

DUTY BASED MODULATING HYDRONIC CIRCUIT TECHNOLOGY METHOD AND APPARATUS FOR OPTIMIZED CONFIGURATION OF MULTIPLE HEAT PUMPS

CROSS-REFERENCE

5 [0001] The present application claims the benefit of priority to U.S. Provisional Patent Application No. 63/60,0258 filed November 17, 2023 entitled DUTY BASED MODULATING HYDRONIC CIRCUIT TECHNOLOGY METHOD AND APPARATUS FOR OPTIMIZED CONFIGURATION OF MULTIPLE HEAT PUMPS, the entire contents of which are herein incorporated by reference into the Detailed Description herein below.

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TECHNICAL FIELD

[0002] Example embodiments generally relate to temperature control of spaces and water supplies within premises.

15 BACKGROUND

[0003] Many existing conventional heating systems are carbon based furnaces or natural gas fired boilers. In homes and commercial properties that have hydronic based systems, e.g. the use of water based fluids to transport heat from the mechanical room to the occupied space heat emitter, the hydronic system is usually used just for space heating. That hydronic system would usually get heat from the natural gas, or propane gas boiler. These emit greenhouse gases, and as such there is a goal to convert many existing boiler-based heating systems to electrically driven heat pumps. These heat pumps can extract heat energy from the cold outdoor air and transport the heat energy into the hydronic fluid, in a similar fashion to the heat energy from the boilers but without the burning of fossil fuels.

25 [0004] When replacing a boiler with a heat pump there are several challenges ranging from the cleanliness and condition of the water and heat emitters, to the operating temperatures available from the boiler versus the heat pump. Old boiler systems were designed to take advantage of the boilers ability for a supply temperature upwards of 180 deg F (82.22 deg C), with a return temperature on the order of 130-150 def F (54.44 - 30 65.56 deg C). Modern heat pumps systems in the same design day application will likely

only be able to provide 140 deg F (60 deg C), with a return temperature between 90-100 deg F (32.22 - 37.78 deg C). As a result, in most retrofit applications the heat emitters may not be capable of providing the required heat, and need to be made with large surface area. In addition, to transport the same amount of heat with the smaller spread
5 between supply and return temperature, the flow rates need to be higher, meaning larger pipe work, larger pumps, and larger plant equipment for all elements of the system, e.g. fill, drain, treatment, filtration, control valving, isolation valving, expansion control, etc. Not only is there a challenge for retrofit projects converting to heat pumps, but retrofitting often poses operating efficiency losses where the older system could charge a storage tank of
10 heated domestic hot water regardless of the heating system operation to maintain the occupied space comfort.

[0005] Some heat pump systems feature cascading refrigerant loops internal to what becomes a highly complex machine, in order to get enough temperature lift for the domestic hot water services. Where high lift heat pumps are installed dedicated against
15 domestic hot water, these heat pumps are often strained due to sizing constraints for energy ratings. When the occupant needs hot water the storage tank is low, the rate of recharge by the heat pump is low and does not operate at an efficient operating point. Even worse, if one or any of these related refrigerant heat pumps in a building fail there might be a loss of domestic hot water, space heating hydronic water, or in some cases
20 neither would remain available.

SUMMARY

[0006] It may be advantageous to provide systems, methods, techniques, technology, and apparatus that overcome the above mentioned disadvantages, that get the best from heat
25 pump technology for retrofit challenges with temperature regimes, operating efficiencies under various and extreme conditions, and resilience with lower first expenditures. It should be noted that in heating mode the heat pumps tend to be at their most efficient when at full load, however, most comfort cooling or heating system applications operate below 50% design load for more than 95% of operating hours. Hence, the ability to have
30 dual capacity heat pumps that can be assign multiple configurations (modes) to various scenarios can improve the operating efficiency of a single heat pump operation, and also

potentially reduce the heat pumps operating at on-off cycling at lower loads, through that fact that the size of the two heat pumps can be made smaller than if just one large heat pump was assigned to serve all duty operations. By keeping independent of two refrigerant loops and avoiding cascading or other refrigerant circuit combinations, each heat pump is more resilient as they are not tied or dependent on the other for part or all of their ability to provide the temperature control service.

[0007] Example embodiments relate to the field of automated control system for temperature control systems, flow control systems, and hydronic systems, and circulating devices such as pumps, boosters and fans, centrifugal machines, and related systems.

For example, example embodiments relate to temperature control of spaces and liquid supply systems.

[0008] Example embodiments relate to a hydronic system that can co-ordinate heat pumps, valves, and load circuits based on load-based and condition based factors to assess the optimal operating hydronic circuit configuration.

[0009] Example embodiments relate to heat pump applications in hydronic systems that can incorporate domestic water heating in some examples. In each of these systems there can be an occasional demand for high temperatures, or high temperature lift relative to the heat pump sink. In these circumstances at least one controller can reconfigure the heat pumps to fulfill operating conditions for high or low temperature setpoint, high capacity heat loads, high temperature and low lift scenarios, beyond where the standard stationary configuration would not enable as broad a set of operating conditions, or operating conditions with the much improved energy efficiency delivered through this method. In examples, the various configurations is executed through hydronic inter-connections of the heat pumps.

[0010] Example embodiments relate to an automated digitally based apparatus that enables a population of heat pumps in a hydronic system (e.g., heating and/or cooling) to operating in either a parallel or series configuration, or a combination of the parallel and series configuration. The operating mode of the apparatus uses load based and condition based digital model inputs to assess the optimal operating hydronic circuit configuration for the apparatus that will permit the population of heat pumps to optimally deliver the demanded heating or cooling.

[0011] An example embodiment is a hydronic system, comprising: an air to liquid heat pump interfacing with a first source circuit to air and hydronically connected to a first load circuit having a first load input and a first load output; at least one hydronic coil hydronically connected to the first load circuit; a liquid to liquid heat pump interfacing with
5 a second source circuit having a second source input and a second source output and hydronically connected to a second load circuit having a second load input and a second load output; a water storage hydronically connected to the second load circuit, and hydronically connected to a water consumption circuit having a water supply input and a water consumption output; at least one 3-way valve which hydronically connects the air
10 to liquid heat pump to the liquid to liquid heat pump; and at least one controller configured to co-ordinate control of the at least one 3-way valve, the air to liquid heat pump, and the liquid to liquid heat pump.

[0012] Another example embodiment is a hydronic system, comprising: a first heat pump interfacing with a first source circuit having a first source input and a first source output
15 and hydronically connected to a first load circuit having a first load input and a first load output; a second heat pump interfacing with a second source circuit having a second source input and a second source output and hydronically connected to a second load circuit having a second load input and a second load output; a plurality of 3-way valves, including: a first 3-way valve which hydronically connects the first load output of the first
20 load circuit to the second source input of the second source circuit, a second 3-way valve which hydronically connects the first load input of the first load circuit to the second source output of the second source circuit, a third 3-way valve which hydronically connects the first load output of the first load circuit to the second load output of the second load circuit, and a fourth 3-way valve which hydronically connects the first load input of the first load
25 circuit to the second load input of the second load circuit; and at least one controller configured to co-ordinate control of the plurality of 3-way valves, the first heat pump, and the second heat pump.

[0013] Another example embodiment is method of controlling the hydronic system of any of the above, comprising changing a state of at least one of the 3-way valves.

30 [0014] In another example embodiment of the method, the changing the state includes causing a respective passageway between the air to liquid heat pump and the liquid to

liquid heat pump as between the first load output and the second source input and as between the first load input and the second source output.

[0015] In another example embodiment of the method, the changing the state includes causing a respective passageway between the air to liquid heat pump and the liquid to liquid heat pump as between the second load output and the first load output and as between the first load input and the second load input.

[0016] Another example embodiment is a non-transitory computer readable medium comprising instructions which, when executed by at least one controller, cause the at least one controller to perform any of the above methods.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Embodiments will now be described, by way of example only, with reference to the attached Figures, in which:

[0018] Figure 1 illustrates a hydronic system including a space conditioner system having a first heat pump and a water supply system having a second heat pump, in accordance with an example embodiment;

[0019] Figure 2 illustrates the hydronic system of Figure 1 in a mode of operation to provide supply from the space conditioner system to the water supply system, in accordance with an example embodiment;

[0020] Figure 3 illustrates the hydronic system of Figure 1 in a mode of operation to provide supply from the water supply system to the space conditioner system, in accordance with an example embodiment;

[0021] Figure 4 illustrates an example heat pump to be used in the hydronic system of Figure 1;

[0022] Figure 5 illustrates a flow diagram of a method for controlling the hydronic system of Figure 1 to the mode of operation of Figure 2;

[0023] Figure 6 illustrates a flow diagram of a method for controlling the hydronic system of Figure 1 to the mode of operation of Figure 3;

[0024] Figure 7 illustrates an example load profile for the hydronic system of Figure 1 or an individual load thereof; and

[0025] Figure 8 illustrates an example flow control system for the hydronic system of Figure 1, in accordance with an example embodiment.

[0026] Like reference numerals may be used throughout the Figures to denote similar elements and features.

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DETAILED DESCRIPTION

[0027] At least some example embodiments generally include an automated control system for temperature control systems and circulating devices such as pumps, boosters and fans, centrifugal machines, and related systems.

10 [0028] At least some example embodiments generally include a hydronic system such as a flow control system or temperature control system. Example embodiments relate to "processes" in the industrial sense, meaning a process that outputs product(s) (e.g. hot water, air, temperature control of a space) using inputs (e.g. cold water, fuel, air, etc.).

[0029] In pumping systems where the flow demand changes over time there are several
15 conventional procedures to adapt the operation of the pump(s) to satisfy such demand without exceeding the pressure rating of the hydronic system, and it is advantageous to improve or optimize the energy use.

[0030] Figure 1 illustrates a hydronic system 100 in accordance with an example embodiment, which includes a space conditioner system 102 and a water supply system
20 104. The space conditioner system 102 is configured for conditioning temperature of a space such as a premises, dwelling, building, vessel, etc. The space conditioner system 102 can be part of a Heating, Ventilation, and Air Conditioning (HVAC) of the premises, for example. The water supply system 104 is configured to supply water for consumption. The hydronic system 100 can operate in a cooling mode or a heating mode, as required
25 by the needs of the premises. An example of a cooling system is a chiller plant, air conditioner, data cooling center, etc. An example of a heating system is a boiler plant, hot water supply, furnace, etc.

[0031] The space conditioner system 102 includes a first heat pump 106 (e.g., an air to liquid heat pump such as an air to water heat pump 106) and the water supply system
30 104 includes a second heat pump 114 (e.g., a liquid to liquid heat pump such as a water to water heat pump 114). The first heat pump 106 and the second heat pump 114 are

each configured to extract heat energy or cooling energy from a source, as appropriate to the particular needs of the premises. In examples, the source, which can be a heating source or a cooling source, can be ambient, thermal energy storage, a data center, hydrogen power, a district energy system, geothermal, a boiler, thermal solar, waste water, ground source heat sink, a cooling tower, natural water, etc. In examples, a wall 156 separates the indoor of the premises from the outdoor (ambient) of the premises. The first heat pump 106 and the second heat pump 114 can be configured to have their flow and operation reversed in order to be in a heating mode or a cooling mode, as appropriate. In examples, the first heat pump 106 and the second heat pump 114 have a variably controllable motor. In examples, the first heat pump 106 and the second heat pump 114 have one or more sensors 160 for detecting parameters such as speed, power, pressure, flow, and/or temperature.

[0032] Generally, the hydronic system 100 has controllable hydronic interconnections to control flow as between the space conditioner system 102 and the water supply system 104. The hydronic system 100 includes a circulation fluid such as water. For example, the controllable hydronic interconnections can be controlled to improve efficiency of one or both of the first heat pump 106 and the second heat pump 114. For example, the controllable hydronic interconnections can be controlled to source particular demand loads of one or both of the space conditioner system 102 or the water supply system 104, especially at extreme temperatures. In an example, output of the water supply system 104 can be partially or wholly redirected to the space conditioner system 102. In an example, output of the space conditioner system 102 can be partially or wholly redirected to the water supply system 104. At least one controller 150 (one shown, also referred to herein as the “controller 150”) can be configured to receive parameters of the hydronic system 100 from sensors 160 and control operation of one or more devices in the hydronic system 100. In examples, the controller 150 can configured to operate automatically (autonomously) or receive instructions for manual control. In examples, the controller 150 is configured to improve or optimize energy efficiency or to achieve required temperature regulation of the hydronic system 100 for the premises.

[0033] As shown in Figure 1, referring to the space conditioner system 102, the air to water heat pump 106 interfaces with a first source circuit 108 to air (e.g. ambient) and is

hydronically connected to a first load circuit 110 having a first load input 128 and a first load output 130. A first pump 146(1) is configured to boost water flow from the air to water heat pump 106 to the first load output 130 to source a load. In an example, the first pump 146(1) is integrated with the air to water heat pump 106 (e.g., during factory assembly or onsite). In an example, the first pump 146(1) is a variable pump with a variably controllable motor.

[0034] The first load circuit 110 includes, as the load, at least one hydronic coil 112 which is hydronically connected to the first load output 130. The at least one hydronic coil 112 can receive cool water for cooling one or more spaces in the premises, and can receive hot water for heating the one or more spaces. In some examples, not shown here, a fan is configured to blow air across at least one hydronic coil 112 to facilitate temperature circulation and distribution. In another example, not shown here, a heat exchanger interfaces with at least one hydronic coil 112 to provide temperature regulation to another subsystem to source another load.

[0035] The water supply system 104 includes a second load circuit 118, a third load circuit 126, and a water consumption circuit 122. The water supply system 104 is configured to supply water for consumption, e.g. by loads, plumbing, sprinklers, taps, users and/or devices at the premises.

[0036] The water supply system 104 includes a water storage 120, which can be a tank water heater. The water storage 120 is configured to heat and store water, therefore acting as a thermal storage tank. In an example, the water consumption circuit 122 for the water storage 120 has water supply input 136, e.g. from municipal, waste treatment system, filter, or other potable water supplies. The water storage 120 outputs to water consumption output 138 for consumption, e.g. premises or domestic water consumption. The water storage 120 is hydronically connected to the second load circuit 118. The water storage 120 has a water to water heat exchanger (not shown here) between the second load circuit 118 and the water consumption circuit 122, so as not transfer the required heat energy without mixing the potable water from the water supply input 136 with the second load circuit 118.

[0037] In examples, such as when there is a sufficient amount of hot water in the water storage 120, water of the second load circuit 118 can be redirected and circulated to the space conditioner system 102 to source loads such as the hydronic coils 112.

[0038] The water to water heat pump 114 is hydronically connected to a second source circuit 116. The second source circuit 116 includes a second source input 140 and a second source output 142. The water to water heat pump 114 is hydronically connected to the second load circuit 118. The second load circuit 118 has a second load input 132 and a second load output 134. A second pump 146(2) is configured to boost flow from the water to water heat pump 114 through the second load output 134 to the water storage 120. In an example, the second pump 146(2) is integrated with the water to water heat pump 114 (e.g., during factory assembly or onsite). In an example, the second pump 146(2) is a variable pump with a variably controllable motor. In examples, the first pump 146(1) and the second pump 146(2) are in different positions in the hydronic system 100, and/or additional pumps are in the hydronic system 100.

[0039] An air to water heat exchanger 124 includes a radiator 148 which interfaces with the third source circuit 154, e.g. the air (ambient). In examples, the radiator 148 can include a fan coil. The air to water heat exchanger 124 is hydronically connected to the third load circuit 126 which is hydronically connected to the second source circuit 116. The air to water heat exchanger 124 operates as a heat rejection and/or a heat sink interface. In other examples, the radiator 148 can be replaced by a ground source circuit or other heat source interface.

[0040] Similarly, not shown here, in an example, the first heat pump 106 can include a second liquid to liquid heat pump and a radiator which interfaces with the first source circuit 108 to air (e.g. ambient).

[0041] The hydronic system 100 includes at least one 3-way valve (each or collectively referred to as 144) which hydronically connects the air to water heat pump 106 to the water to water heat pump 114. The example shown in Figure 1 includes a first 3-way valve 144(1), a second 3-way valve 144(2), a third 3-way valve 144(3), and a fourth 3-way valve 144(4). The first 3-way valve 144(1) hydronically connects the first load output 130 of the first load circuit 110 to the second source input 140 of the second source circuit 116. The second 3-way valve 144(2) hydronically connects the first load input 128 of the

first load circuit 110 to the second source output 142 of the second source circuit 116. The third 3-way valve 144(3) hydronically connects the first load output 130 of the first load circuit 110 to the second load output 134 of the second load circuit 118. The fourth 3-way valve 144(4) which hydronically connects the first load input 128 of the first load
5 circuit 110 to the second load input 132 of the second load circuit 118.

[0042] In examples, as shown in Figure 1, the hydronic system 100 includes at least one tee fitting 152 to provide for hydronic interconnections in the hydronic system 100 . As shown in Figure 1, there are a plurality of tee fittings 152 which hydronically connect the space conditioner system 102 and the water supply system 104. As shown in Figure 1,
10 each tee fitting 152 includes a 3-way open passageway. In other examples, any one of the fittings can be a different fitting with more or fewer passageways than three passageways. In examples, the tee fitting 152 can be interchanged with other tee fittings 152 and/or share the same circuits as other tee fittings 152 in the hydronic system 100.

[0043] The controller 150 is configured to co-ordinate control of at least the 3-way valves
15 144, the air to water heat pump 106, and the water to water heat pump 114. In some examples, the controller 150 is also configured to co-ordinate control of the first pump 146(1), and/or the second pump 146(2). The controller 150 is configured to receive data such as sensor data from the sensors 160, programming instructions, and manual instructions. Examples of the sensors 160 include a pressure sensor, a flow sensor, a
20 temperature sensor, a pump motor speed sensor, or a power sensor, and the relevant data can be detected and sent by those sensors 160. In examples, the motor speed sensor and the power sensor can relate to the first heat pump 106, the second heat pump 114, the first pump 146(1), and/or the second pump 146(2). In examples, the respective motor of the first heat pump 106, the second heat pump 114, the first pump 146(1), and/or
25 the second pump 146(2) is a variably controllable motor and the controller 150 can control the variably controllable motor. In examples, the controller 150 can be a dedicated computer or server on the premises, or can be a remote server such as a cloud server. In examples, functional elements of the controller 150 can be in the first heat pump 106 and/or the second heat pump 114, or other devices of the hydronic system 100.

[0044] In examples, as shown in Figure 1, the water or circulation fluid in the first load
30 circuit 110, the second source circuit 116, and the second load circuit 118 are in a fully

enclosed loop (closed loop) during operation of the hydronic system 100. Such an arrangement means that the water or circulation fluid is not exposed to outside contaminants, and does not mix with the potable water for the water consumption output 138.

5 [0045] In examples, the 3-way valves 144 are 3-way isolation diverter valves. The controller 150 is configured to change a state of a particular 3-way variable diverter valve to selectively provide a passage between two of the three ports of the particular 3-way diverter valve 144.

10 [0046] In other examples, the 3-way valves 144 are 3-way variable diverter valves. The controller 150 is configured to change a state of a particular 3-way variable diverter valve 144 to maintain a partial variable position of that 3-way isolation diverter valves 144. The partial variable position is another variable that can be optimized by the controller 150.

[0047] In some examples, not shown, the hydronic system 100 includes at least one or a plurality of further heat pumps with respective further 3-way valves 144 that can be
15 selectively controlled by the controller 150 so that at least one of the plurality of further heat pumps operates in a parallel or series configuration with the first heat pump 106 and/or the second heat pump 114.

[0048] In some examples, now shown, the controller 150 is further configured to co-ordinate control with other devices in the hydronic system 100 such as at least one plant
20 component, a microprocessor based device, or a sequence of controls.

[0049] Figure 2 illustrates the hydronic system 100 of Figure 1 in a mode of operation to provide supply from the space conditioner system 102 to the water supply system 104, in accordance with an example embodiment. Figure 2 illustrates how the controller 150 controls hydronic interconnections in the hydronic system 100 so as to provide a very
25 high supply temperature to the water storage 120 (e.g. for domestic water consumption). As shown in Figure 2, the first 3-way valve 144(1) is controlled to cause a passageway between the air to water heat pump 106 and the water to water heat pump 114, as between the first load output 130 and the second source input 140. As shown in Figure 2, the second 3-way valve 144(2) is controlled to cause a passageway between the first
30 load input 128 and the second source output 142. The mode of operation in Figure 2

illustrates the first heat pump 106 and the second heat pump 114 working in series operation to source the water storage 120.

[0050] Figure 3 illustrates the hydronic system 100 of Figure 1 in a mode of operation to provide supply from the water supply system 104 to the space conditioner system 102, in accordance with an example embodiment. Figure 3 illustrates how the controller 150 controls hydronic interconnections in the hydronic system 100 so as to permit high capacity or high efficiency operation of the space conditioner system 102, should it be determined that the hot water storage level in the water storage 120 will suffice. As shown in Figure 3, the third 3-way valve 144(3) is controlled to cause a passageway between the air to water heat pump 106 and the water to water heat pump 114, as between the second load output 134 and the first load output 130. As shown in Figure 3, the fourth 3-way valve 144(4) is controlled to cause a passageway between the first load input 128 and the second load input 132. The mode of operation in Figure 3 illustrates the first heat pump 106 and the second heat pump 114 working in parallel operation to source the hydronic coils 112 or other loads of the space conditioner system 102.

[0051] Therefore, the water to water heat pump 114 achieves a setpoint that uses less energy when compared to individual respective output of the air to water heat pump 106 and the water to water heat pump 114. Each of the air to water heat pump 106 and the water to water heat pump 114 can be selected so that they are operating at full capacity when needed or a majority of the time (or design day). Each of the air to water heat pump 106 and the water to water heat pump 114 can be turned off when not needed or when one of the air to water heat pump 106 and the water to water heat pump 114 can maintain the load of both the space conditioner system 102 and the water supply system 104. In an example, the setpoint is a parameter of at least one load, e.g. the hydronic coils 112 and/or the water consumption output 138. Examples of the setpoint include temperature of the hydronic coils 112 or temperature of a space to be sourced by the hydronic coils 112. Examples of the setpoint include temperature of the water consumption output 138 or a downstream load to be sourced by the water consumption output 138.

[0052] In some examples, additional control valves (not shown here) are used manage the flow rate to the hydronic coils 112. The control valves can be a 2-way valve. In an example, each 2-way valve may be used to manage the flow rate to each respective

hydraulic coil 112. As a valve opens, the differential pressure across the valve decreases. The controller 150 responds to this change by increasing the pump speed of the first heat pump 106 (or the first pump 146(1)) to achieve a specified output setpoint. If a control valve closes, the differential pressure across the valve increases, and the controller
5 responds to this change by decreasing the pump speed of the first heat pump 106 (or the first pump 146(1)) to achieve a specified output setpoint. A similar operation is performed by the controller 150 for the water supply system 104, which can have faucets or other valves.

[0053] In examples of the hydronic system 100, the ability by the controller 150 to assess
10 the real time load demand requirements based on the situation, whether base loading for heating or cooling, or extreme temperature loads (e.g., high temperatures for laundry, showers, or extreme weather situation) can be accommodated by altering the hydronic piping arrangement between the first heat pump 106 and the second heat pump 114 to achieve:

- 15 A. parallel configurations to a single load,
- B. independent configuration of a heat pump to two loads,
- C. heat pumps in parallel to a second load with the primary base heat pump serving the heating cooling load, and/or
- D. two or more heat pumps in full series configuration for one extreme load scenario
20 heating high temperature, or cooling low temperature.

[0054] In examples of the hydronic system 100, the ability by the controller 150 to sense the load scenarios and best response configuration from the flows, and temperatures of the external heat sinks and the load scenarios permits the deliver of heat or cooling services by two separate heat pump loops, that are hydraulically inter-connected to
25 provide better operating range of capacity, lift, temperature extremes, operating efficiency, with a lower total installed capacity than if they were not able to operate in an inter-connected fashion. The hydronic system 100 which can interconnect the first heat pump 106 and the second heat pump 114, of either the same refrigerant or different refrigerants, same or differing capacities, or in combination with other heat sources /
30 sinks, such as a data center, hydrogen power, a district energy system, thermal energy

storage tanks, ground source coils, waste water flows or any other possible heat source / sink permit better performance.

[0055] In examples of the hydronic system 100, the control method of the controller 150 is further enhanced when combined with performance parameterization for mapping the equipment and devices of the hydronic system 100.

[0056] In examples of the hydronic system 100, the control method of the controller 150 is further enhanced when combined with self learning optimization algorithms, model optimization and/or machine learning.

[0057] In some example embodiments, the controller 150 operates a control system for the hydronic system 100. The hydronic system 100 operates in a control loop to regularly optimize a model with respect at least one optimizable input variable based on the detected variables. The model provides prediction of input variable use in all possible operation points or paths of the system variables which achieve an output setpoint. In some example embodiments, the control loop is performed during initial setup and subsequent operation of the one or more operable elements in the operable system. In some example embodiments, the control system is self-learning in that at least some of the initial and subsequent parameters of the system are determined automatically during runtime, e.g., would not require manual configuration.

[0058] In examples, the hydronic system 100 can include a mode for heat recapture, for example heat from hot water return to the water storage 120.

[0059] In examples, the first heat pump 106 and the second heat pump 114 can service the same or different loads.

[0060] In examples, the first heat pump 106 and the second heat pump 114 can be either in the same or differing modes (e.g., heat or cooling).

[0061] In examples, the controller 150 includes, or controls, or obtains data from, the necessary 3-way valves 144, and sensors 160 (e.g. temperature sensors, flow and load indicating or their inherent calculation capabilities).

[0062] In examples, the controller 150 is configured to adjust the interconnecting hydronic circuit configuration of the hydronic system 100 in a transition mode not to disrupt the load side comfort, or cause harm to the heat pump refrigeration cycles of the first heat pump 106 and the second heat pump 114.

[0063] In examples, the hydronic system 100 incorporates and leverages the addition of storage tanks, e.g. water storage 120, for such uses as thermal energy storage, or domestic water.

5 [0064] In examples, the hydronic system 100 is able to incorporate and leverage the addition of ground source heat sinks or thermal storage.

[0065] In examples of the controller 150, the application of the automation logic, that performs the sequencing of the hydronic circuits of the hydronic system 100, e.g. the space conditioner system 102 and the water supply system 104, to optimally configure the first heat pump 106 and the second heat pump 114 and other plant components, and
10 can be performed manually, automatically, autonomously, or any operation methodology.

[0066] In examples, the hydronic system 100 is factory built, or is constructed by a third party, in a factory or at the premises (site), or at some other location.

[0067] In examples, any or all of the first heat pump 106, the second heat pump 114, the first pump 146(1), and/or the second pump 146(2) are so-called intelligent sensorless
15 pumps that can self regulate their own speed and communicate flow readings. Flow data respectively from the particular intelligent sensorless pump is used to determine the various system heating or cooling loads. The intelligent sensorless pumps can share their power consumption, speed and other important operating parameters to the controller 150 for the controller 150 to predict, model, and control the optimal operating
20 configuration and operating points.

[0068] In examples, the intelligent sensorless pumps do not require exterior sensor data. Intelligent sensorless control enables an intelligent sensorless pump to decrease or increase the motor speed to match system requirements without an external signal. In other words, intelligent sensorless pumps emulate the performance of a remotely
25 mounted sensor by pre-programming pump curve characteristics into the pump's integrated controls. One example of intelligent sensorless control is co-ordinating the intelligent sensorless pump's self-detected power and speed with the resultant flow and head in accordance with the system design of the hydronic system 100 for the particular premises. Two or more of the intelligent sensorless pumps can also operate in
30 conjunction, which can be denoted as co-ordinated sensorless or can be denoted as parallel sensorless, as applicable.

[0069] In examples, there are more or fewer pumps than the first pump 146(1) and/or the second pump 146(2) that are configured to cause circulation within the hydronic system 100. For example, not shown, the load output by the air to water heat exchanger 124 to the third load circuit 126 has a third pump (not shown).

5 [0070] The controller 150 can include a diagnostic technology utilization digital modelling, such as performance parameterization. In an example, the performance parameterization is learned at the site in field during operation to gather the operating base line data. In examples, that data is used to validate the system and apparatus performance. In examples, in real time the early data parameters can be set as the benchmark for
10 comparison of the future performance so as to detect performance degradation of the devices in the plant. In examples, the identification of digital performance degradation provides the ability to recommend service activities under the format of condition based maintenance.

[0071] In some examples, initial performance parameterization is performed on a device
15 after assembly of that device and before installation or maintenance of that devices within the hydronic system 100. An independent testing jig or testing rig can be used to test parameters of the device under a multiplicity of conditions in order to assess the performance parameterization.

[0072] The ability to have the first heat pump 106 and the second heat pump 114 with
20 available on-demand capacity can be used to assign multiple configurations (modes) to various scenarios can improve the operating efficiency of a single heat pump operation, and also potentially reduce the first heat pump 106 and the second heat pump 114 operating at on-off cycling at lower loads, through that fact that the size of the first heat pump 106 and the second heat pump 114 can be made smaller than if just one large heat
25 pump was assigned to serve all duty operations. By keeping independent of two refrigerant loops and avoiding cascading or other refrigerant circuit combinations, each of the first heat pump 106 and the second heat pump 114 are more resilient as they are not tied or dependent on the other for part or all of their ability to provide the temperature control service.

30 [0073] Figure 4 illustrates an example heat pump 400 to be used in the hydronic system 100 of Figure 1. An example of the heat pump 400 as illustrated is an air to liquid heat

pump (such as air to water heat pump 106 in Figure 1). A similar heat pump 400 can be used for a liquid to liquid heat pump (such as water to water heat pump 114 in Figure 1), with appropriate modifications. The heat pump 400 can be used to output temperature control to a circulation medium to provide one of heat or cold, as appropriate. In an example, the heat pump 400 can be reversed to cause the other of the cold or the heat to the circulation medium, as appropriate.

[0074] The heat pump 400 illustrated in Figure 4 includes a circulation medium such as a refrigerant, an evaporator 402, a compressor 404, a condenser 406, and an expansion valve 408. Air moving through the evaporator 402 picks up heat which is then transferred to the circulating refrigerant. The refrigerant, now vaporized, is compressed by the compressor 404, amplifying the heat of the refrigerant before the refrigerant reaches the condenser 406. The refrigerant releases heat to the surrounding water using a heat exchanger (not shown here). The condenser 406 condenses the refrigerant back to liquid to start the cycle again.

[0075] The heat pump 400 as a water to water heat pumps operates on a similar principle, but the water to water heat pumps extract heat from water sources instead of air. The heat pump 400 is effective in consistent temperature environments, such as geothermal or water-recirculating systems. The heat pump 400 is useful for settings where water is a more stable thermal reservoir than air, providing an efficient alternative for heating water in various conditions.

[0076] As understood in the art, the heat pump 400 can be reversed to provide cold water as load output, for example.

[0077] In another example, not shown, the heat pump 400 as an air to water heat pump includes: a liquid to liquid heat pump and a radiator interfacing with the air or ambient.

[0078] Referring to Figure 1, sensors 160 can be used by the controller 150 to determine parameters of the heat pump 400, such as motor power and motor speed of the respective motor. The sensors 160 can include, for the refrigerant, the input circulation medium, and/or the output circulation medium: a pressure sensor, a flow sensor, and/or temperature sensor. For examples, the sensors 160 can relate to input source circuits, output load circuits, and/or intermediary circuits (e.g. of the refrigerant circuit) of the heat pump 400.

[0079] Figure 5 illustrates a flow diagram of a method 500 by the controller 150 for controlling the hydronic system 100 of Figure 1 to the mode of operation of Figure 2. The method 500 includes, at step 502, the controller 150 controlling the first 3-way valve 144(1) to cause a passageway as between the first load output 130 and the second source input 140. At step 504, the controller 150 controls the second 3-way valve 144(2) to cause a passageway as between the first load input 128 and the second source output 142. Steps 502 and 504 can be performed concurrently. The respective passageways at steps 502 and 504 can also be closed by the controller 150 and reverted to the original passageways of the first 3-way valve 144(1) and the second 3-way valve 144(2), e.g. based on the particular requirements of the hydronic system 100 and to have the first heat pump 106 only source the first load output 130 (e.g. to the hydronic coils 112 in this example). The controller 150 reverts the hydronic system 150 to the original separate circuits when fulfilling excess demand to the first load output 130 is no longer required.

[0080] Figure 6 illustrates a flow diagram of a method 600 by the controller 150 for controlling the hydronic system 100 of Figure 1 to the mode of operation of Figure 3. The method 600 includes, at step 602, the controller 150 controlling the third 3-way valve 144(3) to cause a passageway as between the second load output 134 and the first load output 130. The method 600 includes, at step 604, the controller 150 controlling the fourth 3-way valve 144(4) to cause a passageway between the first load input 128 and the second load input 132. Steps 602 and 604 can be performed concurrently. The respective passageways at steps 602 and 604 can also be closed by the controller 150 and reverted to the original passageways of the third 3-way valve 144(3) and the fourth 3-way valve 144(4), e.g. based on the particular requirements of the hydronic system 100 and to have the second heat pump 114 only source the second load output 134 (e.g. to the water storage 120 in this example). The controller 150 reverts the hydronic system 150 to the original separate circuits when fulfilling excess demand to the second load output 134 (e.g. to the water storage 120 in this example) is no longer required.

[0081] In some examples, as applicable, the controller 150 can be configured to control the passageways defined by the 3-way valves 144 to partially open or partially closed passageways, as appropriate.

[0082] Figure 7 illustrates an example load profile 700 for a particular load of the hydronic system 100 of Figure 1, such as the flow load of the space conditioner system 102 (e.g. hydronic coils 112) or the flow load of the water supply system 104 (e.g. water consumption). In some examples, the load profile 700 can represent the total overall load for the entire premises or building for the hydronic system. In other examples, not shown here, there are separate load profiles 700 for the premises (building), such as a first load profile 700 that is set or settable for the first load output 130 and a second load profile 700 that is set or settable for the water consumption output 138.

[0083] An example of the load profile 700 is, for example, for a projected or measured “design day”. The load profile 700 illustrates the operating hours percentage versus the heating/cooling load percentage. For example, as shown, many example systems may require operation at only 0% to 60% load capacity 90% of the time or more. Accordingly, the particular pump can be selected or designed for the particular hydronic system 100 to operate at best or improved efficiency a majority of the time. Examples of the particular pump in the hydronic system 100 to be optimized include first heat pump 106, second heat pump 114, the first pump 146(1), and/or the second pump 146(2).

[0084] In some examples, the particular may be selected or designed for best efficiency operation at partial load, for example on or about 50% of peak load. Note that, ASHRAE 90.1 standard for energy savings requires control of devices that will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow (e.g. 70% energy savings at 50% of peak load). It is understood that the “design day” may not be limited to 24 hours, but can be determined for shorter or long system periods, such as one month, one year, or multiple years.

[0085] In an example, for example in view of the load profile 700, a first maximum capacity of the first heat pump 106 or the first pump 146(1) is selected or designed to be at most 60% of a first full load or a first design point of the first load circuit 110. In another example, the first maximum capacity is between 40%-60% of the first full load or the first design point, or in another example is on or about 50%. In an example, the design point is the maximum pressure (taking into account temperature and/or flow) required by the load, e.g. the hydronic coils 112 for the first load circuit 110.

[0086] In an example, a second maximum capacity of the second heat pump 114 or the second pump 146(2) is selected or designed to be at most 60% of a second full load or a second design point of the second load circuit 118 or the water consumption circuit 122. In another example, the second maximum capacity is between 40%-60%, or in another example is on or about 50%. In an example, the design point is the maximum pressure (taking into account temperature and/or flow) required by the load, e.g. the water consumption circuit 122.

[0087] Therefore, the first heat pump 106 or the first pump 146(1) can be selected or designed to be at close to maximum capacity a majority of the time, which is more efficient than have having excess capacity. Referring to Figure 3, as more demand is required by the first load circuit 110 beyond the maximum capacity of the first heat pump 106 or the first pump 146(1), the second heat pump 114 (and/or the second pump 146(2)) can be controlled and co-ordinated by the controller 150 to fulfill the remaining demand by activating the applicable settings of the third 3-way valve 144(3) and the fourth 3-way valve 144(4).

[0088] Similarly therefore, the second heat pump 114 or the first pump 146(2) can be selected or designed to be at close to maximum capacity a majority of the time, which is more efficient than have having excess capacity. Referring to Figure 2, as more demand is required by the water consumption circuit 122 beyond the maximum capacity of the second heat pump 114 or the second pump 146(2), the first heat pump 106 (and/or the second pump 146(2)) can be controlled and co-ordinated by the controller 150 to fulfill the remaining demand by activating the applicable settings of the first 3-way valve 144(1) and the second 3-way valve 144(2).

[0089] In an example, the controller 150 or another device includes a graphical interface which can be used to configure or adjust the load profile 700.

[0090] In an example, the controller 150 or another device determines or adjusts the load profile 700 based on real-time operation of the premises (building) and/or using a testing jig or testing rig.

[0091] Further, or in the alternative, not shown, another example of the load profile 700 for the premises (building) is a temperature load profile 700. In examples, the temperature load can be the heating load, or the cooling load, either combined on the same

temperature load profile 700 or as separate load profiles. In examples, there are separate load profiles 700 for the premises (building), such as a first load profile 700 for temperature that is set or settable for the first load output 130 of the space conditioner system 102 and a second load profile 700 for temperature that is set or settable for the water consumption output 138 of the water supply system 104.

[0092] Figure 8 illustrates an example control system 800 operated by the controller 150 for the hydronic system 100 of Figure 1, in accordance with an example embodiment. Generally, in the control system 800, outputs 810 and inputs including optimizable inputs 804 are measured and an estimation method 806 or algorithm is updated or adjusted for the particular requirements of the premises. In some example embodiments, the control system 800 includes continuous feedback loop(s) which operate during initial setup as well as indefinite runtime of the hydronic system 100 (continuously or at discrete times). In some example embodiments, no or little prior knowledge of the hydronic system 100 is required. Rather, the control system 800 initiates, controls and adapts its performance and control models based on self-learning of the controller 150.

[0093] The hydronic system 100 produces certain output(s) 810 characterized by one of more variables (e.g. flow, temperature, viscosity, thickness, speed, thermal energy, items per minute, distance, etc.), composed of several parts whose operation points/path can be characterized by a finite number of continuous or discrete variables (e.g. speed, temperature, power, run status, rpm, mode of operation, gear, breaks position, etc.).

[0094] These continuous or discrete variables work together to produce the output(s) 810 of the hydronic system 100 and interact in such a way that the operation point/path of one output variable determines or restricts the operation points of the other output variables. There may also be restrictions to the operation of each part, i.e., limited range(s) for the values its operation point characterizing variable(s) can take. These continuous or discrete variables variable(s) may include device properties of controllable operable element(s), e.g. a respective pump motor of the first heat pump 106, the first pump 146(1), the second heat pump 114, and/or the second pump 146(2). The output(s) 810 can be used by the controller 150 to control one or more of the 3-way valves 144, which can each be a 3-way isolation diverter valve or a 3-way variable diverter valve. A respective valve(s) (not shown) for each hydronic coil 112 can also be controlled by the output(s) 810.

[0095] The hydronic system 100 includes input variable(s), which may include non-controllable variable(s) 814 which are externally determined and cannot be controlled (e.g. outdoor temperature, commodities prices, output demand, etc.), that affect the operation of the system parts or should be taken into account when deciding how to operate the hydronic system 100 efficiently. The hydronic system 100 includes input variables such as optimizable input(s) 804 which can be optimized. Example optimizable input(s) 804 may be consumable inputs, e.g., energy, chemicals, water, money or time. Other input variables 824 may also be input into the hydronic system 100. As shown, the input variables can be measured using a measurement module 808 from the sensor(s) 160 in order to adjust a parameter of, determine, or calculate the appropriate model by the model adjust module 820. Various input variables can include consumable inputs (energy, chemicals, etc.) or other inputs (outdoor temperature, demand, speed, line voltage, etc.).

[0096] In the hydronic system 100, there is more than one operation point or path that can give a desired output 810. The control system 800 is configured to produce the required output 810 (to satisfy the output demand) optimizing the use of one or more of the optimizable inputs 804 required to produce that output 810.

[0097] In some example embodiments, the controller 150 determines a method or model for each part of the hydronic system 100, such as e.g. formula(s), table(s), vector(s), matrix(es), machine learning model(s), or algorithm, to predict the amount the hydronic system 100 uses the optimizable inputs 804, for all the points of operation in its allowed range. An optimum point/path 812 is then determined and updated by the estimation method 806.

[0098] The system operation point or system status 822 is given by all of the characterizing variables of the system parts, reduced by the restrictions imposed by the interaction or interconnection of the variables, and limited in range by the parts operational restrictions.

[0099] For each system allowed operation point, the amount of optimizable inputs 804 the hydronic system 100 would consume can be calculated as the sum of the amounts consumed by each of its parts. The system controllable variables are its characterizing variables minus those externally determined non-controllable variable(s) 814.

[00100] As shown in Figure 8, in example embodiments, given the non-controllable variable(s) 814 (the conditions in which the system has to work), the optimization module 816 uses the estimation method 806 to find an optimal point/path 812 compatible with the given conditions, then the devices of the hydronic system 100 are commanded by the controller 150 to operate at that point or follow that path.

[00101] The use of input variables including the optimizable input(s) 804 is measured and the estimation method 806 is updated using the model adjust module 820 to make its prediction for the reported system status 822 closer to the use or consumption measured by measurement module 808 of the optimizable inputs 804.

[00102] In examples, the optimization module 816, controller 150 and measurement module 808 can reside in one or more devices, or be embedded in the controller 150, in various example embodiments. In some example embodiment, the optimization method by the optimization module 816 can be executed upfront, by a microprocessor device or the controller 150. A particular model or method can then be subsequently selected from a set of predetermined models or methods which best optimizes the optimum point/path 812.

[00103] Accordingly, the control system 800 controls the hydronic system 100, to produce the desired output(s) 810 while optimizing the use of one or more optimizable input(s) 804 by dynamically determining an optimization using the optimization module 816 to predict the amount of the optimizable input(s) 804 used at each possible operation point or path (e.g. operation trajectory in time) that produces the desired output(s) 810, then finding the optimal point/path 812, and finally commanding the controllable variables and optimizable inputs 804 to achieve said trajectory to the optimal point/path 812.

[00104] In some example embodiments, rather than through the measurements module 808, the use of the optimizable inputs is estimated using explicit analytical formulas. In some example embodiments, the system's optimizable inputs use is estimated using numerical tables.

[00105] In some example embodiments, the optimizable inputs of the estimation module 806 or formulae is simple enough that they allow solving analytically the optimization and obtaining explicit formulas, parametric in the output(s) 810 and non-

controllable variables 814, to command the controllable variables and optimizable inputs 804.

[00106] In some example embodiments, the optimization module 816 is numerically solved upfront, thus resulting in numerical table(s) and/or explicit formulas to command
5 the controllable variables and optimizable inputs 804.

[00107] In some example embodiments, the optimization module 816 is performed by a microprocessor based device executing software while the system is running, and for the particular non-controllable conditions the optimization module 816 is encountering.

[00108] In some example embodiments, the estimation module 806 or formulas
10 have tuning parameters and these and/or the values in the table(s) are periodically adjusted based on the actual use of optimizable inputs measured. A system test can be implemented at specified times to eliminate some variables to increase the accuracy of the estimation module 806.

[00109] Referring to Figure 1, an example embodiment is a method for capturing
15 and mapping equipment performance data of at least one or a plurality of devices for operating in the hydronic system 100. In an example, the method includes: determining, in relation to testing performed on the device, model values of a performance parameter of the device over an operating range of at least two operating parameters which affect the performance parameter, wherein each model value is representative of an operating
20 point of the at least two operating parameters; storing to memory the determined model values of the performance parameter along with a time of said determining; and comparing, when the device is installed in the system, detected numerical properties of the performance parameter of the device, with respect to the at least two operating parameters, with the stored determined model values of the performance parameter. The
25 controller 150 can determine or receive the performance parameters.

[00110] Regarding the equipment performance data (e.g. equipment performance maps), in an example embodiment, n-dimensional operating parameters may be used to characterize a featured performance parameter of the mechanical item while operating. Given a set of n-parameter coordinates, the map demarcates the expected utilization of
30 the featured performance parameter for the piece of equipment.

[00111] The performance maps can be generated at the time of factory testing prior to shipment, post manufacturing. Performance of each device is compared to the maps in real-time, subsequent to installation. In this way, diagnostics, monitoring, and performance verification processes can easily detect degradation in performance for the device, and trigger remedial responses from local or remote operations managers before catastrophic failures can occur, or wasted energy consumption can accrue.

[00112] In some example embodiments, a performance parameter of each device performance is modeled by way of model values. In some example embodiments, the model values are discrete values that can be stored in a table, map, database, tuple, vector or multi-parameter computer variables. In some other example embodiments, the model values are values of the performance parameter (e.g. the standard unit of measurement for that particular performance parameter, such as in Imperial or SI metric).

[00113] In some example embodiments, the model values are coefficients for the performance parameter. The equipment coefficients are used to prescribe the behavioral responses of the individual units within each equipment group category. Each individual unit within each equipment category can individually be modeled by ascribing each coefficient corresponding to a specific set of operating conditions that transcribe the behavioral parameter in question. The equipment coefficients can be used for direct comparison or as part of one or more equations to model the behavioral parameter. It can be appreciated that individual units can have varied individual behavior parameters, and can be individually modeled and monitored in accordance with example embodiments.

[00114] Mathematical models prescribing mechanical equipment efficiency performance have constants and coefficients which parameterize the equations. Specifying these coefficients at the time of manufacturing, and tracking their ability to accurately predict real-time performance through the life-cycle of the mechanical item allows for preventative maintenance, fault detection, installation and commissioning verification, as well as energy performance or fluid consumption performance benchmarking and long term monitoring.

[00115] In an example embodiment, control schemes dependent on coefficient based plant modeling architectures can be configured to optimize energy consumption or fluid consumption of individual equipment, or the system as a whole, and monitored over

the life-cycle of equipment comprising the central cooling plant. These energy control coefficients can subsequently be adjusted as building, plant, and outdoor environment conditions change over time.

[00116] Variations may be made in example embodiments. The relationship
5 between parameters may be approximated by particular affinity laws, which may be affected by volume, pressure, and Brake Horsepower (BHP). For example, for variations in impeller diameter, at constant speed: $D1/D2 = Q1/Q2$; $H1/H2 = D1^2/D2^2$; $BHP1/BHP2 = D1^3/D2^3$. For example, for variations in speed, with constant impeller diameter: $S1/S2 = Q1/Q2$; $H1/H2 = S1^2/S2^2$; $BHP1/BHP2 = S1^3/S2^3$. Wherein: D = Impeller Diameter (Ins
10 / mm); H = Pump Head (Ft / m); Q = Pump Capacity (gpm / lps); S = Speed (rpm / rps); BHP = Brake Horsepower (Shaft Power - hp / kW).

[00117] Some example embodiments may be applied to any variable speed device, and not limited to variable speed control pumps. For example, some additional embodiments may use different parameters or variables, and may use more than two
15 parameters (e.g. three parameters on a three dimensional graph). For example, the speed (rpm) is also illustrated on the described control curves. Further, temperature (Fahrenheit or Celsius) versus temperature load (BTU/hr or Joule/hr) may be parameters or variables which are considered for control curves, for example for variable temperature control which can be controlled by a variable speed circulating fan. Some example
20 embodiments may be applied to any devices which are dependent on two or more correlated parameters. Some example embodiments can include variables dependent on parameters or variables such as liquid, temperature, viscosity, suction pressure, site elevation and number of pump operating.

[00118] In examples, the controller 150 can be a processor, which can be a general
25 central processing unit (Central Processing Unit, CPU), a microprocessor, an application-specific integrated circuit (Application Specific Integrated Circuit, ASIC), a graphics processing unit (graphics processing unit, GPU), or one or more integrated circuits.

[00119] In addition, the processor may be an integrated circuit chip with a signal processing capability. In an implementation process, steps of the method of site
30 optimization as described herein can be performed by an integrated logical circuit in a form of hardware or by an instruction in a form of software in the processor. In addition,

the processor can be a general purpose processor, a digital signal processor (Digital Signal Processor, DSP), an application-specific integrated circuit (ASIC), a field programmable gate array (Field Programmable Gate Array, FPGA) or another programmable logic device, a discrete gate or a transistor logic device, or a discrete hardware assembly. The processor can implement or execute the methods, steps, and logical block diagrams that are described in example embodiments. The general purpose processor can be a microprocessor, or the processor may be any conventional processor or the like. The steps of the method disclosed with reference to the example embodiments may be directly performed by a hardware decoding processor, or may be performed by using a combination of hardware in the decoding processor and a software module. The software module may be located in a mature storage medium in the art, such as a random access memory, a flash memory, a read-only memory, a programmable read-only memory, an electrically erasable programmable memory, or a register.

[00120] In example embodiments, as appropriate, each illustrated block or module may represent software, hardware, or a combination of hardware and software. Further, some of the blocks or modules may be combined in other example embodiments, and more or less blocks or modules may be present in other example embodiments. Furthermore, some of the blocks or modules may be separated into a number of sub-blocks or sub-modules in other embodiments.

[00121] While some of the present embodiments are described in terms of methods, a person of ordinary skill in the art will understand that present embodiments are also directed to various apparatus such as a server apparatus including components for performing at least some of the aspects and features of the described methods, be it by way of hardware components, software or any combination of the two, or in any other manner. Moreover, an article of manufacture for use with the apparatus, such as a pre-recorded storage device or other similar non-transitory computer readable medium including program instructions recorded thereon, or a computer data signal carrying computer readable program instructions may direct an apparatus to facilitate the practice of the described methods. It is understood that such apparatus, articles of manufacture, and computer data signals also come within the scope of the present example embodiments.

[00122] While some of the above examples have been described as occurring in a particular order, it will be appreciated to persons skilled in the art that some of the messages or steps or processes may be performed in a different order provided that the result of the changed order of any given step will not prevent or impair the occurrence of subsequent steps. Furthermore, some of the messages or steps described above may be removed or combined in other embodiments, and some of the messages or steps described above may be separated into a number of sub-messages or sub-steps in other embodiments. Even further, some or all of the steps of the conversations may be repeated, as necessary. Elements described as methods or steps similarly apply to systems or subcomponents, and vice-versa.

[00123] The term "computer readable medium" as used herein includes any medium which can store instructions, program steps, or the like, for use by or execution by a computer or other computing device (e.g. processor, microprocessor) including, but not limited to: magnetic media, such as a diskette, a disk drive, a magnetic drum, a magneto-optical disk, a magnetic tape, a magnetic core memory, or the like; electronic storage, such as a random access memory (RAM) of any type including static RAM, dynamic RAM, synchronous dynamic RAM (SDRAM), a read-only memory (ROM), a programmable-read-only memory of any type including PROM, EPROM, EEPROM, FLASH, EAROM, a so-called "solid state disk", other electronic storage of any type including a charge-coupled device (CCD), or magnetic bubble memory, a portable electronic data-carrying card of any type including COMPACT FLASH, SECURE DIGITAL (SD-CARD), MEMORY STICK, and the like; and optical media such as a Compact Disc (CD), Digital Versatile Disc (DVD) or BLU-RAY Disc.

[00124] An example embodiment is a hydronic system, comprising: an air to liquid heat pump interfacing with a first source circuit to air and hydronically connected to a first load circuit having a first load input and a first load output; at least one hydronic coil hydronically connected to the first load circuit; a liquid to liquid heat pump interfacing with a second source circuit having a second source input and a second source output and hydronically connected to a second load circuit having a second load input and a second load output; a water storage hydronically connected to the second load circuit, and hydronically connected to a water consumption circuit having a water supply input and a

water consumption output; at least one 3-way valve which hydronically connects the air to liquid heat pump to the liquid to liquid heat pump; and at least one controller configured to co-ordinate control of the at least one 3-way valve, the air to liquid heat pump, and the liquid to liquid heat pump.

5 [00125] In another example embodiment of the hydronic system of any of the above, the hydronic system further comprises at least one sensor to provide sensor data of the hydronic system, wherein the co-ordinate control is based on the sensor data.

[00126] In another example embodiment of the hydronic system of any of the above, the at least one sensor includes at least one of a pressure sensor, a flow sensor, a
10 temperature sensor, a pump motor speed sensor, or a power sensor.

[00127] In another example embodiment of the hydronic system of any of the above, the at least one sensor is configured to respectively detect a property of the air to liquid heat pump and/or the liquid to liquid heat pump.

[00128] In another example embodiment of the hydronic system of any of the above,
15 the co-ordinate control includes controlling the at least one 3-way valve, the air to liquid heat pump, and the liquid to liquid heat pump to achieve a setpoint that is beyond an individual respective capacity of the air to liquid heat pump to the first load circuit or the liquid to liquid heat pump to the second load circuit.

[00129] In another example embodiment of the hydronic system of any of the above,
20 the co-ordinate control includes controlling the at least one 3-way valve, the air to liquid heat pump, and the liquid to liquid heat pump that uses less energy when compared to individual respective output of the air to liquid heat pump to the first load circuit or the liquid to liquid heat pump to the second load circuit.

[00130] In another example embodiment of the hydronic system of any of the above,
25 a first maximum capacity of the air to liquid heat pump is at most 60% of a first full load or a first design point of the first load circuit, and/or wherein a second maximum capacity of the liquid to liquid heat pump at most than 60% of a second full load or a second design point of the second load circuit.

[00131] In another example embodiment of the hydronic system of any of the above,
30 the co-ordinate control includes controlling the at least one 3-way valve to configure the air to liquid heat pump and the liquid to liquid heat pump in parallel operation.

[00132] In another example embodiment of the hydronic system of any of the above, the co-ordinate control includes controlling the at least one 3-way valve to configure the air to liquid heat pump and the liquid to liquid heat pump in series operation.

5 [00133] In another example embodiment of the hydronic system of any of the above, the hydronic system further comprises at least one further heat pump and a respective 3-way valve for the at least one further heat pump, wherein the co-ordinate control includes controlling the respective 3-way valve to cause the at least one further heat pump to be in parallel and/or series operation with the air to liquid heat pump and/or the liquid to liquid heat pump.

10 [00134] In another example embodiment of the hydronic system of any of the above, the at least one 3-way valve includes: a first 3-way valve which hydronically connects the first load output of the first load circuit to the second source input of the second source circuit; a second 3-way valve which hydronically connects the first load input of the first load circuit to the second source output of the second source circuit; a third 3-way valve
15 which hydronically connects the first load output of the first load circuit to the second load output of the second load circuit; and a fourth 3-way valve which hydronically connects the first load input of the first load circuit to the second load input of the second load circuit.

[00135] In another example embodiment of the hydronic system of any of the above,
20 the co-ordinate control includes changing a state of the at least one 3-way valve during sourcing to the first load circuit or to the second load circuit.

[00136] In another example embodiment of the hydronic system of any of the above, the hydronic system further includes water or circulation fluid in the first load circuit, the second source circuit, and the second load circuit which is in a fully enclosed loop.

25 [00137] In another example embodiment of the hydronic system of any of the above, at least one of the 3-way valves is a 3-way isolation diverter valve.

[00138] In another example embodiment of the hydronic system of any of the above, at least one of the 3-way valves is a 3-way variable diverter valve, wherein the at least one controller is configured to change a state of the 3-way variable diverter valve to
30 maintain a partial variable position.

[00139] In another example embodiment of the hydronic system of any of the above, the hydronic system further includes a first variable pump at the first load circuit and a second variable pump at the second load circuit.

5 [00140] In another example embodiment of the hydronic system of any of the above, the first variable pump is integrated with the air to liquid heat pump during factory assembly or onsite, or wherein the second variable pump is integrated with the liquid to liquid heat pump during the factory assembly or the onsite.

10 [00141] In another example embodiment of the hydronic system of any of the above, a first maximum capacity of the first variable pump at most 60% of a first full load or a first design point of the first load circuit, and/or wherein a second maximum capacity of the second variable pump is at most 60% of a second full load or a second design point of the second load circuit.

[00142] In another example embodiment of the hydronic system of any of the above, the water storage is a tank water heater.

15 [00143] In another example embodiment of the hydronic system of any of the above, the hydronic system further includes an air to liquid heat exchanger interfacing with a third source circuit to the air and hydronically connected to a third load circuit which is hydronically connected to the second source circuit.

20 [00144] In another example embodiment of the hydronic system of any of the above, the air to liquid heat exchanger includes a radiator interfacing with the air.

[00145] In another example embodiment of the hydronic system of any of the above, the co-ordinate control includes further controlling at least one plant component, a microprocessor based device, or a sequence of controls.

25 [00146] In another example embodiment of the hydronic system of any of the above, the air to liquid heat pump and the liquid to liquid heat pump is controlled by the at least one controller to operate in a heating mode or a cooling mode.

30 [00147] Another example embodiment is a hydronic system, comprising: a first heat pump interfacing with a first source circuit having a first source input and a first source output and hydronically connected to a first load circuit having a first load input and a first load output; a second heat pump interfacing with a second source circuit having a second source input and a second source output and hydronically connected to a second load

circuit having a second load input and a second load output; a plurality of 3-way valves, including: a first 3-way valve which hydronically connects the first load output of the first load circuit to the second source input of the second source circuit, a second 3-way valve which hydronically connects the first load input of the first load circuit to the second source output of the second source circuit, a third 3-way valve which hydronically connects the first load output of the first load circuit to the second load output of the second load circuit, and a fourth 3-way valve which hydronically connects the first load input of the first load circuit to the second load input of the second load circuit; and at least one controller configured to co-ordinate control of the plurality of 3-way valves, the first heat pump, and the second heat pump.

[00148] In another example embodiment of the hydronic system of any of the above, the first heat pump is an air to liquid heat pump.

[00149] In another example embodiment of the hydronic system of any of the above, the first source circuit is to air or ambient.

[00150] In another example embodiment of the hydronic system of any of the above, the second heat pump is a liquid to liquid heat pump.

[00151] In another example embodiment of the hydronic system of any of the above, the hydronic system further includes an air to liquid heat exchanger interfacing with a third source circuit to air or ambient and hydronically connected to a third load circuit to the second source circuit.

[00152] In another example embodiment of the hydronic system of any of the above, the hydronic system further includes at least one sensor to provide sensor data of the hydronic system, wherein the co-ordinate control is based on the sensor data.

[00153] In another example embodiment of the hydronic system of any of the above, the at least one sensor includes at least one of a pressure sensor, a flow sensor, a temperature sensor, a pump motor speed sensor, or a power sensor.

[00154] In another example embodiment of the hydronic system of any of the above, the at least one sensor respectively is configured to respectively detect a property of the first heat pump and/or the second heat pump.

[00155] In another example embodiment of the hydronic system of any of the above, the co-ordinate control includes controlling the plurality of 3-way valves, the first heat

pump, and the second heat pump to achieve a setpoint that is beyond an individual respective capacity of the first heat pump to the first load circuit or the second heat pump to the second load circuit.

[00156] In another example embodiment of the hydronic system of any of the above,
5 the co-ordinate control includes controlling the plurality of 3-way valves, the first heat pump, and the second heat pump that uses less energy when compared to individual respective output of the first heat pump to the first load circuit or the second heat pump to the second load circuit.

[00157] In another example embodiment of the hydronic system of any of the above,
10 a first maximum capacity of the first heat pump at most 60% of a first full load or a first design point of the first load circuit, and/or wherein a second maximum capacity of the second heat pump is at most 60% of a second full load or a second design point of the second load circuit.

[00158] In another example embodiment of the hydronic system of any of the above,
15 the co-ordinate control includes controlling the plurality of 3-way valves to configure the first heat pump and the second heat pump in parallel operation.

[00159] In another example embodiment of the hydronic system of any of the above, the co-ordinate control includes controlling the plurality of 3-way valves to configure the first heat pump and the second heat pump in series operation.

20 [00160] In another example embodiment of the hydronic system of any of the above, the hydronic system further comprises at least one further heat pump and a respective 3-way valve for the at least one further heat pump, wherein the co-ordinate control includes controlling the respective 3-way valve to cause the at least one further heat pump to be in parallel and/or series operation with the first heat pump and/or the second heat pump.

25 [00161] In another example embodiment of the hydronic system of any of the above, the co-ordinate control includes changing a state of at least one of the 3-way valves during sourcing to the first load circuit or to the second load circuit.

[00162] In another example embodiment of the hydronic system of any of the above, the hydronic system further includes water or circulation fluid in the first load circuit, the
30 second source circuit, and the second load circuit which is in a fully enclosed loop.

[00163] In another example embodiment of the hydronic system of any of the above, at least one of the 3-way valves is a 3-way isolation diverter valve.

5 [00164] In another example embodiment of the hydronic system of any of the above, at least one of the 3-way valves is a 3-way variable diverter valve, wherein the at least one controller is configured to change a state of the 3-way variable diverter valve to maintain a partial variable position.

[00165] In another example embodiment of the hydronic system of any of the above, the hydronic system further includes a first variable pump at the first load circuit and a second variable pump at the second load circuit.

10 [00166] In another example embodiment of the hydronic system of any of the above, the first variable pump is integrated with the first heat pump during factory assembly or onsite, or wherein the second variable pump is integrated with the second heat pump during the factory assembly or the onsite.

[00167] In another example embodiment of the hydronic system of any of the above, 15 a first maximum capacity of the first variable pump at most 60% of a first full load or a first design point of the first load circuit, and wherein a second maximum capacity of the second variable pump is at most 60% of a second full load or a second design point of the second load circuit.

[00168] In another example embodiment of the hydronic system of any of the above, 20 the co-ordinate control includes further controlling at least one plant component, a microprocessor based device, or a sequence of controls.

[00169] In another example embodiment of the hydronic system of any of the above, the first heat pump and the second heat pump is controlled by the at least one controller to operate in a heating mode or a cooling mode.

25 [00170] In another example embodiment of the hydronic system of any of the above, the first source circuit or the second source circuit is thermally coupled to a cooling source, wherein the cooling source comprises a ground source heat sink, a cooling tower, or natural water.

[00171] In another example embodiment of the hydronic system of any of the above, 30 the first source circuit or the second source circuit is thermally coupled to a heat source,

wherein the heat source comprises a data center, hydrogen power, a district energy system, thermal energy storage, geothermal, a boiler, thermal solar, or waste water.

[00172] In another example embodiment of the hydronic system of any of the above, the hydronic system further includes a water storage hydronically connected to the
5 second load circuit, and hydronically connected to a water consumption circuit having a water supply input and a water consumption output.

[00173] Another example embodiment is method of controlling the hydronic system of any of the above, comprising changing a state of at least one of the 3-way valves.

[00174] In another example embodiment of the method, the changing the state
10 includes causing a respective passageway between the air to liquid heat pump and the liquid to liquid heat pump as between the first load output and the second source input and as between the first load input and the second source output.

[00175] In another example embodiment of the method, the changing the state includes causing a respective passageway between the air to liquid heat pump and the
15 liquid to liquid heat pump as between the second load output and the first load output and as between the first load input and the second load input.

[00176] Another example embodiment is a non-transitory computer readable medium comprising instructions which, when executed by at least one controller, cause the at least one controller to perform any of the above methods.

[00177] Variations may be made to some example embodiments, which may include
20 combinations and sub-combinations of any of the above. The various embodiments presented above are merely examples and are in no way meant to limit the scope of the example embodiments. Variations of the innovations described herein will be apparent to persons of ordinary skill in the art having the benefit of the present example
25 embodiments, such variations being within the intended scope. In particular, features from one or more of the above-described embodiments may be selected to create alternative embodiments comprised of a sub-combination of features which may not be explicitly described above. In addition, features from one or more of the above-described
30 embodiments may be selected and combined to create alternative embodiments comprised of a combination of features which may not be explicitly described above. Features suitable for such combinations and sub-combinations would be readily

apparent to persons skilled in the art upon review of the example embodiments as a whole. The subject matter described herein intends to cover all suitable changes in technology.

WHAT IS CLAIMED IS:

1. A hydronic system, comprising:
an air to liquid heat pump interfacing with a first source circuit to air and
5 hydronically connected to a first load circuit having a first load input and a
 first load output;
at least one hydronic coil hydronically connected to the first load circuit;
a liquid to liquid heat pump interfacing with a second source circuit having a
 second source input and a second source output and hydronically
10 connected to a second load circuit having a second load input and a
 second load output;
a water storage hydronically connected to the second load circuit, and
 hydronically connected to a water consumption circuit having a water
 supply input and a water consumption output;
15 at least one 3-way valve which hydronically connects the air to liquid heat pump
to the liquid to liquid heat pump; and
 at least one controller configured to co-ordinate control of the at least one 3-way
valve, the air to liquid heat pump, and the liquid to liquid heat pump.
- 20 2. The hydronic system as claimed in claim 1, further comprising at least one
sensor to provide sensor data of the hydronic system, wherein the co-ordinate control is
based on the sensor data.
3. The hydronic system as claimed in claim 2, wherein the at least one sensor
25 includes at least one of a pressure sensor, a flow sensor, a temperature sensor, a pump
motor speed sensor, or a power sensor.
4. The hydronic system as claimed in claim 2, wherein the at least one sensor is
configured to respectively detect a property of the air to liquid heat pump and/or the
30 liquid to liquid heat pump.

5. The hydronic system as claimed in claim 1, wherein the co-ordinate control includes controlling the at least one 3-way valve, the air to liquid heat pump, and the liquid to liquid heat pump to achieve a setpoint that is beyond an individual respective capacity of the air to liquid heat pump to the first load circuit or the liquid to liquid heat pump to the second load circuit.
6. The hydronic system as claimed in claim 1, wherein the co-ordinate control includes controlling the at least one 3-way valve, the air to liquid heat pump, and the liquid to liquid heat pump that uses less energy when compared to individual respective output of the air to liquid heat pump to the first load circuit or the liquid to liquid heat pump to the second load circuit.
7. The hydronic system as claimed in claim 1, wherein a first maximum capacity of the air to liquid heat pump is at most 60% of a first full load or a first design point of the first load circuit, and/or wherein a second maximum capacity of the liquid to liquid heat pump is at most 60% of a second full load or a second design point of the second load circuit.
8. The hydronic system as claimed in claim 1, wherein the co-ordinate control includes controlling the at least one 3-way valve to configure the air to liquid heat pump and the liquid to liquid heat pump in parallel operation.
9. The hydronic system as claimed in claim 1, wherein the co-ordinate control includes controlling the at least one 3-way valve to configure the air to liquid heat pump and the liquid to liquid heat pump in series operation.
10. The hydronic system as claimed in claim 1, further comprising at least one further heat pump and a respective further 3-way valve for the at least one further heat pump, wherein the co-ordinate control includes controlling the respective further 3-way valve to cause the at least one further heat pump to be in parallel and/or series operation with the air to liquid heat pump and/or the liquid to liquid heat pump.

11. The hydronic system as claimed in claim 1, wherein the at least one 3-way valve includes:

a first 3-way valve which hydronically connects the first load output of the first load circuit to the second source input of the second source circuit;

5 a second 3-way valve which hydronically connects the first load input of the first load circuit to the second source output of the second source circuit;

a third 3-way valve which hydronically connects the first load output of the first load circuit to the second load output of the second load circuit; and

10 a fourth 3-way valve which hydronically connects the first load input of the first load circuit to the second load input of the second load circuit.

12. The hydronic system as claimed in claim 11, wherein the co-ordinate control includes changing a state of the at least one 3-way valve during sourcing to the first load circuit or to the second load circuit.

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13. The hydronic system as claimed in claim 1, further comprising water or circulation fluid in the first load circuit, the second source circuit, and the second load circuit which is in a fully enclosed loop.

20 14. The hydronic system as claimed in claim 1, wherein at least one of the 3-way valves is a 3-way isolation diverter valve.

15. The hydronic system as claimed in claim 1, wherein at least one of the 3-way valves is a 3-way variable diverter valve, wherein the at least one controller is
25 configured to change a state of the 3-way variable diverter valve to maintain a partial variable position.

16. The hydronic system as claimed in claim 1, further comprising a first variable pump at the first load circuit and a second variable pump at the second load circuit.

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17. The hydronic system as claimed in claim 16, wherein the first variable pump is integrated with the air to liquid heat pump during factory assembly or onsite, or wherein the second variable pump is integrated with the liquid to liquid heat pump during the factory assembly or the onsite.

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18. The hydronic system as claimed in claim 16, wherein a first maximum capacity of the first variable pump at most 60% of a first full load or a first design point of the first load circuit, and/or wherein a second maximum capacity of the second variable pump is at most 60% of a second full load or a second design point of the second load circuit.

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19. The hydronic system as claimed in claim 1, wherein the water storage is a tank water heater.

20. The hydronic system as claimed in claim 1, further comprising an air to liquid heat exchanger interfacing with a third source circuit to the air and hydronically connected to a third load circuit which is hydronically connected to the second source circuit.

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21. The hydronic system as claimed in claim 20, wherein the air to liquid heat exchanger includes a radiator interfacing with the air.

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22. The hydronic system as claimed in claim 1, wherein the co-ordinate control includes further controlling at least one plant component, a microprocessor based device, or a sequence of controls.

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23. The hydronic system as claimed in claim 1, wherein the air to liquid heat pump and the liquid to liquid heat pump is controlled by the at least one controller to operate in a heating mode or a cooling mode.

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24. The hydronic system as claimed in claim 1, wherein the air to liquid heat pump includes a second liquid to liquid heat pump and a radiator interfacing with the first source circuit to the air.

25. A hydronic system, comprising:
- 5 a first heat pump interfacing with a first source circuit having a first source input and a first source output and hydronically connected to a first load circuit having a first load input and a first load output;
- a second heat pump interfacing with a second source circuit having a second source input and a second source output and hydronically connected to a second load circuit having a second load input and a second load output;
- 10 a plurality of 3-way valves, including:
- a first 3-way valve which hydronically connects the first load output of the first load circuit to the second source input of the second source circuit,
- a second 3-way valve which hydronically connects the first load input of the first load circuit to the second source output of the second source circuit,
- 15 a third 3-way valve which hydronically connects the first load output of the first load circuit to the second load output of the second load circuit, and
- a fourth 3-way valve which hydronically connects the first load input of the first load circuit to the second load input of the second load circuit; and
- 20 at least one controller configured to co-ordinate control of the plurality of 3-way valves, the first heat pump, and the second heat pump.
26. The hydronic system as claimed in claim 25, wherein the first heat pump is an air to liquid heat pump.
- 25 27. The hydronic system as claimed in claim 26, wherein the first source circuit is to air or ambient.
28. The hydronic system as claimed in claim 25, wherein the second heat pump is a liquid to liquid heat pump.

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29. The hydronic system as claimed in claim 28, further comprising an air to liquid heat exchanger interfacing with a third source circuit to air or ambient and hydronically connected to a third load circuit to the second source circuit.
- 5 30. The hydronic system as claimed in claim 25, wherein the first heat pump includes a liquid to liquid heat pump and a radiator interfacing with a third source circuit to air or ambient.
31. The hydronic system as claimed in claim 25, further comprising at least one
10 sensor to provide sensor data of the hydronic system, wherein the co-ordinate control is based on the sensor data.
32. The hydronic system as claimed in claim 31, wherein the at least one sensor includes at least one of a pressure sensor, a flow sensor, a temperature sensor, a pump
15 motor speed sensor, or a power sensor.
33. The hydronic system as claimed in claim 31, wherein the at least one sensor respectively is configured to respectively detect a property of the first heat pump and/or the second heat pump.
- 20 34. The hydronic system as claimed in claim 25, wherein the co-ordinate control includes controlling the plurality of 3-way valves, the first heat pump, and the second heat pump to achieve a setpoint that is beyond an individual respective capacity of the first heat pump to the first load circuit or the second heat pump to the second load
25 circuit.
35. The hydronic system as claimed in claim 25, wherein the co-ordinate control includes controlling the plurality of 3-way valves, the first heat pump, and the second heat pump that uses less energy when compared to individual respective output of the
30 first heat pump to the first load circuit or the second heat pump to the second load circuit.

36. The hydronic system as claimed in claim 25, wherein a first maximum capacity of the first heat pump at most 60% of a first full load or a first design point of the first load circuit, and/or wherein a second maximum capacity of the second heat pump is at most 60% of a second full load or a second design point of the second load circuit.

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37. The hydronic system as claimed in claim 36, wherein the first maximum capacity is on or about 50%, and/or wherein the second maximum capacity is on or about 50%.

38. The hydronic system as claimed in claim 25, wherein the co-ordinate control
10 includes controlling the plurality of 3-way valves to configure the first heat pump and the second heat pump in parallel operation.

39. The hydronic system as claimed in claim 25, wherein the co-ordinate control
15 includes controlling the plurality of 3-way valves to configure the first heat pump and the second heat pump in series operation.

40. The hydronic system as claimed in claim 25, further comprising at least one
further heat pump and a respective further 3-way valve for the at least one further heat
pump, wherein the co-ordinate control includes controlling the respective further 3-way
20 valve to cause the at least one further heat pump to be in parallel and/or series
operation with the first heat pump and/or the second heat pump

41. The hydronic system as claimed in claim 25, wherein the co-ordinate control
25 includes changing a state of at least one of the 3-way valves during sourcing to the first
load circuit or to the second load circuit.

42. The hydronic system as claimed in claim 25, further comprising water or
circulation fluid in the first load circuit, the second source circuit, and the second load
circuit which is in a fully enclosed loop.

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43. The hydronic system as claimed in claim 25, wherein at least one of the 3-way valves is a 3-way isolation diverter valve.
44. The hydronic system as claimed in claim 25, wherein at least one of the 3-way valves is a 3-way variable diverter valve, wherein the at least one controller is configured to change a state of the 3-way variable diverter valve to maintain a partial variable position.
45. The hydronic system as claimed in claim 25, further comprising a first variable pump at the first load circuit and a second variable pump at the second load circuit.
46. The hydronic system as claimed in claim 45, wherein the first variable pump is integrated with the first heat pump during factory assembly or onsite, or wherein the second variable pump is integrated with the second heat pump during the factory assembly or the onsite.
47. The hydronic system as claimed in claim 45, wherein a first maximum capacity of the first variable pump at most 60% of a first full load or a first design point of the first load circuit, and wherein a second maximum capacity of the second variable pump is at most 60% of a second full load or a second design point of the second load circuit.
48. The hydronic system as claimed in claim 47, wherein the first maximum capacity is on or about 50%, and/or wherein the second maximum capacity is on or about 50%.
49. The hydronic system as claimed in claim 25, wherein the co-ordinate control includes further controlling at least one plant component, a microprocessor based device, or a sequence of controls.
50. The hydronic system as claimed in claim 25, wherein the first heat pump and the second heat pump is controlled by the at least one controller to operate in a heating mode or a cooling mode.

51. The hydronic system as claimed in claim 25, wherein the first source circuit or the second source circuit is thermally coupled to a cooling source, wherein the cooling source comprises a ground source heat sink, a cooling tower, or natural water.
- 5 52. The hydronic system as claimed in claim 25, wherein the first source circuit or the second source circuit is thermally coupled to a heat source, wherein the heat source comprises a data center, hydrogen power, a district energy system, thermal energy storage, geothermal, a boiler, thermal solar, or waste water.
- 10 53. The hydronic system as claimed in claim 25, further comprising a water storage hydronically connected to the second load circuit, and hydronically connected to a water consumption circuit having a water supply input and a water consumption output.
- 15 54. A method of controlling the hydronic system as claimed in any one of claims 1-53, comprising changing a state of at least one of the 3-way valves.
55. The method as claimed in claim 54, wherein the changing the state includes causing a respective passageway between the air to liquid heat pump and the liquid to liquid heat pump as between the first load output and the second source input and as
20 between the first load input and the second source output.
56. The method as claimed in claim 54, wherein the changing the state includes causing a respective passageway between the air to liquid heat pump and the liquid to liquid heat pump as between the second load output and the first load output and as
25 between the first load input and the second load input.
57. A non-transitory computer readable medium comprising instructions which, when executed by at least one controller, causes the at least one controller to perform the
30 method of any one of claims 1-56.