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# (54) HYPERLOOP ENVIRONMENTAL CONTROL SYSTEM

(57) An environmental control system for conditioning a cabin of a vehicle positioned in an enclosed air-evacuated environment includes a first inlet (24) for receiving a first medium (A1), a second inlet (26) for receiving a second medium (A2), and a thermodynamic device (30) including an electric generator (32) and at least one turbine operably coupled by a shaft. A first mixing point (M1) is fluidly coupled to the second inlet (26) and an outlet of the at least one turbine.

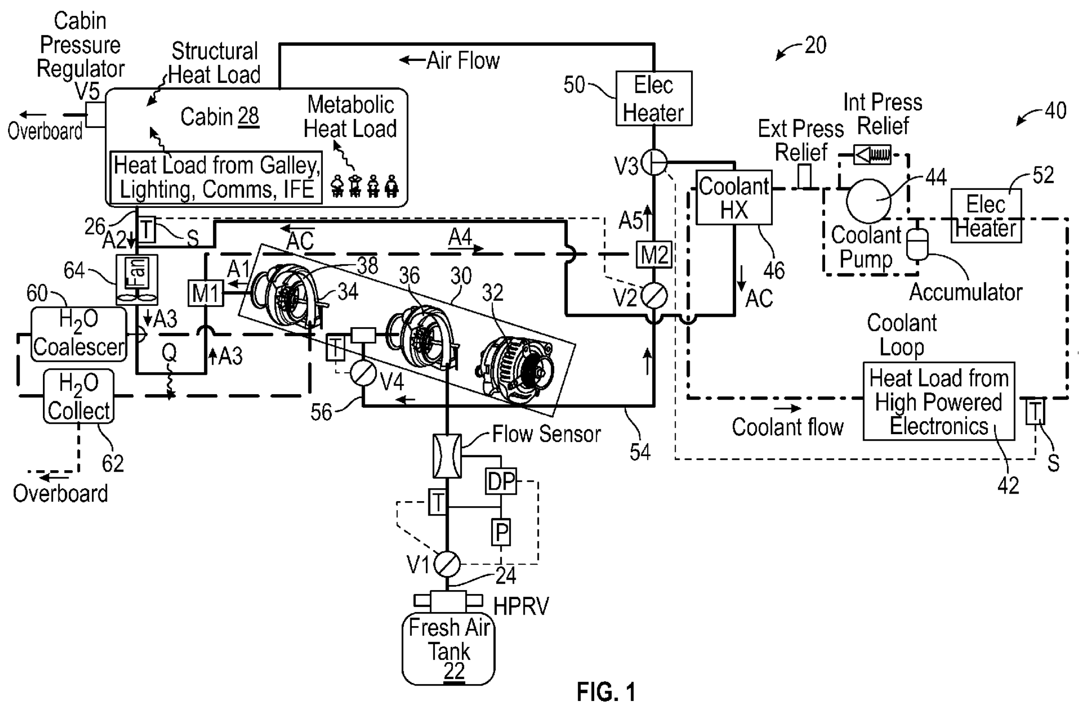


FIG. 1

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## Description

### BACKGROUND

**[0001]** The present disclosure relates to an environmental control system of a vehicle, and more particularly, to an environmental control system (ECS) for a vehicle travelling in a low pressure or zero pressure environment.

**[0002]** In general, a high-speed public transportation concept called the hyperloop has been proposed that can include a vehicle similar to a train car that travels inside of a tube. The air in the tube can be evacuated to a very deep vacuum, allowing the train to reach very high speeds without incurring the high-power demand that would otherwise be needed to overcome the high aerodynamic drag at normal atmospheric pressure. An air lock can permit passenger boarding and disembarking from the train station to the train without discharging the atmospheric air in the station into the vacuum in the tube.

**[0003]** As with similar transportation vehicles, environmental control of the occupied cabin is generally required to maintain adequate comfort and to provide heating, cooling and/or a continual supply of fresh air. Some typical methods used to provide air conditioning may not be conducive to this application. For example, many air conditioning systems exist which provide cool air to the cabin and on-board electronics may draw air from or ultimately exhaust the heat to the ambient atmosphere via convection heat transfer. When the ambient atmosphere is nonexistent, as in space applications, heat can be rejected to deep space via radiation heat transfer. In the case of the hyperloop, there is little to no atmosphere in the tube, so rejecting heat into the tube via convection may not be practical while maintaining a reasonably sized heat exchanger to reject the heat. Moreover, heat rejection via radiation may also not be practical, since unlike radiating to space, which is near absolute zero degrees in temperature, the walls of the tube can be warmer than inside the cabin when the outside ambient temperature is warm. Moreover, while the train is moving at high speed, the amount of available electrical power consumption is limited since power is generally supplied solely by on-board batteries that have a limited quantity of electrical energy.

### BRIEF DESCRIPTION

**[0004]** According to an embodiment, an environmental control system for conditioning a cabin of a vehicle positioned in an enclosed air-evacuated environment includes a first inlet for receiving a first medium, a second inlet for receiving a second medium, and a thermodynamic device including an electric generator and at least one turbine operably coupled by a shaft. A first mixing point is fluidly coupled to the second inlet and an outlet of the at least one turbine.

**[0005]** In addition to one or more of the features described above, or as an alternative, in further embodiments the thermodynamic device is absent a compressor.

**[0006]** In addition to one or more of the features described above, or as an alternative, in further embodiments the at least one turbine further comprises a first turbine and a second turbine operably coupled by the shaft.

**[0007]** In addition to one or more of the features described above, or as an alternative, in further embodiments an outlet of the first turbine is fluidly coupled to an inlet of the second turbine such that the first turbine and the second turbine are arranged in series relative to a flow of the first medium.

**[0008]** In addition to one or more of the features described above, or as an alternative, in further embodiments the second medium is mixed with a medium output from a cooling system to form a third medium at a location upstream from the first mixing point.

**[0009]** In addition to one or more of the features described above, or as an alternative, in further embodiments including a circulation fan operable to pump the third medium to the first mixing point.

**[0010]** In addition to one or more of the features described above, or as an alternative, in further embodiments the third medium is mixed with the first medium provided from an outlet of the at least one turbine at the first mixing point to form a fourth medium.

**[0011]** In addition to one or more of the features described above, or as an alternative, in further embodiments a bypass conduit is fluidly connected to the first inlet. The bypass conduit is arranged in parallel with the thermodynamic device. A valve is associated with the bypass conduit and is operable to control the flow of the first medium within the bypass conduit.

**[0012]** In addition to one or more of the features described above, or as an alternative, in further embodiments including a second mixing point fluidly coupled to the first mixing point and to the bypass conduit. A conditioned medium is output from the second mixing point.

**[0013]** In addition to one or more of the features described above, or as an alternative, in further embodiments including at least one vessel of the first medium located on board the vehicle.

**[0014]** In addition to one or more of the features described above, or as an alternative, in further embodiments the vehicle is a train.

**[0015]** According to an embodiment, a method of operating an environmental control system to condition a cabin of a vehicle positioned in an enclosed, air-evacuated tube includes extracting energy from a first medium at at least one turbine of a thermodynamic device to form an expanded first medium and further extracting energy from the expanded first medium at the at least one turbine to form a further expanded first medium and forming a conditioned medium including the further expanded first medium and a second medium. The extracted energy is used to generate power at the generator.

**[0016]** In addition to one or more of the features described above, or as an alternative, in further embodiments the at least one turbine further comprises a first turbine and a second turbine and energy is extracted from the first medium at the first turbine to form the expanded first medium and energy is extracted from the expanded first medium at the second turbine to form the further expanded first medium.

**[0017]** In addition to one or more of the features described above, or as an alternative, in further embodiments mixing the second medium and a medium from a cooling system to form a third medium.

**[0018]** In addition to one or more of the features described above, or as an alternative, in further embodiments forming the conditioned medium includes mixing the third medium with the further expanded first medium at a first mixing point to form a fourth medium and mixing the fourth medium with a flow of the first medium provided from a bypass conduit to form the conditioned medium, the flow of the first medium provided from the bypass conduit having bypassed the thermodynamic device.

**[0019]** In addition to one or more of the features described above, or as an alternative, in further embodiments including pumping the third medium to the first mixing point via a circulation fan.

**[0020]** In addition to one or more of the features described above, or as an alternative, in further embodiments including providing a first portion of the conditioned medium to the cabin and providing a second portion of the conditioned medium to the cooling system.

**[0021]** In addition to one or more of the features described above, or as an alternative, in further embodiments providing the second portion of the conditioned medium to the cooling system including removing heat from the cooling system.

**[0022]** In addition to one or more of the features described above, or as an alternative, in further embodiments the conditioned medium heated at the cooling system is the medium from the cooling system of the third medium.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0023]** The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

**[0024]** The Figure (Figure 1) is a schematic diagram of an example environmental control system (ECS) for a vehicle travelling within a hyperloop tube according to an embodiment.

## DETAILED DESCRIPTION

**[0025]** A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

**[0026]** The example embodiments disclosed herein are illustrative of a hyperloop environmental control system, and assemblies of the present disclosure and methods/techniques thereof. It should be understood, however, that the disclosed embodiments are merely examples of the present disclosure, which may be embodied in various forms. Therefore, details disclosed herein with reference to example hyperloop environmental control systems and associated processes/techniques of fabrication/assembly and use are not to be interpreted as limiting, but merely as the basis for teaching one skilled in the art how to make and use the systems/assemblies and/or alternative systems/assemblies of the present disclosure.

**[0027]** With reference now to the Figure, an example of an environmental control system 20 suitable for use with a vehicle movable within an enclosed air-evacuated environment is illustrated. The air-evacuated environment has a substantially zero-pressure or is a vacuum. In an embodiment, the vehicle is a car or train movable through a tube of a hyperloop system. As shown, the environmental control system 20 includes one or more vessels 22 located on-board the vehicle and configured to store a pressurized medium therein, such as high-pressure air for example. In an embodiment, the pressure of the medium within the at least one vessel 22 is between about 2000psi about 3000psi. The one or more vessels 22 may be considered a first fluid source and are fluidly coupled to a first inlet 24 of the environmental control system 20 to deliver a controlled flow of a first medium A1 to the environmental control system 20. The one or more vessels 22 may be filled, refilled, or replaced when the vehicle is stopped at a station or other facility.

**[0028]** The environmental control system 20 may additionally receive a flow of second medium A2 at a second inlet 26. In one embodiment, the second inlet 26 is operably coupled to a volume 28, such as the cabin or chamber of the vehicle in which the people are typically located. In such embodiments, the second medium A2 is cabin recirculation air. The environmental control system 20 is operable to provide a conditioned flow of one or both of the first medium A1 and the second medium A2 to the cabin 28 at standard atmospheric pressure of about 14.7 psi.

**[0029]** The environmental control system 20 may include at least one thermodynamic device, and in some embodiments, includes a plurality of thermodynamic devices. A thermodynamic device, as described herein, is a mechanical device that includes one or more components for performing thermodynamic work on a medium (e.g., extracts work from or applies work to the first medium A1 or the second medium A2 by raising and/or lowering pressure and by raising and/or lowering temperature). The thermodynamic device may not include or may be absent a compressor. In an embodiment, the thermodynamic device 30 is a turbogenerator. The thermodynamic device 30 includes at least one turbine that directly drives an electric generator 32 via a shaft 34. In the illustrated, non-limiting embodiment, the turbogenerator includes a first turbine 36 and a second turbine 38. Although the turbines, 36, 38 and the electric generator 32 are illustrated as being connected directly to the same shaft 34, it should be understood that embodiments where the generator 32 is indirectly connected to one or both of the turbines 36, 38, such as where the generator 32 includes a separate shaft connected to the shaft 34 via a coupler for example, are also within the scope of the disclosure. In operation, rotation of each turbine 36, 38 extracts energy from the medium provided thereto and converts it into electrical energy via the generator 32. The energy created at the generator 32 may be stored, such as within a battery (not shown) and/or may be sent to at least one electrical load of the vehicle.

**[0030]** In addition to providing a conditioned medium to the cabin 28, the environmental control system 20 may be used to transfer or redistribute heat between various systems onboard the vehicle. In an embodiment, the environmental control system 20 is operably coupled to a cooling system 40 used to cool high-powered electronics 42 located onboard the vehicle. As shown, a coolant, such as propylene glycol or ethylene glycol for example, is configured to circulate through the electronics 42 via a coolant pump 44, then is then provided to an electronics heat exchanger 46. In the illustrated, non-limiting embodiment, the environmental control system 20 is operably coupled to the cooling system 40 via the electronics heat exchanger 46. Accordingly, at the electronics heat exchanger 46, during operation of the environmental control system 20 in a "cooling mode" where the air provided to the cabin 28 is intended to reduce the temperature therein, heat is transferred from the coolant to the relatively cool medium of the environmental control system 20. Heat may also be transferred from the coolant to the relatively cool medium of the environmental control system 20 during operation in a "heating mode" where the air provided to the cabin is intended to increase the temperature therein.

**[0031]** The elements of the environmental control system 20 are connected via valves, tubes, pipes, conduits and the like. Valves (e.g., flow regulation device or mass flow valve) are devices that regulate, direct, and/or control a flow of a medium by opening, closing, or partially obstructing various passageways within the tubes, pipes, etc. of the system. Valves can be operated by actuators, such that flow rates of the medium in any portion of the environmental control system 20 can be regulated to a desired value. For instance, a first valve V1, such as an airflow regulator for example, is configured to control the flow of the first medium A1 provided to the environmental control system 20 via the first inlet 24. A second valve V2 may be operable to selectively divert the flow of the first medium to bypass the substantially entire environmental control system 20, including the thermodynamic device 30. A third valve V3 can control the flow of a conditioned medium to both the cabin 28 and to the cooling system 40 and in some embodiments, a fourth valve V4 may be operable to allow a portion of a medium to bypass a portion of the thermodynamic device 30, such as the first turbine 36 for example. The environmental control system 20 may additionally include a valve V5 operable to exhaust a flow of medium from the cabin 28 or the environmental control system 20 overboard from the vehicle, such as into the atmosphere surrounding the exterior of the vehicle.

**[0032]** One or more of the valves V1-V5 may be configured to receive commands from an ECS controller (not shown), such as in response to feedback provided from one or more sensors S located in specific/desired locations in the environmental control system 20. Although various pressure and temperature sensors are illustrated, it should be appreciated that other sensors operable to monitor any suitable parameter of the environmental control system 20 and/or the cooling system 40 are within the scope of the disclosure.

**[0033]** Furthermore, a heater 50, such as an electrical heater for example, may also be provided for instances where the conditioned medium to be delivered to the cabin 28 needs to be heated. In such embodiments, the heater 50 may be arranged directly upstream from the cabin 28 relative to a flow of the conditioned medium. Alternatively, or in addition, a heater 52, such as an electrical heater, may be provided in the cooling system 40 for instances where the conditioned medium to be delivered to the cabin 28 needs additional heat beyond the load exhausted by the electronics 42.

**[0034]** In operation, a flow of the first medium A1 at the first inlet 24, controlled by valve V1, is provided to the environmental control system 20. When the downstream valve V2 is in a first position, all or at least a portion of the flow of the first medium A1 is provided to the thermodynamic device 30, such as to the first turbine 36 for example. However, when the valve V2 is in a second position, some or all of the flow of the first medium A1 is directed to a bypass conduit 54 arranged in parallel with an inlet of the first turbine 36. Within the bypass conduit 54, the first medium A1 is configured to bypass the entire thermodynamic device 30.

**[0035]** Within the first turbine 36, the first medium A1 is expanded and work is extracted therefrom to form an expanded first medium. As a result, the expanded first medium A1 provided at the outlet of the first turbine 36 is cooler and/or has a lower pressure than the first medium A1 provided to the inlet of the first turbine 36. The work extracted from the first medium A1 within the first turbine 36 is used to drive the generator 32 and therefore generate power.

**[0036]** It should be appreciated that in some embodiments, valve V4 may be positioned such that at least a portion of the flow of the first medium A1 provided at the first inlet 24 is directed into a bypass conduit 56 and is therefore configured to bypass the first turbine 36. In such embodiments, the flow output from the bypass conduit 56 is configured to mix with the flow output from the first turbine 36 at or directly downstream from the outlet of the first turbine 36. Accordingly, it should be appreciated that the term "expanded first medium A1" used hereafter is intended to include the expanded first medium output from an outlet of the first turbine 36, the first medium A1 from the bypass conduit 56, or some combination thereof.

**[0037]** In an embodiment, the first medium A1 is configured to flow through the first turbine 36 and the second turbine 38 in series. The expanded first medium A1 may be provided directly to an inlet of the second turbine 38. However, in other embodiments, the expanded first medium A1 may be dried upstream from the inlet of the second turbine 38. As shown, a condenser or coalescer 70 and/or a water collector 72 may be located directly downstream from the outlet of the first turbine 36. As the expanded first medium A1 passes through the water coalescer 70 and then the water collector 72, any liquid present within the expanded first medium A1 is removed.

**[0038]** Within the second turbine 38, the expanded first medium A1 is expanded and work is extracted therefrom to form a further extracted first medium A1. The work extracted from the first medium A1 in the second turbine 38 is used alone or in combination with the work extracted at the first turbine 36 is used to drive the generator 32 and therefore generate power. Accordingly, the further expanded first medium A1 provided at the outlet of second turbine 38 is cooler and/or has a lower pressure than the first medium A1 provided to the inlet of the second turbine 38.

**[0039]** At the same time, the second medium A2 is provided to the second inlet 26 of the environmental control system 20 from the cabin 28. Operation of a circulation fan 64 associated with the cabin 28 is configured not only to move the air within the cabin 28, but also to pump the second medium A2 into and through one or more conduits of the environmental control system 20.

**[0040]** In an embodiment, the second medium A2 is mixed with a flow of medium Ac returned from the cooling system 40, such as output from the electronics heat exchanger 46 for example, to form a third medium A3. In an embodiment, the second medium A2 is mixed with the flow medium Ac returned from the cooling system 40 at a location upstream from the circulation fan 64. In such embodiments, operation of the circulation fan 64 may additionally or alternatively facilitate movement of the third medium A3 through the environmental control system 20, such as toward a first mixing point M1. As shown, the third medium is configured to mix with the flow of the further expanded first medium A1 output from the outlet of the second turbine 38 at the first mixing point M1. The resulting fourth medium A4 is then provided to a second mixing point M2 fluidly coupled to the bypass conduit 54. Accordingly, in embodiments where a portion of the first medium A1 provided at the first inlet 24 is directed to the bypass conduit 54, this flow of first medium A1 mixes with the fourth medium A4 at the second mixing point M2 to form a conditioned medium A5. It should be appreciated that in embodiments where none of the first medium A1 is directed into the bypass conduit 54, the conditioned medium A5 output from the second mixing point M2 is simply the fourth medium A4.

**[0041]** Depending on the operating conditions of the environmental control system 20, in some embodiments, the conditioned medium A5 may be separated into a first portion or flow of conditioned medium A5a used to condition the cabin 28 and a second portion or flow of conditioned medium A5b for use by the cooling system 40, as previously described herein. The amount of conditioned medium A5 provided to the cabin 28 and the cooling system 40, respectively, is controlled by the position of the valve V3. In an embodiment, the volume of conditioned air or the rate at which the conditioned air A5a is provided to the cabin 28 is equal to the volume or rate at which air is exhausted from the cabin 28 overboard into the surrounding environment via the cabin pressure regulator V4. As a result, the pressure within the cabin 28 remains generally constant.

**[0042]** As previously described, the second conditioned flow A5b may be provided to an electronics heat exchanger 46 of the cooling system 40. Within the electronics heat exchanger 46, the second conditioned flow A5b typically acts as a heat sink to absorb heat from the coolant. The resulting heated medium output from the electronics heat exchanger 46, represented as flow Ac, is then returned to the environmental control system 20 where it is mixed with the second medium A2 upstream from the first mixing point M1.

**[0043]** An environmental control system 20 as illustrated and described here provides an efficient system for conditioning a cabin 28 of a vehicle travelling within a vacuum.

**[0044]** The term "about" is intended to include the degree of error associated with measurement of the particular quantity based upon the equipment available at the time of filing the application.

**[0045]** The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As used herein, the singular forms "a," "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, element components, and/or groups thereof.

**[0046]** While the present disclosure has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made, and equivalents may be substituted for elements thereof without departing from the scope of the present disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the present disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this present disclosure, but that the present disclosure will include all embodiments falling within the scope of the claims.

## Claims

1. An environmental control system for conditioning a cabin of a vehicle positioned in an enclosed air-evacuated environment, the environmental control system comprising:

   a first inlet (24) for receiving a first medium (A1);
   a second inlet (26) for receiving a second medium (A2);
   a thermodynamic device (30) including an electric generator (32) and at least one turbine operably coupled by a shaft; and
   a first mixing point (M1) fluidly coupled to the second inlet (26) and an outlet of the at least one turbine.

2. The environmental control system of claim 1, wherein the thermodynamic device (30) is absent a compressor.

3. The environmental control system of claim 1 or 2, wherein the at least one turbine further comprises a first turbine (36) and a second turbine (38) operably coupled by the shaft.

4. The environmental control system of claim 3, wherein an outlet of the first turbine (36) is fluidly coupled to an inlet of the second turbine (38) such that the first turbine (36) and the second turbine (38) are arranged in series relative to a flow of the first medium (A1).

5. The environmental control system of any preceding claim, wherein the second medium (A2) is mixed with a medium output from a cooling system to form a third medium at a location upstream from the first mixing point (M1).

6. The environmental control system of claim 5, further comprising a circulation fan operable to pump the third medium to the first mixing point (M1).

7. The environmental control system of claim 5, wherein the third medium is mixed with the first medium (A1) provided from an outlet of the at least one turbine at the first mixing point (M1) to form a fourth medium.

8. The environmental control system of claim 5, further comprising:

   a bypass conduit fluidly connected to the first inlet (24), the bypass conduit being arranged in parallel with the thermodynamic device (30); and
   a valve associated with the bypass conduit, the valve being operable to control the flow of the first medium (A1) within the bypass conduit, and preferably further comprising a second mixing point fluidly coupled to the first mixing point (M1) and to the bypass conduit, wherein a conditioned medium is output from the second mixing point.

9. The environmental control system of any preceding claim, further comprising at least one vessel of the first medium (A1) located on board the vehicle.

10. The environmental control system of any preceding claim, wherein the vehicle is a train.

11. A method of operating an environmental control system to condition a cabin of a vehicle positioned in an enclosed, air-evacuated tube, the method comprising:

    extracting energy from a first medium (A1) at at least one turbine of a thermodynamic device (30) to form an expanded first medium, the extracted energy being used to generate power at a generator;
    extracting energy from the expanded first medium at the at least one turbine to form a further expanded first medium, the extracted energy being used to generate power at the generator; and
    forming a conditioned medium including the further expanded first medium and a second medium (A2).

12. The method of claim 11, wherein the at least one turbine further comprises a first turbine (36) and a second turbine (38) and energy is extracted from the first medium at the first turbine (36) to form the expanded first medium and energy is extracted from the expanded first medium at the second turbine (38) to form the further expanded first medium.

13. The method of claim 11 or 12, further comprising mixing the second medium (A2) and a medium from a cooling system to form a third medium.

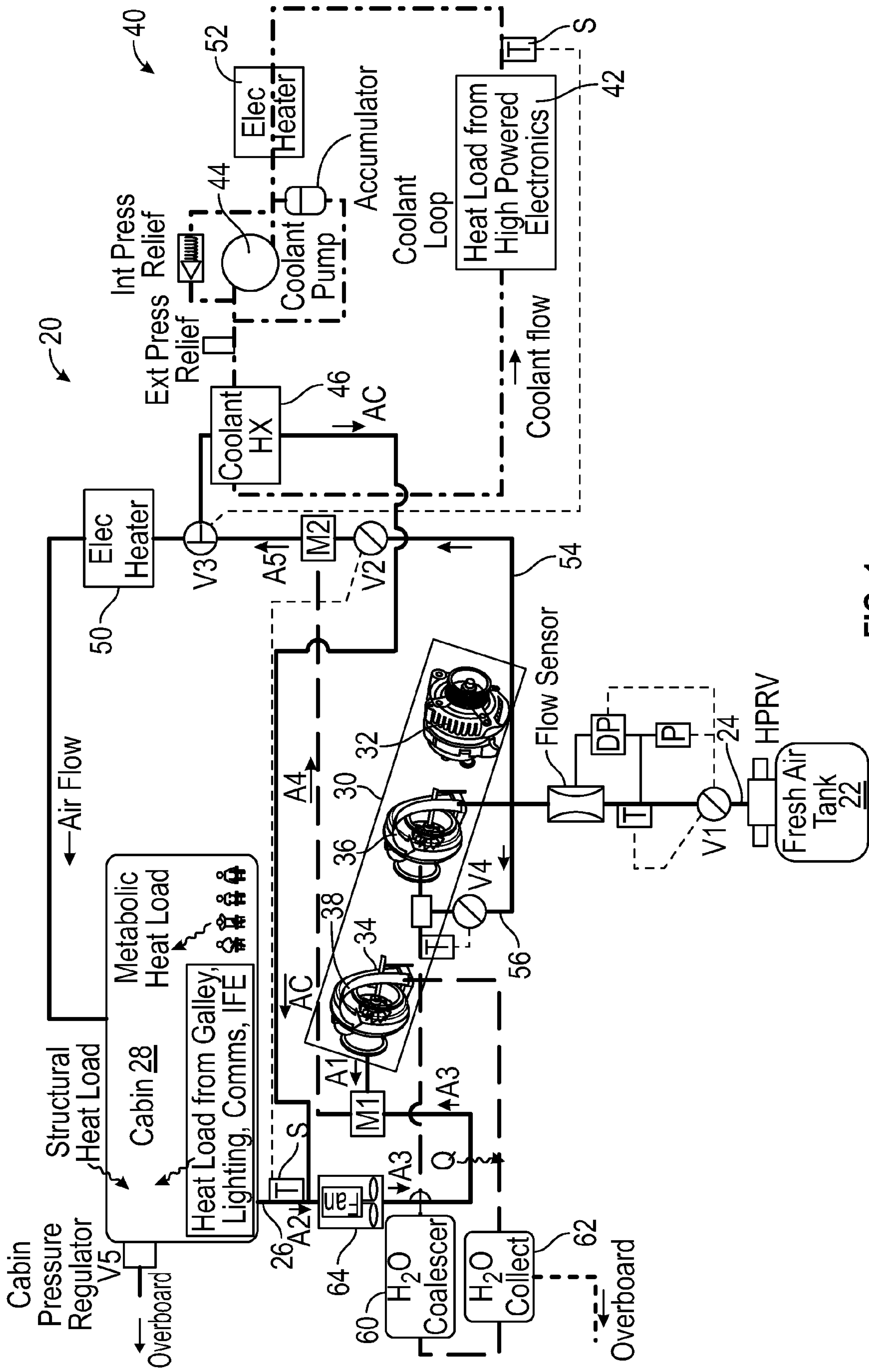
14. The method of claim 13, wherein forming the conditioned medium further comprises:

    mixing the third medium with the further expanded first medium at a first mixing point (M1) to form a fourth medium; and
    mixing the fourth medium with a flow of the first medium provided from a bypass conduit to form the conditioned medium, the flow of the first medium provided from the bypass conduit having

bypassed the thermodynamic device (30), and preferably further comprising pumping the third medium to the first mixing point (M1) via a circulation fan.

**15.** The method of claim 13, further comprising:

providing a first portion of the conditioned medium to the cabin; and
providing a second portion of the conditioned medium to the cooling system, and preferably wherein providing the second portion of the conditioned medium to the cooling system further comprises removing heat from the cooling system, and more preferably wherein the conditioned medium heated at the cooling system is the medium from the cooling system of the third medium.


20
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Elec Heater
Accumulator
Int Press Relief
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Coolant Pump
Ext Press Relief
Coolant Loop
Heat Load from High Powered Electronics
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S
T
Coolant flow
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Coolant HX
AC
Elec Heater
50
V3
A5
M2
V2
54
Air Flow
Metabolic Heat Load
Structural Heat Load
Cabin 28
Heat Load from Galley, Lighting, Comms, IFE
Cabin Pressure Regulator V5
Overboard
Flow Sensor
DP
P
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HPRV
Fresh Air Tank 22
V1
T
32
30
A4
36
V4
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38
34
AC
A1
M1
A3
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26
A2
64
$H_2O$ Coalescer
60
$H_2O$ Collect
62
Overboard

FIG. 1

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# EUROPEAN SEARCH REPORT

Application Number
EP 24 16 0653

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The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| Munich | 11 July 2024 | Schultze, Yves |

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