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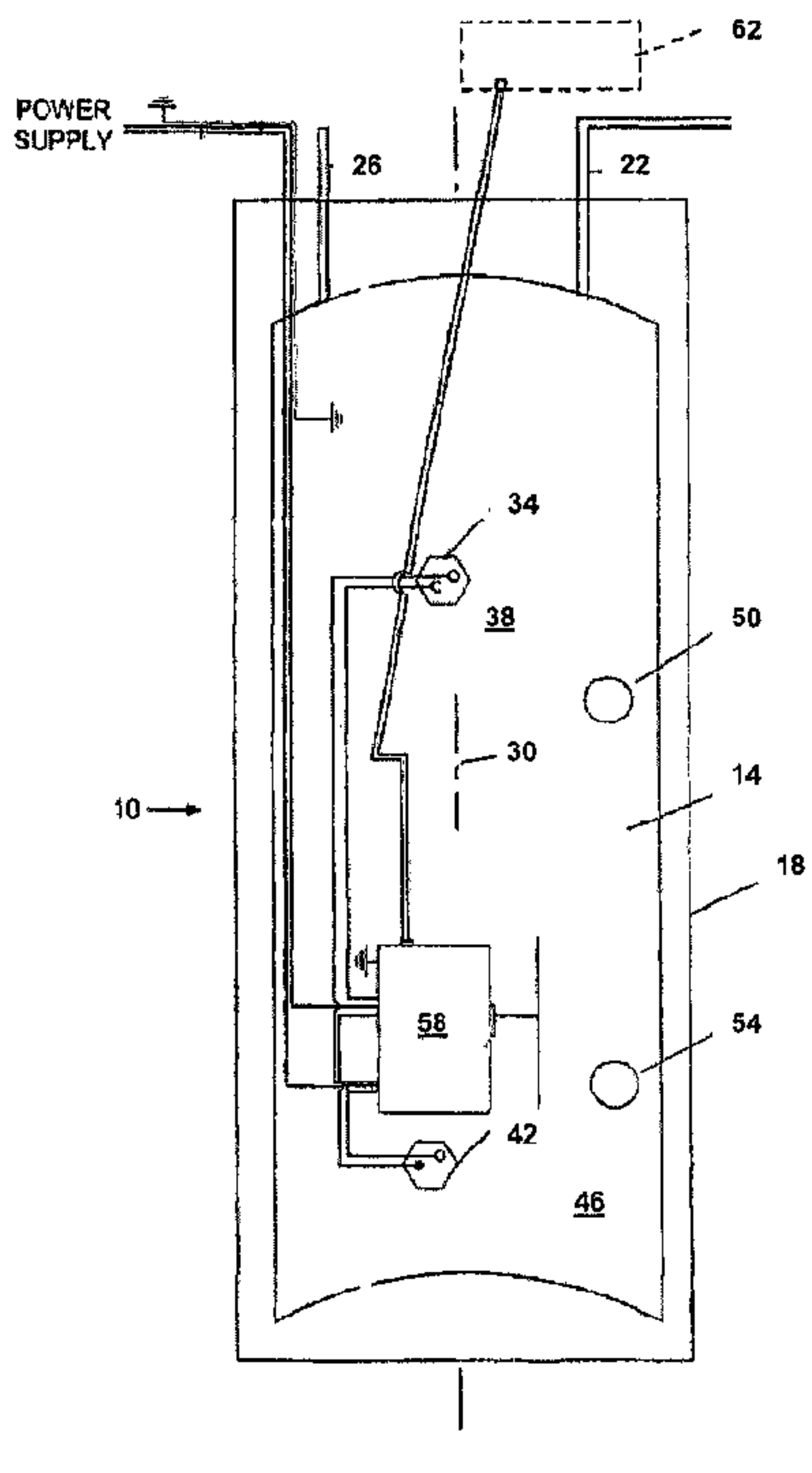
(54) Titre : CHAUFFE-EAU DE TYPE ENTREPOSAGE ET CONTROLE ASSOCIE FONDE SUR LA DEMANDE D'EAU
(54) Title: STORAGE-TYPE WATER HEATER AND CONTROL THEREOF BASED ON WATER DEMAND



(57) Abrégé/Abstract:
A storage-type water heater with a controller. The controller controls an upper heating element such that an upper zone water temperature is maintained proximate a temperature setpoint. The controller calculates a temperature differential based on a difference between an upper zone water temperature and a lower zone water temperature. The controller controls a lower heating element such that the temperature differential does not exceed a first limit during periods of low predicted water demand and such that the temperature differential does not exceed a second limit during periods of high predicted water demand. Periodically, the controller switches from the first limit to the second limit during periods of low predicted water demand.

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ABSTRACT

A storage-type water heater with a controller. The controller controls an upper heating element such that an upper zone water temperature is maintained proximate a temperature setpoint. The controller calculates a temperature differential based on a difference between an upper zone water temperature and a lower zone water temperature. The controller controls a lower heating element such that the temperature differential does not exceed a first limit during periods of low predicted water demand and such that the temperature differential does not exceed a second limit during periods of high predicted water demand. Periodically, the controller switches from the first limit to the second limit during periods of low predicted water demand.

STORAGE-TYPE WATER HEATER AND CONTROL THEREOF BASED ON WATER DEMAND

[0001]

BACKGROUND

[0002] The invention relates to water heaters and methods of operating water heaters.

[0003] Some aspects of the invention address the problem of reducing electrical energy consumption in water heaters through a method of controlled, intentional thermal stratification of the water within the tank. While reducing the differential between the average internal water temperature and the ambient air temperature surrounding the water tank reduces heat loss from the tank, reducing the internal water temperature below 60 degrees centigrade can promote undesirable bacterial growth.

SUMMARY

[0004] In one embodiment, the invention provides a method of limiting bacterial growth while simultaneously reducing energy consumption throughout various cyclic periods.

[0005] In another embodiment, the invention provides a storage-type water heater including a water tank and a control system. The water tank has an inner surface and a vertical axis. The control system includes upper and lower electric-resistance heating elements. The upper and lower heating elements include upper and lower thermal surfaces, respectively, disposed within the inner surface of the tank at first and second locations, respectively. The control system also includes upper and lower temperature sensors. The upper and lower temperature sensors can be located proximate the upper and lower heating elements, respectively.

[0006] In another embodiment the invention provides a method of heating water stored by a storage-type water heater. In one embodiment, the method includes sensing a first temperature with an upper temperature sensor; sensing a second temperature with a lower temperature sensor, controllably powering the lower heating element and controllably powering the upper heating element, including powering the upper heating element based on if the first temperature is below a first set point, and powering the lower heating element based on if the difference between the first and second sensed temperatures is less than a difference set point. The method can further include periodically reducing the difference set point. In one implementation, reducing the difference set point allows the lower heating element to be periodically energized to raise the temperature throughout the water heater volume to a level sufficient to limit, or possibly prevent, bacterial growth.

[0007] In another embodiment, the invention provides a storage-type water heater. The water heater includes a water tank having an inner surface, a vertical axis, an upper zone, a lower zone, an upper heating element and a lower heating element disposed below the upper heating element with respect to the vertical axis. The upper heating element and the lower heating element are provided for heating water within the water tank. An upper temperature sensor is configured to produce a signal having a relation to a water temperature within the upper zone. A lower temperature sensor is configured to produce a signal having a relation to a water temperature within the lower zone. A controller is configured to receive the signal from the upper temperature sensor and determine an upper zone water temperature and to receive the signal from the lower temperature sensor and determine a lower zone water temperature. The controller controls the upper heating element such that the upper zone water temperature is maintained proximate to a temperature setpoint. The controller controls the lower heating element such that a temperature differential does not exceed a first limit during periods of a first water demand and such that the temperature differential does not exceed a second limit during periods of a second water demand, wherein the first water demand is smaller than the second water demand and the first limit is larger than the second limit.

[0008] In another embodiment, the invention provides a method of heating water stored by a storage-type water heater having an upper heating element, a lower heating element, an upper temperature sensor, a lower temperature sensor and a controller. The method includes sensing a first temperature with the upper temperature sensor and sensing a second temperature with the lower temperature sensor. The lower heating element and the upper heating element are controllably powered, including powering the upper heating element based on if the first temperature is below a first set point, and powering the lower heating element based on if the difference between the first and second sensed temperatures is less than a difference setpoint. The difference setpoint is adjusted based on water demand such that the difference setpoint has a first value during periods of a first water demand and such that the difference setpoint has a second value during periods of a second water demand, wherein the first water demand is smaller than the second water demand and the first value is larger than the second value. In some embodiments, the difference set point is periodically reduced such that the

lower heating element is periodically energized to raise the temperature throughout the water heater volume to a level sufficient to limit bacterial growth.
The difference setpoint may also be reduced in response to actual water usage.

[0009] In yet another embodiment, the invention provides a method of heating water stored by a storage-type water heater having an upper heating element, a lower heating element, an upper temperature sensor, a lower temperature sensor and a controller. The method includes sensing a first temperature with the upper temperature sensor and sensing a second temperature with the lower temperature sensor. The lower heating element and the upper heating element are controllably powered, including powering the upper heating element based on if the first sensed temperature is below a first set point, and powering the lower heating element based on if the second sensed temperatures is below a second set point. The second set point is periodically increased such that the lower heating element is periodically energized to raise a temperature throughout a water volume to a level sufficient to limit bacterial growth.

[0010] Other aspects of the invention will become apparent by consideration of the detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a schematic representation of a water heater incorporating the invention.

[0012] FIG. 2 is a block diagram of a primary electrical system for the water heater of FIG. 1.

[0013] FIG. 3 is a flow chart representation of a method of operating the water heater of FIG. 1.

DETAILED DESCRIPTION

[0014] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways.

[0015] As shown in the FIG.1, a water heater 10 has a water tank 14 surrounded by an insulation jacket 18. A cold water inlet tube 22 and a hot water outlet tube 26 are provided for connection to a cold water supply and a hot water manifold of a building, respectively. When installed, the water tank 14 is oriented with a vertical axis 30.

[0016] An upper electric heating element 34 is disposed within an upper zone 38 of the water tank 14 relative to axis 30. A lower electrical heating element 42 is disposed within a lower zone 46 of the water tank 14 relative to axis 30. As used herein, the zones may also be described as regions or portions of the water tank. An upper temperature sensor 50 is disposed proximate the upper heating element 34 in the upper zone 38. A lower temperature sensor 54 is disposed proximate the lower heating element 42 in the lower zone 46. Other constructions of the water heater can include a different number of heating elements or temperature sensors and the location of the elements and sensors may vary.

[0017] The upper and lower heating elements 34 and 42 and upper and lower temperature sensors 50 and 54 are part of an overall water heater control system including a control module 58 and an operator interface 62. In some embodiments, a cold water inlet temperature sensor is included at an internal location adjacent or within the water inlet tube 22. In the construction shown, temperature sensors 50 and 54 provide inputs to the control module 58 in order to control the upper and lower heating elements 34 and 42. The temperature inputs may take the form of a voltage, current, resistance, frequency, or other value or signal type that may be correlated or related to a temperature. Other constructions of the water heater can include different or additional control sensors, and it should be understood that not all of the control sensors shown are required for all constructions. Furthermore, in some constructions the control module and operator interface may be integrated into a single unit.

[0018] The control module 58 is mounted within, outside of, or on top of the water heater jacket 18. The control module 58 derives its power from a 110 volt, 240 volt, or 480 volt power supply. The control module 58 may receive control instructions (or signals) from the operator interface 62. The control module 58 provides all of the current-handling interfaces between the heating elements 34 and 42 and the electrical mains (not shown). The control module 58 contains power switching components for the heating elements 34 and 42, the controller power supply, one or more processing devices, and various sensing and power connection terminations. The control sensors are electrically connected to the control module 58.

[0019] The interface 62 shown in FIG. 1 allows an operator (a user or technician, for example) to interact with the control module 58. Further, it is envisioned that other programmable devices and/or processing or control modules or circuits can be used with the water heater 10. For example, a second input/output interface can be used to allow the water heater to interact with an external control device. The interface 62 operates on utility power. In some constructions, the interface 62 may also include a battery backup power source for program retention in the event of a power failure. The interface 62 may be mounted on the water heater jacket 18, remotely from the water heater 10 in the same room (e.g., on a wall), in another room in the building, outside of the building, or even incorporated with the control module 58. The connection between the control module 58 and the interface 62 may include a 2-wire bus system, a 4-wire bus system, or a radio wave signal.

[0020] As shown in FIG. 2, the control module 58 includes a microcontroller 66. The microcontroller 66 is set via the interface 62. In one construction, the interface 62 includes a touch pad or keyboard and a visual display, both of which are backlit for ease of operation. Using the interface, the operator may determine the nominal hot water temperature set point within a permissible range (e.g., 60-65° C). Although the term "set point" has been used in the singular to refer to a single point of reference, it should be recognized by one skilled in the art that for some implementations, multiple set points, or thresholds, about a nominal reference point may be desirable to prevent excessive thermal cycling of the heater elements, to minimize temperature overshoot, and for greater efficiency. In some constructions, an "ON" temperature set point may be selected below an "OFF" temperature set point. As the names imply, the OFF temperature is the temperature at which the control system turns the upper heating element 34 OFF, and the ON temperature is the temperature at which the control system turns the upper heating elements 34 ON.

[0021] In addition to setting a hot water set point for the upper heating element 34, the operator may also select one or more allowable temperature differentials. In some implementations, the allowable temperature differential is the difference between the higher temperature sensed by the upper temperature sensor 50 and the lower temperature sensed by the lower temperature sensor 54. As described in greater detail below, a larger differential value is used during periods of low water demand, resulting in a greater degree of temperature stratification, while a smaller differential value is used during periods of higher water demand, resulting in reduced temperature stratification. As one skilled in the art will recognize, other implementations may use separate set points for the lower heating element 42 instead of relying on a temperature differential and dependence on the upper set point. Also, as one skilled in the art will recognize, other implementations may use a percentage of the set point for activating the upper heating element as a set point for activation of the lower heating element. It also envisioned that different arrangements for activating the heating elements may be used depending on the number of heating elements and the number of temperature sensors.

[0022] In some constructions, the interface 62 may include indicators for the mode of the control system (e.g., manual, automatic, or vacation). The interface 62 may include a "power on" indicator and an indicator for each heating element 34 and 42 to indicate whether the element is active. Such indicators would aid both the installer and the end user. The interface 62 may also include a port (e.g., an RS232 port) for computer hookup.

[0023] FIG. 2 is a block diagram for one construction of a control system 70 used for controlling the heating elements 34 and 42. The control system 70 includes the control module 58 with the microcontroller 66. The microcontroller 66 receives signals or inputs from the temperature sensors 50 and 54 via signal conditioners 74 and 78, respectively. The microcontroller 66 then analyzes the inputs, and generates one or more outputs to control the upper and/or lower heater elements 34 and 42 via relays 82 and 86, respectively. In one construction, the microcontroller 66 includes a microprocessor 90 and memory 94. The memory 94 includes one or more modules having instructions. The microprocessor 90 obtains, interprets, and executes the instructions to control the water heater. Although the microcontroller 66 is described as having a processor and memory, the invention may be implemented with other controllers or devices including a variety of timers, integrated circuits (e.g., an application-specific-integrated circuit) and discrete devices, as would be apparent to one of ordinary skill in the art.

[0024] In one mode of operation, the time between demands for hot water is monitored to determine when the need for hot water is likely to be absent, such as when a home is unoccupied during the day. Over a period of multiple use cycles, the microcontroller 66 determines during which periods the demand for hot water is likely to be low and during which periods the demand for hot water is likely to be high. In other constructions, periods of predicted low and high demand may be manually selected with a programmable or mechanical timer.

[0025] The logic described by the following paragraphs is generally shown graphically in FIG. 3. During periods of predicted high hot water demand, the microcontroller 66 causes the upper heating element 34 to maintain the upper zone 38 of the tank at its nominal hot thermostat set point. Relying on a small allowable temperature differential set point (e.g., 3°C), the microcontroller 66 causes the lower heating element 42 to maintain the lower zone 46 of the tank's water volume within a small temperature differential of the upper zone 38 of the water volume. Thus, during periods of predicted high hot water demand, temperature stratification throughout the water volume is minimized and a large volume of hot water is ready for use.

[0026] During the periods of predicted low demand, the microcontroller 66 again causes the upper heating element 34 to maintain the upper zone 38 of the tank at its nominal hot thermostat set point. However, during these periods of predicted low demand, the microcontroller 66 switches to a large temperature differential set point. In one embodiment, the large differential set point may be in the range of 10-30°C. In a preferred embodiment, the large differential set point may be in the range of 15-25°C. In an even more preferred embodiment, the large differential set point may be in the range of 18-22°C. By increasing the allowable differential between the upper and lower temperature sensors 50 and 54, the lower heating element 42 remains de-energized for longer periods of time and the lower zone 46 of the tank volume settles to temperatures significantly below those in the upper zone 38 of the tank volume. Thereby, the system induces intentional thermal stratification of the water within the tank between the upper and lower zones 38 and 46 within. By maintaining only the upper zone 38 of the tank at the nominal "hot" set point, a reserve of hot water is maintained in standby for immediate use. However, the reduced temperature in the lower zone 46 of the tank reduces the overall average temperature of the water volume as a whole. Thereby, the average temperature differential between the inside of the tank and the ambient air surrounding the tank is reduced. Reducing the average temperature gradient across the tank wall reduces the rate of heat losses to the ambient surroundings, and thereby makes the water heater more efficient.

[0027] In some implementations, the hot water outlet tube 26 draws from the upper zone 38 of the water volume, while the cold water inlet tube 22 feeds cold supply water into the cooler, lower zone 46 of the water volume. Therefore, from perspective of the end-user, a volume of hot water remains available for immediate draw at both high and low degrees of stratification.

[0028] While thermally stratifying the water heater tank between a hot, upper zone 38 and a cooler, lower zone 46 results in increased energy efficiency during periods of predicted non-use, maintaining stagnant water within certain temperature ranges can promote the growth of certain bacteria (e.g., legionella). Warm, stagnant water provides ideal conditions for growth. At temperatures between 20°C-50°C (68°-122°F) the organism can multiply. Temperatures of 32°C-40°C (90°-105°F) are ideal for growth. Rust (iron), scale, and the presence of other microorganisms can also promote the growth of bacteria.

[0029] In order to limit or prevent the growth of legionella and other bacteria during low demand periods, the maximum temperature differential between the upper temperature sensor 50 and the lower temperature sensor 54 is periodically reduced based on a programmed timing sequence. The timing sequence may be user-determined in some implementations, or pre-set by the factory or installing technician in other implementations. Periodically reducing the allowable differential (e.g., to 0-3°C) causes the lower heating element 42 to be energized, raising the temperature within the lower zone 46 of the water volume sufficient to limit and/or reverse bacterial growth that occurred during the period of elevated stratification. Once the lower zone 46 of the water volume has been elevated to within the smaller temperature differential for a sufficient period of time, the microcontroller 66 once again increases the allowable temperature differential, allowing the lower heating element 42 to remain de-energized and stratification to once again occur. Through this process, the control system 70 minimizes bacterial growth by periodically interrupting the conditions necessary to promote actual growth.

[0030] In most constructions, the microcontroller 66 will automatically reduce the allowable temperature differential between the upper and lower temperature sensors 50 and 54 during periods of actual or predicted use. For example, a small amount of cold water entering the tank from a water draw, similar to what is needed for washing hands, signals the microcontroller 66 that the home is now occupied. The microcontroller 66 responds by switching to the smaller temperature differential setting and a larger volume of hot water becomes available for use.

[0031] Thus, the invention provides, among other things, a new and useful method of controlling bacterial growth in a water heater tank while simultaneously reducing energy consumption throughout various cyclic periods.

CLAIMS:

1. A storage-type water heater comprising:

a water tank having an inner surface, a vertical axis, an upper zone and a lower zone;

an upper heating element;

a lower heating element disposed below the upper heating element with respect to the vertical axis, the upper heating element and the lower heating element for heating water within the water tank;

an upper temperature sensor configured to produce a signal having a relation to a water temperature within the upper zone;

a lower temperature sensor configured to produce a signal having a relation to a water temperature within the lower zone;

a controller configured to:

receive the signal from the upper temperature sensor and determine an upper zone water temperature;

receive the signal from the lower temperature sensor and determine a lower zone water temperature;

control the upper heating element such that the upper zone water temperature is maintained proximate to a temperature setpoint; and

control the lower heating element such that a temperature differential does not exceed a first limit during periods of a first water demand and such that the temperature differential does not exceed a second limit during periods of a second water demand,

wherein the first water demand is smaller than the second water demand and the first limit is larger than the second limit.

2. The storage-type water heater of claim 1, wherein the controller is further configured to determine a temperature differential based on the difference between the upper zone water temperature and the lower zone water temperature.

3. The storage-type water heater of claim 1, wherein the first water demand occurs during a period of low predicted water demand and the second water demand occurs during a period of high predicted water demand.

4. The storage-type water heater of claim 3, wherein the controller is further configured to periodically switch from the first limit to the second limit during periods of low predicted water demand in order to limit the growth of bacteria within the water tank.

5. The storage-type water heater of claim 1, wherein the controller is a programmable microcontroller.

6. The storage-type water heater of claim 5, wherein the controller includes a memory module.

7. The storage-type water heater of claim 3, wherein the controller determines the periods of low predicted water demand and high predicted water demand from past usage.

8. The storage-type water heater of claim 3, wherein the controller includes a timer for setting the periods of low predicted water demand and high predicted water demand.

9. The storage-type water heater of claim 1, further comprising an operator interface configured for the entry and display of operating parameters of the controller.

10. The storage-type water heater of claim 1, wherein the controller is configured to respond to actual water usage by switching from the first limit to the second limit.

11. The storage-type water heater of claim 1, wherein the setpoint includes an ON setpoint and an OFF setpoint.

12. The storage-type water heater of claim 1, wherein the first limit is in the range of 10-30°C.

13. The storage-type water heater of claim 1, wherein the second limit is in the range of 0-3°C.

14. A method of heating water stored by a storage-type water heater having an upper heating element, a lower heating element, an upper temperature sensor, a lower temperature sensor and a controller, the method comprising:

sensing a first temperature with the upper temperature sensor;

sensing a second temperature with the lower temperature sensor;

controllably powering the lower heating element and controllably powering the upper heating element, including powering the upper heating element based on if the first temperature is below a first setpoint, and powering the lower heating element based on if the difference between the first and second sensed temperatures is less than a difference setpoint; and

adjusting the difference setpoint based on water demand such that the difference setpoint has a first value during periods of a first water demand and such that the difference setpoint has a second value during periods of a second water demand,

wherein the first water demand is smaller than the second water demand and the first value is larger than the second value.

15. The method of claim 14, further comprising

periodically reducing the difference setpoint such that the lower heating element is periodically energized to raise the temperature throughout the water heater volume to a level sufficient to limit bacterial growth.

16. The method of claim 14 or 15, wherein adjusting the difference setpoint based on water demand comprises

reducing the difference setpoint in response to actual water usage.

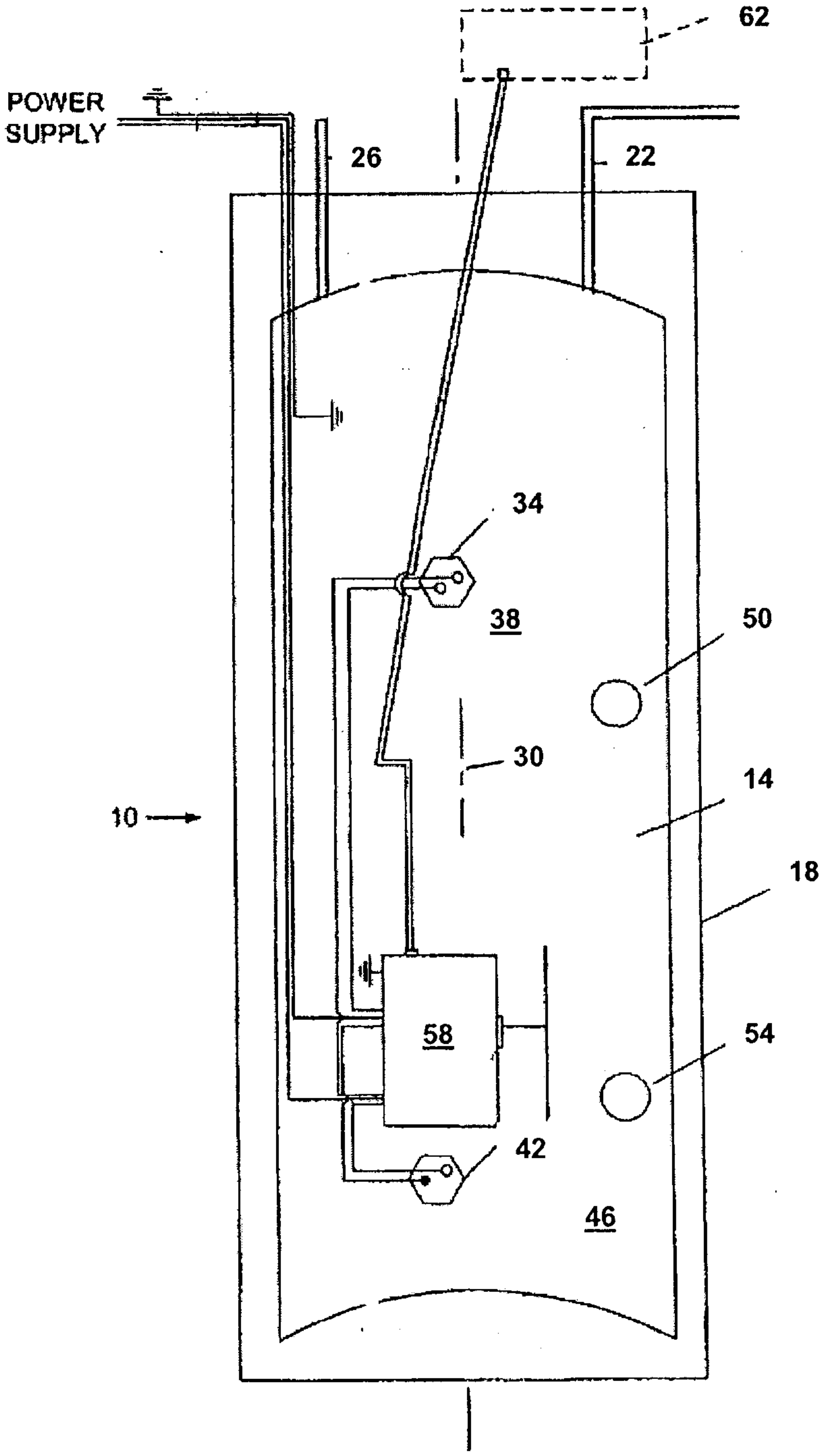


FIG. 1

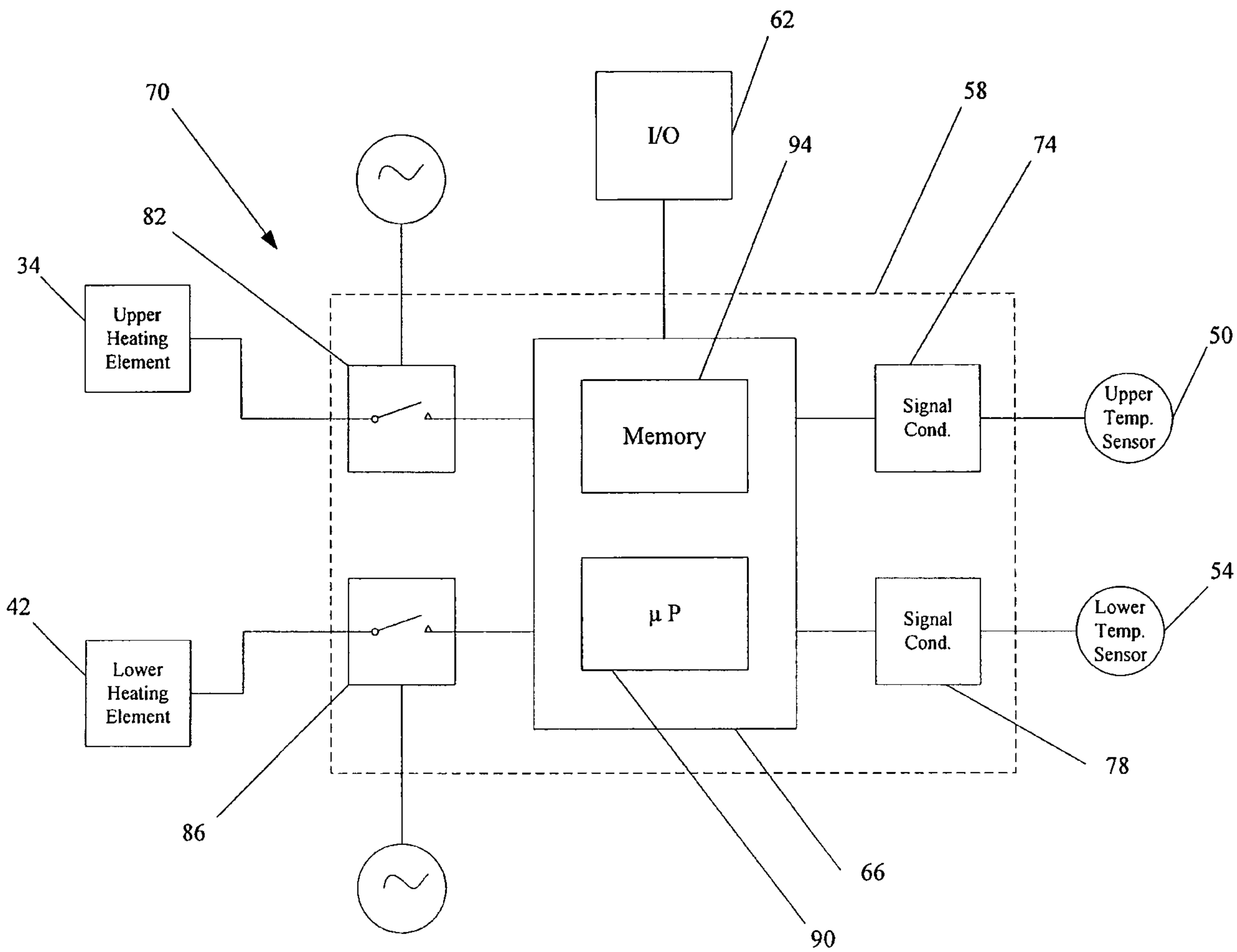

62
70
I/O
58
94
74
82
34
Upper Heating Element
50
Memory
Signal Cond.
Upper Temp. Sensor
54
42
μ P
Signal Cond.
Lower Temp. Sensor
Lower Heating Element
78
86
66
90

FIG. 2

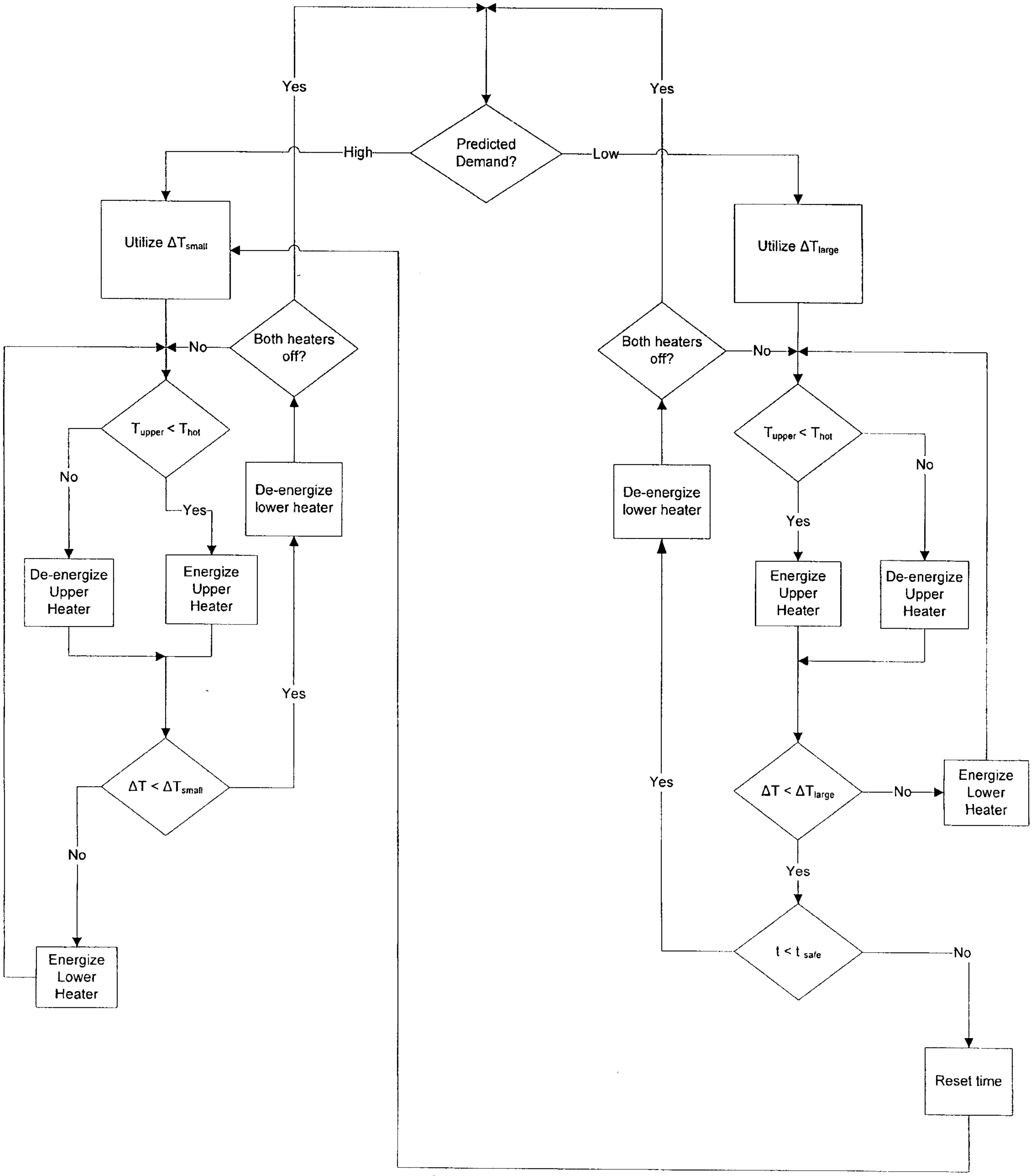
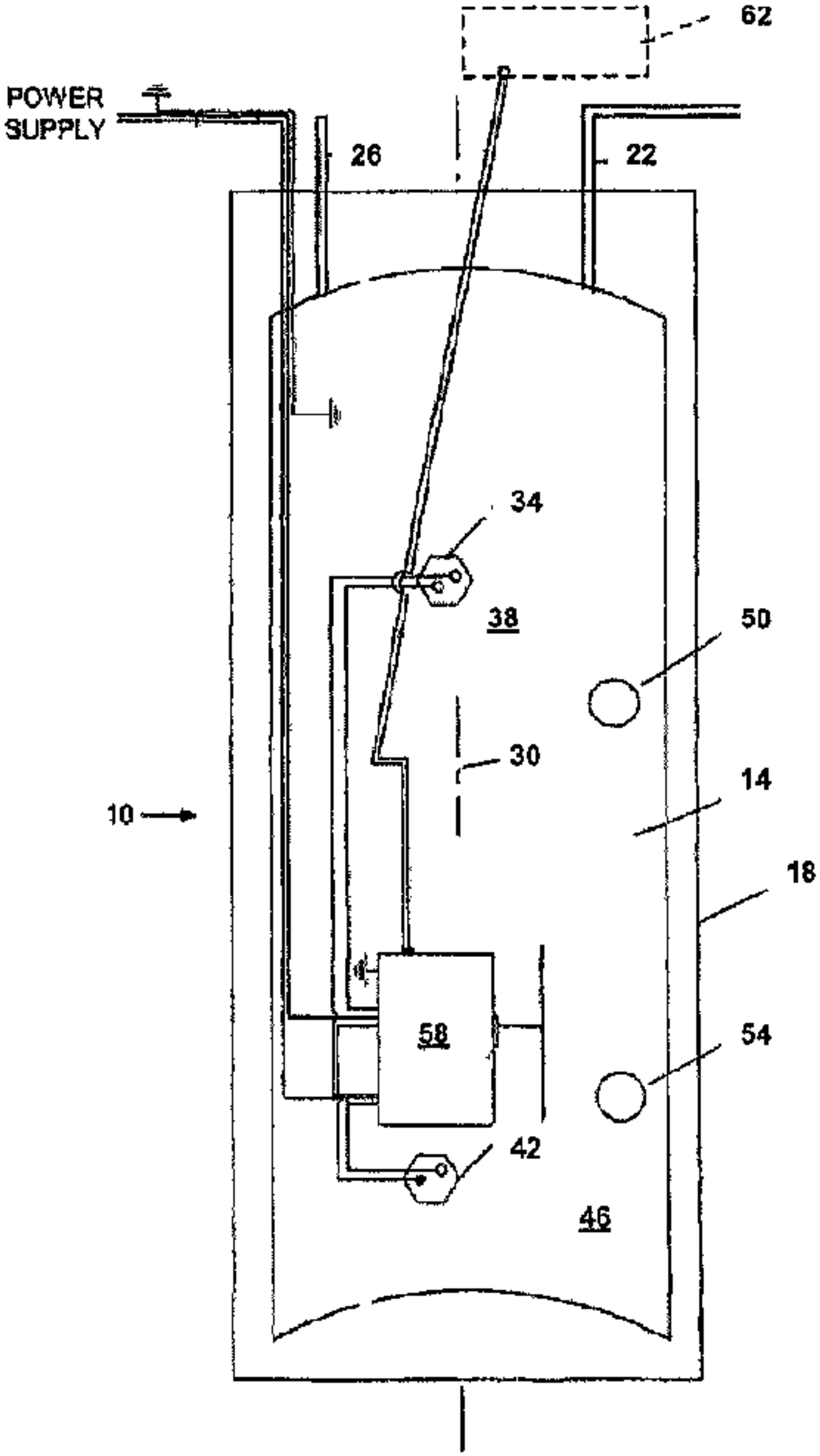

Predicted Demand?
High
Low
Yes
Yes
Utilize ΔT_{small}
Utilize ΔT_{large}
Both heaters off?
No
Both heaters off?
No
$T_{upper} < T_{hot}$
No
Yes
$T_{upper} < T_{hot}$
No
Yes
De-energize lower heater
De-energize lower heater
De-energize Upper Heater
Energize Upper Heater
Energize Upper Heater
De-energize Upper Heater
Yes
$\Delta T < \Delta T_{small}$
No
Energize Lower Heater
Yes
$\Delta T < \Delta T_{large}$
No
Energize Lower Heater
Yes
$t < t_{safe}$
No
Reset time

Fig. 3


62
POWER
SUPPLY
26
22
34
38
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14
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18
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42
46