environment sustainability which translate to considerable savings over

the conventional vapor compression systems. Evaporative cooling devices use the latent heat of vaporization of water to achieve a water temperature reduction that is close to the passing air wet bulb temperature, whilst increasing the moisture content and reducing the temperature of the passing air. The cooling potential for evaporative cooling is dependent on the wet-bulb depression, the difference between the dry bulb temperature and wet-bulb temperature. However, this advantage is limited by the ambient air psychrometric conditions. In this regard adiabatic cooling is most effective in hot and dry weather conditions rather than humid climates.

[0004] A dedicated outdoor air system (DOAS) is a type of heating, ventilation and air-conditioning (HVAC) system which delivers outdoor air that handles both the latent and sensible loads of conditioning into indoor spaces. Typical HVAC systems include two parts, that is: 1) a DOAS that handles only the outdoor air heat load and 2) a recirculation system running in parallel that handles the room internal load. Depending on the environment and the other parallel systems involved, the DOAS will handle some of the sensible and latent heat loads generated indoor, in addition to the heat load of the ventilation air. The DOAS does this by providing air that is slightly cooler and drier than the target temperature and humidity level respectively. Efforts have been put into increasing the efficiency of these systems.

[0005] For example, Germany Patent application DE 102006004513 A1, discloses a cooling device and process for cooling outdoor air. The process includes a step of feeding the outdoor air through a rotary heat exchanger in which the outdoor air is cooled by exhaust air that is adiabatically cooled and saturated with moisture upstream of the heat exchanger.

[0006] Australian Patent application AU2017204552B2, discloses an energy exchange system for conditioning air in an enclosed structure. The energy exchange system includes a supply airflow path, an exhaust airflow path, an energy recovery device disposed within the supply and exhaust airflow paths, and a supply conditioning unit disposed within the supply airflow path. The supply conditioning unit may be downstream from the energy recovery device. Certain embodiments provide a method of conditioning air including introducing outside air as supply air into a supply airflow path, pre-conditioning the supply air with an energy recovery device, and fully conditioning the supply air with a supply conditioning unit that is downstream from the energy recovery device. The energy recovery device may be one or more of various types of energy recovery devices such as an enthalpy wheel, a sensible wheel, a desiccant wheel, a plate heat exchanger, a plate energy (heat and moisture) exchanger, a heat pipe, a run-around loop, a passive run-around membrane energy exchange (RAMEE). Some of the technologies may store energy in the form of water instead of air.

[0007] European Patent application EP 3204697 B1, discloses an air handling unit and method of operating the same. The air handling unit includes the following components: (a) a first inlet to receive a flow of return air from a conditioned space; (b) a first outlet to deliver a flow of supply air to the conditioned space; (c) a second inlet to receive a flow of ambient cooling air; (d) a second outlet to expel the flow of ambient cooling air; (e) a first airflow path extending between the first inlet and the first outlet; (f) a second airflow path extending between the second inlet and the second outlet; and (g) an air-to-air heat exchanger arranged along both the first and the

second flow paths to transfer heat from the flow of return air to the flow of ambient cooling air. A make-up air section is fluidly coupled to the first airflow path and the flow of supply air includes ambient air received through the make-up air section and the flow of return air.

[0008] The above references use relatively inefficient rotary type heat exchangers or plate heat exchangers to recover the cold energy from the return air. Further, the cold energy is recovered using air-to-air system and are transferred to the supply air using the air-to-air heat exchanger. Storing cold energy in air which has less heat capacity makes is less efficient. Hence, overall effective use of the cold energy from return air of the conditioned room is low.

[0009] Similarly, PCT Patent application WO/2018/191805, discloses systems and methods for managing conditions in an enclosed space. The conditioning system includes a first plenum and a second plenum. The second plenum receives heated air from an enclosed space and supplies cooled air to the space. The system also includes a first liquid-to-air membrane energy exchanger (LAMEE1) arranged inside the first plenum. LAMEE1 is configured to use a liquid desiccant to lower an enthalpy of the first air stream. A LAMEE2 is arranged inside the first plenum downstream of LAMEE1. LAMEE2 is configured to use the first air stream to evaporatively cool water flowing through LAMEE2. A first liquid-to-air heat exchanger (LAHX1) is arranged inside the second plenum. LAHX1 is configured to directly and sensibly cool the second air stream using a first cooling fluid. A second LAHX (LAHX2) is in fluid communication with LAMEE1 and is configured to receive the liquid desiccant from LAMEE1 and cool the liquid desiccant using outdoor air. This reference specifically

does not perform energy recovery using room/enclosed space air and the recovery is performed by cooling the water using the cooled air post evaporative cooling. The cited reference focuses on taking in ambient air, dehumidify such ambient air, and then super charge it through evaporative cooling to produce cold water for return air pre-cooling.

[0010] EP Patent application 3667191A1 discloses a liquid desiccant air conditioning system. The air-conditioning system includes a plurality of liquid desiccant in-ceiling units, each installed in a building for treating air in a space in the building. DOAS for providing a stream of treated outside air to the building are also disclosed. This system does not perform energy recovery using room or enclosed space air, instead, the room return air is used to absorb the moisture of the liquid desiccant optionally with the aid of hot water, acting as a sensible and/or latent energy recovery device. Further, the system uses liquid desiccant as the medium for energy recovery. Depending on the industrial application, this DOAS system requires separate water loops; or cooling and heating source; or vapor compression circuit to cool/heat the liquid desiccant. Additionally, a three-way heat and mass exchanger is needed for exchanges between the liquid desiccant, water and air. The concentration and temperature of liquid desiccant for example, lithium chloride and calcium chloride must be controlled at optimum levels for operation. This further complicates the unit control and monitoring.

[0011] While offering some improvements over conventional designs, these air conditioning units are generally inefficient and require a lot of energy for use. A need, therefore, exists for a more energy efficient and comprehensive DOAS that can accommodate various outdoor weather conditions with smart and multi-operational

controls. Such a system should effectively recover cold energy harnessed from the return air of an enclosed space to provide pre-cooling to the outdoor air in the Energy Recovery Ventilation (ERV) unit before further treatment to a condition suitable for indoor thermal comfort.

SUMMARY OF THE INVENTION

[0012] The following summary is provided to help with an understanding of some of the innovative features that are unique to the disclosed embodiments and is not intended to be a full description. A full appreciation of the various aspects of the embodiments disclosed herein can be gained by taking into consideration the entire specifications, drawings, and abstract as a whole.

[0013] In a first aspect of the present disclosure, an Energy Recovery Ventilation (ERV) unit for a dedicated outdoor air system (DOAS) is provided, comprising: a cold-water generation unit (CGU) comprising an evaporative media configured for generating cold water by recovering cold energy from return air of enclosed space through evaporative cooling water circulating and storing the cold water in a water reservoir; a main cooling unit (MCU) comprising one or two heat exchangers; one heat exchanger is arranged in fluid communication with the cold-water generation unit (CGU), main cooling unit (MCU) and water reservoir, another heat exchanger is arranged in the same air passageway as the exhaust air expelled from the CGU before exhausting into an outdoor environment; the another heat exchanger is arranged either in cold-water generation unit downstream of evaporative media or upstream of the main cooling unit; the another heat exchanger is configured to first cool the outdoor

air entering the main cooling unit in an air-to-air heat exchange with the exhaust air obtained from cold-water generation unit before undergoing a second heat exchange with cold water generated in a liquid-to-air heat exchanger, an exhaust fan configured to draw in return air from an enclosed space and direct the return air through the CGU for exhausting to an outdoor environment; or the exhaust fan configured to draw in return air from an enclosed space and direct the return air through the CGU and MCU for exhausting into an outdoor environment; and a supply fan configured to draw in outdoor air and direct air through the one or two heat exchangers of MCU for producing the pre-cooled air to be supplied to the enclosed space or for further treatment by at least one additional unit.

[0014] According to an embodiment in conjunction to the first aspect of the present disclosure, the cold-water generation unit (CGU) comprises another heat exchanger configured to bring down the temperature of water before circulating the water back to the evaporative media for cold water regeneration.

[0015] According to an embodiment in conjunction to the first aspect of the present disclosure, the one or two heat exchangers of the main cooling unit configured to treat the outdoor air entered through the one or two heat exchangers by circulating the cold water from the water reservoir and with the exhaust air from return air.

[0016] According to an embodiment in conjunction to the first aspect of the present disclosure, another heat exchanger is configured to first heat exchange the outdoor air entering the main cooling unit in an air-to-air heat exchange with the exhaust air obtained from cold-water generation unit to yield a cooled outdoor air.

[0017] According to an embodiment in conjunction to the first aspect of the present disclosure, the cooled outdoor air obtained from the first heat exchanger undergoes a second heat exchange with cold water circulation of water reservoir in a liquid-to-air heat exchanger to produce a deep cooled pre-cooled air.

[0018] According to an embodiment in conjunction to the first aspect of the present disclosure, the cold water absorbs heat after second heat exchange and circulated back to the evaporative media of cold- water generation unit to absorb cold energy from return air of enclosed space and passed to water reservoir for recirculation.

[0019] According to an embodiment in conjunction to the first aspect of the present disclosure, the one or two heat exchangers are of sensible and latent cooling type.

[0020] In a second aspect of the present disclosure, a dedicated outdoor air system (DOAS) for conditioning outdoor air supply to an enclosed space is provided. The DOAS system comprising: an energy recovery ventilation (ERV) unit disclosed herein; at least one additional unit for further treating the pre-cooled air from the ERV unit, wherein the at least one additional unit is selected from a Liquid Desiccant and Direct Expansion (LDDX) unit; a heater unit; and a humidifier unit, and a control system for selectively activating or deactivating the ERV unit or individual components therein alone or in combination with at least one additional unit, wherein the DOAS is configured to operate in a plurality of different modes, depending on the ambient weather conditions and targeted indoor environment.

[0021] According to an embodiment in conjunction to the second aspect of the present disclosure, the at least one additional unit comprises a LDDX unit, a heater unit and a humidifier unit.

[0022] According to an embodiment in conjunction to the second aspect of the present disclosure, the control system selectively activates a free cooling mode, wherein the supply fan in the ERV unit is activated, when a dry bulb temperature is in the range of about 24 to 26 °C and a relative humidity level is in the range of about 30% to 65%.

[0023] According to an embodiment in conjunction to the second aspect of the present disclosure, the control system selectively activates a heating mode, wherein the supply fan in the ERV unit and the heater unit is activated, when the ambient conditions 1: the dry bulb temperature is less than about 24°C and a dew point temperature is in a range of about 5.4°C to 19°C, or, 2: when at ambient conditions, the dry bulb temperature is less than about 26°C, a relative humidity level that is greater than about 65%, dew point temperature is in a range of about 5.4°C to 19°C.

[0024] According to an embodiment in conjunction to the second aspect of the present disclosure, the control system selectively activates a heating and humidification mode, wherein the supply fan in the ERV unit, the heater unit and humidification unit are activated, when the ambient conditions 1, the dry bulb temperature is less than or equal to about 26 °C and when the ambient conditions 2 the dew point temperature is less than about 5.4 °C.

[0025] According to an embodiment in conjunction to the second aspect of the present disclosure, the control system selectively activates an energy recovery mode, wherein the ERV unit is activated, when the ambient conditions 1: the dry bulb temperature is greater than about 26°C and the dew point temperature is in the range of about 5.4°C to 19°C, or, 2: when at ambient conditions, the dry bulb temperature is greater than about 24°C, the relative humidity level is less than about 30% and the dew point temperature is in the range of about 5.4°C to 19°C.

[0026] According to an embodiment in conjunction to the second aspect of the present disclosure, the control system selectively activates an energy recovery and humidification mode, wherein the ERV unit and humidification unit are activated when the ambient conditions 1, the dry bulb temperature is greater than about 26°C and the dew point temperature is less than about 5.4°C.

[0027] According to an embodiment in conjunction to the second aspect of the present disclosure, the control system selectively activates a booster mode, wherein the ERV unit and LDDX unit are activated when the ambient conditions 1, the dew point temperature is greater than about 19 °C.

[0028] In a third aspect of the present disclosure, a method for conditioning outdoor air supply to an enclosed space disclosed herein is provided, comprising: the selectively activating or deactivating components in the dedicated outdoor air system disclosed herein, wherein the dedicated outdoor air system is configured to operate in a plurality of different operational modes depending on ambient weather conditions and a targeted indoor environment.

[0029] According to an embodiment in conjunction to a fourth aspect of the present disclosure, further comprising a step of treating pre-cooled air produced by the energy recovery ventilation (ERV) unit with one or more additional units, wherein the one or more additional units comprise a LDDX unit, a heater unit and/or a humidifier unit.

[0030] According to an embodiment in conjunction to the fourth aspect of the present disclosure, further comprising a step of using a control system to activate one of a plurality of operating modes depending on ambient weather conditions and a targeted indoor environment by selectively activating or deactivating components in the dedicated outdoor air system. From the foregoing disclosure and the following more detailed description of various embodiments it will be apparent to those skilled in the art that the present invention provides a significant advance in the technology of air conditioning systems. Particularly significant in this regard is the potential the invention affords for providing a relatively low-cost air-conditioning system for use as an evaporative cooler. Additional elements and advantages of various embodiments will be better understood in view of the detailed description provided below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] It should be understood that the appended drawings are not necessarily to scale, presenting a somewhat simplified representation of various features illustrative of the basic principles of the invention. The specific design features of the evaporative cooler as disclosed here, including, for example, the specific dimensions of the cold-water generation unit, will be determined in part by the particular intended application

and use environment. Certain features of the illustrated embodiments have been enlarged or distorted relative to others to help provide clear understanding. In particular, thin features may be thickened, for example, for clarity of illustration. All references to direction and position, unless otherwise indicated, refer to the orientation illustrated in the drawings..

[0032] FIG. 1(a) is a schematic diagram of a first embodiment of Energy Recovery Ventilation Ventilator (ERV) used in a Dedicated Outdoor Air System (DOAS) having single heat exchanger, in accordance with an embodiment of the invention.

[0033] FIG. 1(b) is a schematic diagram of a First embodiment of Energy Recovery Ventilation (ERV) used in a Dedicated Outdoor Air System (DOAS) having two heat exchangers, in accordance with an embodiment of the invention.

[0034] FIG. 2 is a schematic diagram of a Second embodiment of Energy Recovery Ventilation (ERV) used in a Dedicated Outdoor Air System (DOAS), in accordance with an embodiment of the invention.

[0035] FIG. 3 is a schematic diagram of a Third embodiment of Energy Recovery Ventilation (ERV) used in a Dedicated Outdoor Air System (DOAS), in accordance with an embodiment of the invention.

[0036] FIG. 4 is a schematic diagram of a DOAS, in accordance with an embodiment of the invention.

[0037] FIG. 5 is a psychrometric chart showing the processes in a DOAS, in accordance with the disclosed embodiment of the invention.

[0038] FIG. 6 is a schematic diagram of a DOAS operated in free cooling mode, in accordance with another embodiment of the invention.

[0039] FIG. 7 is a schematic diagram of a DOAS operated in heating mode, in accordance with another embodiment of the invention.

[0040] FIG. 8 is a psychrometric chart of the DOAS in heating mode, in accordance with another embodiment of the invention.

[0041] FIG. 9 is a schematic diagram of a DOAS operated in heating and humidification mode, in accordance with another embodiment of the invention.

[0042] FIG. 10 is a psychrometric chart of the DOAS in heating and humidification mode, in accordance with another embodiment of the invention.

[0043] FIG. 11 is a schematic diagram of a DOAS operated in energy recovery mode, in accordance with another embodiment of the invention.

[0044] FIG. 12 is a psychrometric chart of the DOAS in energy recovery mode, in accordance with another embodiment of the invention.

[0045] FIG. 13 is a schematic diagram of a DOAS operated in energy recovery and

humidification mode, in accordance with another embodiment of the invention.

[0046] FIG. 14 is a psychrometric chart of a DOAS in energy recovery and humidification mode, in accordance with another embodiment of the invention.

[0047] FIG. 15 is a schematic diagram of a DOAS operated in booster mode, in accordance with another embodiment of the invention.

[0048] FIG. 16 is a psychrometric chart of the DOAS in booster mode, in accordance with another embodiment of the invention.

[0049] FIG. 17 is a flowchart of steps involved in the process of energy recovery and pre-cooling outdoor air in the ERV unit, in accordance with the disclosed embodiment of the invention.

[0050] FIGS. 18 and 19 are flowcharts of steps involved in the process of selectively operating at least one of the components that comprise the ERV unit, the Liquid Desiccant and Direct Expansion (LDDX) unit, the heater unit or the humidifier unit within the DOAS depending upon the ambient air conditions to obtain suitable modes of operation, in accordance with the disclosed embodiment of the invention.

DETAILED DESCRIPTION OF CERTAIN EMBODIMENTS

[0051] It will be apparent to those skilled in the art, that is, to those who have knowledge or experience in this area of technology, that many uses and design

variations are possible for the evaporative air conditioners disclosed here. The following detailed discussion of various alternate elements and embodiments will illustrate the general principles of the invention with reference to an evaporative cooler suitable for use as a dedicated outdoor system, that is, a unit where cooled, dehumidified outside air is supplied (such as to a building in the summer) and heated outside air can be provided in the winter. Other embodiments suitable for other applications will be apparent to those skilled in the art given the benefit of this disclosure. The terms used in this disclosure generally have their ordinary meanings in the art, within the context of the disclosure, and in the specific context where each term is used. Certain terms that are used to describe the disclosure are discussed below, or elsewhere in the specification, to provide additional guidance to the practitioner regarding the description of the disclosure. For convenience, certain terms may be highlighted, for example using italics and/or quotation marks. The use of highlighting has no influence on the scope and meaning of a term; the scope and meaning of a term is the same, in the same context, whether or not it is highlighted. It will be appreciated that the same thing can be said in more than one way.

[0052] Consequently, alternative language and synonyms may be used for any one or more of the terms discussed herein. Nor is any special significance to be placed upon whether or not a term is elaborated or discussed herein. Synonyms for certain terms are provided. A recital of one or more synonyms does not exclude the use of other synonyms. The use of examples anywhere in this specification including examples of any terms discussed herein is illustrative only, and is not intended to further limit the scope and meaning of the disclosure or of any exemplified term. Likewise, the disclosure is not limited to various embodiments given in this

specification.

[0053] Without intent to further limit the scope of the disclosure, examples of instruments, apparatus, methods and their related results according to the embodiments of the present disclosure are given below. Note that titles or subtitles may be used in the examples for convenience of a reader, which in no way should limit the scope of the disclosure. Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure pertains. In the case of conflict, the present document, including definitions, will control.

[0054] The term “adiabatic” refers to a process that occurs without transfer of heat or matter between a thermodynamic system and its surroundings. In an adiabatic process, energy is transferred to its surroundings only as work (e.g., vaporization of water).

[0055] The term "ambient" refers to a condition of outside air at the location at or near the DOAS.

[0056] The term “cold energy” refers to capacity of low temperature materials or environment to provide cooling. For example, cold air remains at low temperature by means of its cold energy and this cold energy can be used to cool another substance such as air or water.

[0057] The term “dew point temperature” refers to the temperature at which air must

be cooled to become saturated with water. Air normally contains a certain amount of water vapor. The maximum amount of water vapor that air can hold at a given temperature is known as the saturation point, also known as 100% relative humidity.

[0058] The “dry-bulb temperature” refers to the temperature indicated by a thermometer exposed to the air in a place sheltered from radiation and moisture. The term “dry-bulb” is customarily added to temperature to distinguish it from wet-bulb and dew point temperature.

[0059] The term “evaporative media” refers to a material that permits the relatively unobstructed evaporation of water into air. For example, a sheet of cotton fabric can be used to allow water to evaporate into ambient air. Evaporation behavior in layered porous media is affected by thickness and sequence of layering and capillary characteristics of each layer.

[0060] The term “heat exchanger” refers to a device used to transfer heat between two or more fluids and/or gases. The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact. As used herein, temperature change is achieved sensibly with a heat exchanger.

[0061] The term “sensible” refers to heat exchanged by a body or thermodynamic system in which the exchange of heat changes the temperature of the body or system, and some macroscopic variables of the body or system, but leaves unchanged certain other macroscopic variables of the body or system, such as volume or pressure.

[0062] The “wet-bulb depression” refers to the difference between the dry-bulb temperature and the wet-bulb temperature.

[0063] The term “wet bulb temperature” refers to the temperature read by a thermometer covered in water-soaked cloth over which air is passed. At 100% relative humidity, the wet-bulb temperature is equal to the air temperature and is lower at lower humidity. Wet bulb temperature can be defined as the temperature of a parcel of air cooled to saturation at 100% relative humidity by the evaporation of water into it, with the latent heat supplied by the parcel. The wet-bulb temperature is the lowest temperature that can be reached under current ambient conditions by the evaporation of water only.

[0064] The term “relative humidity” refers to the ratio of the amount of water vapor in the air and the maximum amount of water vapor the air could potentially contain at a given temperature.

[0065] The term “latent heat” refers to the energy released or absorbed, by a body or a thermodynamic system, during a constant-temperature process. Latent heat can be understood as energy in hidden form which is supplied or extracted to change the state of a substance without changing its temperature.

NUMERICAL REFERENCES

[0066] The following numerical indices are provided for ease in cross-referencing between some of the structural features illustrated in the figures and the accompanying descriptions provided herein.

- 100 – First embodiment of Energy Recovery Ventilation (ERV)
- 200 – Second embodiment of Energy Recovery Ventilation (ERV)
- 300 – Third embodiment of Energy Recovery Ventilation (ERV)
- 500 – Dedicated Outdoor Air System (DOAS)
- 102 – Cold-Water Generation Unit (CGU)
- 103 – Evaporative Media
- 104 – Water Reservoir
- 105 – Pump
- 106 – Main Cooling Unit (MCU)
- 107 – Heat Exchanger 1
- 108 – Heat Exchanger 2
- 111 – Exhaust Fan
- 112 – Exhaust Air (EA)
- 114 – Return Air (RA)
- 122 – Outdoor Air (OA)
- 123 – Supply Fan
- 124 – Pre-cooled Air
- 126 – Supply Air (SA)
- 154 – Liquid Desiccant and Direct Expansion (LDDX) Unit

- 164 – Heater Unit
- 167 – Humidifier Unit
- 170 – Controller

[0067] The particular values and configurations discussed in these non-limiting examples can be varied and are cited merely to illustrate at least one embodiment and are not intended to limit the scope thereof.

[0068] Reference in this specification to "one embodiment/aspect" or "an embodiment/aspect" means that a particular feature, structure, or characteristic described in connection with the embodiment/aspect is included in at least one embodiment/aspect of the disclosure. The use of the phrase "in one embodiment/aspect" or "in another embodiment/aspect" in various places in the specification are not necessarily all referring to the same embodiment/aspect, nor are separate or alternative embodiments/aspects mutually exclusive of other embodiments/aspects. Moreover, various features are described which may be exhibited by some embodiments/aspects and not by others. Similarly, various requirements are described which may be requirements for some embodiments/aspects but not for other embodiments/aspects. Embodiment and aspect can be in certain instances be used interchangeably.

[0069] The particular configurations discussed in the following description are non-limiting examples that can be varied and are cited merely to illustrate at least one embodiment and are not intended to limit the scope thereof.

[0070] A dedicated outdoor air system and method of use for efficiently treating outdoor air for an enclosed space are disclosed herein that can support multi-operational modes.

[0071] The system and method disclosed herein can supply conditioned air to an enclosed or contained space or building, such as offices, apartments, supermarkets, houses, and data centers.

[0072] While the invention is described for the conditioning air that is supplied into an enclosed space, it is understood that the invention is not so limited and can be used to assist with other types of applications that require conditioned air. Other applications include, for example, using the system to condition air for controlled environments. The devices disclosed herein can condition air and/or remove heat from industrial settings and/or areas with electronic circuits that generate heat. The invention can also be scaled down and up for an intended use. As such, it will be appreciated to those skilled in the art, given the benefit of this disclosure, that the enclosed space to be cooled does not need to be airtight and is merely intended to relate to any structure that is desired to be ventilated and is not limited to a building. For example, the invention can be used for indoor spaces in any commercial/industrial buildings such as hospitals, schools, shopping centers, data centers etc. that require fresh air ventilation.

[0073] In achieving a more efficient and comprehensive system and method focused on energy recovery, the Dedicated Outdoor Air System (DOAS) can generally include an Energy Recovery Ventilation (ERV) unit, a control system and optionally at least

one additional unit for further air treatment.

[0074] The ERV unit can pre-treat Outdoor Air (OA) with subsequent pre-cooled air being sent to an enclosed space or for further treatment by at least one additional unit in the DOAS, whereby the ERV unit recovers energy from Return Air (RA) received from the enclosed space before producing Exhaust Air (EA) to the outdoor space or ambient environment. In this regard, the ERV unit can separately condition two air streams with the return air and exhaust air representing a first air stream, and the outdoor air and pre-cooled air representing a second air stream.

[0075] Accordingly, in one embodiment, the system uses two separate air streams: (1) return air and exhaust air stream and (2) outdoor air and pre-cooled air stream. Each stream can flow through the ERV separately. They are not mixed with one another because each stream has separate and distinct passageways.

[0076] In one embodiment, DOAS is a smart controlled multi-operational system that leverages on the principle of liquid cooling technology, as well as a comprehensive logic control system to determine the most energy efficient mode of operation through the actuation of different components in response to ambient psychrometric conditions and targeted indoor cooling environment.

[0077] The ERV unit, in particular focuses largely on cold energy recovery from previous air streams and the concept of evaporative cooling to deliver efficient cooling. The energy recovery unit uses the latent heat of vaporization of water to achieve a water temperature reduction that is close to the passing air wet bulb temperature. The

ERV unit comprises of three key segments: a cold-water generation unit (CGU), a main cooling unit (MCU) and a water storage system.

[0078] The ERV unit is used in tandem with a combination of secondary units, to provide a more efficient and comprehensive dedicated outdoor air system (DOAS) of different efficiencies to suit varying ambient conditions. The combination of equipment such as Energy Recovery (ERV) unit, Liquid Desiccant and Direct Expansion unit, Humidifier and Heater which also supports multi-operational mode is highly advantageous in realizing these requirements. Various fluid pathways within the ERV unit and their system configuration are illustrated below.

[0079] Return air (RA) enters the evaporative media in the cold-water generation unit (CGU) to produce cool air and water via a direct evaporative cooling process. This cooled air (by-product) then undergoes a heat exchange with the outdoor air in a first air-to-air heat exchanger in the main cooling unit (MCU). In an example, the cooled air undergoes a latent heat exchange with moisture transferred to the exhaust air stream instead of producing a condensate. Heat is absorbed by the cooled air during the heat exchange process while the outdoor air is cooled simultaneously. In another example, the cooled air (by-product) can undergo a sensible heat exchange with the refrigerant in a heat pipe (another type of air-to-air heat exchanger), resulting in condensing of the vapor refrigerant into liquid form. The liquid refrigerant in the same heat pipe can then be used to transfer its cold energy to the outdoor air. The resulting cooled air then enters a second liquid-to-air heat exchanger for further treatment, producing deep cooled pre-cooled air that is supplied to the enclosed space directly or to the secondary units for further treatment. At the same time, water circulating

through this second, liquid-to-air heat exchanger is heated during the process. This heated water is then circulated back to the evaporative media for cold water regeneration and thereafter delivered to the water reservoir, forming an open water loop. In some cases, as the air is cooled in the second heat exchanger, latent cooling of the air stream can take place as well producing condensate water at the dew point temperature of the pre-cooled air stream. This condensate water is then collected and fed back to the water tank, to further lower the water temperature, which will help to increase the efficiency of the heat exchange, and at the same time reduce the water consumption of the system. Output of the ERV unit comprises of exhaust air that is expelled to the outdoor space or ambient surroundings and deep pre-cooled air that is directly supplied to an enclosed space or be used as an input to additional units for further treatment before being delivered to the enclosed space as supply air (SA).

[0080] In one embodiment, return air (RA) enters the evaporative media in the cold-water generation unit (CGU) to produce cool air and water via a direct evaporative cooling process. The first heat exchanger in the main cooling unit (MCU) provides sensible cooling to the outdoor air. At the same time, the water circulating through this heat exchanger is heated during the process. This heated water is then circulated back to the evaporative media for cold water regeneration and thereafter delivered to the water reservoir, forming an open water loop. The cooled air exiting the first heat exchanger then enters the second air-to-air heat exchanger for heat exchange with the exhaust air expelled from the CGU, producing deep cooled pre-cooled air. This deep cooled pre-cooled air is then supplied to the enclosed space directly or to the secondary units for further treatment. Thus, the output of the ERV unit comprises the exhaust air and the pre-cooled air, and the exhaust air is released in the environment,

and the pre-cooled air is directly supplied to an enclosed space or be used as an input to additional units for further treatment before being delivered to the enclosed space as supply air (SA).

[0081] In another embodiment, return air (RA) enters the evaporative media in the cold-water generation unit (CGU) to produce cool air and water via a direct evaporative cooling process. The liquid-to-air heat exchanger 1 in the main cooling unit (MCU) provides cooling to the outdoor air. At the same time, the water circulating through this heat exchanger is heated during the process. This heated water is then circulated to the second liquid-to-air heat exchanger to further bring down the temperature of the heated water using the cold exhaust air produced after the evaporative media in the CGU, before circulating the water back to the evaporative media for cold water regeneration and thereafter delivered to the water reservoir, forming an open water loop. With this regeneration process, a colder water temperature is achieved by leveraging on the cold energy from the RA stream. Cooled air exiting the first heat exchanger is then supplied to the enclosed space directly or to the secondary units for further treatment. Thus, the output of the ERV unit comprises of exhaust air that is expelled to the outdoor space or ambient surroundings and pre-cooled air that is directly supplied to an enclosed space or be used as an input to additional units for further treatment before being delivered to the enclosed space as supply air (SA).

[0082] In particular, the DOAS harvests energy from a building's return air, transfers the energy into the circulating water through evaporative cooling, before sending the air back for heat exchange with outdoor air. The ERV unit used in the DOAS disclosed herein stores the energy in the water rather than air, as the heat capacity of water is

four times more than that of air, which makes water relatively efficient in energy storage. Further, unlike conventional air-to-air heat exchange methods, the present invention adopts air-to-water heat exchange and air-to-air heat exchange methods. This provides a higher heat transfer efficiency with a smaller equipment footprint. The ERV unit is essentially using and recycling energy from the natural process of water evaporation. The process of pre-cooling the incoming outdoor air occurs without addition of moisture into the outdoor air stream. Thus, the devices disclosed herein are free of contamination and do not add to the heat load while ensuring a clean supply air for the enclosed space.

[0083] The ERV unit used in the DOAS can harvest or recover increased cold energy from the return air with a simple system design. Further, the free energy from the return air can be used to evaporatively cool the water, thereby boosting the cooling of the water circulating into the cold-water generation unit (CGU).

[0084] In the ERV unit there is no mass transfer, instead water-to-air heat transfer and air-to-air heat transfer is involved. Efficient evaporative cooling produces water close to the return air wet bulb temperature. This provides water with sufficiently low temperature by using the evaporative media. The cold energy stored in the return air can be transferred and stored in the water that flows through it, from which the coolness is transferred to the outdoor air via an air-to-water heat exchanger.

[0085] In this regard, the CGU can operate to harness cold energy from Return Air (RA) from the enclosed space. The cold energy can then be used to generate a reservoir of cold water in the water management system through the evaporation of

water via the process of Direct Evaporative Cooling (DEC). This cold water can then be used to fuel the cooling cycle in the MCU where the outdoor air can be cooled via the process of Indirect Evaporative Cooling (IEC).

[0086] Cold energy is subjected to the wet bulb temperature of the return air. In this context, outdoor air cooling happens (or cold energy from the return air is available) when the wet bulb temperature of the return air is lower than the outdoor air temperature.

[0087] The ERV unit disclosed herein can be contained within a housing or casing. Each housing or casing can have one or more outlets and an outer periphery provided with inlet openings on its sides for air to flow through. The outer periphery can include removable screens located across the inlet openings. The housing and screens can be formed of any suitable material in the art. The dimension of the casing can be of any shape and size, but one skilled in the art given the benefit of this disclosure would understand that the size of the apparatus is largely dependent on the airflow and cooling capacity that is desired, and that the size of the apparatus is in some way proportional to the airflow and cooling capacity. The CGU and MCU and water management system can be enclosed in a housing with their respective inlets and outlets.

[0088] Accordingly, the ERV unit focuses largely on the concept of evaporative cooling to produce a water temperature reduction that is close to the passing air wet bulb temperature and leverages on this cold-water generation to pre-treat the outdoor air.

[0089] In one embodiment, the ERV unit can comprise a plurality of cooling units and a water management system. The cooling units can include a Cold-Water Generation unit (CGU) and a Main Cooling Unit (MCU).

[0090] The CGU can be positioned either above or beside the MCU in the ERV unit. In one embodiment, CGU can be positioned above the MCU. The different arrangements will affect the ERV unit overall dimension and actual footprint. For instance, the CGU being on top of the MCU will allow a reduced footprint at the expense of increased unit height. On the contrary, when the CGU is located beside the MCU, the unit has a larger footprint but reduced height.

[0091] The Cold-Water Generation (CGU) unit can include at least one evaporative media configured to allow return air to be passed therethrough and subsequently to the heat exchanger and exhausted out of the ERV unit. The CGU can be an air-to-water type heat rejection unit that recovers the energy from the return air and evaporatively cools the water circulating therethrough. In this regard, the CGU can be used for cooling the water flowing therethrough using the return air, thereby recovering the energy from the return air.

[0092] In one embodiment, the CGU can include a single evaporative media as the only cooling component. In another embodiment, the CGU can include one or more heat exchangers in addition to evaporative media as the cooling components.

[0093] The MCU can include at least one heat exchanger configured to allow outdoor air to be passed therethrough and out of the ERV unit as pre-cooled air. In one

embodiment, the MCU comprises one heat exchanger. In another embodiment, the MCU comprises two or more heat exchangers.

[0094] The MCU can include a heat exchanger that applies air-to-water heat exchange for transferring cold energy from the water to the supply air to be output from the ERV unit. In this regard, the MCU uses sensible and latent cooling type heat exchangers. Typically, the outdoor air drawn into the MCU will first undergo sensible cooling and subsequently latent cooling when the outdoor air is cooled below the air dew point temperature. In that instance, water condenses and the outdoor air losses moisture or humidity.

[0095] The water management system can maintain fluid connectivity between the CGU and MCU. In this regard, the water management system can include at least one water circuit to fluidly connect at least one water reservoir to the CGU and MCU.

[0096] The water circuit can fluidly connect the components (i.e., CGU, MCU and reservoirs) by water lines, pipes or tubes which provide substantially fluid-tight passages for water circulating therethrough. The water management system can include conventional components such as pumps, valves and flow restriction devices, for enabling water flow circulation and regulation as well as adjusting the water flow through said circuits.

[0097] In one embodiment, the water management system can include one or more pumps to create pressure to drive the liquid water through the at least one water circuit. In one embodiment, the water management system can include one pump.

[0098] Furthermore, a plurality of fans can be placed in the ERV unit, which are configured to draw air from the outdoor environment and enclosed space through the unit. In one embodiment, the ERV unit can include at least one exhaust fan and at least one supply fan.

[0099] The supply fan can draw ambient air (i.e., outdoor air) into the MCU and direct the air therethrough. In one embodiment, the supply fan can be a variable speed fan with an adjustable fan speed to vary the airflow volume through the MCU.

[00100] The exhaust fan can draw return air from the enclosed space into the CGU and direct the air therethrough. In one embodiment, the exhaust fan can be a variable speed fan with an adjustable fan speed to vary the airflow volume through the CGU.

[00101] It will be appreciated that the supply and the exhaust fan can be positioned and arranged accordingly for achieving the above function. In one embodiment, the supply fan can be positioned downstream of the MCU in relation to the outdoor airflow. In one embodiment, the exhaust fan can be positioned downstream of the CGU in relation to the return airflow.

[00102] A water management system can be arranged and configured for circulation of water throughout the ERV unit. The water management system can leverage on the high specific heat capacity of water to store energy, which translates to a smaller equipment footprint. Fluids or coolants other than water can be used in the system disclosed herein.

[00103] In this regard, the water reservoir can store energy recovered by the CGU in the circulating water. The MCU can then be used for transferring the energy stored in the water reservoir to outdoor air, thereby pre-cooling the outdoor air. Thus, the water reservoir can be used to store the cold energy recovered from the return air by the CGU and pre-cool the outdoor air to provide pre-cooled air.

[00104] In one embodiment, the water circuit can form an open loop that circulates water from the water reservoir to the MCU and then subsequently the CGU before being circulated back to the water reservoir for subsequent re-circulation.

[00105] As will be appreciated, the flow of water can be dependent on the positioning of the MCU and CGU relative to one another. It is of interest to reduce the number of components required within the system and use the help of gravity where possible.

[00106] The design of the water circuit can be modified dependent on the physical arrangement of the components in the ERV unit. In particular, the arrangement of the water circuits and connections to components can be modified dependent upon if the MCU unit is positioned on top or beside the CGU unit.

[00107] The CGU can be positioned either above or beside the MCU in the ERV unit. Apart from the dimension and actual footprint, the different arrangements can affect pump pressure or head. For instance, in a top-down arrangement, more pump head is required to deliver water to the CGU at higher elevation. However, in a sideways arrangement, less pump head is needed.

[00108] The rate of water flow through the water circuits can be enhanced to provide variable cooling. Higher water flow through the CGU can allow the ERV unit to transfer more heat from the MCU to the CGU and to be expelled in exhaust air. In one embodiment, the ERV unit can comprise a means for adjusting the water flow rate through the at least one water circuit. In one embodiment, the means for adjusting the water flow rate may be a valve, a flow restriction device and/or a variable speed pump.

[00109] The pre-cooled air exiting the ERV unit can be further treated by at least one additional unit. In one embodiment, in addition to the ERV unit, the system can include at least one additional unit. The additional unit can include a Liquid Desiccant and Direct Expansion unit (LDDX), a heater unit and/or a humidifier unit. The integration of the additional unit can be enhanced for operational control.

[00110] In the ERV of an embodiment of Dedicated Outdoor Air System (DOAS), in the CGU, cold energy harnessed from the return air (RA) stream of a building's enclosed space is used to generate cold water through the evaporation of water via the process of direct evaporative cooling (DEC). This cold water generated, together with its by-product (exhaust air), can be used in another embodiment to pre-treat the outdoor air as the outdoor air enters the MCU. In the MCU, the ambient/outdoor air undergoes a first heat exchange with the exhaust air (EA) in an air-to-air heat exchanger, before undergoing a second heat exchange with the cold water generated via the process of indirect evaporative cooling (IEC) in a liquid-to-air heat exchanger (LAHX). In the process of the IEC, condensation of water from the air could also occur and this condensate water is collected and fed to the water storage system to further increase the heat recovery, boost the cooling capacity and at the same time, reduce

the overall water consumption of the system. The pre-cooled air from the MCU is then further treated by a combination of secondary units i.e. Liquid Desiccant and Direct Expansion unit, Heater and Humidifier, before being delivered to the building as make-up fresh air. The water storage system also comprises of primary units for the circulation of water within the unit and leverages on the high specific heat capacity of water to store energy.

[00111] The ERV unit can be used in conjunction with the additional unit to provide necessary cooling to an enclosed space. The activation of the additional units is dependent on the ambient air psychrometric conditions. The ERV unit can operate independently without the additional units when the ambient conditions allow. Likewise, the additional units can operate without the ERV unit being activated.

[00112] In an embodiment, before being delivered to the enclosed space as supply air, the pre-cooled air can be treated by the LDDX unit, the heater unit and/or the humidifier unit. The direct expansion system can comprise components such as a compressor, evaporator coil, metering device and condenser coil to transfer heat from one area to another through the evaporation and condensation of a refrigerant, which serves as the medium through which heat is captured and removed from one area (i.e., evaporator) and released in another (i.e., condenser). On top of the direct expansion system, a liquid desiccant system **154** can be used to aid the sensible and latent cooling of the direct expansion system. The liquid desiccant system can include an absorber (conditioner) or desorber (regenerator), desiccant pump and internal heat exchanger. At the absorber, air can be dehumidified and cooled by the liquid desiccant. At the desorber, the moisture captured by the liquid desiccant can be

released via heating. The heat source may be coming from the condenser in the direct expansion system. In one embodiment, both direct expansion and liquid desiccant system constitute the LDDX unit.

[00113] The LDDX unit can be used to remove both the remaining sensible and latent heat load in the pre-cooled air.

[00114] The heater unit can be used to achieve a higher supply air temperature that is suitable for the enclosed space. The heater unit can comprise a heating element powered by electric, hot water and/or any other medium that are able to convert energy into heat.

[00115] The humidifier unit can be used to increase the moisture content of the supply air. An example of humidifier is similar to the CGU in which external supplied water and air pass through an evaporative media. The water is evaporated and transferred to the air that passes through. This produces air with increased humidity or moisture content.

[00116] In one embodiment, the additional unit can include a LDDX unit, a heater unit and a humidifier unit. In one embodiment, these additional units can be arranged such that the pre-cooled air from the ERV unit first flows through the LDDX unit, then secondly through the heater unit and then thirdly through the humidifier unit.

[00117] The units of the system disclosed herein can be arranged as follows (outdoor airflow through the components/unit from left to right):

- 1) ERV – LDDX – Heater – Humidifier;
- 2) ERV – Heater – Humidifier – LDDX;
- 3) ERV – Heater – LDDX – Humidifier;
- 4) Heater – ERV – LDDX – Humidifier or
- 5) Heater – ERV – Humidifier – LDDX.

[00118] A control system can be used with the system disclosed herein which will trigger the actuation of different units and/or components in response to the air psychrometric conditions. The controller can be any computing device having a set of pre-programed instructions and/or manual human control, to perform selective activation of one or more elements of the present invention.

[00119] The control system can contain the logic operation of the system and a series of input conditions and output requirements. The control system can include a control algorithm and input/output devices to operate the DOAS. The control system can operate the DOAS to deliver a comfortable apparent temperature and humidity level to the enclosed space by using the preferred operational mode based on ambient air psychrometric conditions, including temperature and humidity.

[00120] A user can activate the DOAS and enter preferred criteria through a user interface. The criteria can include temperature, humidity, and fan speed preferences along with input related to energy use. The DOAS can also include sensors to detect temperature and humidity levels of different airstreams (i.e., supply/return/outdoor/exhaust), water temperatures and water levels.

[00121] User criteria and data collected from the temperature and/or humidity sensors can be stored and analyzed in a computer or central processing unit. Logic and one or more algorithms can be used to control units/components. In response to ambient weather conditions, the control system is able to provide feedback to the unit level controller to trigger the actuation of the necessary components and thus the most preferred mode of operation.

[00122] In this regard, the control system can balance economy with a user's desired temperature. An algorithm can analyze ambient conditions to select the most energy efficient operational mode to achieve a desired temperature or humidity.

[00123] In one embodiment, the control system or controller can selectively activate components in the ERV unit.

[00124] In one embodiment, the control system or controller can selectively activate the ERV unit or the component (i.e., supply fan) in the ERV unit and/or at least one of the additional units depending upon the ambient air conditions to obtain the most energy efficient mode of operation.

[00125] **FIG. 1(a)** is a schematic diagram of an embodiment of the ERV unit **100** for the DOAS disclosed herein. The ERV unit **100** comprises a CGU **102**, a water reservoir **104** and a Main Cooling Unit (MCU) **106** having one heat exchanger **107**. The heat exchanger **107** may be an air to water heat exchanger, as shown. The CGU **102** evaporatively cools circulating water flowing therethrough by using the return air **114** from the enclosed space. The energy from the return air **114** is recovered or extracted

by the water circulating through the CGU **102**. The water reservoir **104** can be used to collect water which has the cold energy recovered by the CGU **102**. The MCU **106** can then be used for transferring cold energy stored in the water reservoir **104** (that is, cooling the outdoor air by heat transfer from the outdoor air to the fluid/heat transfer medium/water) to outdoor air **122** flowing through the MCU **106**, thereby pre-cooling the outdoor air **122** and providing pre-cooled air **124**. The pre-cooled air **124** can be supplied to the building enclosed space directly or can be further treated by at least one additional units before supplied to the enclosed space. The illustrated arrows in **FIG. 1(a)** are representative of the direction of the airflow through the ERV unit.

[00126]As shown in **FIG. 1(a)**, the CGU **102** is in fluid connection with the MCU **106** through the water reservoir **104** and a single water circuit that forms an open loop, to achieve energy recovery with reduced supervision and control.

[00127]For example, the return air (from buildings) **114** conditions can be about 25 °C, 50% Relative Humidity (RH), whereby the cold energy stored in the return air will be stripped off at the CGU **102** and stored in the water that flows through. The exhaust air **112** after the cold energy has been stripped off will be warmer than before entry into the cold-water generation unit, and is let out to the atmosphere. As the water flows through the CGU **102**, evaporative cooling is created with the return air. The evaporative process further cools the water to about 19°C and stores the water in the water reservoir **104**. The cold water at about 19°C then flows through the MCU **106**, to transfer its cooling energy to the incoming outdoor air **122**, which in hot and humid climates can routinely be about 34°C, 50% RH. Without direct contact with the water, the incoming outdoor air **122** to be fed into the DOAS cooling system will be pre-cooled

by the MCU **106** to about 25°C without adding any moisture content. The pre-cooled air **124** can be used by the DOAS system as supply air for cooling the enclosed space directly or further treated by at least one additional unit before being delivered to the enclosed space.

[00128] Various passageways for transfer of air and for pipes for transfer of fluid/water between elements are disclosed in **FIG. 1a**. For example, an exhaust air/return air passageway is formed from first passageway **115** which operatively connects return air **114** from inside the building or structure to the evaporative media **103** of the cold-water generation unit **102**, and second passageway **116** which routes exhaust air from the evaporative media **103** to the outdoors. The exhaust air passageway may have an exhaust fan **111**, either directly as shown in the embodiment of **FIG. 1a**, or indirectly after exhaust air passes through a heat exchanger as shown in the several of the other embodiments discussed in greater detail below. Thus, the exhaust air passageway is shown to transfer exhaust air from the inside of a building, pass such exhaust air through one or more components for heat transfer, and then is pulled by the exhaust fan to transfer the exhaust air away from the components (CGU and sometimes MCU), and out of the building. Meanwhile outdoor air **122** travels in an outdoor air passageway comprising first outlet passageway **117** to the heat exchanger **107** and cooled air passageway **131**. From the heat exchanger, cooled air is transferred to the cooled air passageway **131** to a supply fan **124**. The supply fan **124** is positioned in the outdoor air passageway, typically between the main cooling unit and the interior of the building, as is adapted to pull conditioned air away from the main cooling unit, and push such conditioned air into the building.

[00129] The outdoor air passageway allows for transfer of outdoor air, conditioning of the air, then transfer/supply conditioned air into the building. In the embodiments of **FIGs. 1a** and **3**, a single heat exchanger may be used at the main cooling unit, but in the embodiments of **FIGs. 1b** and **2**, a pair of heat exchangers may be used at the main cooling unit, as discussed in greater detail below. The first heat exchanger **107** transfers heat from the outdoor air to the fluid/water. Water flow forms a fluid circuit in a fluid pipe, and is shown along a first pipe **133** from tank **104**, through a pump (pulling water from a tank of cooled water) to the heat exchanger, a cooling pipe **118** transferring water from the heat exchanger to the evaporative media **103**, (where the fluid/water is cooled by heat transfer to the exhaust air), and a return pipe **132** fluidly connecting the evaporative media **103** and the water tank **104**.

[00130] **FIG. 1(b)** is a schematic diagram of another embodiment of the ERV unit **101** for the DOAS disclosed herein. The ERV unit **101** comprises a CGU **102**, a water reservoir **104** and a MCU **106**. The CGU **102** through use of evaporative media **103** cools circulating water flowing therethrough by using the return air **114** from the enclosed space to produce cool air (by product) and water. The energy from the return air **114** is recovered or extracted by the water circulating through the CGU **102**. The water reservoir **104** can be used to collect water which has the cold energy recovered by the CGU **102**. The cooled air (by product) is used for sensible or sensible and latent air-to-air heat exchange with the outdoor air **122** using a heat exchanger **107** of the main cooling unit (MCU).

[00131] Various passageways for transfer of air and for pipes for transfer of fluid/water between elements are disclosed in **FIG. 1b**. For example, an exhaust air/return air

passageway is formed from first passageway **115** which operatively connects return air **114** from inside the building or structure to the evaporative media **103** of the cold-water generation unit **102**, connecting passageway **136** which routs exhaust air from the evaporative media **103** to the first heat exchanger **107**, and from the first heat exchanger **107** to the outside via exit passageway **146**. The exhaust air passageway may have an exhaust fan **111**, in this case, positioned between the first heat exchanger and the outdoors. The outdoor air passageway comprises first outlet passageway **117** to the heat exchanger **107**, connecting passageway **119** between the first and second heat exchangers **107**, **108**, and first outlet passageway **141** to the building. The second heat exchanger **108** is connected in series with the first heat exchanger such that outdoor air passes sequentially first through the first heat exchanger **107**, then passageway **119**, then second heat exchanger **108** (where the air is cooled in a second, further iteration). The return air flow passageway is shown to extend through both the cold-water generation unit and the main cooling unit, such that heat transfer from occurs from the fluid to the exhaust air (at the ERV), and from the outdoor air to the exhaust air (at the MCU). The fluid circuit of the fluid pipe has also been modified, and now comprises the first pipe **133** from tank **104**, through a pump (positioned in the fluid pipe and pulling water from a tank of cooled water) to the second heat exchanger **108**, a cooling pipe **138** transferring water from the second heat exchanger to the evaporative media **103**, (where the fluid/water is cooled by heat transfer to the exhaust air), and a return pipe **132** fluidly connecting the evaporative media **103** and the water tank **104**. After being heated while passing through the evaporative media, the connecting passageway **136** operatively connects heated exhaust air from the evaporative media **103** to the first heat exchanger **107**. The first heat exchanger **107** may be an air-to-air heat exchanger, or a heat pipe type heat exchanger (HPHE), and

the second heat exchanger **108** may be an air-to-water heat exchanger, as shown in the embodiment of **FIG. 1b**. Second heat exchanger **108** transfers heat from the outdoor air to the fluid, further conditioning the previously precooled air.

[00132] Cooled outdoor air enters to heat exchanger **108** for further heat transfer using cold energy stored in the water reservoir **104**, thereby deep cooling the outdoor air **122** and providing deep cooled pre-cooled air **124**. The deep cooled pre-cooled air **124** can be supplied to the building enclosed space directly or can be further treated by at least one additional unit before supplied to the enclosed space. The cold water circulated through this liquid-to-air heat exchanger **108** is heated during the process. This heated water is then circulated back to the evaporative media **103** for cold water regeneration and thereafter delivered to the water reservoir **104**, forming an open water loop, that is, the fluid has direct contact with ambient air (as opposed to a closed loop system where the fluid is not in direct contact with ambient air). In some cases, as the outdoor air **122** is cooled in heat exchanger **108**, latent cooling of the air stream as well as producing condensate water take place at the dew point temperature of the pre-cooled air stream. This condensate water is then collected and fed back to the water tank **104**, to further lower the water temperature. The illustrated arrows in **FIG. 1(b)** are representative of the direction of the airflow through the ERV unit.

[00133] As shown in **FIGs. 1(a)** and **(b)**, the CGU **102** is in fluid connection with the heat exchanger **108** of MCU **106** through the water reservoir **104** and a single water circuit that forms an open loop, to achieve energy recovery with reduced supervision and control.

[00134] FIG. 2 is a schematic diagram of another embodiment of the energy recovery ventilator (ERV) **200** for the dedicated outdoor air system (DOAS) disclosed herein. The ERV unit **200** comprises a CGU **102**, a water reservoir **104** and a MCU **106**. The CGU **102** through evaporative media **103** cools circulating water flowing therethrough by using the return air **114** from the enclosed space to produce cool air (by product) and water. The cold energy from the return air **114** is recovered or extracted by the water circulating through the CGU **102**. The water reservoir **104** can be used to collect water which has the cold energy recovered by the CGU **102**. The cooled outdoor air **122** exiting the liquid-to-air heat exchanger **107** then enters a second air-to-air heat exchanger **108** for heat exchange with the exhaust air **112** expelled from the CGU, producing deep cooled pre-cooled air **124**. This deep pre-cooled air **124** is then supplied to the enclosed space directly or to the secondary units for further treatment. Thus, the output of the ERV unit comprises of exhaust air **112** and deep pre-cooled air **124**, where the exhaust air **112** is released in the environment and the deep-cooled air **124** is directly supplied to an enclosed space or be used as an input to additional units for further treatment before being delivered to the enclosed space as supply air (SA). The illustrated arrows in **FIG. 2** are representative of the direction of the airflow through the ERV unit.

[00135] Various passageways for transfer of air and for pipes for transfer of fluid/water between elements are disclosed in the embodiment of **FIG. 2**. For example, an exhaust air/return air passageway is formed from first passageway **115** which operatively connects return air **114** from inside the building or structure to the evaporative media **103** of the cold-water generation unit **102**, connecting passageway **146** which routes exhaust air from the evaporative media **103** to the second heat

exchanger **108**, and from the second heat exchanger **108** to the outside via exit passageway **147**. The exhaust air passageway may have an exhaust fan **111**, in this case, positioned between the second heat exchanger **108** and the outdoors.

[00136] Compared to the embodiment of **FIG. 1b**, the positions of the heat exchangers (and therefore the positions of the return air passageway and the fluid pipe) are reversed. Thus, the first heat exchanger **107** is an air-to-fluid heat exchanger, and the second heat exchanger **108** is an air-to-air heat exchanger. The outdoor air passageway comprises first outlet passageway **117** to the heat exchanger **107**, connecting passageway **149** between the first and second heat exchangers **107**, **108**, and first outlet passageway **141** to the building. The second heat exchanger **108** is connected in series with the first heat exchanger such that outdoor air passes sequentially through the first heat exchanger **107**, then passageway **119**, then second heat exchanger **108** (where the air is cooled in a second, further iteration). The fluid circuit of the fluid pipe now comprises the first pipe **143** from tank **104**, through a pump (pulling water from a tank of cooled water) to the first heat exchanger **107**, a cooling pipe **148** transferring water from the first heat exchanger to the evaporative media **103**, (where the fluid/water is cooled by heat transfer to the exhaust air), and a return pipe **132** fluidly connecting the evaporative media **103** and the water tank **104**. Fluid can flow in the fluid circuit in a generally clockwise direction as shown in **FIG. 2**, and transfer heat from the outdoor air at the first heat exchanger, and transfer heat to the exhaust air at the cold-water generation unit.

[00137] Note that with the embodiment of **FIG. 2**, with two heat exchangers **107** and **108** at the main cooling unit **106**, exhaust air is routed along 2nd heat exchange

passageway **156** from the evaporative media **103** to the second heat exchanger **108**, and a second heat exchanger exhaust pipe routs exhaust air from the second heat exchanger **108** to the exhaust fan and then to the outside. Fluid from the first heat exchanger **107** is routed/circulated to cold water generation unit for cooling via cooling pipe **148**, and water is circulated/delivered from the water tank **104** to the first heat exchanger **107** (and then back to the evaporative media) via a pump positioned along transfer pipe **143**.

[00138] **FIG. 3** is a schematic diagram of another embodiment of an ERV **300** for the DOAS. The ERV unit **300** comprises a CGU **102**, a water reservoir **104** and a MCU **106**. The CGU **102** through evaporative media **103** cools circulating water flowing therethrough by using the return air **114** from the enclosed space. The cold energy from the return air **114** is recovered or extracted by the water circulating through the CGU **102**. The water reservoir **104** can be used to collect water which has the cold energy recovered by the CGU **102**. The liquid-to-air heat exchanger **107** in the main cooling unit (MCU) **106** provides sensible cooling to the outdoor air **122**. At the same time, the water circulating through this heat exchanger **107** is heated during the process. This heated water is then circulated to a second liquid-to-air heat exchanger **108** to further bring down the temperature of the heated water before circulating the water back to the evaporative media **103** for cold water regeneration. The cooled water after heat exchange, delivered to the water reservoir **104**, forming an open water loop. Pre-cooled air **124** obtained from the air-to-water heat exchanger **107** is then supplied to the enclosed space directly or to the secondary units for further treatment. Thus, the output of the ERV unit comprises exhaust air **112** that is expelled to the outdoor space or ambient surroundings. The pre-cooled air **124** that is directly supplied to an

enclosed space or be used as an input to additional units for further treatment before being delivered to the enclosed space as supply air (SA).

[00139] Various passageways for transfer of air and for pipes for transfer of fluid/water between elements are disclosed in the embodiment of **FIG. 3**. For example, an exhaust air/return air passageway is formed from first passageway **115** which operatively connects return air **114** from inside the building or structure to the evaporative media **103** of the cold-water generation unit **102**, bridge passageway **169** which routs exhaust air from the evaporative media **103** to the second heat exchanger **108**, (except that this time the second heat exchanger is positioned in the cold-water generation unit), and from the second heat exchanger **108** to the outside via exit passageway **166**. The exhaust air passageway may have an exhaust fan **111**, in this case, positioned between the second heat exchanger **108** and the outdoors. The outdoor air passageway is essentially the same as the outdoor air passageway of the embodiment of **FIG. 1a**, and comprises first outlet passageway **117** to the heat exchanger **107**, and first outlet passageway **131** to the building. The fluid pipe now comprises the first pipe **133** from tank **104**, through a pump (pulling water from a tank of cooled water) to the first heat exchanger **107**, a cooling pipe **158** transferring water from the first heat exchanger to the second heat exchanger positioned in the cold water generation unit, a linking pipe **161** connecting the second heat exchanger **108** to the evaporative media **103**, (where the fluid/water is further cooled by heat transfer to the exhaust air), and a return pipe **132** fluidly connecting the evaporative media **103** and the water tank **104**. The fluid pipe is shown to carry fluid from the water tank to the first heat exchanger and then to the second heat changer, and then back to the evaporative media, and the first heat exchanger allows for transfer of heat from the

outdoor air to the fluid in the fluid pipe.

[00140] Instead of routing fluid directly from the heat exchanger **107** to the evaporative media **103** as shown in the embodiment of **FIG. 2**, in the embodiment of **FIG. 3**, fluid is routed via heat exchange pipe **158** from the heat exchanger **107** in the main cooling unit to the heat exchanger **108** in the cold-water generation unit. Heat exchanger **108** in the ERV relies on heat transfer to the exhaust air to cool the fluid (and of course heat the exhaust air), instead of heat transfer from the previously heated return air to the fluid in the heat exchanger **108** in the embodiment of **FIG. 2**). Thus, the second heat exchanger **108** is positioned in series in the exhaust air passageway with the evaporative media **103**, the first heat exchanger **107** is an air-to-fluid heat exchanger, and the second heat exchanger is also an air-to-fluid heat exchanger.

[00141] To help increase efficiency, in each of these embodiments, the exhaust air passageway is not in fluid communication with the outdoor air passageway inside the energy recovery ventilator of the dedicated outdoor air system. That is, the two passageways are isolated such that exhaust air does not mix with conditioned outdoor air delivered to the building. Fans drive air from the building to the energy recovery ventilator and then ultimately to the outside. The embodiments disclosed herein advantageously focus on taking return air and super charging it via the cold-water generation unit for cold water generation (to be used at the MCU). The by-product produced (lower temp exhaust air) is also used to pre-cool the outdoor air, thus to enhance the energy recovery efficiency of the energy recovery ventilator.

[00142] **FIG. 4** is a schematic diagram of a DOAS **500** using the embodiment of the

ERV unit **101** of **FIGs. 1(b)** in combination with three additional units for further conditioning of the conditioned air from the heat exchanger(s). Air flow is represented by line arrows. The water circuit is represented by dash-dot lines and the control signal is represented by dotted lines. The additional units include a LDDX unit **154**, a heater unit **164** and a humidifier unit **167**, all operatively positioned in the outdoor air passageway, and can be shown positioned after the outdoor air has passed through the main cooling unit, as shown in **FIG. 4**. As disclosed in **FIG. 4**, the CGU **102** evaporatively cools water flowing therethrough using the return air **114** from the enclosed space to produce cool air (by product) for use in the building and water. The exhaust fan **111** is used for drawing the return air **114** through the CGU **102** after extracting the cold energy from the return air **114** through heat exchanger **107** of MCU and exhausting the warmed exhaust air out of the ERV unit. The cold energy from the return air **114** is recovered or extracted by the water flowing through the CGU **102**. The water reservoir **104** can be used to collect water which has the cold energy recovered by the CGU **102**. The cooled air (by product) is used for a sensible or sensible and latent air-to-air heat exchange with the outdoor air **122** using a heat exchanger **107** of the main cooling unit (MCU). Pre-cooled outdoor air exiting heat exchanger **107** then enters into a heat exchanger **108** for further heat transfer using cold energy stored in the water reservoir **104**, thereby deep cooling the outdoor air and providing deep cooled pre-cooled air **124**. The deep cooled pre-cooled air **124** can be further conditioned in at least one of the additional units a LDDX unit **154**, a heater unit **164** and/ or a humidifier unit **167** before delivering such air into the building as supply air **126**.

[00143] A pump **105** is used to transport the water from the water reservoir **104** to the

MCU **106**, CGU **102** and back to the water reservoir **104**.

[00144] The supply fan **123** can be used for drawing outdoor air through the MCU **106** and supplying the deep pre-cooled air **124** to the enclosed space or to at least one additional unit of LDDX unit **154**, heater unit **162** and humidifier unit **167**, for further treatment before being delivered to the enclosed space in the building as supply air **126**.

[00145] The ERV unit, the LDDX unit, the heater unit and the humidifier unit can be operated independently or in combination, depending upon the ambient air conditions and user commands to obtain efficient modes of operation. In this regard, the ERV unit is used to treat the sensible and latent load, the LDDX unit is used to treat the remaining sensible and latent load, the heater unit is used for post heating and the humidifier unit is used to increase air moisture content.

[00146] As shown in **FIG. 4**, a control system including a controller **170** can form part of the dedicated outdoor air system. The controller **170** can select the most energy efficient operation to deploy to meet the targeted supply air conditions, in response to the detected ambient air humidity level (RH), dry bulb (DB) and dew point (DP) temperature. The dedicated outdoor air system controller allows automatic or manual control of various units to achieve the desired mode of operation based on ambient air conditions. That is, the controller can adjust the heat main cooling unit, the cold-water generation unit, and the flow of fluid in the fluid pipe, as well as the fans and pumps, to meet a preferred state of conditioned air. Depending on environmental conditions and programming, the controller can have one of several modes, such as a free

cooling mode, a heating mode, a heating and humidification mode, and a booster mode. The controller can shut off some elements of the system while leaving others on, as needed. The preferred state of conditioned air can be determined using sensors, and can be automatic in response to the detected ambient air humidity level (RH), the dry bulb (DB) temperature, and the dew point (DP) temperature. Other sensors for measuring other elements or temperatures and humidity of air at various locations in the energy recovery ventilator of the dedicated outdoor air system will be readily apparent to those skilled in the art given the benefit of this disclosure.

[00147] The control system can include a processor with the logic operation for the apparatus and a series of input conditions and output requirements.

[00148] In this regard, the operational modes of the system disclosed herein can depend on the air conditions in the outdoor and enclosed environment as well as the core cooling technologies used. As such, the system disclosed herein can include one or more environmental sensors to sense temperature and humidity in order to determine the most energy efficient operation mode. Each operation mode can activate or inactivate appropriate units and components. The placement of the environmental sensors can vary depending on the system setup, such as an inlet, outlet or alternatively, at each individual unit or component.

[00149] **FIG. 5** is a psychrometric chart **180** showing the process in a DOAS, in accordance with the disclosed embodiment of the invention. The process shown in **FIG. 5** is a typical cooling process in a DOAS, when the ERV unit and LDDX unit are activated (booster mode). The psychrometric chart is drawn taking dry bulb

temperature of air along X-axis and the absolute humidity of air along Y-axis. As shown in **FIG. 5**, the process from point **202** to point **204** refers to the evaporative cooling process of the return air from the enclosed space such as a building, which in turn cools the water that passes through. For example, the return air from the building, at temperature 25 °C is used to cool the water from 25°C to 19 °C.

[00150] The process from point 204 to point 205 refers to the air-to-air heat exchange process, where the by-product (exhaust air) of the CGU undergoes heat exchange with the outdoor air, producing pre-cooled outdoor air. This pre-cooled outdoor air then enters a second heat exchanger for further treatment. On the other hand, the exhaust air gets heated up and is expelled out of the ERV unit to an outdoor environment. For example, exhaust air at temperature 22°C is increased to a temperature of 27°C.

[00151] The process from point **206** to point **208** refers to the air-to-air heat exchange process, where the outdoor air is cooled by the exhaust air of the CGU. For example, the outdoor air at a temperature of 31°C is cooled in the heat exchanger to a temperature of 26°C.

[00152] The process from point **208** to point **210** refers to the air-to-water heat exchange process, also refers as sensible cooling, where cold energy in the water reservoir is used to further cool the pre-cooled outdoor air. For example, pre-cooled air at a temperature of 26°C is cooled using the heat exchanger to a temperature of 23°C before being sent directly to an enclosed space or to at least one additional unit for further treatment.

[00153] The process from point **210** to point **212** refers to further treatment of the deep cooled pre-cooled air using the LDDX unit, in which the remaining sensible and latent heat removal is taken place. In this process, the deep pre-cooled air at temperature of 23°C and relative humidity of 90% is further cooled, dehumidified and supplied to the enclosed space at temperature of 25°C and relative humidity of 50%. The heater unit and humidifier unit are not activated in this case.

[00154] The system and method disclosed herein can provide an efficient way of energy recovery and air conditioning. Based on the above example, up to 30% of energy spent can be saved as compared to conventional systems, such as conventional pre-cooled air-handling-units.

[00155] FIGs. 6, 7, 9, 11, 13 and 15 show various ways of integrating the units, whereby activation and or deactivation of the ERV unit (treat sensible and latent load) or the individual components therein alone, the LDDX unit (treat sensible and latent load), the heater unit (post heating) and/or the humidifier unit (increase air moisture content) can result in different modes of operation based on the ambient air conditions.

[00156] In an embodiment, the different modes of operation to be activated are dependent on the ambient air conditions and units used in the DOAS.

[00157] In one embodiment, the system disclosed herein can include the ERV unit with the LDDX unit, the heater unit and the humidifier unit. The operational modes can be selected from the following:

- Mode 1: Free Cooling mode

- Mode 2: Heating mode
- Mode 3: Heating and Humidification mode
- Mode 4: Energy Recovery mode
- Mode 5: Energy Recovery and Humidification mode
- Mode 6: Booster mode

[00158] Table 1 shows the different modes of operation that are activated depending on the ambient air psychrometric conditions.

Table: 1

Ambient conditions 1	Ambient conditions 2	Operating mode	Components activated
DBT ≥ 24 °C and ≤ 26 °C and RH $\geq 30\%$ and $\leq 65\%^*$		Free Cooling	Supply fan in ERV unit
DBT < 24 °C (or) DBT < 26 °C ; RH $> 65\%$	DPT ≥ 5.4 °C and ≤ 19 °C	Heating	Supply fan in ERV unit + Heater unit
DBT ≤ 26 °C	DPT < 5.4 °C	Heating + Humidification	Supply fan in ERV unit + Heater unit + Humidifier unit
DBT > 26 °C (or) DBT > 24 °C and RH $< 30\%$	DPT ≥ 5.4 °C and ≤ 19 °C	Energy Recovery	ERV unit
DBT > 26 °C	DPT < 5.4 °C	Energy Recovery + Humidification	ERV unit + Humidifier unit

DPT >19 °C		Booster	ERV unit + LDDX Unit
DPT = Dew Point Temperature DBT = Dry Bulb Temperature RH = Relative Humidity *RH of less than 65% is applicable to new buildings only, based on, Singapore Indoor Air Quality Code for air-conditioned buildings.			

[00159] FIG. 6 is a schematic diagram of an embodiment of the DOAS **500** operating in free cooling mode. The system **500** operates in the free cooling mode when air conditioning is not required. The system **500** delivers 100% outdoor air **122** to the enclosed space. In this free cooling mode, only the supply fan **123** in the ERV unit **100** is active. The active units are depicted with solid lines and the inactive units are depicted with dashed lines.

[00160] FIG. 7 is a schematic diagram of an embodiment of the DOAS **500** operating in heating mode. In this mode, all components in the ERV unit **100** are inactive except for the supply fan **123**, as the outdoor air **122** condition is colder than the targeted enclosed space temperature. The heater unit **164** is activated to achieve a higher supply air temperature suitable for indoor conditions. This is represented by process points 1-2 on the psychrometric chart **550** of **FIG. 8**.

[00161] FIG. 9 is a schematic diagram of an embodiment of the DOAS **500** operating in the heating and humidification mode. All components in the ERV unit **100** are inactive except for the supply fan **123** since pre-cooling of the outdoor air **122** is not necessary. A combination of both the heater unit **164** and humidifier unit **167** is used and activated to achieve a higher supply air temperature with greater moisture content

that is good for thermal comfort. This is represented by process 1-2-3 on the psychrometric chart **552** of **FIG. 10**.

[00162] FIG. 11 is a schematic diagram of an embodiment of the DOAS **500** operating in the energy recovery mode. Activation of the ERV unit **100** alone is sufficient to adequately condition the outdoor air **122** without the aid of any additional units. All components in the ERV unit **100** are active. This is represented by process 1-2 on the psychrometric chart **554** of **FIG. 12**.

[00163] FIG. 13 is a schematic diagram of an embodiment of the DOAS **500** operating in energy recovery and humidification mode. In this mode, all components in the ERV unit **100** are activated to provide pre-cooling to the outdoor air **122**. The resulting pre-cooled air **124** is then further treated using a humidifier unit **167** before delivering such air to the enclosed space as supply air **126**. In detail, cold energy extracted from the return air **114** undergoes a direct heat exchange with the circulating water flowing therethrough to produce cool air (by-product) for use in the building and water. The cool air is then fed through an air-to-air heat exchanger arranged in the MCU to first cool the outdoor air **122**. The cold water circulated through the ERV unit **101**, is presumed to have a temperature as low as the wet bulb of the return air stream through the CGU. The cold water is then used to boost the cooling potential by further cooling the cooled outdoor air through an air-to-water heat exchanger in the MCU via the process of Indirect Evaporative Cooling (IEC). The deep cooled pre-cooled air is then further treated by a humidifier unit **167** to increase its moisture content. This is represented by process 1-2-3 on the psychrometric chart **556** of **FIG. 14**.

[00164] FIG. 15 is a schematic diagram of an embodiment of the DOAS **500** operating in booster mode. The pre-cooled air is treated by both sensible and latent heat removal which requires a combination of both the ERV unit **100** and the LDDX unit **154** to adequately condition the outdoor air to a comfortable level. In detail, the ERV unit **100** generates the cold water needed to pre-cool the pre-cooled air **124** before entering the LDDX unit **154** to remove both the remaining sensible and latent heat load. This is represented by process 1-2-3 on the psychrometric chart **558** of **FIG. 16**.

[00165] FIG. 17 is a flowchart **700** listing steps involved in the process of energy recovery and pre-cooling outdoor air in ERV unit **100**. At step **702**, the CGU is used to evaporatively cool water flowing therethrough using the first stream of return air from the enclosed space to flow through the evaporative media. The CGU allows recovering the cold energy from the return air of the enclosed space through the water at this step **702**. At step **704**, a second stream of air (outdoor air) is directed through an air-to-air heat exchanger for first heat exchange with exhaust air (EA) arranged inside MCU. At step **706**, cooling water (fluid) is directed to liquid-to-air heat exchanger in fluid communication with evaporative media. At step **708**, the second stream of air (outdoor air) directed to a second heat exchange with liquid-to-air heat exchanger, arranged inside the MCU to produce deep pre-cooled air. At step **710**, deep pre-cooled air is supplied to the enclosed space of a building or further treated by at least one additional unit. Based on the ambient air relative humidity (RH), dry bulb (DB) and dew point (DP) temperature, the control system or user can select the most energy efficient operation by activation or deactivation of the ERV unit or individual components therein alone or in combination with at least one additional unit.

[00166] The process of energy recovery and pre-cooling air in the energy recovery ventilator can follow the following sequence of steps: (a) directing a stream of return air through the evaporative media arranged within the CGU to obtain a cool air and water; (b) transferring the cooled air from the CGU to the first heat exchanger in the MCU to pre-cool the outdoor air entered into MCU; (c) transferring the pre-cooled air obtained from the first heat exchanger to a second heat exchanger in the MCU and further cooled by circulating cooled water (liquid-to-air heat exchange) from water reservoir to produce deep cooled pre-cooled air; (d) heating, during the liquid-to-air heat exchange, the cold water circulated back to the evaporative media for cold water regeneration; and (e) directing the stream of deep cooled pre-cooled air directly to an enclosed space or for further treatment by at least one additional unit, depending on the ambient air psychrometric conditions.

[00167]FIGS. 18 and 19 are flowcharts listing steps involved in the process of selectively operating and activating, by the control system, an ERV unit or the individual components therein alone or in combination with at least one of the LDDX unit, the heater unit or the humidifier unit depending upon the ambient air conditions to obtain efficient modes of operation. The ambient air psychrometric conditions for the activation of different operational modes in the **FIG. 18** and **19** are based on a targeted enclosed space environment. In case of any changes in the targeted indoor space conditions, the ambient air conditions for the activation of different modes will vary accordingly.

[00168]At step **402**, the pre-cooling process starts followed by the psychrometric conditions of the ambient air being checked by the control system, as at step **404**. The

psychrometric conditions are detected and monitored by environmental sensors which can be located at varying location depending on the system setup.

[00169] At steps **406** and **408**, when a dry bulb temperature is greater than or equal to 24°C and less than or equal to 26°C and a relative humidity level is greater than or equal to 30% and less than or equal to 65%, only the supply fan in the ERV unit is activated for the system to operate in a free cooling mode.

[00170] Alternatively, at steps **410** and **412**, when the dry bulb temperature is less than 24°C and a dew point temperature is greater than or equal to 5.4°C and less than or equal to 19°C; or when the dry bulb temperature is less than 26°C, the relative humidity level is greater than 65% and the dew point temperature is greater than or equal to 5.4°C and less than or equal to 19°C, only the supply fan in the ERV unit and the heater unit are activated for the system to operate in a heating mode.

[00171] Alternatively, at steps **414** and **416**, when the dry bulb temperature is less than or equal to 26°C and the dew point temperature is less than 5.4°C, only the supply fan in the ERV unit, the heater unit and the humidifier unit are activated for the system to operate in a heating and humidification mode.

[00172] Alternatively, at steps **418** and **420**, when the dry bulb temperature is greater than 26°C and the dew point temperature is greater than or equal to 5.4°C and less than or equal to 19°C; or when the dry bulb temperature is greater than 24°C, the relative humidity level is less than 30% and the dew point temperature is greater than or equal to 5.4°C and less than or equal to 19°C, the ERV unit and all its components

are activated for the system to operate in an energy recovery mode.

[00173] Alternatively, at steps **422** and **424**, when the dry bulb temperature is greater than 26°C and the dew point temperature is less than 5.4°C, the ERV unit and all its components along with the humidifier unit are activated for the system to operate in an energy recovery and humidification mode.

[00174] Alternatively, at steps **426** and **428**, when the dew point temperature is greater than 19°C, the ERV unit and the LDDX unit are activated for the system to operate in a booster mode.

[00175] In this regard, the control system functions to continually monitor the psychometric condition and change the operational mode accordingly. The process **400** ends at step **430**.

[00176] From the foregoing disclosure and detailed description of certain embodiments, it will be apparent that various modifications, additions and other alternative embodiments are possible without departing from the true scope of the invention. The embodiments discussed were chosen and described to provide the best illustration of the principles of the invention and its practical application to thereby enable one of ordinary skill in the art to use the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the invention as determined by the appended claims when interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled.

CLAIMS

What is claimed is:

1. A dedicated outdoor air system for conditioning air entering a building, with an energy recovery ventilator for transferring energy from return air to a fluid comprising, in combination:

a main cooling unit for cooling outdoor air having an inlet for the outdoor air and a first heat exchanger;

a cold-water generation unit for cooling the fluid, provided with evaporative media;

an outdoor air passageway adapted to transfer outdoor air through the first heat exchanger to create conditioned air, and then transfer the conditioned air to the building;

an exhaust air passageway adapted to transfer return air from the building to the cold-water generation unit, and to transfer the return air from the evaporative media to outside the building as exhaust air, wherein the cold-water generation unit is connected to an inlet for the return air;

an exhaust fan positioned in the exhaust air passageway; and

a fluid pipe adapted to receive the fluid and form a fluid circuit connecting at least one of the first heat exchanger and a second heat exchanger to the evaporative media to a tank for storing the fluid, and the tank to same of the first heat exchanger and the second heat exchanger;

wherein the return air is first routed to the evaporative media, the evaporative media is adapted to transfer heat from the fluid to the return air, and the exhaust air

passageway between the inlet for the return air and the exhaust fan is not in fluid communication with the outdoor air passageway inside the energy recovery ventilator.

2. The dedicated outdoor air system of Claim 1 wherein the return air is routed from the evaporative media to the first heat exchanger;

the first heat exchanger, the second heat exchanger and the evaporative media are heat transfer components, with the first heat exchanger positioned between the evaporative media and the exhaust fan in the exhaust air passageway;

the second heat exchanger is positioned in the fluid circuit between the water tank and the evaporative media; and

no more than a pair of heat transfer component are positioned in the exhaust air passageway.

3. The dedicated outdoor air system of Claim 1 further comprising a supply fan positioned in the outdoor air passageway, wherein the supply fan is adapted to pull conditioned air away from the main cooling unit; and

the second heat exchanger is positioned in series in the outdoor air passageway between first heat exchanger and the supply fan, and no more than two heat exchangers are positioned in the outdoor air passageway between the inlet for the outdoor air and the supply fan.

4. The dedicated outdoor air system of Claim 1 further comprising a pump positioned in the fluid pipe, wherein the pump is adapted to supply pressure to the fluid in the fluid pipe, and thereby circulate the fluid through the fluid circuit.

5. The dedicated outdoor air system of Claim 1 further comprising a controller, wherein the controller can adjust the main cooling unit, the cold-water generation unit and flow of fluid in the fluid pipe to meet a preferred state of conditioned air.

6. The dedicated outdoor air system of Claim 1 wherein the first heat exchanger is adapted to transfer heat from the outdoor air to the return air.

7. The dedicated outdoor air system of Claim 1 wherein the second heat exchanger is positioned at the main cooling unit in series with the first heat exchanger along the outdoor air passageway; and

the first heat exchanger is one of an air-to-air heat exchanger and a heat pipe type heat exchanger, and the second heat exchanger is an air-to-fluid heat exchanger.

8. The dedicated outdoor air system of Claim 7 wherein the outdoor air passageway is configured such that outdoor air reaches the first heat exchanger first and then is passed to the second heat exchanger.

9. The dedicated outdoor air system of Claim 7 wherein the exhaust air passageway extends from the evaporative media and through the first heat exchanger, and the first heat exchanger is adapted to transfer heat from the outdoor air to the return air; and

the second heat exchanger is positioned in the fluid circuit between the water tank and the evaporative media, and the second heat exchanger is adapted to transfer heat from the outdoor air to the fluid.

10. The dedicated outdoor air system of Claim 8 wherein the fluid pipe is adapted to carry fluid from the tank to the second heat exchanger and back to the evaporative media along the fluid circuit, the exhaust fan is adapted to pull return air through the first heat exchanger, and the second heat exchanger is adapted to transfer heat from the outdoor air to the fluid.

11. The dedicated outdoor air system of Claim 1 wherein the second heat exchanger is positioned at the main cooling unit in series with the first heat exchanger along the outdoor air passageway; and

the first heat exchanger is an air-to-fluid heat exchanger, and the second heat exchanger is an air-to-air heat exchanger.

12. The dedicated outdoor air system of Claim 11 wherein

the exhaust air passageway extends from the evaporative media and through the second heat exchanger, and the second heat exchanger is adapted to transfer heat from the outdoor air to the return air; and

the fluid pipe is adapted to carry fluid from the tank to the first heat exchanger and back to the evaporative media, and the first heat exchanger is adapted to transfer heat from the outdoor air to the fluid.

13. The dedicated outdoor air system of Claim 1 wherein the second heat exchanger is positioned at the cold-water generation unit; and

the first heat exchanger is an air-to-fluid heat exchanger, and the second heat exchanger is an air-to-fluid heat exchanger.

14. The dedicated outdoor air system of Claim 13 wherein the exhaust air passageway extends from the evaporative media and through the second heat exchanger to an exhaust fan, and the second heat exchanger is adapted to transfer heat from the fluid in the fluid pipe to the return air; and

the fluid pipe is adapted to carry fluid from the tank to the first heat exchanger and then to the second heat exchanger, and then back to the evaporative media, and the first heat exchanger is adapted to transfer heat from the outdoor air to the fluid in the fluid pipe.

15. The dedicated outdoor air system of Claim 1 further comprising a liquid desiccant and direct expansion unit, a heater and a humidifier all operatively connected to the outdoor air passageway for further conditioning the conditioned air.

16. A dedicated outdoor air system for conditioning air entering a building from the outside, with an energy recovery ventilator for transferring energy from return air to a fluid comprising, in combination:

a main cooling unit for cooling outdoor air and having both a first heat exchanger and a second heat exchanger positioned along an outdoor air passageway;

a cold-water generation unit for cooling the fluid, provided with evaporative media, wherein the cold-water generation unit is connected to an inlet for the return air;

the outdoor air passageway is adapted to transfer outdoor air through the first heat exchanger and then through the second heat exchanger to create conditioned air, and then transfer the conditioned air to the building;

an exhaust air passageway adapted to transfer return air from the building to the cold-water generation unit and to transfer return air from the evaporative media to outdoors;

an exhaust fan positioned in the exhaust air passageway, wherein the exhaust fan is adapted to pull the return air away from the cold-water generation unit;

a supply fan positioned in the outdoor air passageway, wherein the supply fan is adapted to pull conditioned air away from the main cooling unit and into the building; and

a fluid pipe adapted to receive the fluid and form a fluid circuit connecting the second heat exchanger to the cold-water generation unit, the cold-water generation unit to a tank, and the tank to the second heat exchanger;

wherein the return air is first routed to the evaporative media, and then to the first heat exchanger, the evaporative media is adapted to transfer heat from the fluid to the return air, and the exhaust air passageway is not in fluid communication with the outdoor air passageway inside the energy recovery ventilator between the inlet for the return air and the exhaust fan.

17. The dedicated outdoor air system of claim 16 further comprising a connecting passageway between the evaporative media and the first heat exchanger which routes return air from the evaporative media to the first heat exchanger, and from the first heat exchanger to the outside via an exit passageway;

the first heat exchanger, the second heat exchanger and the evaporative media are heat transfer components, with the first heat exchanger positioned between the evaporative media and the exhaust fan in the exhaust air passageway, and the evaporative media positioned in the exhaust air passageway between the first heat

exchanger and the inlet for the return air, and no more than a pair of heat transfer components are positioned in the exhaust air passageway; and

the second heat exchanger is positioned in series in the outdoor air passageway between the first heat exchanger and the supply fan, and no more than two heat exchangers are positioned in the outdoor air passageway between the inlet for the outdoor air and the supply fan.