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(54) **TEMPERATURE CONTROL SYSTEM AND METHOD**

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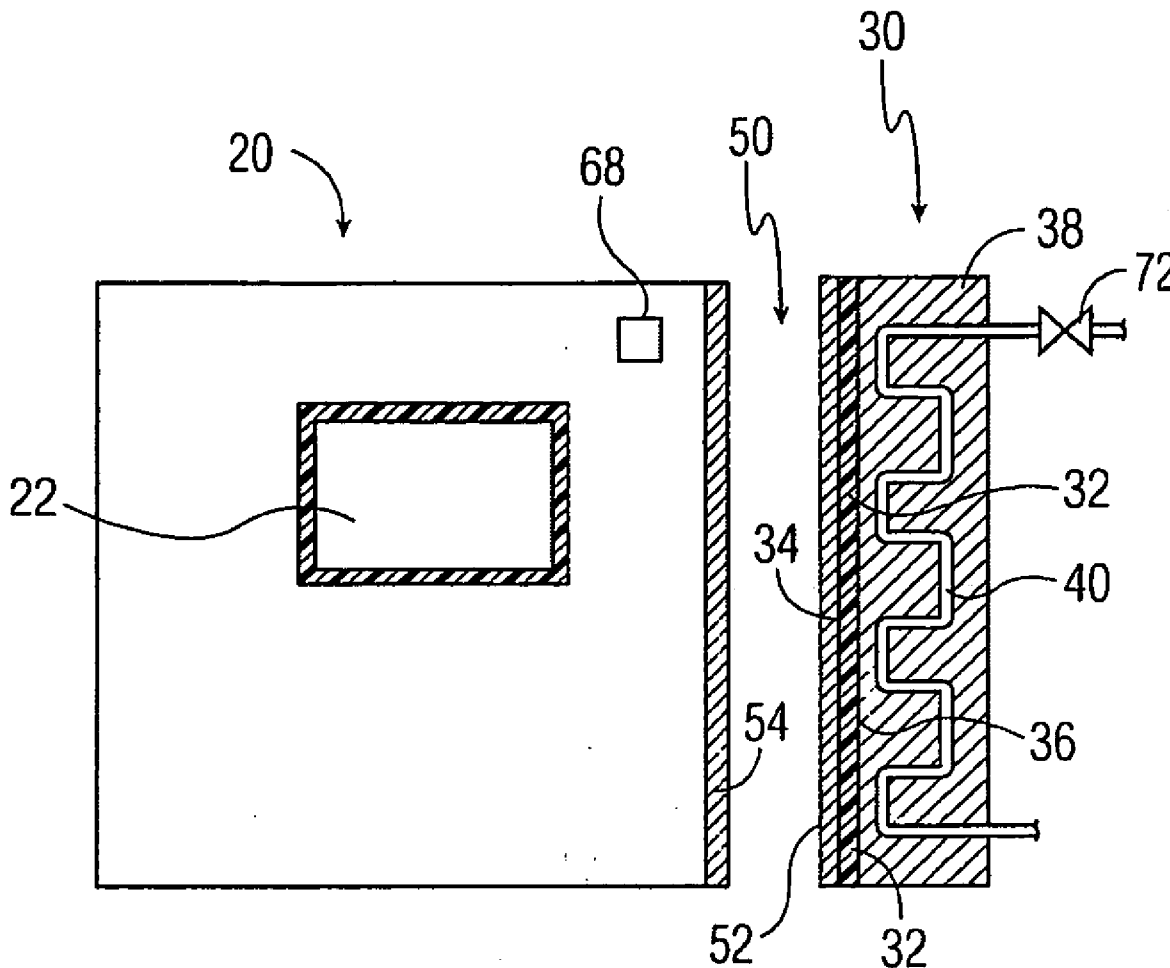
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(57) **ABSTRACT**

A temperature control system for a frame (20) including a thermal electric cooling (TEC) element (32) having a first face (34) and a second face (36), the TEC element (32) disposed to form a gap (50) between the first face (34) and the frame (20), and a fluid heat transfer element (38) thermally connected to the second face (36). The temperature control system also employs a thermal group, a flushable reservoir, and/or a phase change element, as desired.



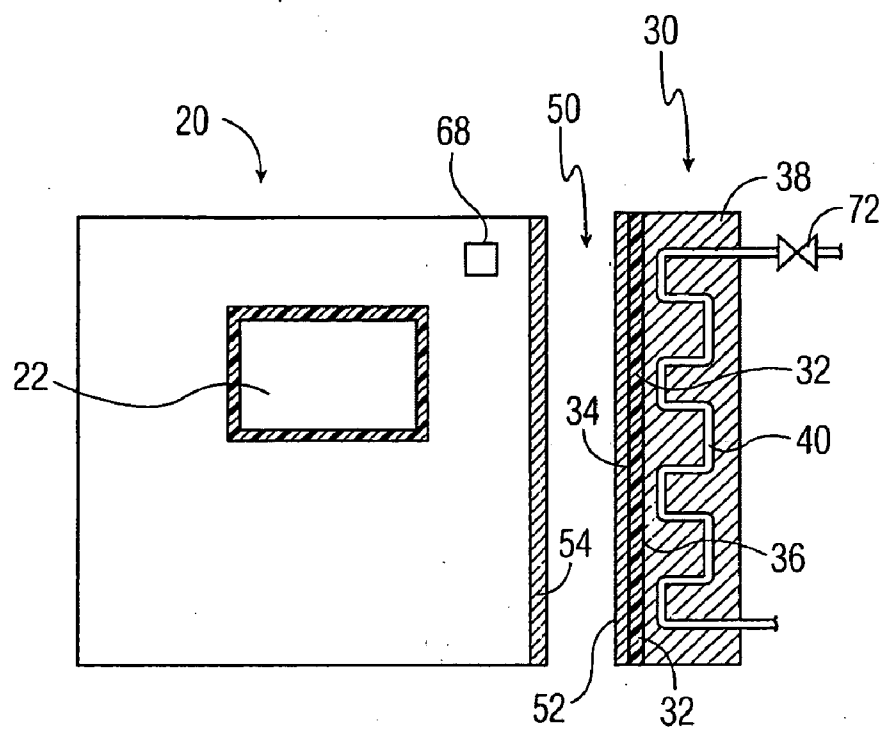


FIG. 1

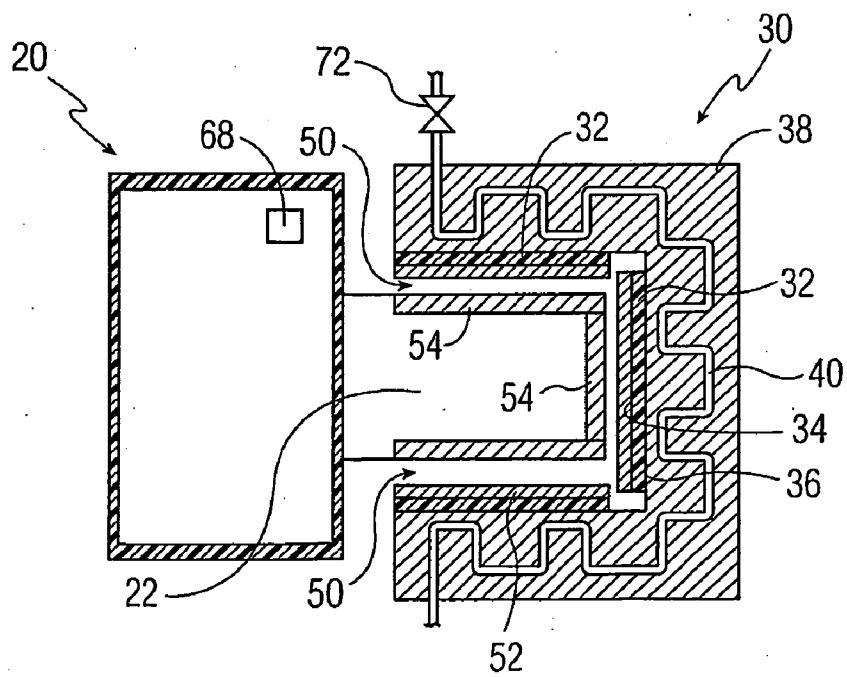


FIG. 2

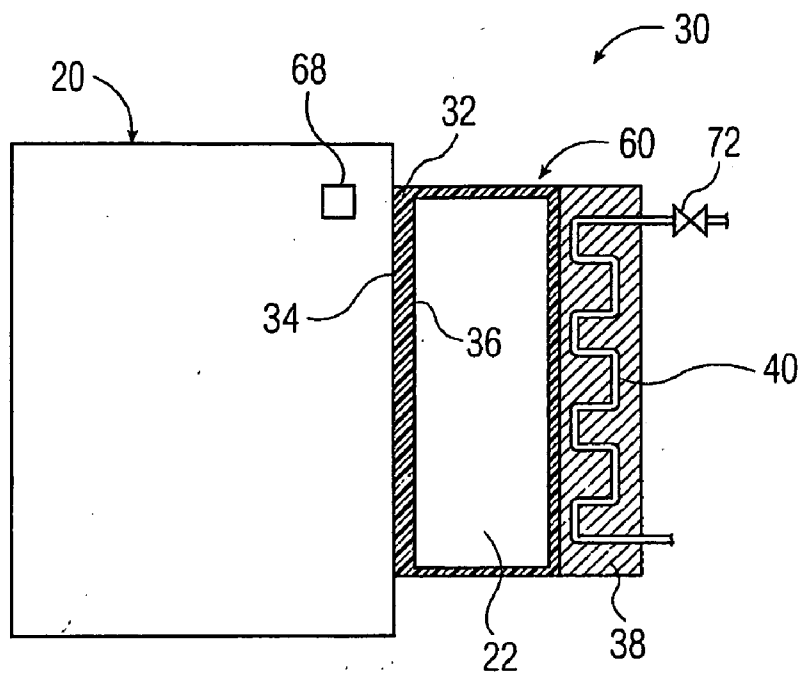


FIG. 3

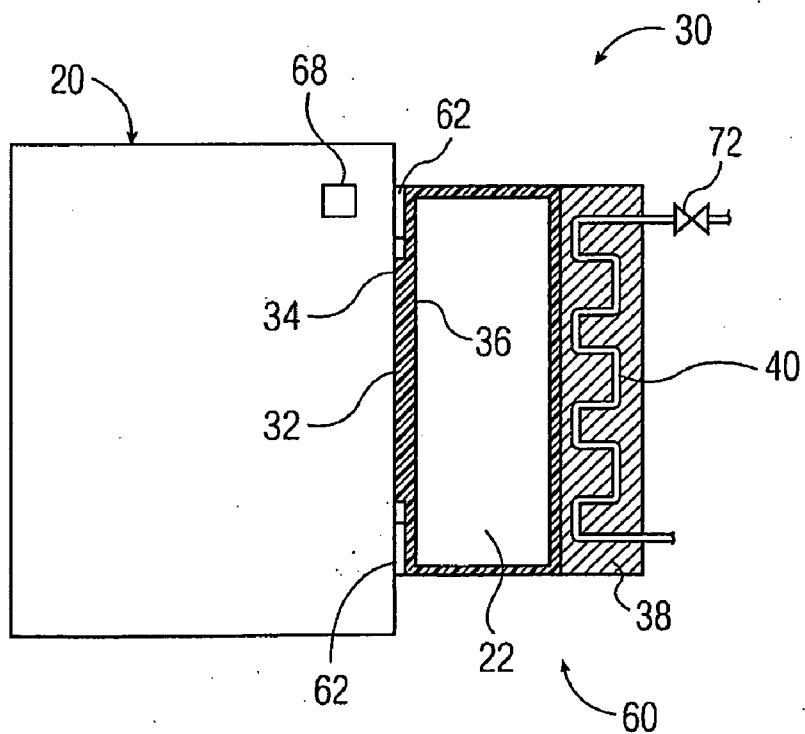


FIG. 4

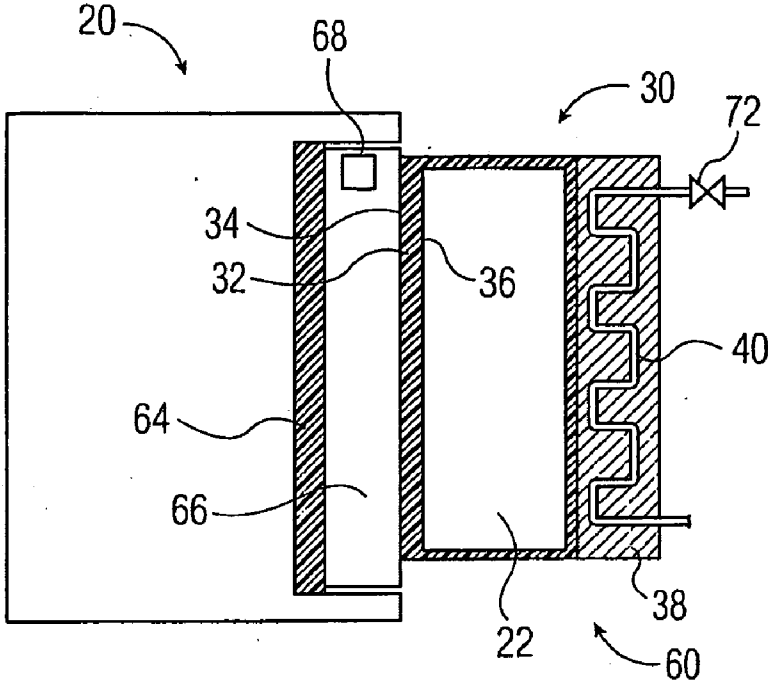


FIG. 5

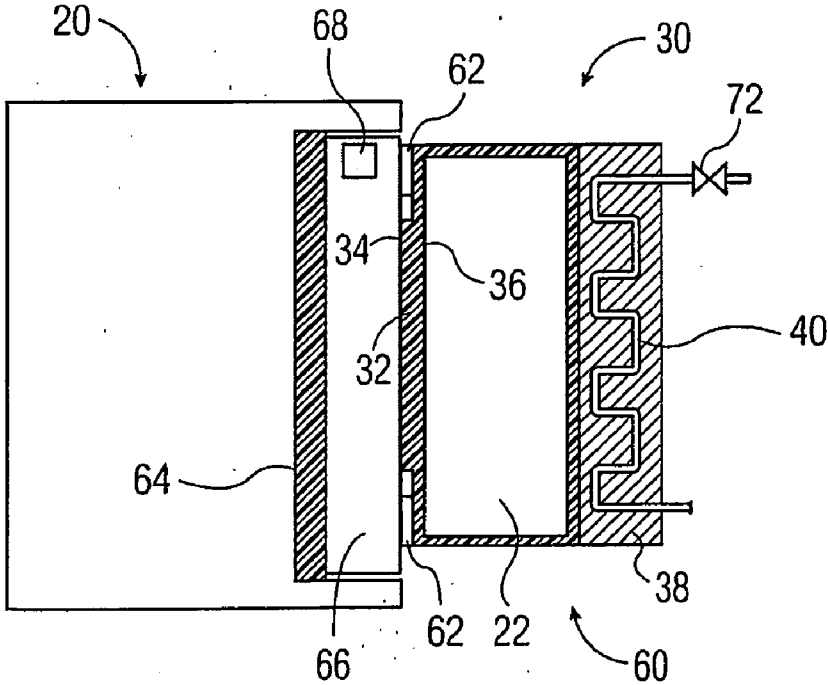


FIG. 6

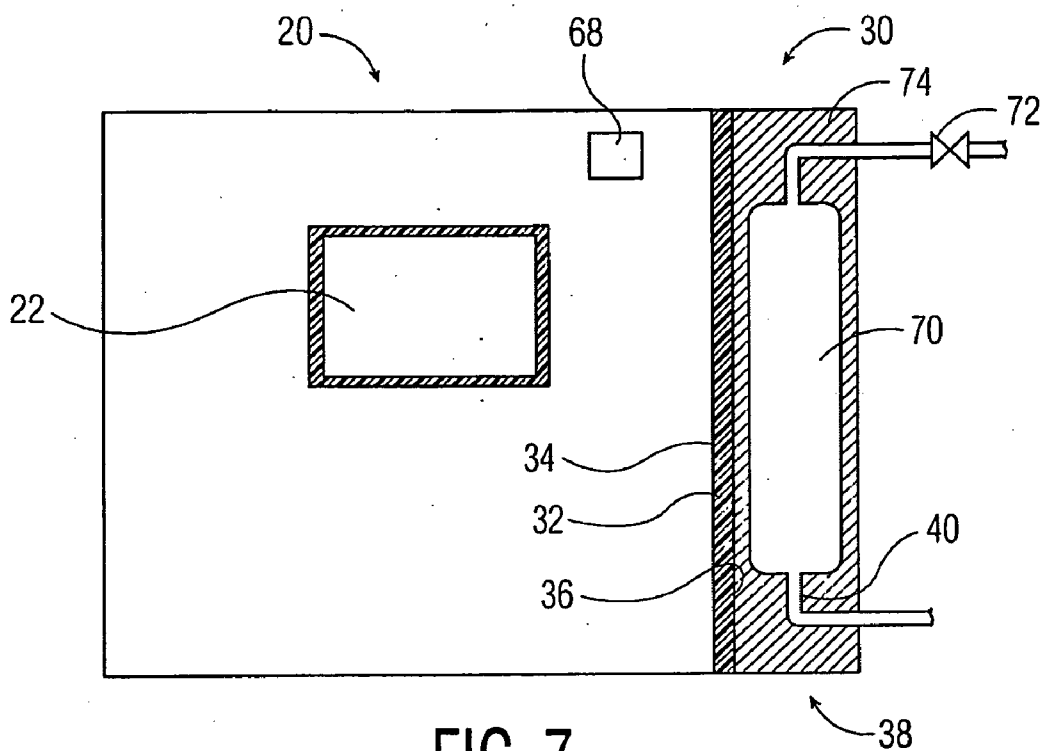


FIG. 7

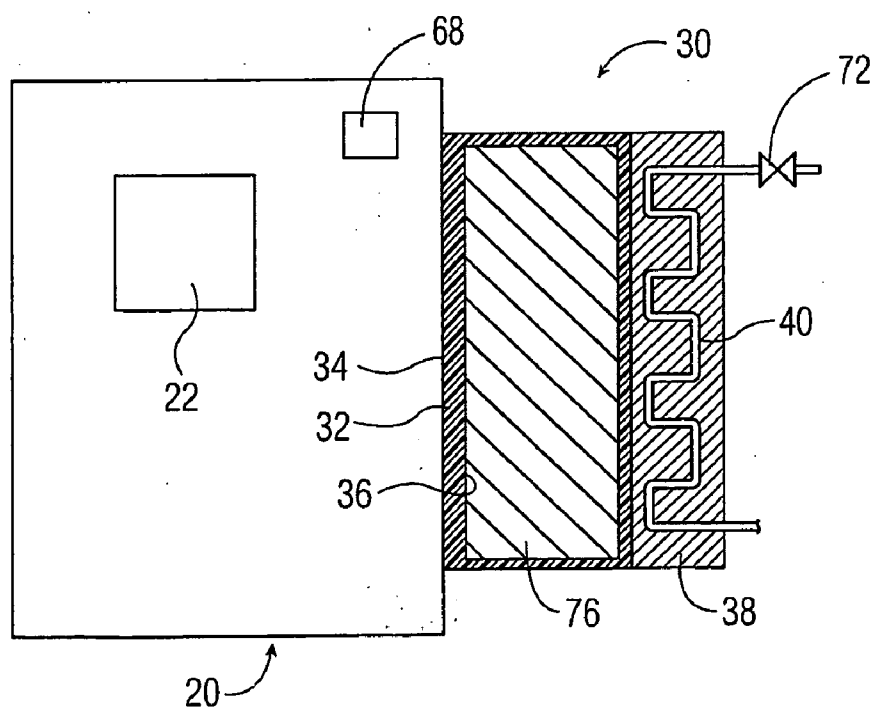


FIG. 8

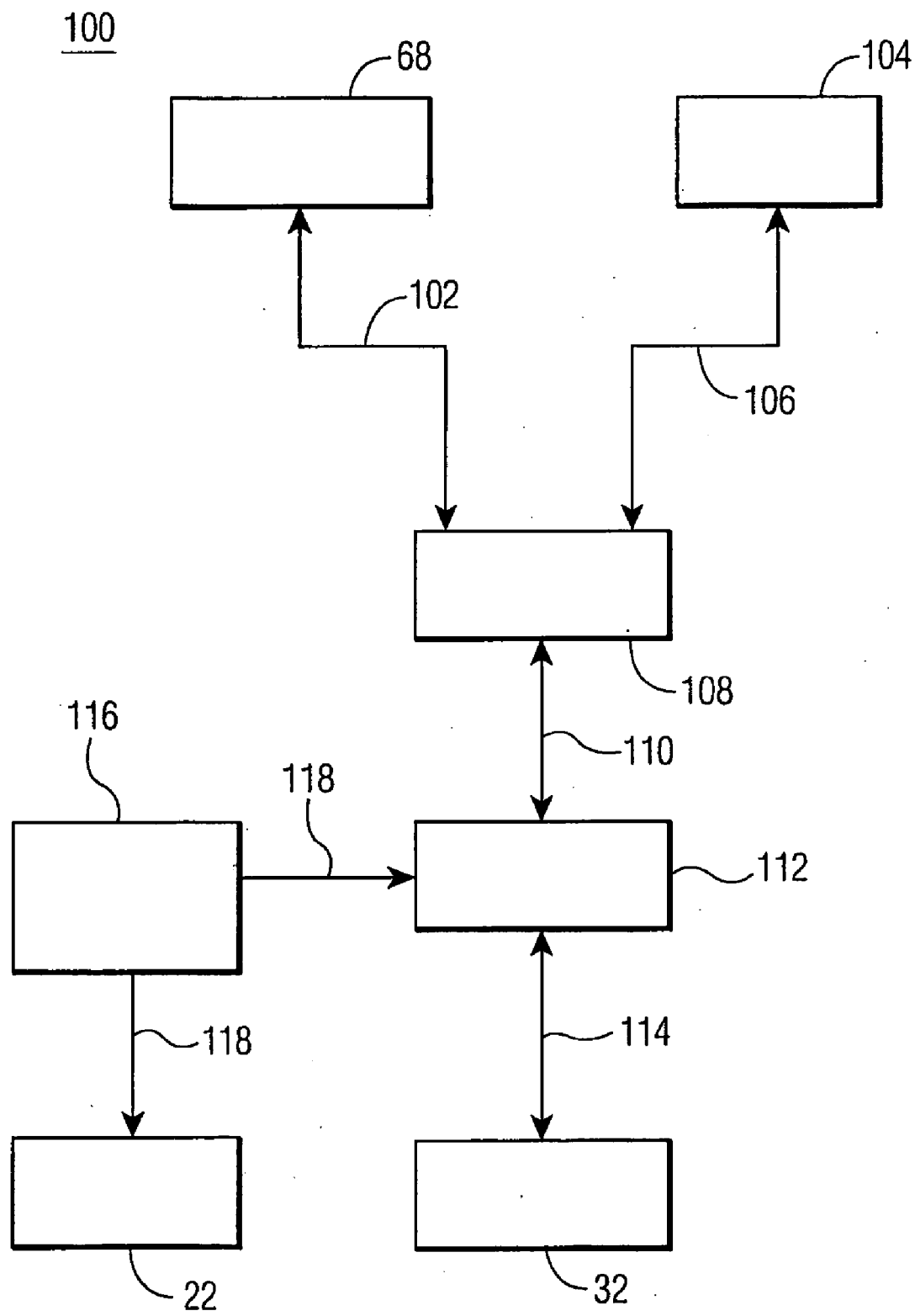


FIG. 9

TEMPERATURE CONTROL SYSTEM AND METHOD

[0001] This invention relates generally to metrology and manufacturing systems, and more specifically to metrology and manufacturing system temperature control.

[0002] Metrology systems are increasingly important as component sizes decline and precision requirements increase. The component under test must be held stationary throughout the measurement to provide accurate measurement. The component rests on a metrology frame, which must be dimensionally stable and vibration free to provide a stable geometric reference for the physical measurement. Problems arise, however, when the metrology frame includes or is in contact with a heat source causing thermal expansion in the metrology frame, or includes or is in contact with a vibration source.

[0003] Attempting to cure the thermal expansion problem can give rise to the vibration problem. For example, one approach to maintain the temperature of the metrology frame is to pump fluid at a precisely controlled temperature through holes in the metrology frame. The fluid flow induces vibrations in the metrology system reducing the accuracy. Therefore, it is necessary to trade off temperature control for vibration control.

[0004] Other problems occur with heat sources in or on the metrology frame. More than one heat source can be present on or in the metrology frame. This causes complex distortions of the metrology frame, which cannot be accounted for through simple post-measurement correction. The heat production of the heat source can also be a function of time. For example, when the heat source is a drive motor, the drive motor produces the most heat when it is driving, changing temperature as it is turned on and off. Controlling the metrology frame temperature through cooling fluid temperature limits the ability to adapt to such changing conditions. The cooling fluid temperature must also be precisely controlled throughout the measurement to avoid introducing uncertainty.

[0005] Similar problems occur with other precision manufacturing operations requiring a dimensionally stable and vibration free work frame, such as optical semiconductor processing using wafer steppers and precision machining using precision milling machines.

[0006] It would be desirable to have a metrology system temperature control that overcomes the above disadvantages.

[0007] One aspect of the present invention provides a temperature control system for a frame, including a thermal electric cooling (TEC) element having a first face and a second face, the TEC element disposed to form a gap between the first face and the frame, and a fluid heat transfer element thermally connected to the second face.

[0008] Another aspect of the present invention provides a temperature control system for a frame, including a thermal electric cooling (TEC) element having a first face and a second face, and a thermal group including a thermal device and a fluid heat transfer element, the thermal device being thermally connected to the fluid heat transfer element, wherein the first face is thermally connected to the frame and the second face is thermally connected to the thermal group.

[0009] Another aspect of the present invention provides a temperature control system for a frame, including a thermal electric cooling (TEC) element having a first face and a sec-

ond face, and a fluid heat transfer element having a flushable reservoir, wherein the first face is thermally connected to the frame and the second face is thermally connected to the fluid heat transfer element.

[0010] Another aspect of the present invention provides a method of temperature control for a frame, including providing a thermal electric cooling (TEC) element and a fluid heat transfer element thermally connected to the TEC element, locating the TEC element near the frame to form a gap, and controlling the TEC element to transfer heat across the gap.

[0011] Another aspect of the present invention provides a temperature control system for a frame including a thermal electric cooling (TEC) element having a first face and a second face, a phase change element, and a fluid heat transfer element, wherein the first face is thermally connected to the frame and the second face is thermally connected to the phase change element, and the phase change element is thermally connected to the fluid heat transfer element.

[0012] The foregoing and other features and advantages of the invention will become further apparent from the following detailed description of the presently preferred embodiment, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the invention rather than limiting, the scope of the invention being defined by the appended claims and equivalents thereof.

[0013] FIGS. 1 & 2 are schematic diagrams of a temperature control system employing a gap made in accordance with the present invention;

[0014] FIGS. 3-6 are schematic diagrams of a temperature control system employing a thermal group made in accordance with the present invention;

[0015] FIG. 7 is a schematic diagram of a temperature control system employing a flushable reservoir made in accordance with the present invention;

[0016] FIG. 8 is a schematic diagram of a temperature control system employing a phase change element made in accordance with the present invention; and

[0017] FIG. 9 is a schematic diagram of an operational control system for a temperature control system made in accordance with the present invention.

[0018] FIGS. 1 & 2 are schematic diagrams of a temperature control system employing a gap made in accordance with the present invention. The temperature control system is separated from the frame by a gap, which avoids vibration from the temperature control system being transferred to the frame. Heat is exchanged between the temperature control system and the frame across the gap by radiative and/or conductive heat transfer.

[0019] Referring to FIG. 1, frame 20 includes a thermal device 22, such as a heat source or cold source. Temperature control system 30 includes thermal electric cooling (TEC) elements 32 and a fluid heat transfer element 38. The TEC elements 32 each have a first face 34 disposed toward the frame 20 and a second face 36 thermally connected to the fluid heat transfer element 38. A temperature controller (not shown) provides a TEC control signal to the TEC elements 32 to control heat transfer across the TEC elements 32. Temperature sensor 68 thermally connected to the frame 20 provides a measured frame temperature signal to the operational control system. The fluid heat transfer element 38 includes a fluid passage 40 permitting flow of a temperature control fluid, which is controlled by valve 72. The frame 20 is separated from the temperature control system 30 by gap 50. In one

embodiment, a TEC radiative coating **52** and/or a frame radiative coating **54** are disposed on the first face **34** of the TEC elements **32** and/or the frame **20**, respectively, to promote heat transfer across the gap **50**. In an alternative embodiment, no radiative coating is used.

[0020] The frame **20** is any frame for which dimensional stability and freedom from vibration are required, such as a metrology frame, semiconductor wafer stepper, precision milling machine stage, or the like. The thermal device **22** can be associated with operation and control of the frame **20**, such as a motor, drive system, hydraulic lines, or the like. The thermal device **22** can also be a specimen or workpiece being examined or worked on the frame **20**, or heating, cooling, motion, or control equipment associated with the specimen or workpiece. The thermal device **22** can be in direct contact with the frame **20** and exchange heat with the frame **20** by conduction, or can be near the frame **20** and exchange heat with the frame **20** by radiation and/or convection.

[0021] The TEC elements **32** are thermoelectric coolers, also known as Peltier coolers. The TEC elements **32** act as heat pumps, moving heat from one face to the other in response to a DC current TEC control signal. The direction of heat flow through the TEC elements **32** can be reversed by reversing the polarity of the DC current TEC control signal, providing precise temperature control. A typical TEC element includes semiconductor material between plates forming the faces. The TEC elements **32** can be a single TEC element or a number of individual TEC elements.

[0022] The gap **50** is of any width permitting radiative heat transfer between the frame **20** and the temperature control system **30**. Avoiding contact between the frame **20** and the temperature control system **30** prevents vibrations from the temperature control system **30**, such as vibrations from the fluid flow through the fluid heat transfer element **38**, from transferring to the frame **20**. The gap **50** can be large or small, as desired. In one embodiment, the gap **50** is about 4 millimeters or larger.

[0023] The fluid heat transfer element **38** exchanges heat with the TEC elements **32** and transfers the heat to the temperature control fluid flowing through the fluid passage **40**. The fluid heat transfer element **38** can include internal and/or external fins to further promote heat transfer from the temperature control fluid to the fluid heat transfer element **38** or from the fluid heat transfer element **38** to the surrounding environment. The temperature control fluid flowing through the fluid passage **40** can be water, oil, or any other fluid suitable for the temperature range of intended use. The valve **72**, such as a stop valve or a flow control valve, controls flow of the temperature control fluid through the fluid passage **40**. In one embodiment, the fluid passage **40** can include a flushable reservoir allowing rapid exchange of the temperature control fluid within the flushable reservoir. In an alternative embodiment, the flow of the temperature control fluid within the fluid passage **40** can be shut off during the measurement or manufacturing process on the frame **20** to further reduce any disturbances near the frame **20**.

[0024] The optional TEC radiative coating **52** and frame radiative coating **54** are high emissivity, high thermal conductivity coatings to promote radiative heat transfer between the frame **20** and the temperature control system **30** across the gap **50**. The coatings can be any high emissivity, high conductivity coating, such as those used in vacuum or solar applications, including metallic oxide coatings, glass (SiO₂) coatings, or ceramic coatings. In one embodiment, the coat-

ings are applied directly to the respective faces of the frame **20** and the fluid heat transfer element **38**. In an alternative embodiment, the coatings are applied to an additional layer, such as a copper plate, and the additional layer applied to the respective faces of the frame **20** and the fluid heat transfer element **38**.

[0025] Referring to FIG. 2, in which like elements share like reference numbers with FIG. 1, the temperature control system **30** controls the temperature locally by exchanging heat with the thermal device **22** directly. The gap **50** is formed about the thermal device **22**. In one embodiment, the TEC radiative coating **52** and/or a frame radiative coating **54** are disposed on the first face **34** of the TEC elements **32** and/or the thermal device **22**, respectively, to promote heat transfer across the gap **50**.

[0026] In operation, the temperature control system **30** exchanges heat with the frame **20** and/or the thermal device **22** to maintain the frame **20** at a constant temperature. For metrology applications, the temperature of the frame **20** is held stable to maintain a constant geometry for the frame **20**: the absolute temperature of the frame **20** is not critical. For manufacturing and biological applications, the temperature of the frame **20** is held at the desired temperature required by the process. The temperature sensor **68** thermally connected to the frame **20** provides an indication of the frame temperature. The temperature sensor **68** can be physically located anywhere on the frame **20** or fluid heat transfer element **38** that provides a suitable temperature measurement for the operational control system. As discussed in connection with FIG. 8 below, the control of the heat flow through the TEC elements **32** can use feedback control on temperature error and can optionally use feed forward control anticipating thermal load from the thermal device **22**. In one embodiment, the flow rate and/or temperature of the temperature control fluid through the fluid heat transfer element **38** can be varied to provide additional temperature control.

[0027] FIGS. 3-6, in which like elements share like reference numbers with each other and with FIG. 1, are schematic diagrams of a temperature control system employing a thermal group made in accordance with the present invention. The temperature control system employs a thermal group including a thermal device, which is associated with the frame, and a fluid heat transfer element.

[0028] Referring to FIG. 3, temperature control system **30** includes thermal electric cooling (TEC) elements **32** and a thermal group **60**. The TEC elements **32** each have a first face **34** thermally connected to the frame **20** and a second face **36** thermally connected to the thermal group **60**. The thermal group **60** includes a thermal device **22**, such as a heat source or cold source, associated with the frame **20** and a fluid heat transfer element **38**. The thermal device **22** is mechanically connected to the frame **20**, with the TEC elements **32** disposed between the thermal device **22** and the frame **20** in the embodiment illustrated. In one embodiment, the thermal device **22** is adjacent to the TEC elements **32**, the fluid heat transfer element **38** is further away from the frame **20** than the thermal device **22**, and the thermal device **22** is thermally connected to the second face **36**. In an alternative embodiment, the fluid heat transfer element **38** is adjacent to the TEC elements **32**, the thermal device **22** is further away from the frame **20** than the fluid heat transfer element **38**, and the fluid heat transfer element **38** is thermally connected to the second face **36**. A temperature controller (not shown) provides a TEC control signal to the TEC elements **32** to control heat transfer

across the TEC elements 32 between the frame 20 and the thermal group 60. The TEC elements 32 provide perfect insulation of the frame 20 by zeroing out heat transfer with the frame 20.

[0029] Referring to FIG. 4, the temperature control system 30 includes mounting pads 62 located between the thermal group 60 and the frame 20, in parallel with the TEC elements 32. The mounting pads 62 allow a firm mechanical connection between the thermal group 60 and the frame 20, while the TEC elements 32 manage heat transfer between the thermal group 60 and the frame 20.

[0030] In the embodiment illustrated in FIG. 5, the frame 20 includes an insulating layer 64 and a conducting layer 66 with the conducting layer 66 disposed on the insulating layer 64. The conducting layer 66 is thermally connected to the first face 34 of the TEC elements 32. The conducting layer 66 includes a temperature sensor 68 thermally connected to the conducting layer 66 to generate a measured frame temperature signal. The conducting layer 66 provides a homogeneous indication of frame temperature by being highly conductive, better smoothing out local temperature variations. The conducting layer 66 can be any material with high thermal conductivity, such as aluminum, copper, or the like. The insulating layer 64 can be any material with low thermal conductivity, such as plastic, ceramic, foam, or the like.

[0031] In the embodiment illustrated in FIG. 6, the frame 20 includes the insulating layer 64 and the conducting layer 66, with mounting pads 62 located between the thermal group 60 and the conducting layer 66 in parallel with the TEC elements 32. The mounting pads 62 allow a firm mechanical connection between the thermal group 60 and the frame 20, while the TEC elements 32 manage heat transfer between the thermal group 60 and the frame 20.

[0032] FIG. 7 is a schematic diagram of a temperature control system employing a flushable reservoir made in accordance with the present invention. The flushable reservoir allows rapid replacement of the temperature control fluid to provide fresh heat transfer capacity.

[0033] Temperature control system 30 includes thermal electric cooling (TEC) elements 32 and a fluid heat transfer element 38. The fluid heat transfer element 38 includes a body 74 and a fluid passage 40. Flushable reservoir 70 is included in the fluid passage 40 of the fluid heat transfer element 38 and contains the temperature control fluid (not shown). Valve 72 controls the flow through the fluid passage 40. Typically, the heat capacity of the temperature control fluid in the flushable reservoir 70 is larger than the heat capacity of the body 74 of the fluid heat transfer element 38, so that the temperature control fluid in the flushable reservoir 70 acts as the heat source or heat sink for the TEC elements 32. The temperature control fluid is flushed from the flushable reservoir 70 and replaced by fresh temperature control fluid, so that the heat source or heat sink is replenished for the next use.

[0034] In operation, the flushable reservoir 70 is filled and the valve 72 is shut to avoid any flow vibrations from the fluid heat transfer element 38 which could be transferred to the frame 20. The temperature control system 30 exchanges heat with the frame 20 through the TEC elements 32. The temperature of the temperature control fluid increases or decreases depending on whether the flushable reservoir 70 is a heat sink or heat source. When the temperature of the temperature control fluid reaches a limit, or the measuring or monitoring operation requiring minimal vibration has been completed, the valve 72 is opened to rapidly flush the tem-

perature control fluid from the flushable reservoir 70 and to provide fresh temperature control fluid. The valve 72 is closed and the fluid heat transfer element 30 is ready for the next use. Those skilled in the art will appreciate that the flushable reservoir 70 can be used with any of the temperature control systems described herein.

[0035] FIG. 8 is a schematic diagram of a temperature control system employing a phase change element made in accordance with the present invention. The phase change element acts as a thermal reservoir, allowing flow through the fluid heat transfer element to be shut off when minimal frame vibration is required.

[0036] Temperature control system 30 includes thermal electric cooling (TEC) elements 32, phase change element 76, and fluid heat transfer element 38. The TEC elements 32 are thermally connected to the frame 20 and the phase change element 76. The phase change element 76 is thermally connected to the fluid heat transfer element 38, which includes a fluid passage 40 for flow of a temperature control fluid. Valve 72 controls the flow through the fluid passage 40. The phase change element 76 includes phase change materials which change phase at or near the operating temperature of the TEC elements 32. In one embodiment, the fluid heat transfer element 38 is included as part of and incorporated within the phase change element 76 to increase the heat transfer between the phase change materials and the temperature control fluid.

[0037] The phase change in the phase change element 76 can be any phase change that absorbs or releases heat as desired for a particular application, such as a solid-liquid transition (heat of fusion), liquid-gas transition (heat of vaporization), or solid-gas transition (heat of sublimation). Examples of phase change materials that can be used in the phase change element 76 include water; salt hydrate, such as potassium fluoride tetrahydrate ($\text{KF}\cdot 4\text{H}_2\text{O}$) or calcium chloride hexahydrate ($\text{CaCl}_2\cdot 6\text{H}_2\text{O}$); or a eutectic mixture, such as a salt-water mixture, like a sodium chloride (NaCl)-water mixture. Those skilled in the art will appreciate that a number of phase change materials are suitable for use in the phase change element 76 depending on the particular phase change temperature desired. For example, salt hydrate can be used around room temperature and a salt-water eutectic mixture can be used around a low temperature of about -20 degrees C.

[0038] In operation, the valve 72 is shut to avoid any flow vibrations from the fluid heat transfer element 38 which could be transferred to the frame 20. The temperature control system 30 exchanges heat with the frame 20 through the TEC elements 32. The phase change materials in the phase change element 76 change phase in response to the heat transfer with the TEC elements 32. When the measuring or monitoring operation requiring minimal vibration has been completed, the valve 72 is opened to provide temperature control fluid through the fluid passage 40. The phase change materials return to their initial state and the phase change element 76 is ready for the next use. Those skilled in the art will appreciate that the phase change element 76 can be used with any of the temperature control systems described herein.

[0039] FIG. 9, in which like elements share like reference numbers with FIG. 1, is a schematic diagram of an operational control system for a temperature control system made in accordance with the present invention. The operational control system provides a TEC control signal to the TEC elements to control heat transfer across the TEC elements.

[0040] The operational control system 100 includes a temperature sensor 68 being thermally connected to the frame

and generating a measured frame temperature signal 102. In one embodiment, a number of temperature sensors can be a thermally connected to the frame and their outputs combined so that the measured frame temperature signal indicates an average or weighted average frame temperature. A desired temperature T_{set} 104 is set manually or determined by another control system and a desired temperature signal 106 generated. The measured frame temperature signal 102 and the desired temperature signal 106 are compared at comparator 108 and a temperature difference signal 110 generated. A temperature controller 112 is responsive to the temperature difference signal 110 and generates a TEC control signal 114, which controls heat flow through the TEC elements 32.

[0041] In one embodiment, the temperature controller 112 is additionally responsive to a thermal device signal 118, providing feed forward control. A thermal device controller 116 controls the thermal device 22, such as a motor or drive system. The thermal device controller 116 generates the thermal device signal 118, which is provided to both the thermal device 22 and the temperature controller 112. The temperature controller 112 adjusts the TEC control signal 114 to anticipate the change in heat load to the frame from any change in operation of the thermal device 22. The temperature controller 112 can include modeling of the thermal transient response of the frame and the thermal device 22 to account for lag between the control signal and the thermal response. Those skilled in the art will appreciate that the operational control system 100 can be used with any of the temperature control systems described herein.

[0042] While the embodiments of the invention disclosed herein are presently considered to be preferred, various changes and modifications can be made without departing from the scope of the invention. The scope of the invention is indicated in the appended claims, and all changes that come within the meaning and range of equivalents are intended to be embraced therein.

1. A temperature control system for a frame 20 comprising:
 - a thermal electric cooling (TEC) element 32, the TEC element 32 having a first face 34 and a second face 36, the TEC element 32 disposed to form a gap 50 between the first face 34 and the frame 20; and
 - a fluid heat transfer element 38, the fluid heat transfer element 38 being thermally connected to the second face 36.
2. The system of claim 1 further comprising a TEC radiative coating 52 disposed on the first face 34.
3. The system of claim 1 wherein the frame 20 has a frame radiative coating 54.
4. The system of claim 1 wherein the frame 20 has a thermal device 22 and the gap 50 is formed about the thermal device 22.
5. The system of claim 1 further comprising:
 - a temperature sensor 68, the temperature sensor 68 being thermally connected to the frame 20 and generating a measured frame temperature signal 102;
 - a comparator 108, the comparator 108 determining a difference between the measured frame temperature signal 102 and a desired temperature signal 106, and generating a temperature difference signal 110; and
 - a temperature controller 112, the temperature controller 112 being responsive to the temperature difference signal 110 and generating a TEC control signal 114; wherein the TEC element 32 is responsive to the TEC control signal 114.

6. The system of claim 5 wherein the frame 20 has a thermal device 22, further comprising:

- a thermal device controller 116, the thermal device controller 116 operably connected to control the thermal device 22, and generating a thermal device signal 118; wherein the temperature controller 112 is additionally responsive to the thermal device signal 118.

7. The system of claim 1 wherein the fluid heat transfer element 38 has a flushable reservoir 70.

8. The system of claim 1 wherein the fluid heat transfer element 38 has a fluid passage 40 and a valve 72 connected to control flow through the fluid passage 40, the valve 72 being selected from the group consisting of a stop valve and a flow control valve.

9. A temperature control system for a frame 20 comprising:
 - a thermal electric cooling (TEC) element 32, the TEC element 32 having a first face 34 and a second face 36; and

a thermal group 60, the thermal group 60 having a thermal device 22 and a fluid heat transfer element 38, the thermal device 22 being thermally connected to the fluid heat transfer element 38;

wherein the first face 34 is thermally connected to the frame 20 and the second face 36 is thermally connected to the thermal group 60.

10. The system of claim 9 wherein the thermal device 22 is thermally connected to the second face 36.

11. The system of claim 9 wherein the fluid heat transfer element 38 is thermally connected to the second face 36.

12. The system of claim 9 further comprising a mounting pad between the thermal group 60 and the frame 20 in parallel with the TEC element 32.

13. The system of claim 9 wherein the frame 20 has an insulating layer 64 and a conducting layer 66, wherein the conducting layer 66 is disposed on the insulating layer 64, and the conducting layer 66 is thermally connected to the first face 34.

14. The system of claim 13 further comprising a mounting pad 62 between the first face 34 and the frame 20 in parallel with the TEC element 32.

15. The system of claim 13 further comprising a temperature sensor 68 thermally connected to the conducting layer 66, the temperature sensor generating 68 a measured frame temperature signal.

16. The system of claim 9 further comprising:

- a temperature sensor 68, the temperature sensor 68 being thermally connected to the frame 20 and generating a measured frame temperature signal 102;

a comparator 108, the comparator 108 determining a difference between the measured frame temperature signal 102 and a desired temperature signal 106, and generating a temperature difference signal 110; and

a temperature controller 112, the temperature controller 112 being responsive to the temperature difference signal 110 and generating a TEC control signal 114;

wherein the TEC element 32 is responsive to the TEC control signal 114.

17. The system of claim 16 wherein the frame 20 has a thermal device 22, further comprising:

- a thermal device controller 116, the thermal device controller 116 operably connected to control the thermal device 22, and generating a thermal device signal 118; wherein the temperature controller 112 is additionally responsive to the thermal device signal 118.

18. The system of claim 9 wherein the fluid heat transfer element 38 has a flushable reservoir 70.

19. The system of claim 9 wherein the fluid heat transfer element 38 has a fluid passage 40 and a valve 72 connected to control flow through the fluid passage 40, the valve 72 being selected from the group consisting of a stop valve and a flow control valve.

20. A temperature control system for a frame 20 comprising:

a thermal electric cooling (TEC) element 32, the TEC element 32 having a first face 34 and a second face 36; and

a fluid heat transfer element 38, the fluid heat transfer element 38 having a flushable reservoir 70;

wherein the first face 34 is thermally connected to the frame 20 and the second face 36 is thermally connected to the fluid heat transfer element 38.

21. The system of claim 20 further comprising:

a temperature sensor 68, the temperature sensor 68 being thermally connected to the frame 20 and generating a measured frame temperature signal 102;

a comparator 108, the comparator 108 determining a difference between the measured frame temperature signal 102 and a desired temperature signal 106, and generating a temperature difference signal 110; and

a temperature controller 112, the temperature controller 112 being responsive to the temperature difference signal 110 and generating a TEC control signal 114; wherein the TEC element 32 is responsive to the TEC control signal 114.

22. The system of claim 21 wherein the frame 20 has a thermal device 22, further comprising:

a thermal device controller 116, the thermal device controller 116 operably connected to control the thermal device 22, and generating a thermal device signal 118;

wherein the temperature controller 112 is additionally responsive to the thermal device signal 118.

23. The system of claim 20 wherein the fluid heat transfer element 38 has a valve 72 connected to control flow through the flushable reservoir 70, the valve 72 being selected from the group consisting of a stop valve and a flow control valve.

24. A method of temperature control for a frame comprising:

providing a thermal electric cooling (TEC) element and a fluid heat transfer element thermally connected to the TEC element;

locating the TEC element near the frame to form a gap; and controlling the TEC element to transfer heat across the gap.

25. A temperature control system for a frame 20 comprising:

a thermal electric cooling (TEC) element 32, the TEC element 32 having a first face 34 and a second face 36; a phase change element 76; and

a fluid heat transfer element 38;

wherein the first face 34 is thermally connected to the frame 20 and the second face 36 is thermally connected to the phase change element 76, and the phase change element 76 is thermally connected to the fluid heat transfer element 38.

26. The system of claim 25 further comprising:

a temperature sensor 68, the temperature sensor 68 being thermally connected to the frame 20 and generating a measured frame temperature signal 102;

a comparator 108, the comparator 108 determining a difference between the measured frame temperature signal 102 and a desired temperature signal 106, and generating a temperature difference signal 110; and

a temperature controller 112, the temperature controller 112 being responsive to the temperature difference signal 110 and generating a TEC control signal 114;

wherein the TEC element 32 is responsive to the TEC control signal 114.

27. The system of claim 26 wherein the frame 20 has a thermal device 22, further comprising:

a thermal device controller 116, the thermal device controller 116 operably connected to control the thermal device 22, and generating a thermal device signal 118;

wherein the temperature controller 112 is additionally responsive to the thermal device signal 118.

28. The system of claim 25 wherein the fluid heat transfer element 38 has a valve 72 connected to control flow through the flushable reservoir 70, the valve 72 being selected from the group consisting of a stop valve and a flow control valve.

29. The system of claim 25 wherein the phase change element 76 comprises a phase change material selected from the group consisting of water, salt hydrate, potassium fluoride tetrahydrate, calcium chloride hexahydrate, a eutectic mixture, a salt-water mixture, and a sodium chloride-water mixture.

* * * * *