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(54) Title: DEVICE AND METHODOLOGY FOR EARLY DETECTION OF FLUID LOSS AND NOTIFICATION AND SYSTEM SHUTDOWN FOR A CLOSED LOOP FLUID HEAT TRANSFER SYSTEM

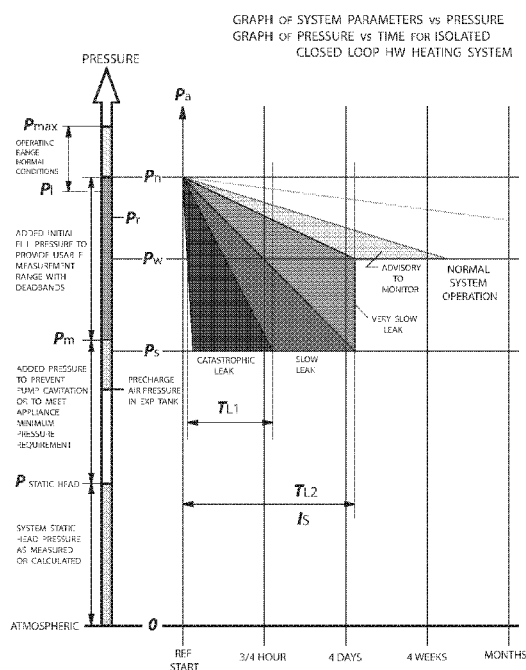


FIGURE 1

(57) Abstract: A hydronic system and method of use that will maintain normal system operating pressure while also reliably detecting even very small fluid losses in any closed loop fluid heat transfer system is described. The system includes a controller in communication with one or more pressure sensors and optionally one or more temperature sensors that provides one or more notifications when the pressure drops below predetermined levels.

Declarations under Rule 4.17:

- *as to the identity of the inventor (Rule 4.17(i))*
- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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Device and methodology for early detection of fluid loss and notification and system shutdown for a closed loop fluid heat transfer system

Related Applications

This application claims the benefit of and hereby incorporates by reference and, as applicable, claim priority to the following patent applications having at least one common inventor as the present application: namely, (1) provisional patent application number 62434762 filed on December 15, 2016 and having the title " Device and methodology for early detection of fluid loss and notification and system shutdown for a closed loop fluid heat transfer system"; (2) provisional patent application number 62554259 filed on September 05, 2017 having the same title as the previous provisional application; (3) PCT application number PCT/US17/65829 filed on December 12, 2017 and having the same title as the first listed provisional application; (4) National stage patent application number 15757519 filed on March 05, 2018 and having the same title as the first listed provisional application; (5) provisional patent application number 62791065 filed on January 11, 2019 having the title "Provisional Patent Application Model Reference Hydronic Leak Mitigation"; and (6) provisional patent application number 62666936 filed on May 04, 2018 and having the title "Device and methodology for very early detection of fluid loss and notification and system shutdown for a closed loop fluid heat transfer system". This application is a Continuation in Part of patent applications (3) and (4) as listed above.

Background

Serious damage can result to homes or structures that incorporate a liquid heat transfer system should the system be breached, either by a slow leakage loss over a long period of time, or by a sudden catastrophic breach of the system. Typical hydronic systems incorporate a boiler feed valve with a backflow preventer, to replace normal water volume losses, which has a component caused by air coming out of solution and being removed by an air separator. A bladder type expansion tank modulates volume due to temperature changes, to maintain system pressure within a narrow range, and will only accommodate very minor actual loss of water volume. The feed valve adds water if and when the system falls below the normal operating set pressure. It is common to operate the system with this

feed valve supplied at all times by the incoming water supply line, so that make-up water can be added as called for.

A very slow leak that develops anywhere in the system may cause a continual water loss less than the rate of fill, and thus may continue for an extended period of time, resulting in possibly hidden and possibly severe water or mold damage before the leak is discovered, even though the heating system may continue to provide heat as usual. A sudden catastrophic breach may result in a very large amount of water being released before discovery, particularly if the structure is not occupied at the time the breach occurs. If the feed valve is able to supply water at a rate at least equal to the rate of water loss, the system will continue to operate, but at greatly diminished heat output and all the while discharging large volumes of water into the structure. With heating disabled, the structure may fall below freezing temperature inside, leading to further damage to the heating and or plumbing systems.

It is a practice of some heating equipment installers to operate a newly filled system for a certain period of time, to remove the bulk of the air in solution, and then close the incoming water supply to the feed valve. This has the effect of limiting possible water release to the amount of water contained within the system, assuming any breach is at the lowest point, or to the amount of water released to bring system pressure to either zero, or to the point of activating a low water cutoff or a low pressure shut-off, either of which may be incorporated in the heating appliance. In a typical medium size residence, the volume loss to reduce pressure to that of static head may be as little as 16 fluid ounces.

This approach of isolating the system prevents catastrophic water damage to the structure, but a very slow leak may reduce system pressure to the point that the circulator pump will cavitate due to insufficient pressure to maintain fluid on the suction side. At that point, it is likely that the pump will burn out due to running dry because of an unsatisfied call for heat. The safety shutoffs on the appliance may or may not come into play, and the likely first warning of a problem is a drop in temperature in the structure, with no readily observable cause. A structure space temperature monitoring system may only be activated after there is a circulator pump failure, necessitating replacement of now failed equipment, which can be problematic during nights and holidays.

Water sensor monitoring systems well known in the prior art have the limitation that they will only detect fluid loss at the location of the sensor. The most damaging leaks in hydronic systems occur at locations remote from the appliances, usually within wall or floor assemblies, and are not initially readily observed until there is a significant water loss and or consequent damage. Water flow monitoring systems are employed as whole-house domestic water system leak detectors. These systems cannot adequately protect the hydronic heating system in an occupied structure. The allowable flow levels must of necessity be far greater than the smallest potential leaks in the hydronic system. If a flow-monitoring detector is dedicated to the hydronic system, that system must be continuously open to supply pressure, in order to detect a flow condition. The detector must then decide if flow is excessive, and actively close off the supply water. Very low leakage rates may be below the sensitivity of such detectors, or less than the allowable volume for a given time period.

If a hydronic system is closed off from the supply water source, it is possible for leakage to disable the circulator pump without any flow being indicated by the detector. A hydronic system requires only a minimum pressure to maintain function. Monitoring flow into the system must therefore infer a pressure condition in order to decide what protective actions to undertake. Heating systems may equally easily develop a leak in both occupied and unoccupied structures, whether in heating mode or during seasonal shutdown, so that a leak detector and safety shutdown must perform equally well under all these circumstances.

Infrared imaging cameras may be successfully used to locate leaks in a hot water heating system, which may occur within floor or wall assemblies, and are thus not readily observable. In typical trade practice, this method will only be employed after the likelihood of a leak has been established, which may come well after the initiation of a very slow and damaging leak into the structure.

An existing device has the primary purpose of a complete separation of the hydronic system from the domestic water supply. Make-up fluid is stored in a tank, and added to the hydronic system by a pump, which is controlled by a pressure switch. This allows for the use of fluids other than water. Leakage is measured indirectly, via an alarm signal when the storage tank is depleted. There may not be any notification of a very slow leak in the

hydronic system until long after initiation, which may result in considerable hidden damage.

Another existing device monitors pressure in an isolated hydronic system, and in the most basic configuration, merely reports a drop in pressure to a preset warning level. It is the responsibility of the warning recipient to take an explicit action to add fluid to the system. An enhancement includes the ability to actively open a supply valve to restore pressure. This version will only warn of presumed leakage if the restore function happens too frequently in a given time period, and may allow for feeding of a very slow leak indefinitely, with consequent hidden damage as the result.

The increase in use of hot water radiant heating systems has resulted in an increase in a particularly insidious type of leak and subsequent water damage. These systems incorporate a large amount of water filled tubing directly under the subfloor, or even the flooring material itself. It is very easy to penetrate the tubing with a misplaced fastener, either during construction or after occupancy. Pneumatic staples and finish nails and drywall screws are the most likely culprits, and any may penetrate one wall or both sides of the tube. The penetration may be sealed by the tubing material sufficiently to hold pressure during a pressure test normally performed during the construction phase of the project.

A fastener may also penetrate and be sealed by the tubing after the system is filled and running, when a much lower operating pressure is in the system than during testing. In either case, the water in the heating system will start a slow process of corroding the fastener and or the aluminum layer of a Pex-AL-Pex tube. At some point, typically a number of months after start-up, water pressure will force its way around the degraded fastener, and a leak ensues.

Brief Summary of the Drawings

Figure 1 is a graph of parameters pertaining to embodiments of a leak detection system as plotted against system pressure, and a graph of system pressure against time for various circumstances of pressure loss in closed loop fluid heat transfer system.

Figure 2 is a schematic representation of a closed loop fluid heat transfer system including a leak detection system according to a first system embodiment of the present invention.

Figure 3 is a schematic representation of a closed loop fluid heat transfer system including a leak detection system according to a variation of a first system embodiment of the present invention.

Figure 4 is a flowchart for a first method of operation of a leak detection system for a closed loop fluid heat transfer system according to a first system embodiment of the present invention.

Figure 5 is a flowchart for a variation of a method of operation of a leak detection system for a closed loop fluid heat transfer system according to a first system embodiment of the present invention.

Figure 6 is a flowchart for a second method of operation of a leak detection system for a closed loop fluid heat transfer system according to a first system embodiment of the present invention.

Figure 7 is a schematic representation of a closed loop fluid heat transfer system including a leak detection system according to a second system embodiment of the present invention.

Figure 8 is a schematic representation of a closed loop fluid heat transfer system including a leak detection system according to a first embodiment of the present invention, with the addition of a domestic water shutoff and pressure monitoring system according to a third system embodiment of the present invention.

Figure 9 is a flowchart for a third method of operation of a domestic water shutoff and pressure monitoring system according to a third system embodiment of the present invention.

Figure 10 is a schematic representation of a closed loop fluid heat transfer system including a leak detection system according to a fourth system embodiment of the present invention.

Figure 11 is a schematic representation of a multi-zone closed loop fluid heat transfer system including a leak detection system according to a variation of a fourth system embodiment of the present invention.

Figure 12 is a schematic representation of a closed loop fluid heat transfer system including a leak detection system according to a fifth system embodiment of the present invention.

Figure 13 is a graph of frequency of fill events against time, pertaining to embodiments of the present invention.

Detailed Description of the Invention

Overview

Embodiments of the invention comprise a device and method of use that will maintain normal system operating pressure while also reliably detecting even very small fluid losses in any closed loop fluid heat transfer system that incorporates a pressure regulated means of supplying make-up fluid, and also an air separator and air vent and a properly sized bladder type expansion tank. Make-up fluid is typically introduced into said hydronic systems at a point on the system piping between said expansion tank and said air separator, at what is termed the “point of no pressure change”.

When the circulator pump is operating, fluid flow generates a dynamic pressure, which is offset by a loss of static pressure. Resistance to flow steadily reduces this dynamic pressure in the piping system, as the fluid flows through the piping loop. A pressure regulated fluid supply entering the system where flow can occur would constantly be trying to compensate for dynamic pressure changes, resulting in overfilling and then fluid release through the pressure relief valve.

The point of no pressure change is a vital concept, as it allows for accurate filling and maintenance of system pressure under all conditions of operation. The bladder type expansion tank typically has a pre-charge air pressure that is equal to or slightly less than the desired system fill pressure. The fill pressure must always be greater than the static head pressure of the system, in order to maintain pressure on the suction side of the circulator pump under all conditions.

After filling the system the air is purged from the fluid, and fluid topped up to operating pressure as necessary. Typically these systems are filled cold, so that even idle at room temperature, the contained fluid expands slightly, and expands more so as operating temperature increases. This thermal expansion is accommodated by the fluid pushing into the bladder of the expansion tank, with a corresponding slight increase in system pressure due to the compression of the contained pre-charge air on the opposite side of the bladder.

If the system is now isolated from the source, such that the feed valve is dis-allowed from adding fluid, pressure at the point of “no pressure change” can vary only due to change in volume due to thermal expansion and contraction, loss of volume due to extraction of entrained air, or loss of fluid mass due to leakage of any type. This is illustrated conceptually in Figure 1. Thermal expansion and contraction by itself will typically result in measured pressure modulating in a range above the initial fill pressure, and presents no issues. Extraction of air is a very slow process, which becomes slower over time, and results in a very small change in volume. This volume loss may eventually be so slight as to only need compensating for after a period of months, or even a year.

In a typical residential system, normal operating pressure may be reduced below system minimum pressure with the loss of as little as one pint of fluid. If the fluid volume is reduced by any cause, the pressure will drop slightly until all of the initial fluid volume in the bladder is evacuated. Any further volume loss will result in a near instantaneous drop in pressure, first to that of the static head of the system, and then the pressure will fall further depending on how much fluid loss and draining down of the system may occur.

Systems depicted each show a system comprised of a hot water appliance and associated system components, and imply the presence of distribution tubing, such as underfloor radiant tubing, but the scope of this invention is not limited to such examples. In the example drawings, the relative positions of the air separator, air vent, expansion tank, feed valve, system shutoff valve and pressure transducers or switches, with respect to each other in the vertical plane, may be construed as the true relationship in the vertical plane in an actual hydronic installation although the actual vertical distances or ratios of the vertical distances between these various components may be different in the actual hydronic system.

Said physical relationships may allow for the extraction and release of trapped air from the system as a whole, and may also prevent disruptive air accumulation at said expansion tank and said pressure transducers or switches. As illustrated in the example drawings, the piping between said elements typically embody no reverse traps or negative slopes. Other physical relationships are contemplated, that differ from the relationship of the various system components shown, and that substantially prevent and minimize the

entrapment of air within the system piping between any of the system shutoff valve, the expansion tank and the air separator.

The method of use of an embodiment of this invention is to allow the feed valve to fill said system to a set pressure value, above the minimum pressure to maintain normal functioning, and then close said system off from said fluid supply source. A pressure transducer with sufficient sensitivity may generate a signal proportional to actual pressure of said system, which may then be utilized to indicate actual loss of fluid volume in said system.

Embodiments of the invention incorporate a power actuated normally closed system shutoff valve in the piping connecting said fluid source to said hydronic system. Said valve thus isolates said hydronic system and allows or dis-allows the possible addition of fluid into said system through said feed valve. With said system shutoff valve closed, fluid may only be lost from said system, and system pressure will respond to volume change due to fluid or volume loss of any causation.

Embodiments of the invention may open said system shutoff valve only for a limited duration, and only after a time delay, in response to a preset falling pressure, and only if associated with a moderate and tolerable loss of fluid volume. Opening of said system shutoff valve may allow said feed valve to restore system pressure and maintain normal system operation. A further loss of pressure, to below the established system minimum operating pressure, is indicative of a serious and probably ongoing loss of volume. If at any time such a reduced pressure level may be detected, said controller may disable the system shutoff valve and a system circulator pump, and possibly also the appliance, to prevent possible equipment failure. Said controller may also issue warning notifications of any type, as will be described.

A second method of use may be to open said system shutoff valve at calendar or timed intervals for only a short duration, thus allowing said feed valve to compensate if and as necessary, for small volume losses of any expected cause such as extraction of dissolved air. This invention may allow for said system to become self-regulating as regards fluid volume, but at all times said system and the surrounding structure is protected from unrestrained fluid loss emanating from any part or location of entire said hydronic system. Leakage is deduced by means of monitoring system pressure, and not by discovery of

actual leaked fluid, which leakage may occur anywhere in the system piping, fittings and components.

Hydronic systems typically employ a feed valve that is allowed to directly and immediately respond to any changes to actual system pressure relative to a single setpoint. Embodiments of this invention rely on measuring and then regulating system pressure as a step function. It is unnecessary to continuously log pressure data in order for the invention to function as intended.

Pre-programmed time intervals may be employed as a notch filter, and look forward from a realized point of intermediate but not directly disabling pressure loss. Said controller then is able to separate critical events from ordinary and necessary system pressure maintenance. In said second method, the action of maintaining system pressure is dis-associated from the response to potentially damaging pressure loss, in order to preclude feeding any system leakage.

The leak detection methodology as disclosed above doesn't take into account the effect of temperature on fluid volume and system pressure. The last two increments of fluid volume loss are made without regard for system fluid temperature. This results in a usable form a practical standpoint, because at some point the combination of loss of fluid mass and thermal contraction of the mass will eventually result in the actual fluid volume being reduced to that which is equivalent to the condition at initial cold fill volume and pressure. It is only at this condition that the leak detection capability of the previously disclosed device can come into play, as any further loss of volume, due to any cause, can now reduce the pressure to that of the warning or shutoff levels.

A fourth method of use of the present invention incorporates one or more temperature sensors in the fluid circulation loop, and may incorporate one or more air temperature sensors or means of ambient temperature data collection, along with a system fluid pressure transducer, all communicating with a controller, which may be a computer or other processing device. A fluid mass model for the mass of the contained heat transfer system fluid may be generated, utilizing pressure and temperature data, to monitor for a loss of system fluid mass. This may facilitate discovery of actual system leakage in real time.

Closed loop systems have an inherent decrease in fluid volume and or mass over time. This can be due to extraction of entrained gasses, very slow gas transport through the materials enclosing the fluid, physical loss of fluid mass, or due to other factors. To compensate for the loss of fluid volume or mass, systems may have an autofill function that adds small amounts of fluid to the system to maintain a usable fluid volume and system pressure. If there is a physical fluid leak in a system so equipped, the automatic feed valve may continually add fluid, which may continue to discharge from the system and may cause significant collateral damage to the surrounding structure.

A fifth method of use of the present invention consists of a fluid mass model reference of the normal amount of fluid that is required to be added to maintain the system, and a method of identifying if said amount of fluid that the system is requiring fits within acceptable variations from that model. If the requested fluid volume exceeds said established acceptable bounds, this invention may provide a response that may minimize the potential fluid release and consequential damage.

Definitions:

The terms and phrases as indicated in quotes (" ") in this section are intended to have the meaning ascribed to them in this Terminology section applied to them throughout this document including the claims unless clearly indicated otherwise in context. Further, as applicable, the stated definitions are to apply, regardless of the word or phrase's case, to the singular and plural variations of the defined word or phrase.

The term "or" as used in this specification and the appended claims is not meant to be exclusive rather the term is inclusive meaning "either or both".

References in the specification to "one embodiment", "an embodiment", "a preferred embodiment", "an alternative embodiment" and similar phrases mean that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least an embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all meant to refer to the same embodiment.

The term "couple" or "coupled" as used in this specification and the appended claims refers to either an indirect or direct connection between the identified elements,

components or objects. Often the manner of the coupling will be related specifically to the manner in which the two coupled elements interact.

Directional and/or relationary terms such as, but not limited to, left, right, nadir, apex, top, bottom, upper, lower, vertical, horizontal, back, front and lateral are relative to each other and are dependent on the specific orientation of an applicable element or article, and are used accordingly to aid in the description of the various embodiments and are not necessarily intended to be construed as limiting.

In this description, “system” shall refer to the totality of the physical components and piping of a hydronic heat transfer system as is typically installed.

The “appliance” is the source or equipment, such as a hot water boiler or heat pump that heats and or cools the fluid, for distribution to the point of use.

In this description, “radiator” is the physical assembly, such as, but not limited to, radiant tubing, fin tube radiators, or fan coils, through which the heat transfer between the contained circulating fluid and the external medium, such as the atmosphere or floor material of a conditioned building space, takes place.

In this description, “domestic system” shall refer to the totality of the physical components and piping of a domestic water supply system as is typically installed, exclusive of the components of said hydronic heating system.

In this description, “controller” shall refer to the totality of the physical components, which receive system inputs, analyze said inputs, and respond with actions or signals as has been programmed or installed. Said controller can consist of, but is not limited to, any of a programmable logic controller, a dedicated microprocessor, a remote server, analog to digital input-output device, mechanical or electromechanical timing devices, and associated power supplies, displays, switches, relays and indicator lights. Said controller can also incorporate any type of wired or wireless Internet connectivity, or wireless connectivity to any type of mobile device. Any or all of the physical components or functionality of said controller may be either proximal to the heat transfer system, or may be located remotely.

In this description “fluid mass model” shall refer to the algorithm that models the mass of the presently contained fluid and gas of the associated fluid heat transfer system, based on current values of one or more measurements of pressure and temperature, and

identifies when the contained mass of fluid and gas deviates and consequently generates an action or notification.

In this description “fluid mass model reference” shall refer to the algorithm that models the contained fluid mass of the associated fluid heat transfer system as a function of time based on mathematical models and on historic data. When executed on a computing device having a processor, such as a controller, the fluid mass model reference facilitates (a) the estimation the current contained fluid mass of the associated fluid heat transfer system based on current values of one or more measurements of fluid pressure or temperature and makeup fluid volume input, (b) the generation of a value for each of these parameters, (c) the generation of an error function that is the difference between the prediction and the estimate, and (d) the generation of an estimate of the time until the system requires an action or notification.

The description refers frequently to the components commonly found in residential hydronic heating systems, but this should not be construed as limiting the application of this device to only hydronic heating systems.

Terminology:

System Parameters, Setpoints and Programmable Values may be as follows:

A) **P_a** Actual System Pressure

P_a is the actual system pressure, as measured at the previously described point of no pressure change, at any given moment in time.

B) **P_{max}** Maximum Normal System Operating Pressure **P_{max}** is the greatest pressure value encountered during normal system operation, which allows for variations due to thermal expansion and contraction of the fluid volume, as mediated by the bladder type expansion tank. Said tank may be sized to prevent **P_{max}** from exceeding the set value of a pressure relief valve as is typically installed in hydronic systems, thus preventing unintended loss of fluid from said system.

C) **P_l** Lowest Normal System Operating Pressure **P_l** is the lowest pressure value encountered during normal system operation, which allows for

variations due to thermal expansion and contraction of the fluid volume, as mediated by the bladder type expansion tank.

D) **P_m** Minimum System Operating Pressure

P_m is the minimum operating pressure at which all components of said system will continue to operate and transfer heat as designed, without mechanical failure due to adverse conditions. **P_m** can be established as the greater of the minimum operating pressure of the appliance, or, of the sum of the static head pressure of the system plus the minimum pressure required to prevent cavitation at the circulator pump or pumps. Static head pressure for water systems may be roughly calculated as one half the total system piping height in feet, expressed as pounds per square inch, and typically a residential hydronic system requires about 5 psi additional to ensure that the circulator pump may operate properly without cavitation. Once established, this value for **P_m** may be entered into the controller as an operating parameter.

E) **P_n** Normal System Operating Pressure **P_n** is the
 normal operating pressure of the system, which can be physically realized by the manual adjustment of the feed valve. Said pressure can be a differential above the minimum operating pressure such that one or more distinct alarm condition setpoints may be reached as the system pressure falls, while maintaining a deadband between each setpoint that will usually exceed twice the sensitivity of the pressure sensor or of the feed valve pressure regulator mechanism. In an embodiment of the invention, **P_n** may be entered into the controller as an operating parameter.

F) **P_w** Pressure at First Warning Notification **P_w**
 is the **P_a** reached on falling system pressure at which the controller will typically send a first notification and or enable an alarm as shall be described below. This value is less than **P_l** and greater than **P_s** by typically an increment greater than twice the sensitivity of the pressure transducer, such that a deadband will exist between **P_w** and **P_s** . **P_w** may be established and programmed into the controller during setup of the system.

G) P_s System Shutdown Pressure

P_s is the P_a reached on falling system pressure at which said controller will typically send a second notification and/or enable an alarm as shall be described below and in some embodiments may also de-energize one or more system components as shall be described below, and may also lock out the energizing of said system shutoff valve to limit further fluid loss. De-energizing system components will protect the structure from continued fluid loss, and protect the appliance and or the circulator pump(s) from mechanical damage due to running dry. If said controller of a particular embodiment has the ability to communicate via the Internet, persons or entities at remote locations may be apprised of the system shutdown. Warning of a heating system shutdown is typically provided earlier in embodiments of the present invention than would be in a system utilizing a prior art structure space temperature sensing device, which would likely not provide an alert until after system components had failed. P_s can be established as the P_a less than the P_m by an increment greater than the sensitivity of the pressure sensor, such that a deadband will exist between P_m and P_s , thus allowing the system to operate at the established P_m . P_s is typically established and programmed into the controller during the startup of the system.

H) P_r Alarm Reset Pressure P_r

is the P_a reached on rising pressure that may cancel previous notifications and/or safety shutdown commands, and may also send a notification to that effect by any means as shall be described below. P_r may be established as the P_a greater than P_w and also less than P_n usually by an increment greater than the sensitivity of the pressure sensor or of the feed valve, such that there is a deadband between P_r and P_n , and may be programmed into the controller during system startup.

I) TL_1 First Time Interval for Lockout of Shutoff Valve Actuation TL_1 is a

time parameter used in an embodiment of this invention. TL_1 is the set duration of time between starting and ending a first consecutive timing function of said controller, commencing when P_a falls to P_w . TL_1 may be an embodied value in said controller, or may be programmed and or altered specific to a given system. Initiation of said first

timing function may preclude any subsequent re-initiation of said first timing function until the conclusion of a third consecutive timing function of duration **TL2**.

- J) **Do** Time Duration For Energizing of the System Shutoff Valve **Do** is a time parameter used in an embodiment of this invention. **Do** is the set duration of time between starting and ending a second consecutive timing function of said controller, commencing at the end of **TL1**. **Do** is the duration of time during which the system shutoff valve may be energized, but is also subject to any other constraints or limitations of operation. **Do** may be established during system setup by measuring the minimum time required to raise **Pa** from **Ps** to **Pn**, under normal incoming fluid supply pressure, and adding a time increment in order to achieve full possible pressure **Pn** while also allowing for variations in system conditions. **Do** may be programmed into said controller during system setup. **Do** will enable said feed valve to compensate for the worst allowable pressure loss that may occur during normal operating conditions but also limits catastrophic fluid loss to only this short time period, which is typically in the range of 30 to 300 seconds. In an embodiment of the invention, **Do** is the maximum amount of time that said system shutoff valve may remain energized, regardless of the value of **Pa**.
- K) **TL2** Second Time Interval for Lockout of System Shutoff Valve Actuation **TL2** is a time parameter used in an embodiment of this invention. **TL2** is the set duration of time between starting and ending a third consecutive timing function of said controller, commencing at the conclusion of **Do**. **TL2** may be an embodied value in said controller, or may be programmed and or altered specific to a given system. At the conclusion of **TL2**, said first timing function may be allowed to re-initiate.
- L) **Is** Time Interval Between Open Intervals of System Shutoff Valve
The controller may be configured such that **Is** may be the time interval from one initiation of the opening of said system shutoff valve to the next initiation of the opening of said system shutoff valve, or may be configured as the interval from the timed closing of said system shutoff valve to the next succeeding opening of said system shutoff valve.

Is may be established and programmed into said controller during system setup. *Is* may be no greater than the maximum time interval that will allow *Pa* to stay greater than *Pw*, while the system is under normal operating conditions and subject to no aberrant fluid or pressure losses. In a typical operating residential heating system that has had the bulk of the dissolved air purged out, this would likely be at least several days, and may likely be programmable for a period of ten days or more. In a variation, interval *Is* may be embodied as a calendar based function, such that said system will open said system shutoff open valve at programmed calendar intervals.

Example calculations and determination of values

The following examples of programmable values and the derivation thereof are intended to be exemplary for a typical residential hydronic heating system and should not be construed as limiting.

Establish system minimum pressure:

$$[(\frac{1}{2} \times \text{system piping height in feet}) + 5] \text{ psi}$$

Verify appliance minimum pressure, for example: 10 psi

Calculate minimum system pressure, for example:

For a typical 2 story house: $[(\frac{1}{2} \times 15 \text{ (feet)}) + 5] \text{ psi} = 12.5 \text{ psi} = P_m$

Ps may be set slightly below *Pm*, such as 12.3 psi

For a single story house: $[(\frac{1}{2} \times 6 \text{ (feet)}) + 5] \text{ psi} = 8 \text{ psi}$; must use *Pm* = 10 psi

In this example, it may be preferable to set *Ps* slightly above *Pm*, in order to insure system pressure will be maintained above any low pressure limit switch embodied in the appliance.

Verify transducer sensitivity, for example: 0-30 psi at 1% accuracy

Determine and verify expansion tank pre-charge pressure:

Pre-charge may be less than P_s by at least 1.5 times transducer sensitivity, so that system setpoints are always in the range of measurable pressure.

For this example $[12.3 - (1.5 \times 0.3)]$ psi = pre-charge pressure; use 11.8 psi

Determine setpoints:

For this example, (2×0.3) psi plus (0.1) psi may be used as the minimum differential between P_s and P_w and also between P_w and P_n .

For the $P_s = 12.3$ psi, P_w may be set at 13.0 psi or above; it may be preferred to use 13.3 psi as a setpoint, to indicate a greater (but still very small) change of fluid volume. With P_w set at 13.3 psi, P_n may similarly be determined to be 14.3 psi, and enabled by a physical setting of the feed valve, or as a programmed setpoint in the controller. P_r may be set at 14.0 psi, to insure a reset even if P_n does not restore to exactly full value.

Establish $D_o = (\text{elapsed time for feed valve to raise } P_a \text{ from } P_s \text{ to } P_n)$
 $\times (\text{Multiplier} > 1)$

For example system: $(150 \text{ seconds measured}) \times (1.5) = 225 \text{ seconds} = D_o$

Establish T_{L1} and T_{L2} :

T_{L1} is reflective of what may be arbitrarily be determined to constitute a rapid or catastrophic leak. Guidance may come by creating a small drip through a system draindown valve, and measuring the elapsed time for P_a to fall from P_n to P_s . In a noticeable leak, this will usually be only a matter of minutes. It may be advisable to also measure the quantity of water released, as this will essentially be a constant that may be correlated with timed events to assist in identifying a possible cause of leakage. It is preferable to set T_{L1} a minimum of five times D_o , and typically not less than 15 minutes.

Setting TL_1 at one hour will typically identify a rapid or catastrophic leak, and may consistently allow an initial system refill when the actual rate of leakage is as yet unknown.

TL_2 is reflective of what may be arbitrarily be determined to constitute a slow or very slow leak. In an intact system, it is possible to operate for an entire heating season without adding any fluid. A corroding fastener that penetrates radiant tubing may typically take several days to initially release a significant volume of water. A typical setting of TL_2 of 5 to 10 days will identify a slow, or possibly accelerating, rate of leakage that may definitely be attributed to some breach of the system. If P_a falls from P_n to P_s during TL_2 , a slow leak is identified. If P_a falls from P_n to P_w during TL_2 , a very slow leak is identified. This may be indicative of a component condition, such as a valve stem leak, or a leaking fitting. At initial system startup, and for a period of a week to a month thereafter, air extraction may be a greater factor. It may be preferred, during this time period, to set TL_2 to a much lower value, typically 1 to 3 days, to allow adding make-up water as necessary.

System elements

A first system embodiment of the invention may consist of the following elements as described herein and illustrated schematically in Figure 2. An electrically operated normally closed system shutoff valve 202 may be installed in the fill piping 110 between a fluid source 100 and a hydronic system, for the purpose of allowing or dis-allowing make-up fluid flow through the feed valve 116. In a typical residential heating system, said make-up fluid fill piping 110 can connect to said hydronic system between an expansion tank 120 and an air separator 112.

Typically fluid is drawn from appliance 102 via a system supply pipe 104 through said air separator 112 by the circulator pump 118. Fluid is pushed away around one or more distribution loops and re-enters said appliance 102 through a return pipe 106. Typically said valve 202 can be self-closing on loss of power, and can be capable of holding against a pressure differential greater than the maximum incoming supply fluid pressure.

Said shutoff valve 202 can communicate with a controller 302, by hard-wired connection or by wireless connection, such as, but not limited to Bluetooth. Power to operate said shutoff valve 202 may be supplied by said controller 302, or may be drawn directly from the structure power grid 300. A pressure transducer 204 that generates a

signal proportional to hydronic system pressure may be installed in said piping between said expansion tank 120 and said air separator 112, which is the point of no pressure change during operation of said circulator pump 118 of said system.

Said transducer 204 may be combined in a manifold 206 with said system shutoff valve 202, and may also include a mechanical pressure gauge or a gauge port. The proximal installation of a manual boiler drain valve 122 may assist in the setup and adjustment of the pressure values, by facilitating fluid release while simultaneously observing said system pressure. It may be preferred to oversize said expansion tank 120 above minimum system requirements, as this may result in a greater change in fluid volume for a given change in pressure, and thus make it possible for the installed detector to more accurately control said system pressure.

In the example drawings, the relative position in the vertical plane of said air separator 112, air vent 114, expansion tank 120, feed valve 116, shutoff valve 202, and pressure transducer 204, may be construed as the true relationship in the vertical plane in an actual installation. This physical relationship, embodying no traps or reverse sloping piping, may allow for the release of trapped air from the system as a whole, and also prevent air accumulation at the pressure transducer 204 and or gauge, which may otherwise affect actuation. Said pressure transducer 204 may communicate with said controller 302 by hard wire connection or by wireless connection such as, but not limited to Bluetooth. If the pressure transducer 204 communicates with the controller 302 wirelessly, power to operate this transducer may be by a contained battery, or drawn directly from the structure power grid 300, which may incorporate a battery backup.

A microprocessor-based controller 302 may be located separately from or may be unitized in a manifold assembly 222 with said valve 202 and transducer 204. Said controller 302 may incorporate a digital display or a monitor screen 316, which may incorporate a touch screen or may utilize any type of touch pad or buttons, to which together provide for entering system parameters and for the monitoring of system status and functioning.

Said controller 302 may have the capability to communicate wirelessly 304 by cellular phone service directly to a mobile device 306. Said controller 302 may have the capability to communicate with a local area network by any means. This means of

communication may be, but is not limited to, a hard-wired connection 308 such as Ethernet or USB, or may be wirelessly 304 by Bluetooth, 802.11 Wi-Fi, or any other system. Wireless communication may be utilized only to communicate with said shutoff valve 202 and said pressure transducer 204, or said controller 302 may communicate with a wireless router 310 that communicates with a local computer 312 or directly with any device that may connect to the Internet 314. Said controller 302 may thusly be programmed and or monitored by said local computer 312 or by any device with an Internet connection.

Said controller 302 may be powered by the structure power grid 300, and may incorporate a battery backup power supply, or may be powered by an integral battery. The controller 302 may monitor said battery and may issue a notification prior to depletion of the battery. Said controller 302 may have an input 320 for the signal from said pressure transducer 204, which may be hard-wired or wireless. Said controller 302 may have an output 328 for operation of said system shutoff valve 202, which may be hard-wired or wireless. If said output 328 is hard-wired, said controller 302 may output a control signal for a power relay that can activate a power circuit for said system shutoff valve 202, or said controller 302 may output the required power to operate said system shutoff valve 202 directly. If said controller 302 communicates with said system shutoff valve 202 wirelessly, the signal received at the valve location may activate a power relay at said location.

The simplest embodiment of this invention may use hard-wired connections between components, with the controller 302 supplying power for the actuation of said system shutoff valve 202, as in a typical residential heating system all components will be located in close proximity to each other in a single building space, thus allowing for short interconnects and visual contact between all components.

Said controller 302 may embody an output 336 for a first notification of falling system pressure, which notification 336 may be the closing of one or more pairs of dry contacts, which may enable the functioning of a local alarm and or enable a first notification via any type of installed home security or monitoring system. Said output 336 for said first notification may simultaneously or exclusively be a power output that may activate a local alarm annunciator, which may be either visual or auditory. Said output 336 for said first notification may be exclusively or simultaneously a wireless signal via Bluetooth, 802.11 Wi-Fi, or any other system, to a LAN router 310, and then to a local computer 312, which

may embody an Internet connection 314. Said first notification may be directed to or available to any device with an Internet connection.

Said controller 302 may embody an output 338 for a second notification of additional loss of system pressure. Said output 338 for said second notification may simultaneously or exclusively be a power output that may activate a local alarm annunciator, which may be either visual or auditory. Said output 338 for said second notification may be exclusively or simultaneously a wireless signal via Bluetooth, 802.11 Wi-Fi, or any other system, to a LAN router 310, and then to a local computer 312, which may embody an Internet connection 314.

Said output 338 for said second notification may simultaneously or exclusively supply actuation power to normally closed output relay 344 and or normally closed output relay 346. Actuation of said relay 344 may interrupt the low voltage control circuit 360 and de-energize a power relay 124 of said pump 118, or may directly interrupt the power supply circuit of said pump 118. Actuation of said relay 346 may interrupt the low voltage control circuit 362 of said appliance 102, or may directly or indirectly interrupt the appropriate power circuit. Certain boilers known to the art have an integral freeze protection system for the boiler itself, which allows heat output at pressures as low as 2 or 3 psi. Said units may not typically be de-energized by the described leak detection and safety shutdown invention, as this may dis-enable the low pressure freeze protection capability.

A second variation of said first system embodiment may eliminate the permanent connection to a domestic water supply. The source of make-up fluid for a hydronic system may be a discrete pressurized make-up fluid containment vessel, and may not be restricted as to type of fluid employed. Said vessel can be a bladder type expansion tank, and can typically be pre-charged to a pressure above P_{max} of said hydronic system, such that fluid contained within said vessel can be introduced into said hydronic system by the action of said pre-charge pressure acting on said bladder. A pressure regulating valve on the discharge piping of said vessel may be set to a desired value of P_n .

Said vessel can utilize a closure valve and hose connection, for the purpose of filling or re-filling said vessel, up to the pressure limit of said vessel or the capability of the fill source employed. Said vessel may incorporate a pressure gauge for visual monitoring of

available make-up fluid, or said vessel may incorporate a pressure transducer or pressure switch on the fluid side of said bladder. When said contained fluid pressure falls to a setpoint at or above P_{max} , an input signal to said controller may cause a third notification to be issued by any embodied means. Said storage vessel may incorporate a bleed valve at the high point of the discharge piping of said vessel to allow for purging of air during or after filling said vessel.

A third variation of said first system embodiment may also eliminate the permanent connection to a domestic water supply. The source of make-up fluid for the hydronic system may be a fluid supply tank, which may be open to atmospheric pressure and may have no restriction on type of fluid employed. Said tank may be manually filled or re-filled as necessary. Said fluid can be transferred into said hydronic system by means of an electrically operated pump which may be enabled by said controller during interval D_o , in lieu of said system shutoff valve. A pressure regulating valve on the discharge of said pump may be set to a desired value of P_n . A check valve may be embodied in the piping succeeding said pump.

A fourth variation of said first system embodiment may consist of the following elements as described herein and illustrated schematically in Figure 3. Said previously disclosed pressure transducer 204 may be supplanted by two pressure switches 208 and 210, which may be installed in the piping between said expansion tank 120 and said air separator 112. Said pressure switches 208 and 210 may be combined in a manifold 206 with said system shutoff valve 202, and may also include a mechanical pressure gauge 212 or a gauge port. A controller 396 may dispense with the analog to digital converter function typically associated with a previously disclosed pressure transducer 204.

Said first pressure switch 208 may be adjusted and set to close a pair of contacts when system pressure P_a falls to a level P_w . The closing of said pressure switch 208 may complete a controller input circuit 322, and enable the sending of a first notification by any means and or close a normally open relay output 336 which may send a first notification to an installed home security system or a monitoring service for same. Said second pressure switch 210 can be adjusted and set to close a pair of contacts when system pressure P_a falls to a level P_s . The closing of said pressure switch 210 may complete a controller input circuit 324, and enable the sending of a second notification by any means. The closing of

said pressure switch 210 may close a normally open relay output 338, which may send a second notification to an installed home security system or a monitoring service for same.

Concurrently said closing of said pressure switch 210 may disable output 328 to said system supply valve 202, so that said valve 202 will self-close and or be prevented from opening. Concurrently said closing of said pressure switch 210 may enable a normally closed relay 344 to interrupt a control circuit 360 in order to de-energize a power relay 124 of said circulator pump 110. Concurrently said closing of said pressure switch 210 may enable a normally closed relay 346 to interrupt an appliance control circuit 362 in order to de-energize said system appliance 102. A plurality of functions may be enabled by an embodiment of said controller 396, or may be enabled by a plurality of external relays that are each energized by the closing of said relay outputs 336 or 338.

Method of operation

A first method of operation of a first system embodiment of this invention is as described herein and illustrated conceptually by Figure 1 and represented as a flowchart in Figure 4. Element numbers of shapes for operational steps shown in Figure 4 are indicated herein in parentheses. Values P_s , P_w , P_n and P_r may be calculated for or assigned to a specific system, and programmed (400) in said controller 302. Values of T_{L1} , D_o and T_{L2} may be embodied in said controller 302, or may be determined and programmed by an installer of a specific system. Said expansion tank 120 pre-charge pressure may be set and verified as less than P_s . Said heat transfer system may be tested and filled (402) to system pressure P_n , and said controller 302 may be tested for proper operation. Said hydronic system and controller 302 may then be made operational (404).

During normal operation of said system, P_a will range from a low pressure of P_l up to some greater pressure P_{max} , resulting from the thermal expansion and contraction of the fluid (406), and may be limited by a pressure relief valve that may be incorporated into said system to prevent damage from over-pressurization. Unless energized by said controller 302, said normally closed system shutoff valve 202 may at all times deny the addition of fluid by the feed valve 116. Said fluid volume may be reduced by the extraction of trapped or dissolved air in said system. Said fluid volume may also be reduced at any time by loss of fluid mass, which is to say, system leakage of any kind or cause (408).

The analog signal from pressure transducer 204 at input 320 may be continuously sampled (404) and processed by an analog to digital converter embodied in said controller 302. A digital value of P_a may then be compared to said programmed values P_w and P_s . As long as P_a is greater than P_w (410), said controller 302 may take no action. When P_a is reduced to P_w or less (412), a first notification (414) may be sent by any means (480) as previously described and/or close a normally open relay output 336 which may send a first notification (482) to an installed home security system or a monitoring service for same.

A series of three consecutive timing functions may simultaneously be initiated. A first timer is initiated (434), counts up to T_{L1} (436), ends (438), and then starts (440) a second timer. Said second timer counts up to D_o (442), ends (444), and then starts (446) a third timer. Said third timer counts up to T_{L2} (448) and then ends (450). At said start (434) of said first timer a timing cycle (432) enablement register is started. At said end (450) of said third timer, a timing cycle (432) enablement register is canceled. For the duration of said timing cycle (432), said controller 302 may block (430) the re-initiation of said timing cycle.

Said system shutoff valve 202 may be energized open (460) at the start of said second timer (440). Said system shutoff valve 202 may be de-energized closed (464) at the end of said second timer (444). Said opening (460) of said system shutoff valve 202 for duration D_o may allow said system feed valve 116 to add fluid (462) as required to raise P_a to P_n , presuming no ongoing fluid losses. De-energizing (464) said system shutoff valve 202 at the conclusion of D_o may deny any continued fill action (466) should said feed valve 116 be unable to restore P_a to P_n due to ongoing fluid loss.

If P_a increases to P_r or above (468), said first notification may be canceled (470) and relay output 336 may be opened (472). A sudden increase in rate of fluid loss during D_o may prevent P_a from reaching either P_r or P_n , but as energizing of said system shutoff valve 202 is time limited, potential discharge of fluid through any breach is consequently limited as well (466). If at any time P_a falls to P_s or less (416), said controller 302 may issue a second notification (418) by any means (484) as previously described and or close a normally open output relay 338, which may send a second notification (486) to an installed home security system or a monitoring service for same.

Said controller 302 may simultaneously (420) block (494) output 328 and therefore end or prevent the energizing (496) of said system shutoff valve 202, insuring isolation (498) of said hydronic system from said fluid source 100. Said controller 302 may simultaneously (420) open a normally closed output relay 344, to interrupt (490) a control circuit or a power circuit for said circulator pump 118. Said controller 302 may simultaneously (420) open a normally closed output relay 346, to interrupt (492) a control or power circuit for said system appliance 102. By disabling said pump 118 or appliance 102, possible damage to any of said equipment due to operation at less than P_m is thus prevented.

Said controller 302 may not have any means of automatically restoring system pressure after said second notification, and may require a manual reset (488) of said second notifications. Said system may be re-started after inspection, repair and the manual filling and purging (402) of said system to pressure P_n .

A loss of grid power (422) may temporarily produce the same results as does system shutdown (420), by de-energizing said circulator pump 118, appliance 102, and system shutoff valve 202, thereby denying feeding of any leak or breach of said system. A restoration of power may allow said controller 302 to resume (404) said pressure monitoring function and take any actions as may be indicated by said detected pressure value.

The volume of fluid associated with a change in P_a from P_n to P_w and also from P_w to P_s may be essentially constant, such that the programmed values of T_{L1} and T_{L2} may create a time frame for such volume losses, and hence be an indicator of the rate of change of said system pressure, without the need for recording P_a . A rapid or catastrophic leak may be discovered should P_a fall to P_s within T_{L1} of said first timer.

Presuming that P_a may be restored to P_n during D_o of said second timer, a slow leak may be discovered should P_a fall to P_s or less within T_{L2} of said third timer, and a very slow leak may be discovered should P_a fall to P_w or less, but remain above P_s , within T_{L2} of said third timer. In such a case, said timing cycle (430) and consequent possible addition of fluid may be allowed to be repeated. Presuming that P_a may be restored to P_n during D_o of said second timer, and should P_a remain above P_w for T_{L2} of said third timer, said system may be monitored for subsequent or repeated loss of pressure to P_w . Monitoring may be

by embodied data logging by said controller 302, or by an alarm monitoring service, or by manually recording instances of said first notification.

If P_a should fall to P_w only two or three times per year, it may be presumed that said hydronic system is intact and fully functioning as intended. Said controller 302 may be made more sensitive to rate of loss by increasing the values of $TL1$ and or $TL2$. Said controller 302 may be made less sensitive to rate of loss by decreasing the values of $TL1$ and or $TL2$. Less sensitivity may be necessary or desirable in the case of an older system, which may be subject to unavoidable but tolerable fluid losses due to such causes as a failing pump seal or valve stem packing. In said case, $TL1$ and or $TL2$ may be adjusted over time, to allow fluid to be added with greater frequency without invoking system shutdown. A change in the frequency of P_a falling to P_w may indicate a change in circumstance of fluid loss, and may indicate the advisability of investigation. If system leakage is indicated, said leakage may then be searched for visually, or by means of an infrared camera device or by any other means, before serious hidden water damage may occur to the structure.

A second variation of said first method embodiment is described herein and represented by a flowchart in Figure 5. Element numbers of shapes for operational steps shown in Figure 5 are indicated herein in parentheses. Said operational steps conform to said first variation methodology, with an additional steps as herein described. Said controller 302 may continuously sample system pressure P_a , and may de-energize (464) output 328 during interval D_o , to allow said system shutoff valve 202 to close when P_a equals or exceeds P_n (576).

Said system shutoff valve 202 may be of a type with rapid response time, which may typically be a fraction of a second, and may also be of a low C_v , or coefficient of flow. If said valve 202 is selected so as to be able to reliably limit P_n without consequential pressure overshoot, said feed valve 116 typically associated with a hydronic system may be eliminated. D_o (442) may remain as a time limitation for said system shutoff valve 202 to possibly be open, for the purpose of preventing limitless water release under any circumstance.

In a third variation of said first method embodiment, said controller 302 can be programmed with a system start-up cycle, which may embody said first methodology, but may utilize reduced or fractional values of $TL1$ and $TL2$ as has been programmed for normal

system operation. Said reduced values can be manually selected, set by programmed calculation relative to said input values, or set to default values by said program logic. At system initiation or at the manual reset and re-starting of said hydronic system after a system shutdown, said controller 302 may run said system methodology for a programmed duration of time, that may typically be seven to thirty days, at said reduced values of $TL1$ and $TL2$. Said duration may be manually programmed or may be embodied in said controller, and may automatically switch to said full values of $TL1$ and $TL2$ at the conclusion of said start-up cycle. Said start-up cycle has the effect of allowing more frequent additions of fluid to said system during the initial period of operation, when there is a probability of greater volume loss due to air extraction.

In a fourth variation of said first method embodiment, said controller 302 can be programmed with a periodic function test cycle for said system shutoff valve 202, in order to regularly verify the ability of said valve 202 to properly operate. Said test cycle may consist of energizing said system shutoff valve 202 open for a short interval, such as, but not limited to, five to thirty seconds. The duration of said interval may be manually programmed or may be embodied in said controller methodology.

Said test cycle may occur at repetitive calendar intervals, which intervals may be a manually entered or at a pre-programmed value, such as but not limited to, once per week or once per month. Said test cycle may occur at repetitive time intervals, which intervals may be a manually entered or a pre-programmed value, such as but not limited to, every seven to thirty days. Said controller 302 may be programmed to deny any said individual test cycle should said test cycle occur during, or overlap with, $TL1$ or $TL2$. Said system shutoff valve 202 may be configured with an end switch, and may be enabled to report each actual successful opening of said valve 202 during said test cycle.

In a fifth variation of said first method embodiment, said controller 302 may not incorporate any or all direct physical control functions or displays 316. Initial set-up and operation of said controller 302 and said associated programming of values may be by action of an ancillary device such as a computer 312 connected directly or through a LAN 310, or by a mobile device 306 connected to said controller 302 through a LAN 310, or directly connected wirelessly 304 by Bluetooth, 802.11 Wi-Fi, or any other means. Said controller 302 may be distributed with, or with access to, a software application for said

computer 312 or mobile device 306. Said application may have any of the following attributes:

- Setpoints may be by user-defined values, or the application may require the installer to enter raw data concerning the hydronic system, and said application may then calculate and install the setpoints in the microprocessor memory of said controller. Examples of data that may be required may be appliance 102 model number and serial number, specified minimum operating pressure of the appliance 102, height of hydronic piping system, and the measured elapsed time for said feed valve 116 to raise P_a from P_s to P_n .
- Operating setpoints such as P_w and P_s may have embedded values relative to input data, or may be configurable by the installer, or alterable by the installer within programmed parameters.
- Initiation can require the successful completion of a verification test cycle that may include, but is not limited to, raising P_a from P_s to P_n during time interval D_o , and manually releasing fluid from said hydronic system so as to test transmittal of said first notification at P_w and test transmittal of said second notification at P_s .
- Said application may receive data from said controller 302 continuously, and or may download data as and when connected to said ancillary or mobile device 306.
- Said application may display any available output or setpoint from said controller 302, including, but not limited to, said system setpoints, pressure P_a , duration of P_a less than P_w , and enabled operation of said system shutoff valve 202 as reported by said previously described end switch.
- Said application may store initialization data and or said verification test result data. Said stored data may be required as supporting documentation for any warranty or liability claim action initiated by the installer and or the end user.
- Said application may send any, or all, available data to a third-party server.

- Said application may be configured to allow firmware updates via Internet connection, either automatically or by user permission.

A second method embodiment of the invention may be as described herein and represented as a flowchart in Figure 6. Element numbers of shapes for operational steps shown in Figure 6 are indicated herein in parentheses. Values ***Ps***, ***Pw***, ***Pn*** and ***Pr*** may be calculated for or assigned to a specific system, and programmed (600) in said controller 302. The values of ***Is*** and ***Do*** may be determined and programmed (600) by an installer for a specific system, or either may be embodied in the programming of said controller 302. ***Is*** may typically be of three to fifteen days duration. Said expansion tank 120 pre-charge pressure may be set and verified as less than ***Ps***. Said hydronic system may be tested and filled (602) to system pressure ***Pn***, and said controller 302 may be tested for proper operation. Said hydronic system and controller 302 may then be made operational (604).

During normal system operation, ***Pa*** will range from a low pressure of ***Pl*** up to some greater maximum pressure value, resulting from the thermal expansion and contraction of the fluid (606). A pressure relief valve may be incorporated into said system to prevent damage from over-pressurization. Unless energized by said controller 302, said normally closed system shutoff valve 202 may deny the addition of fluid by the feed valve 116. Said fluid volume may be reduced by the extraction of trapped or dissolved air in said system. Said fluid volume may also be reduced by loss of fluid mass, which is to say, system leakage of any kind or cause (608).

Upon startup, said controller 302 may start a periodic first timer (634), count up to ***Is*** (636), and then end (638). At each and every timer end (638), the timer count may clear to zero and re-start said timer (634). At the conclusion of each and every interval ***Is***, a second timer may start (640), count up to ***Do*** (642), and then end (644). Said system shutoff valve 202 may be energized open (660) for duration ***Do*** (642) of said second timer. Said system shutoff valve 202 may be de-energized closed (664) at the end of said second timer (644). Said opening (660) of said system shutoff valve 202 may allow said system feed valve 116 to add fluid (662) if and as necessary to raise ***Pa*** to ***Pn*** (610), presuming no ongoing fluid losses. A sudden increase in rate of fluid loss during ***Do*** may prevent ***Pa*** from

reaching either P_r or P_n , but as energizing of said system shutoff valve 202 is time limited, potential discharge of fluid through any breach is consequently limited as well (666).

An analog signal from pressure transducer 204 at input 320 may be continuously sampled (604) and processed by an analog to digital converter embodied in said controller 302. The digital value of P_a may then be compared to said programmed values P_w and P_s . As long as P_a is greater than P_w , said controller 302 may take no action. When P_a is reduced to P_w or less (612), a first notification (614) may be sent as previously described (680) and or output relay 336 may be closed to activate (682) a local alarm or home security monitoring system. If, during scheduled time period D_o , P_a increases to P_r or above (668), said first notification may be canceled (670) and relay 336 may be opened (672) to cancel said local alarm.

If at any time P_a falls to P_s or less (616), said controller 302 may issue a second notification (618) as previously described (684) and or close output relay 338 to activate (686) a local alarm or home security monitoring system. Said controller 302 may simultaneously (620) block (694) output 328 and end or prevent the energizing (696) of said system shutoff 202, insuring isolation (698) of said hydronic system from said fluid source 100. Said controller 302 may simultaneously open (620) an output relay 344, to interrupt (690) a control circuit 360 or a power circuit for said circulator pump 118. Said controller 302 may simultaneously open (620) an output relay 346, to interrupt (692) a control circuit 362 or power circuit for said system appliance 102. By disabling said pump 118 or appliance 102, possible damage to any of said equipment due to operation at less than P_m is thus prevented.

Said controller 302 may not have any means of automatically restoring system pressure after said second notification, and may require a manual reset (680) of said second notification. Said system may be re-started after inspection, repair and the manual filling and purging (602) of said system to pressure P_n . A loss of grid power (622) may temporarily produce the same results as does system shutdown (620), by de-energizing said circulator pump 118, appliance 102, and system shutoff valve 202, thereby denying feeding of any leak or breach of said system. A restoration of power may allow said controller 302 to resume said pressure monitoring function (604) and take any actions as may be indicated by said detected pressure value.

In a second variation of said second method embodiment said controller 302 may continuously sample system pressure P_a , and may de-energize said output 328 to close said system shutoff valve 202 during interval D_o , when P_a equals or exceeds P_n . Said system shutoff valve 202 may be of a type with rapid response time, which may typically be a fraction of a second, and may also be of a low C_v , or coefficient of flow. If said valve is selected so as to enable said controller 302 to reliably limit P_n without consequential pressure overshoot, said feed valve 116 typically associated with a hydronic system may be eliminated. D_o may remain as a time limitation for said system shutoff valve 202 to possibly be open, for the purpose of preventing limitless water release under any circumstance.

In a third variation of said second method embodiment, said controller 302 may be programmed with a system start-up cycle, which may embody said second method, but may utilize a reduced or fractional value of I_s as has been programmed for normal system operation. Said reduced value may typically be, but is not limited to, one to three days. Said reduced value may be manually selected, set by programmed calculation relative to said input value, or set to a default value by said program logic.

At system initiation or at a manual reset and re-starting of said hydronic system after a system shutdown, said controller 302 may run said system methodology for a programmed duration of time, that may typically be seven to thirty days, at said reduced value of I_s . Said duration may be manually programmed or may be embodied in said controller, and may automatically switch to said full value of I_s at the conclusion of said start-up cycle. Said start-up cycle has the effect of allowing more frequent additions of fluid to said system during the initial period of operation, when there is a probability of greater volume loss due to air extraction.

In a fourth variation of said second method embodiment, said first notification may not activate an alarm and or an alarm monitoring entity. Said first notification may be transmitted by any embodied means, and may be manually recorded by the recipient. Said first notification may be an entry in a data logging memory, which may be transmitted or made available to recipients as directed. If P_a equals or exceeds P_r , said controller (302) may take equivalent actions to notify as described.

In a fifth variation of said second method embodiment, said controller 302 may not incorporate any or all direct physical control functions or displays 316. Initial set-up and operation of said controller 302 and said associated programming of values may be by action of an ancillary device such as a computer 312 connected directly or through a LAN 310, or by a mobile device 306 connected to said controller 302 through a LAN 310, or directly connected wirelessly 304 by Bluetooth, 802.11 Wi-Fi, or any other means. Said controller 302 may be distributed with, or with access to, a software application for said computer 312 or mobile device 306. Said application may have any of the following attributes:

- Setpoints may be by user-defined values, or the application may require the installer to enter raw data concerning the hydronic system, and said application may then calculate and install the setpoints in the microprocessor memory of said controller. Examples of data that may be required may be appliance 102 model number and serial number, specified minimum operating pressure of the appliance 102, height of hydronic piping system and the measured elapsed time for said feed valve 116 to raise P_a from P_s to P_n .
- Operating setpoints such as P_w , P_s and P_n may have embedded values relative to input data, or may be configurable by the installer, or alterable by the installer within programmed parameters.
- Initiation can require the successful completion of a verification test cycle that may include, but is not limited to, raising P_a from P_s to P_n during time interval D_o , and manually releasing fluid from said hydronic system so as to test transmittal of said first notification at P_w and test transmittal of said second notification at P_s .
- Said application may receive data from said controller 302 continuously, and or may download data as and when connected to said ancillary or mobile device 306.
- Said application may display any available output or setpoint from said controller 302, including, but not limited to, said system setpoints, pressure P_a , duration of

P_a less than P_w , and enabled operation of said system shutoff valve 202 as reported by said end switch.

- Said application may store initialization data and or said verification test result data. Said stored data may be required as supporting documentation for any warranty or liability claim action initiated by the installer and or the end user.
- Said application may send any, or all, available data to a third-party server.
- Said application may be configured to allow firmware updates via Internet connection, either automatically or by user permission.

System elements for a second system embodiment

A second system embodiment may consist of the following elements as described herein and illustrated schematically in Figure 7. An electro-mechanical timer or electronic timer 380 may be powered by grid power 300 or by a battery source. Said timer 380 may be, but is not limited to, a seven-day timing cycle. It may be preferred to embody a minimum “on” time of no more than one to five minutes. A normally closed relay 348 may interrupt a timer output 328 circuit that may otherwise energize said system shutoff valve 202. A manifold assembly 222, similar to that previously disclosed for a fourth variation of said first system embodiment, may embody a manifold 206, a system shutoff valve 202, a pressure gauge 212, and two pressure switches 208 and 210.

A normally open pressure switch 208 may close at a pre-set falling pressure P_w , and re-open at a pre-set rising pressure P_r . Said switch 208 may enable or disable a relay control circuit. Said relay control circuit may be powered by a source 392 which may be, but is not limited to, 120 volt AC grid power, or 24 volt AC. Said switch 208 may enable a local alarm 384, and or energize a normally open relay 386 to send a first notification to an installed home security system or to a monitoring service for same. Closing said switch 208 may also send an input to an Internet connected device 382. Said device 382 may send a first notification over said Internet by any means, which may be, but is not limited to, cellular phone service or wired or wireless connectivity to a LAN.

A normally open pressure switch 210 may close at a pre-set falling pressure ***P_s***, and re-open at a pre-set rising pressure ***P_r***. Said switch 210 may enable or disable a relay control circuit. Said relay control circuit may be powered by a source 392 which may be, but is not limited to, 120 volt AC grid power, or 24 volt AC. Said switch 210 may enable a local alarm 388, and or energize a normally open relay 390 to send a second notification to an installed home security system or to a monitoring service for same. Closing said switch 210 may also input to an Internet connected device 382. Said device 382 may send a second notification over said Internet by any means, which may be, but is not limited to, cellular phone service or wired or wireless connectivity to a LAN.

Said switch 210 may enable a normally closed relay 348, which may interrupt said output 328 of said timer 380, and cause said valve 202 to close or be prevented from opening. Said switch 210 may enable a normally closed relay 344, which may interrupt a low voltage control circuit 360 to open a power relay 124 and disable said circulator pump 118. Said switch 210 may enable a normally closed relay 346, which may interrupt a low voltage control circuit 362 to disable said appliance 102.

Method of operation

A method of operation of said second system embodiment may be a variation of said previously disclosed second method of operation. Said timer 380 may be set or programmed for one or more “on” intervals of duration ***D_o***. Said value of ***D_o*** may be determined as previously disclosed. Typically, said timer 380 may embody a seven-day timing cycle, typically with one “on” interval per cycle. Said system shutoff valve 202 may be energized open for duration ***D_o*** of said timer. Said periodic opening of said system shutoff valve 202 may allow said system feed valve 116 to add fluid if and as necessary to raise ***P_a*** to ***P_n***, presuming no ongoing system fluid losses. A sudden increase in rate of fluid loss during ***D_o*** may prevent ***P_a*** from reaching either ***P_r*** or ***P_n***, but as energizing of said system shutoff valve 202 is time limited, potential discharge of fluid through any breach is consequently limited as well.

If ***P_a*** is reduced to ***P_w*** or less, said switch 208 closes, and closes said relay 386 and or activates said local alarm 384. A first notification may be sent by said device 382, by any means as previously described. If, during scheduled time period ***D_o***, ***P_a*** increases to ***P_r*** or

above, said alarm 384 and said relay 386 may be de-energized, and cancelation of said first notification may be sent by said device 382.

If at any time P_a is reduced to P_s or less, said switch 210 closes, and activates said alarm 388 and or said relay 390. Said relay 348 may be energized open, to interrupt said output 328 and prevent energizing of said valve 202. Said relay 344 may be energized to disable said circulator pump 118, and said relay 346 may be energized to disable said appliance 102. A second notification may be sent by device 382, by means as previously described. System shutdown may preclude any opening of said valve 202, so that said system may require a manual re-start after inspection, repair and the manual filling and purging of said system to pressure P_n .

System elements for a third system embodiment

A third embodiment may include all elements of a first embodiment and may further consist of the additional following elements as described herein and illustrated schematically in Figure 8. An electrically operated domestic supply valve 252 may succeed a connection to said hydronic system fill piping 110, and may provide for the isolation of the remainder of the installed domestic water system from the incoming water supply 100. Said domestic supply valve 252 may be capable of holding against a pressure differential greater than the full incoming water supply pressure 100.

Said domestic supply valve 252 can be self-closing on loss of power, thus limiting possible fluid loss in case of a grid power outage, but may allow for a manual override to allow domestic water use during a power outage. Said domestic supply valve 252 may be separate from or be physically embodied with said leak detector system shutoff valve 202, in any of said embodiments of said leak detector system.

A bladder type expansion tank 256 that can be rated for potable water use can be installed in the branch piping that supplies the domestic hot water heating appliance 258. If said domestic supply valve 252 should be closed, said expansion tank 256 may allow for thermal expansion or contraction of the water in the domestic plumbing system, and thereby precludes the necessity of simultaneously shutting off the domestic hot water heating appliance 258.

A pressure transducer 254 may be installed downstream of said domestic supply valve 252. Said domestic pressure transducer 254 may communicate with a controller 398 by a hard wire connection 326 or by a wireless connection such as, but not limited to Bluetooth. If said pressure transducer 254 communicates with said controller 302 wirelessly, power to operate said transducer 254 may be by a contained battery, or drawn directly from the structure power grid 300, which may incorporate a battery backup.

A variation may utilize a pressure switch in lieu of said transducer 254. Said normally open pressure switch may close on a preset falling pressure, and re-open on a pre-set rising pressure.

Said controller 398 may include all elements of a first embodiment and may further consist of the following additional input, outputs, and functions. An output 334 may be enabled to energize said domestic shutoff valve 252. An input 326 may receive an analog signal from said domestic pressure transducer 254. A relay output 342 may enable a fourth notification if actual domestic system pressure falls below a programmed setpoint. Said relay 342 may activate a local alarm and or may send a fourth notification to an installed home security system or to a monitoring service for same. Said controller 398 may be connected to an installed home alarm or security system by any wired or wireless means. Said controller 398 may be connected to a LAN router 310 by any wired 308 or wireless 304 means and or directly connect to a mobile device 306. Said controller 398 may by any previously described means receive an input signal for an *UNOCCUPIED* condition, and for an *OCCUPIED* condition.

A method of operation of said third system embodiment may be any of said previously disclosed first or second methods of operation, and other functions as described herein and represented as a flowchart in Figure 9. Element numbers of shapes for operational steps in Figure 9 are indicated herein in parentheses. Said controller 398 may be programmed and linked (900) to an installed alarm system or mobile device.

A signal (902,904) to said controller 398 may cause an activation of an *OCCUPIED* mode (906) and may energize output 334 to cause said domestic supply valve to open (908) and allow normal domestic water use (910). A loss of power (920) may cause said domestic supply valve 252 to close (922), but said valve 252 may provide for a manual override (924) to allow domestic water use during a power outage.

A signal (930,932) to said controller 398 may cause activation of an *UNOCCUPIED* mode (934) and may de-energize said output 334 and may cause said domestic supply valve 252 to close (936). Said closing of said domestic supply valve 252 may limit any source or cause of domestic system water loss to be no more than that which is statically contained within said domestic plumbing system. Said function may have the greatest utility at such times as the structure is unattended for long periods, such as seasonal non-use, or vacation periods during the heating season.

During said *UNOCCUPIED* periods, said controller 398 may continuously sample domestic system pressure (938). Said controller 398 may embody a clock and calendar function (950), and may embody a data log (952) of domestic system pressure values, which may be reported by any embodied means of communication (954). Should the pressure in said domestic system fall (940) to a programmed value (942) below the lowest possible supply pressure and also above the maximum static head pressure of said domestic system, said controller 398 may enable an output 342 to issue a fourth notification (944). Said fourth notification may simultaneously or exclusively be sent to a home alarm system and or to a LAN and or directly to a mobile device. Said fourth notification may indicate a significant loss of pressure in said domestic system during any period while in *UNOCCUPIED* mode. This indicator may be relied on prior to signaling an *OCCUPIED* mode (960).

System elements for a fourth system embodiment

A fourth system embodiment may consist of the following elements as described herein and illustrated schematically in Figure 10. In a typical residential heating system, fluid is drawn from appliance 102 via a system supply pipe 104 through said air separator 112 by the circulator pump 118. Fluid is pushed away around one or more distribution loops through one or more radiators, and re-enters said appliance 102 through a return pipe 106. A conduit can couple an expansion tank 120 and an air separator 112 with an air vent 114. A pressure transducer 204 that generates a signal proportional to hydronic system fluid pressure may be installed in said conduit between said expansion tank 120 and said air separator 112, which is the point of no pressure change during operation of said circulator pump 118 of said system. Said pressure transducer 204 can communicate

with a controller 302, by hard-wired connection or by wireless connection, such as, but not limited to Bluetooth.

One or a plurality of temperature sensors 230 can transmit supply side fluid temperature data to said controller 302, by hard-wired connection or by wireless connection, such as, but not limited to Bluetooth. One or a plurality of temperature sensors 232 can transmit return side fluid temperature data to said controller 302, by hard-wired connection or by wireless connection, such as, but not limited to Bluetooth.

One or a plurality of temperature sensors 234 can transmit indoor air temperature data to said controller 302, by hard-wired connection or by wireless connection, such as, but not limited to Bluetooth. One or a plurality of temperature sensors 236 can transmit outdoor air temperature data to said controller 302, by hard-wired connection or by wireless connection, such as, but not limited to Bluetooth. In a variation, one or a plurality of temperature sensors 236 can transmit outdoor air wind chill temperature data to said controller 302, by hard-wired connection or by wireless connection, such as, but not limited to Bluetooth. One or a plurality of temperature sensors 238 can transmit material surface temperature data, including but not limited to floor surface temperature, to said controller 302, by hard-wired connection or by wireless connection, such as, but not limited to Bluetooth.

Said controller 302 may have the capability to connect to the Internet 314. This means of connection may be, but is not limited to, a hard-wired connection such as Ethernet or USB, or may be wirelessly by Bluetooth, 802.11 Wi-Fi, or any other system. Said controller 302 may thusly be programmed and or monitored by any device with an Internet connection. Any functionality of said controller may thusly be performed at a remote location or by any computer server that may be remotely located and also has an Internet connection.

Said controller 302 may have the capability to receive temperature, wind chill temperature, or weather data from one or a plurality of remote sources 330, through said connection to the Internet 314.

Said controller 302 may have the capability to communicate with any type of mobile device 306, through said connection to the Internet 314.

A variation of said fourth system embodiment may consist of the following elements as described herein and illustrated schematically in Figure 11. In said variation, all elements of said fourth system embodiment may be found, further comprising additional elements pertinent to a typical multi-zone heat transfer system, herein represented as, but not limited to a three zone system. Thermostats 260, 262, 264 each regulate their respective zone valves 240, 242, 244. Each zone valve 240, 242, 244 is independently enabled to communicate the open or closed status of their respective valve to said controller 302. The means of communication may be, but is not limited to, a hard-wired connection, a hard-wired data connection such as Ethernet or USB, or may be wirelessly by Bluetooth, 802.11 Wi-Fi, or any other system.

Method of operation

A fourth method of operation of a fourth system embodiment of this invention is as described herein. After filling a closed loop heat transfer system, air is purged from the contained fluid, and fluid topped up to obtain a pre-determined operating pressure as may be necessary. Typically said systems are filled cold, so that even idle at room temperature, said contained fluid expands slightly, and expands more so as operating temperature increases. Said thermal expansion is accommodated by said fluid pushing into the bladder of said expansion tank 120, with a corresponding slight increase in system pressure due to the compression of the contained pre-charge of air on the opposite side of the bladder. Said thermal expansion or contraction does not by itself have any effect on the value of the fluid mass contained within the system, which may remain constant barring any type of physical fluid mass loss or leakage.

In a closed loop fluid heat transfer system, pressure at the point of “no pressure change” can vary only due to change in volume due to thermal expansion and contraction, loss of volume due to extraction of entrained air, loss of fluid mass due to leakage of any type, or addition of fluid by means of a makeup fluid supply operation. Extraction of air is a very slow process, which becomes slower over time, and eventually results in a very small change in volume over time. This volume loss may eventually be so slight as to only need compensating for after a period of months, or even a year.

Said controller 302 may receive pressure and temperature data from one or more of a plurality of system or environmental sensors. A most basic data set may include system fluid pressure data from said pressure transducer 204, and system fluid temperature data from said supply temperature sensor 230 and or return temperature sensor 232. Said controller 302 may construct a fluid mass model of said contained fluid mass by an algorithm that estimates the presently contained fluid mass from said received pressure and temperature data. Said fluid mass model may be enabled to identify a deviation in fluid mass at any condition of operating temperatures. In simplest form, a deviation in observed pressure downward from said model, relative to any given set of temperature inputs, may be a real-time indicator of a loss of fluid mass.

Said fluid mass model may be made more accurate by incorporating environmental air temperature data into the model. Said temperature data may be derived from one or a plurality of indoor 234 and or outdoor 236 air temperature sensors. A variation may be to utilize wind chill data with or without an associated outdoor air temperature. In a variation, outdoor environmental data may be obtained from a remote source 330, such as the most relevant NOAA weather data.

Said fluid mass model may be made more accurate by incorporating material surface temperature data of the conditioned space into the model. Said temperature data may be derived from, but not limited to, one or a plurality of floor material surface temperature sensors 238. This may be particularly useful when the system radiator or radiators is comprised of in-floor radiant tubing, by providing data on the temperature of circulating or non-circulating fluid temperatures.

By gathering and processing an array of temperature data, along with the fluid pressure data, a fluid mass model for said contained fluid mass can be generated for an individual closed loop heat transfer system, that can provide an accurate and actionable prediction of said system pressure for an observed set of temperature inputs. If said system pressure is observed to fall below the predicted pressure by a previously defined increment, said controller 302 may determine that there is an ongoing loss of fluid mass. Said determination may precede absolute system fluid pressure falling to a value that would require a fill event initiation. This early detection may result in a fifth notification being issued by the controller 302, to occupants and or service personnel, as appropriate.

Said fifth notification may be the closing of one or more switches, which may enable the functioning of a local alarm and or enable a fifth notification via any type of installed home security or monitoring system. Said fifth notification may be exclusively or simultaneously a wireless signal via Bluetooth, 802.11 Wi-Fi, or any other system. Said fifth notification may be exclusively or simultaneously an automated telephone call, a text message, an email, or an electronic notification sent to a predetermined device. Said fifth notification may be directed to or available to any device with an Internet connection. Said fifth notification may assist in diagnosis of actual rate of leakage, as said leakage may be identified in real time, without the limitation of fluid loss being masked due to thermal expansion of the fluid.

When the coefficient in said fluid mass model relating pressure to temperature increases, this may be an early indication of a loss of air pre-charge pressure in said expansion tank 120. Said controller 302 may generate a sixth notification, requesting that service personnel investigate the system. This sixth notification may be by any means as described above for the fifth notification.

A variation of said fourth method of operation of a variation of a fourth system embodiment of this invention pertains to multi-zone closed loop fluid heat transfer systems and is as described herein. Individual radiator zones may or may not be actively circulating fluid from said system appliance at any given moment in time. Said fluid mass model may be made more accurate by receiving data pertaining to the open or closed status of any and all associated zone valves 240, 242, 244. Said data may allow the fluid mass model to more accurately model the fluid temperature of each physical portion or zone of said contained fluid mass, and may thusly generate a more accurate model of system fluid temperature and contained fluid mass.

System elements for a fifth system embodiment

A fifth system embodiment may consist of the following elements as described herein and illustrated schematically in Figure 12. An electrically operated normally closed system shutoff valve 202 may be installed in the fill piping 110 between a fluid source 100 and a hydronic system, for the purpose of allowing or dis-allowing flow of makeup fluid

through the backflow preventer 126 and into said system. In a typical residential heating system, fluid is drawn from appliance 102 via a system supply pipe 104 through said air separator 112 by the circulator pump 118. Fluid is pushed away around one or more distribution loops through one or more radiators, and re-enters said appliance 102 through a return pipe 106. A conduit can couple an expansion tank 120 and an air separator 112 with an air vent 114.

A pressure transducer 204 that generates a signal proportional to hydronic system fluid pressure may be installed in said conduit between said expansion tank 120 and said air separator 112, and may be combined in a manifold 206 with said system shutoff valve 202. Said pressure transducer 204 can communicate with a controller 302, by hard-wired connection or by wireless connection, such as but not limited to Bluetooth. Said controller 302 may communicate with and control the operation of said system shutoff valve 202 by any means. This means may be by hard-wired connection, or wirelessly, by Bluetooth or by any other means. Said controller 302 may actuate said system shutoff valve 202 according to fluid pressure information received from pressure transducer 204. Said actuation of said system shutoff valve 202 may be determined according to any of the previously disclosed leak detection methodologies, or by any method of operation as may be appropriate.

Said controller 302 may have the capability to connect to the Internet 314. This means of connection may be, but is not limited to, a hard-wired connection such as Ethernet or USB, or may be wirelessly by Bluetooth, 802.11 Wi-Fi, or any other system. Said controller 302 may thusly be programmed and or monitored by any device with an Internet connection. Said controller 302 may be an interface for a remote server 332. Any remote computer or server 332 with an Internet connection may perform any of the embodied methodology or functionality as herein described.

Said controller 302 may have the capability to communicate with any type of mobile device 306, through said connection to the Internet 314.

Method of operation

A fifth method of operation of a fifth system embodiment of this invention is as described herein. After filling a closed loop heat transfer system, air is purged from the contained fluid, and fluid topped up to obtain a pre-determined operating pressure as may

be necessary. Typically said systems are filled cold, so that even idle at room temperature, said contained fluid expands slightly, and expands more so as operating temperature increases. Said thermal expansion is accommodated by said fluid pushing into the bladder of the expansion tank 120, with a corresponding slight increase in system pressure due to the compression of the contained pre-charge of air on the opposite side of the bladder. Said thermal expansion or contraction does not by itself have any effect on the value of the fluid mass contained within the system, which may remain constant barring any type of physical fluid mass loss or leakage.

In a closed loop fluid heat transfer system, pressure at the point of “no pressure change” can vary only due to change in volume due to thermal expansion and contraction, loss of volume due to extraction of entrained air, or loss of fluid mass due to leakage of any type. Extraction of air is a very slow process, which becomes slower over time, and eventually results in a very small change in volume over time. This volume loss may eventually be so slight as to only need compensating for after a period of months, or even a year.

In this embodiment, said controller 302 maintains a fluid mass model reference of the contained system fluid mass and volume, which represents an estimate of the mass of fluid that must be added over defined periods of time in order to maintain the operating parameters of said system. Initial parameters of said fluid mass model reference can be entered into the controller's memory as determined by the installer. In a variation, said controller 302 may run one or more test cycles of said system upon initialization to ascertain the parameters of said system. Said controller 302 may also calculate and adjust the parameters of said system continuously.

When data from said pressure transducer 204 generates a request for the addition of makeup fluid, the amount of fluid requested is compared with said fluid mass model reference. The amount of fluid requested may be measured in discrete units of volume, corresponding to the pressure increments between initiation and limitation of fill, as predetermined by the use of either of said first or second method of operation, as described above. In a variation of this fifth method of operation, the fluid mass requested may be modeled and reported as a frequency of occurrence of fill events. In a variation of this embodiment, the amount of fluid requested may be measured in any unit of volume, by any

means, including but limited to, any flow measurement device or method applied to the makeup supply conduit 110.

Said fluid mass model reference of the change in the rate of loss of fluid volume or fluid mass is a function of time. In a variation of this embodiment, said fluid mass model reference may model said rate of loss as a frequency of fill events. In the preferred embodiment of said model, fill frequency decreases from the initial value with a third order equation to a target value, then remains constant. Other mathematical functions such as an exponential decrease may also be utilized. The coefficients of said fluid mass model reference may be entered at setup and may later be adjusted manually. In a variation of this embodiment, said coefficients may be established by the algorithm of said model, based on prior individual or collective heat transfer system history.

If the difference between requested fluid mass and expected fluid mass is greater than a pre-established function, a seventh notification may be issued. If said difference is greater than the expected volume by an established second function, an eighth notification may be sent, and or other actions may be taken, including but not limited to denying additional makeup fluid supply. Said controller 302 may issue either of said seventh or eighth notifications by any means. Said notifications may be the closing of one or more pairs of dry contacts, which may enable the functioning of a local alarm and or enable a seventh and or an eighth notification via any type of installed home security or monitoring system. Said notifications may be exclusively or simultaneously a wireless signal via Bluetooth, 802.11 Wi-Fi, or any other system. Said notifications may be exclusively or simultaneously an automated telephone call, a text message, an email, or an electronic notification sent to a predetermined device. Said notifications may be directed to or available to any mobile device 306 with an Internet connection

Figure 13 is a graph of frequency of fill events vs. time for a closed loop fluid heat transfer system. Said graph illustrates an initial period 801 with a negligible loss of fluid mass but a coincident loss of fluid volume due to air extraction, as is expected on system start-up. A second period 802 is illustrated during which the loss of fluid mass is close to constant, as expected during normal system operation, and presuming no physical damage or defects in any system components. A third period of time 803 is illustrated when one or more system components are starting to break down, with a consequent increase in the

rate of loss of fluid mass. Finally, a short period of time 804 is illustrated, when said system fails due to an unsustainable rate of loss of fluid mass. Said system breakdown may be due to, but is not limited to, a corroding fastener that penetrates the piping, failing seals on a valve or pump 118, or to air diffusion across the bladder membrane, leading to a reduction in effective capacity of said expansion tank 120. In an embodiment of this invention, during the period 803 of increased rate of loss of fluid mass, the controller 302 may issue said seventh notification that said system is weakening and should be replaced or repaired before a catastrophic failure occurs during period 804.

It is intended that any variation of the fourth and or fifth method of operation as disclosed herein may be utilized in isolation as a method of closed loop fluid heat transfer system fluid monitoring, early diagnosis of unhealthy conditions, and early or predictive warning of impending failure of any of the physical components of the system. It is intended that any variation of said fourth and or fifth method of operation as disclosed herein may be utilized in used in conjunction with any other, or with any variation of said first or second method of operation as disclosed herein. It is intended that any variation of said fourth and or fifth method of operation as disclosed herein may be utilized in used in conjunction with any type or manner of closed loop heat transfer system fluid maintenance or monitoring method or device; or in any combination thereof.

Variations and Other Embodiments

The various embodiments and variations thereof, illustrated in the accompanying Figures and/or described above, are merely exemplary and are not meant to limit the scope of the invention. It is to be appreciated that numerous other variations of the invention have been contemplated, as would be obvious to one of ordinary skill in the art, given the benefit of this disclosure. All variations of the invention that read upon appended claims are intended and contemplated to be within the scope of the invention.

A variation of any of the preceding embodiments may be to control the electrically operated system shutoff valve either locally or remotely, after said first notification has been sent, by conscious action of either the local occupant or a remote monitoring service. A further variation may be to employ a manually operated system shutoff valve, which may be actuated manually after said first notification, by either the occupant or a system service

provider. This variation may be utilized for any system not directly connected to a pressurized fluid source, such as, but not limited to, glycol or glycol-water mixes. This variation may dispense with said feed valve and or backflow preventer, as the fill pressure may then be manually controlled.

Another variation may be to send device input data to a remote monitoring service for the purpose of monitoring, recording and acting upon the received inputs; thereby obviating the need for locally installed control logic. Such a variation may also compile data from many systems, and thus be able to learn typical system performance, and thereby be able to better assess causes of system pressure losses. A further variation may be to employ individual electro-mechanical time delay relays to effect intervals T_{L1} , D_o and T_{L2} , in lieu of programmed electronic timing functions embedded in microprocessor memory.

Claims

I claim:

1. A method of detecting a leak in a closed loop heat transfer system, the method comprising:
 - a. providing the closed loop heat transfer system, the heat transfer system including,
 - an appliance for heating or cooling,
 - a circulator pump,
 - an expansion tank,
 - an air separator with an air vent,
 - one or more heat transfer radiators,
 - a controller having a processor and non-volatile memory accessible by the processor, the non-volatile memory including a fluid mass model stored thereon,
 - a first conduit fluidly connecting the appliance, the circulator pump, the air separator and the heat transfer radiators to form a circulation loop,
 - a second conduit separate from the circulation loop for fluidly connecting the expansion tank to the air separator,
 - one or more fluid temperature sensors in operative communication with the controller located on the first conduit, and
 - at least one fluid pressure transducer in operative communication with the controller on the second conduit;
 - b. the controller periodically sampling system temperatures and system pressures through the respective one or more fluid temperature sensors and the at least one fluid pressure transducer to ascertain sampled system temperatures and sampled system pressures;
 - c. the controller evaluating the sampled system pressures and the sampled system temperatures; and
 - d. the controller providing a notification if a sampled system pressure of the sampled system pressures deviates from a calculated pressure level determined by the controller using the fluid mass model based on the sampled system temperatures.

2. The method of claim 1 further comprising the controller modeling the closed loop heat transfer system based on the sampled temperatures and sample pressures and storing data generated therefrom in the fluid mass model.
3. The method of claim 1, wherein the closed loop heat transfer system further includes one or more external temperature sensors, and the method further comprises the controller sampling temperatures from the one or more external temperature sensors to ascertain sampled external temperatures.
4. The method of claim 3, wherein said evaluating the sampled system pressures and the sampled system temperatures further includes evaluating the sampled external temperatures.
5. The method of claim 4, wherein said providing a notification if a sampled system pressure of the sampled system pressures deviates from a calculated pressure level determined by the controller using the fluid mass model based on the sampled system temperatures, further includes providing a notification if a sampled system pressure of the sampled system pressures deviates from a calculated pressure level determined by the controller using the fluid mass model based on the sampled system temperatures and the sampled external temperatures.
6. The method of claim 3, wherein the one or more of external temperature sensors comprise ambient air temperature sensors, and material surface temperature sensors.
6. The method of claim 1, wherein the notification comprises at least one of a visual alarm, an audible alarm, an automated telephone call, and a text message.
7. The method of claim 1, wherein the notification comprises transmitting an electronic message over a data network to predetermined recipients.

8. A method of evaluating a closed loop heat transfer system, the method comprising:

- a. providing the closed loop heat transfer system, the heat transfer system including,
 - an appliance for heating or cooling,
 - a circulator pump,
 - an expansion tank,
 - an air separator with an air vent,
 - one or more heat transfer radiators,
 - a controller having a processor and non-volatile memory accessible by the processor, the non- memory including a fluid mass model reference stored thereon,
 - a first conduit fluidly connecting the appliance, the circulator pump, the air separator and the heat transfer radiators to form a circulation loop,
 - a second conduit separate from the circulation loop for fluidly connecting the expansion tank to the air separator, and
 - at least one fluid pressure transducer in operative communication with the controller on the second conduit;
- b. the controller periodically sampling system pressure through the at least one fluid pressure transmitter to ascertain sampled system pressures;
- c. the controller modeling system fluid mass as a function of time;
- d. the controller determining if changes in a calculated fluid mass deviate over time from a projected fluid mass in the fluid model reference; and
- e. the controller providing notifications based on at least deviation of the calculated fluid mass from the fluid mass model reference, the calculated fluid mass being derived from measured data.

9. A method of remotely detecting a leak in a closed loop heat transfer system, the method comprising:

- a. establishing a connection with the closed loop heat transfer system over a data network, the heat transfer system including,
 - an appliance for heating or cooling,
 - a circulator pump,
 - an expansion tank,

- an air separator with an air vent,
 - one or more heat transfer radiators,
 - a controller having a network interface, the network interface being operationally connected with the data network,
 - a first conduit fluidly connecting the appliance, the circulator pump, the air separator and the heat transfer radiators to form a circulation loop,
 - a second conduit separate from the circulation loop for fluidly connecting the expansion tank to the air separator,
 - one or more fluid temperature sensors in operative communication with the controller located on the first conduit, and
 - at least one fluid pressure transducer in operative communication with the controller on the second conduit;
- b. periodically receiving sampled system temperatures and sampled system pressures from the closed loop heat transfer system;
 - c. evaluating the sampled system pressures and the sampled system temperatures; and
 - d. providing a notification if a sampled system pressure of the sampled system pressures deviates from a calculated pressure level determined by the controller using a fluid mass model based on the sampled system temperatures.

10. A method of remotely evaluating a closed loop heat transfer system, the method comprising:

- a. establishing a connection with the closed loop heat transfer system over a data network, the heat transfer system including,
 - an appliance for heating or cooling,
 - a circulator pump,
 - an expansion tank,
 - an air separator with an air vent,
 - one or more heat transfer radiators,
 - a controller having a network interface, the network interface being operationally connected with the data network,

- reference stored thereon,
- a first conduit fluidly connecting the appliance, the circulator pump, the air separator and the heat transfer radiators to form a circulation loop,
- a second conduit separate from the circulation loop for fluidly connecting the expansion tank to the air separator, and
- at least one fluid pressure transducer in operative communication with the controller on the second conduit;
- b. periodically receiving sampled system pressures from the closed loop heat transfer system;
- c. modeling system fluid mass as a function of time using at least in part the sampled system pressures;
- d. determining if changes in a calculated fluid mass deviate over time from a projected fluid mass in a fluid model reference; and
- e. providing notifications based on at least a deviation of the calculated fluid mass from the fluid mass model reference, the calculated fluid mass being derived from measured data.

GRAPH OF SYSTEM PARAMETERS vs PRESSURE
 GRAPH OF PRESSURE vs TIME FOR ISOLATED
 CLOSED LOOP HW HEATING SYSTEM

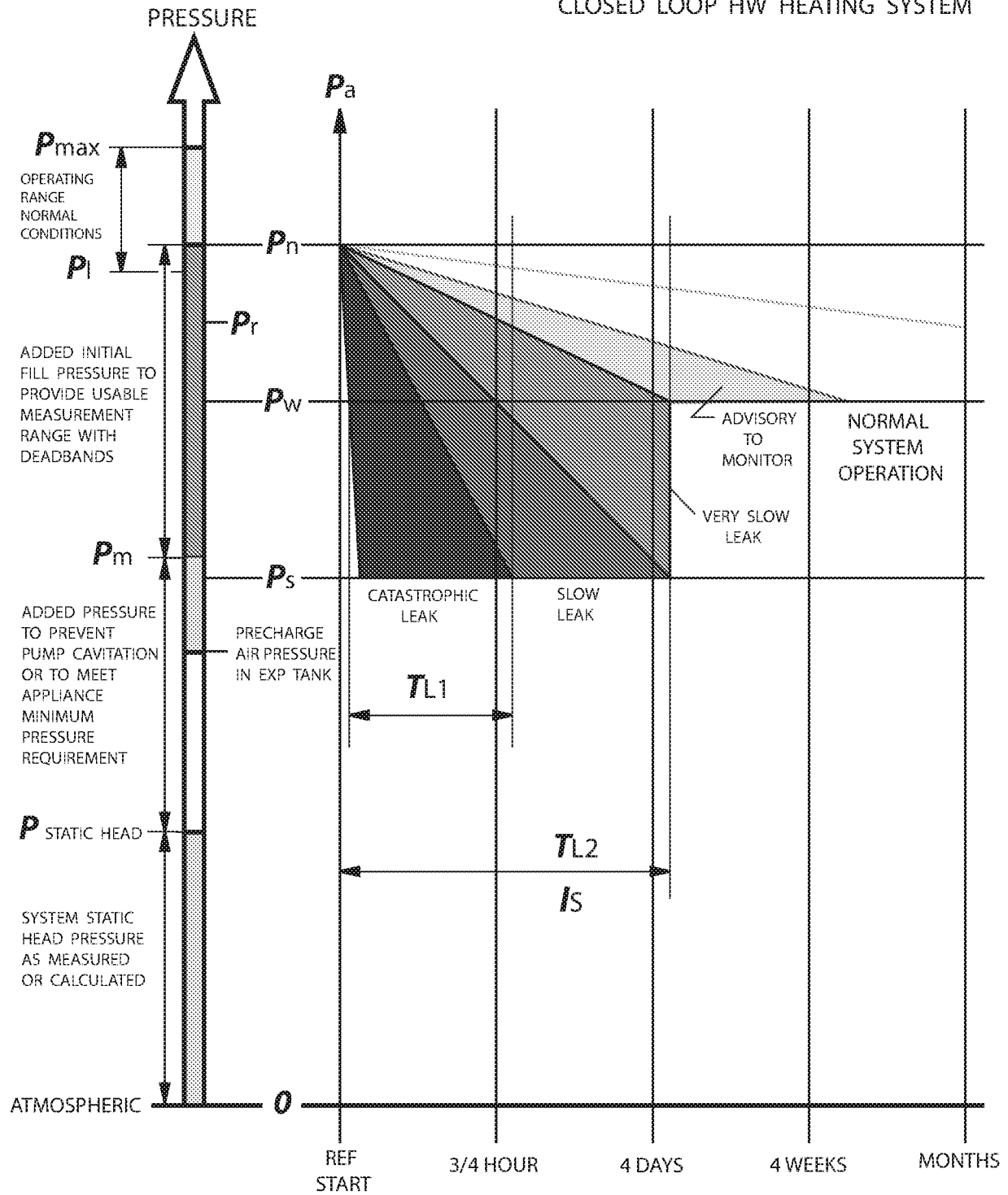


FIGURE 1

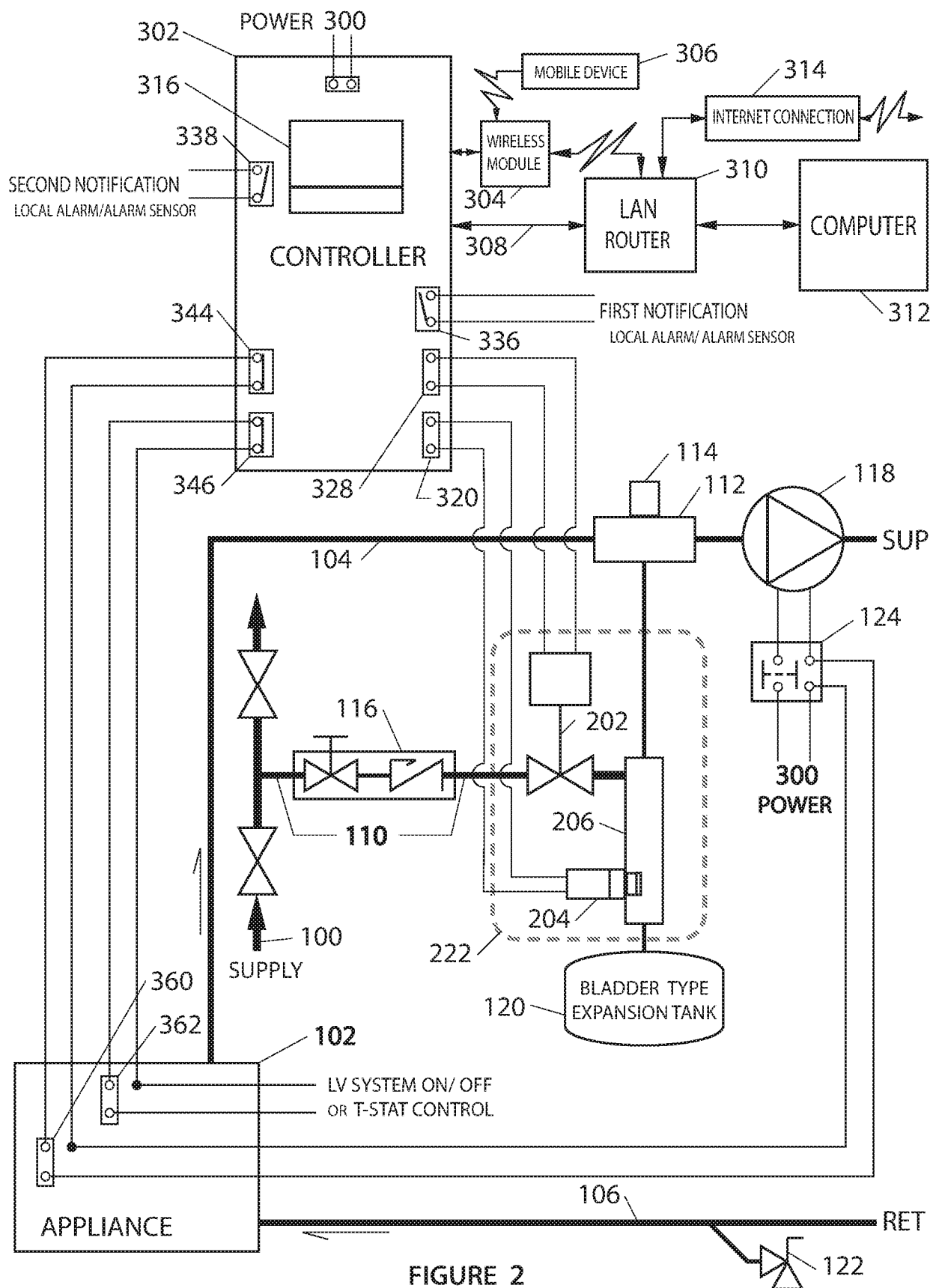


FIGURE 2

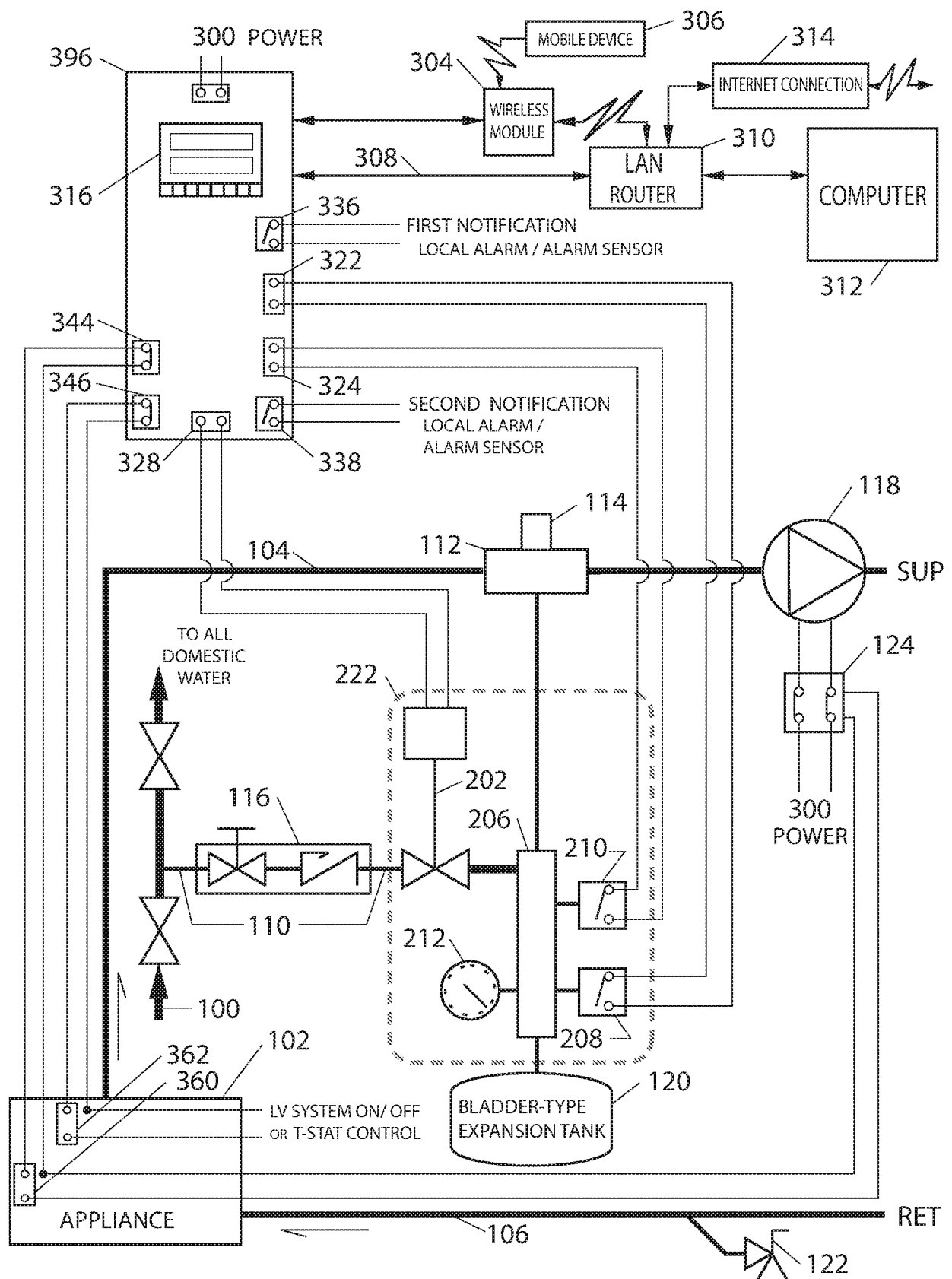


FIGURE 3

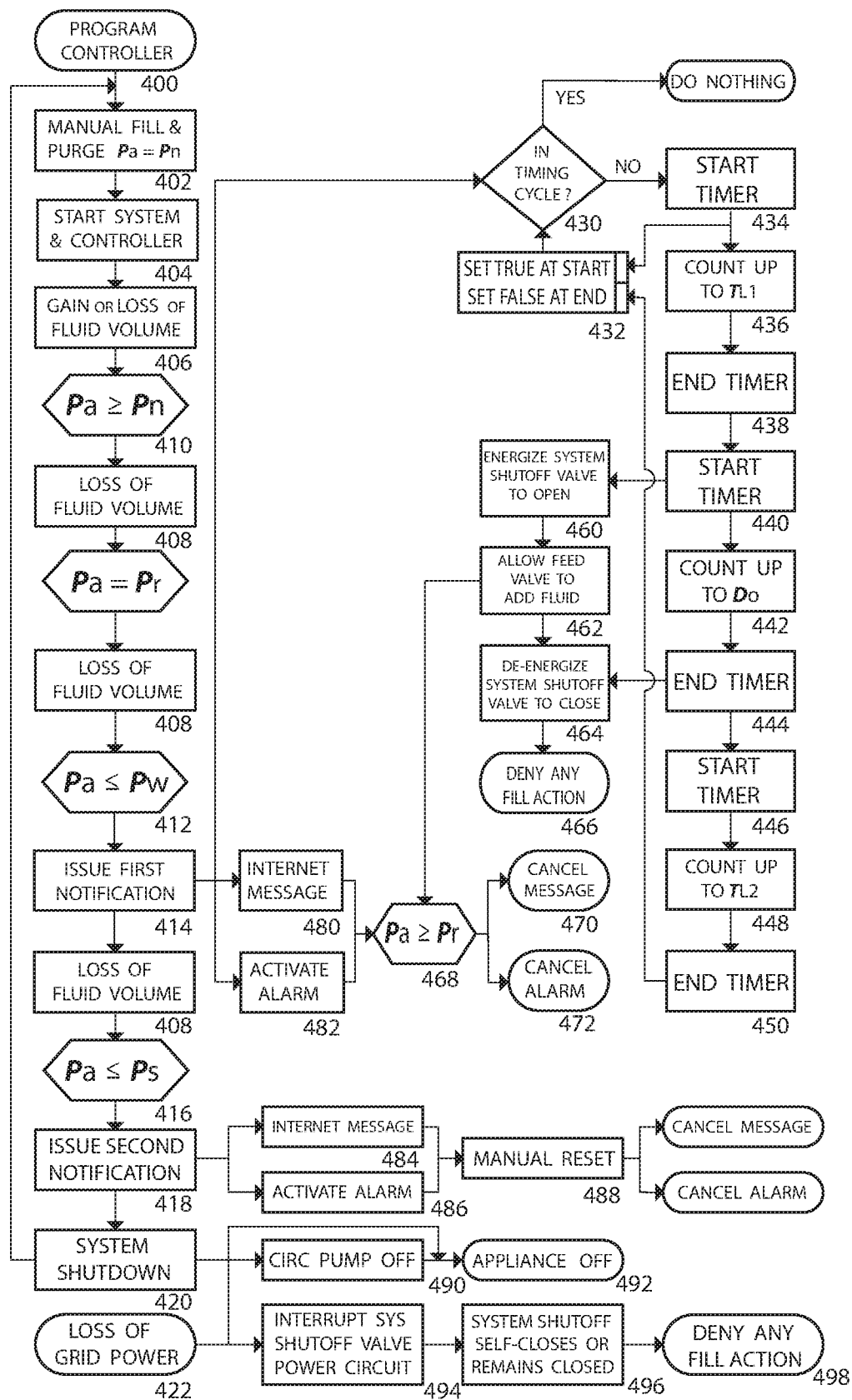


FIGURE 4

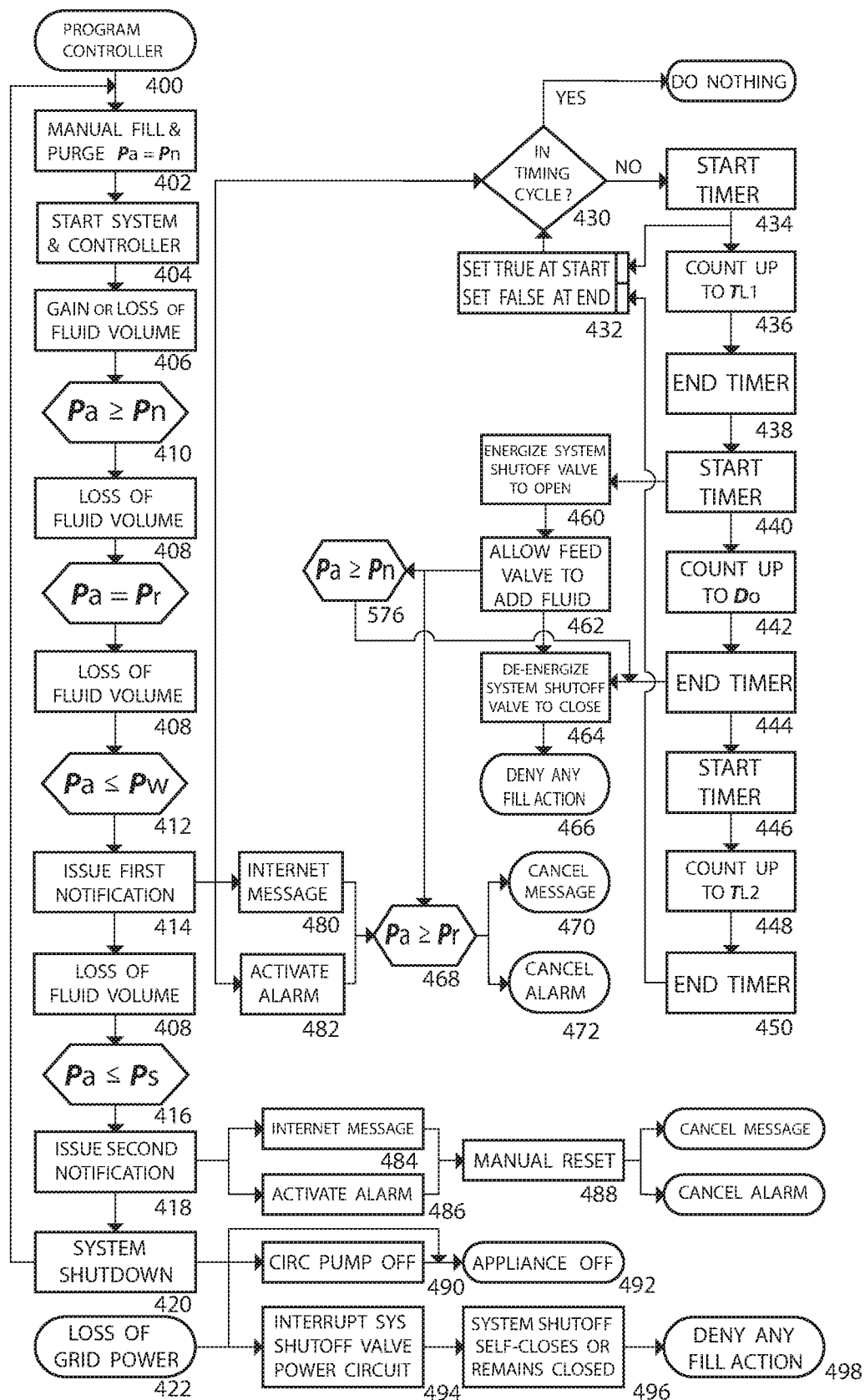


FIGURE 5

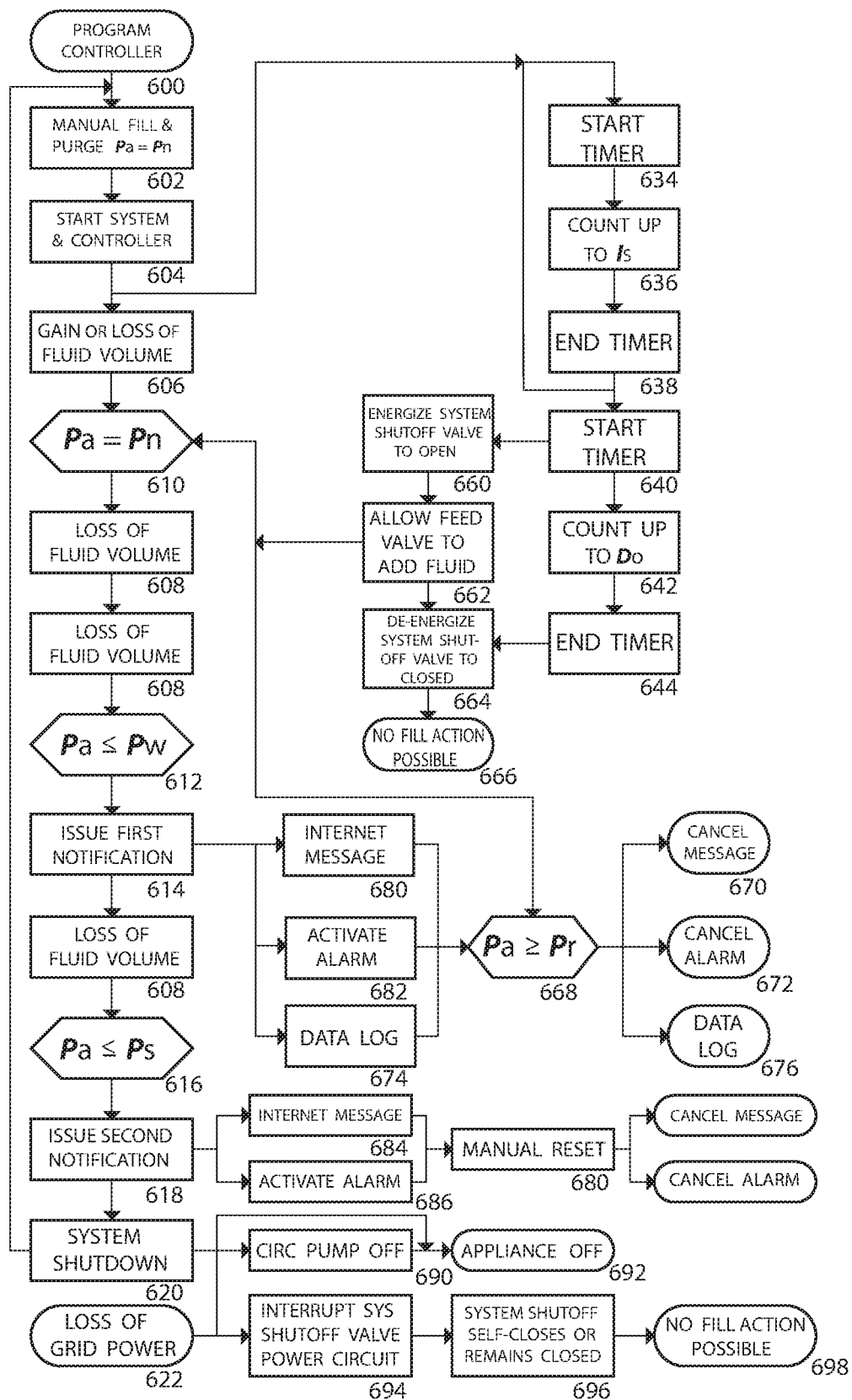
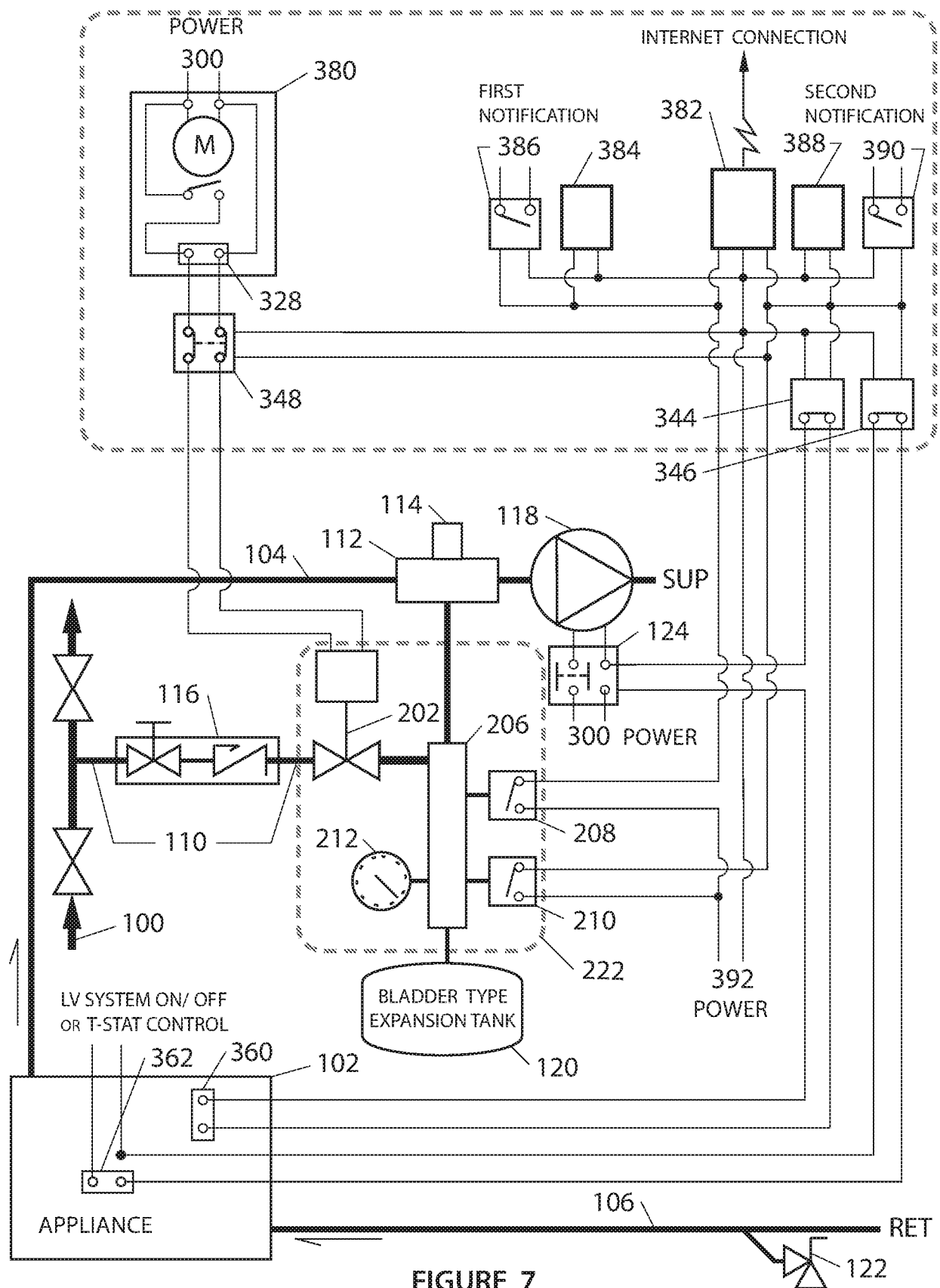


FIGURE 6



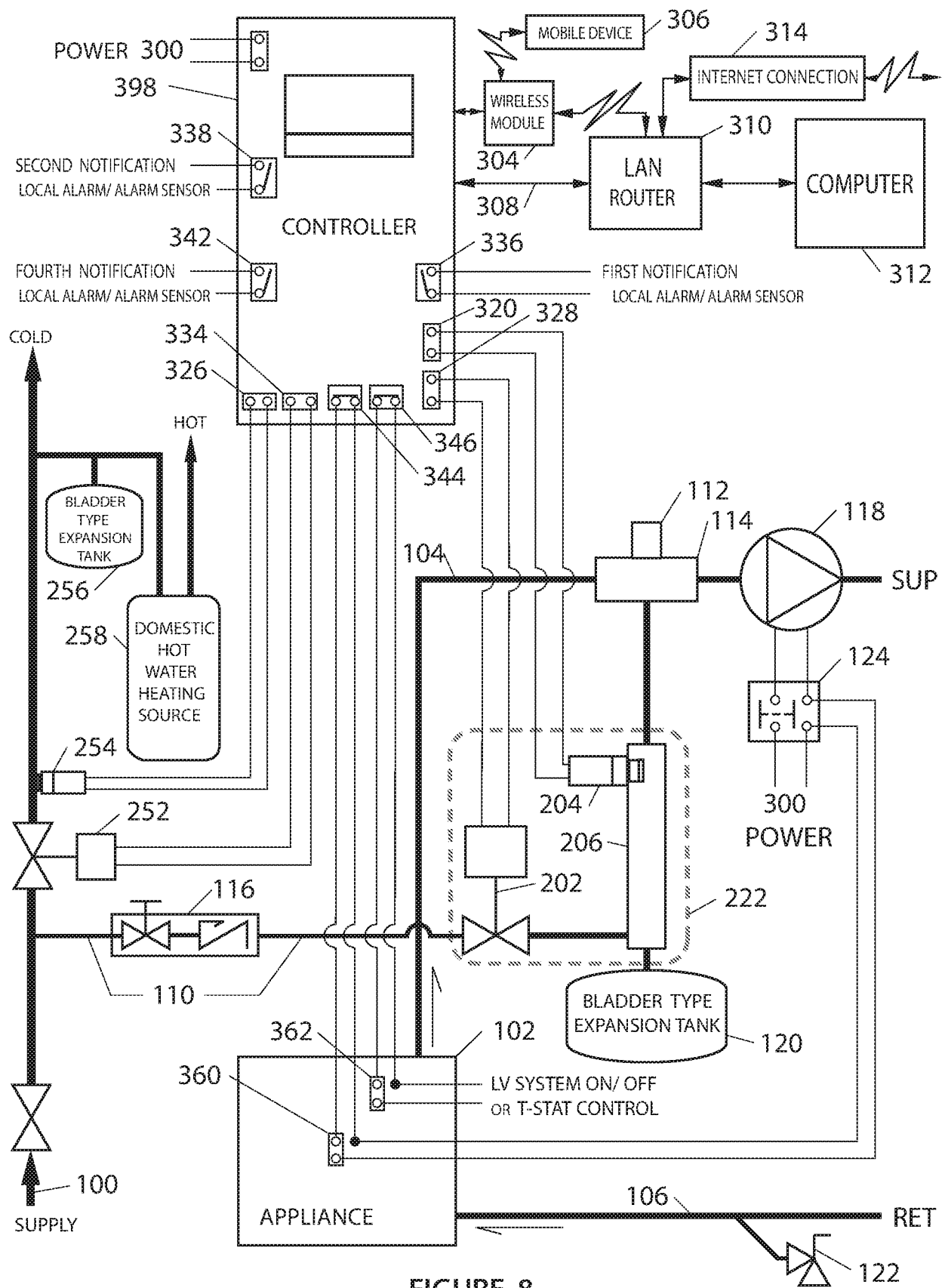
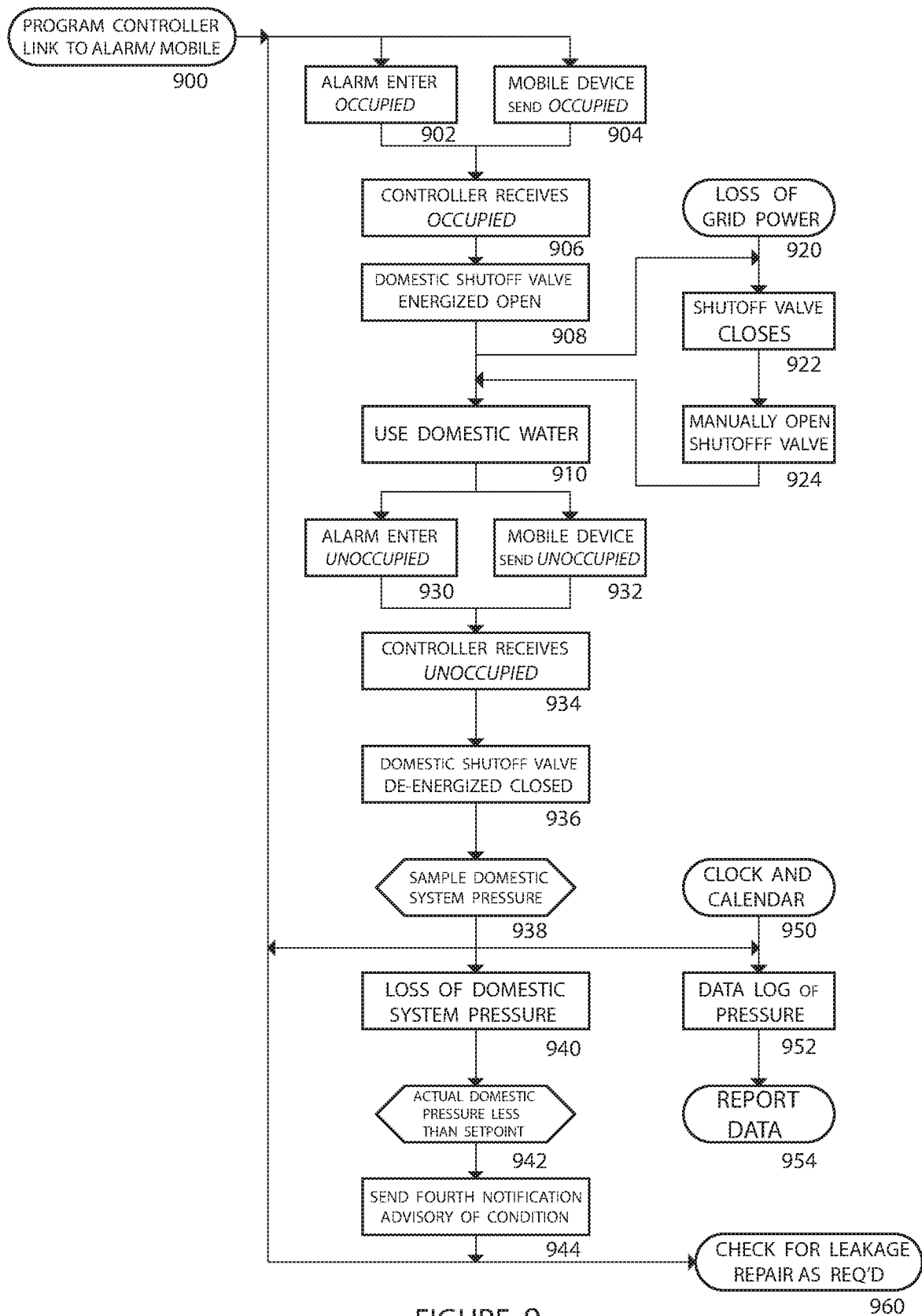


FIGURE 8



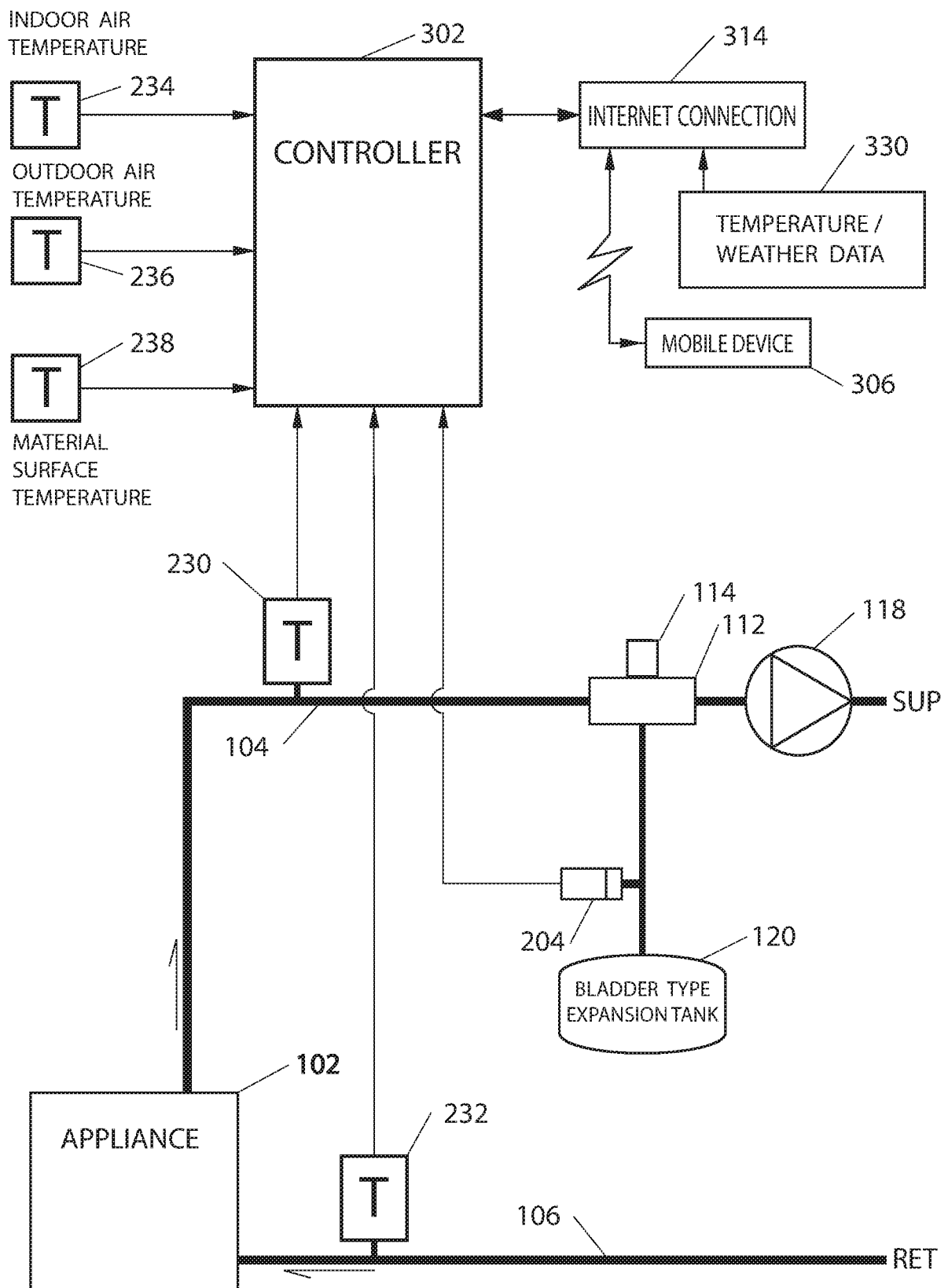


FIGURE 10

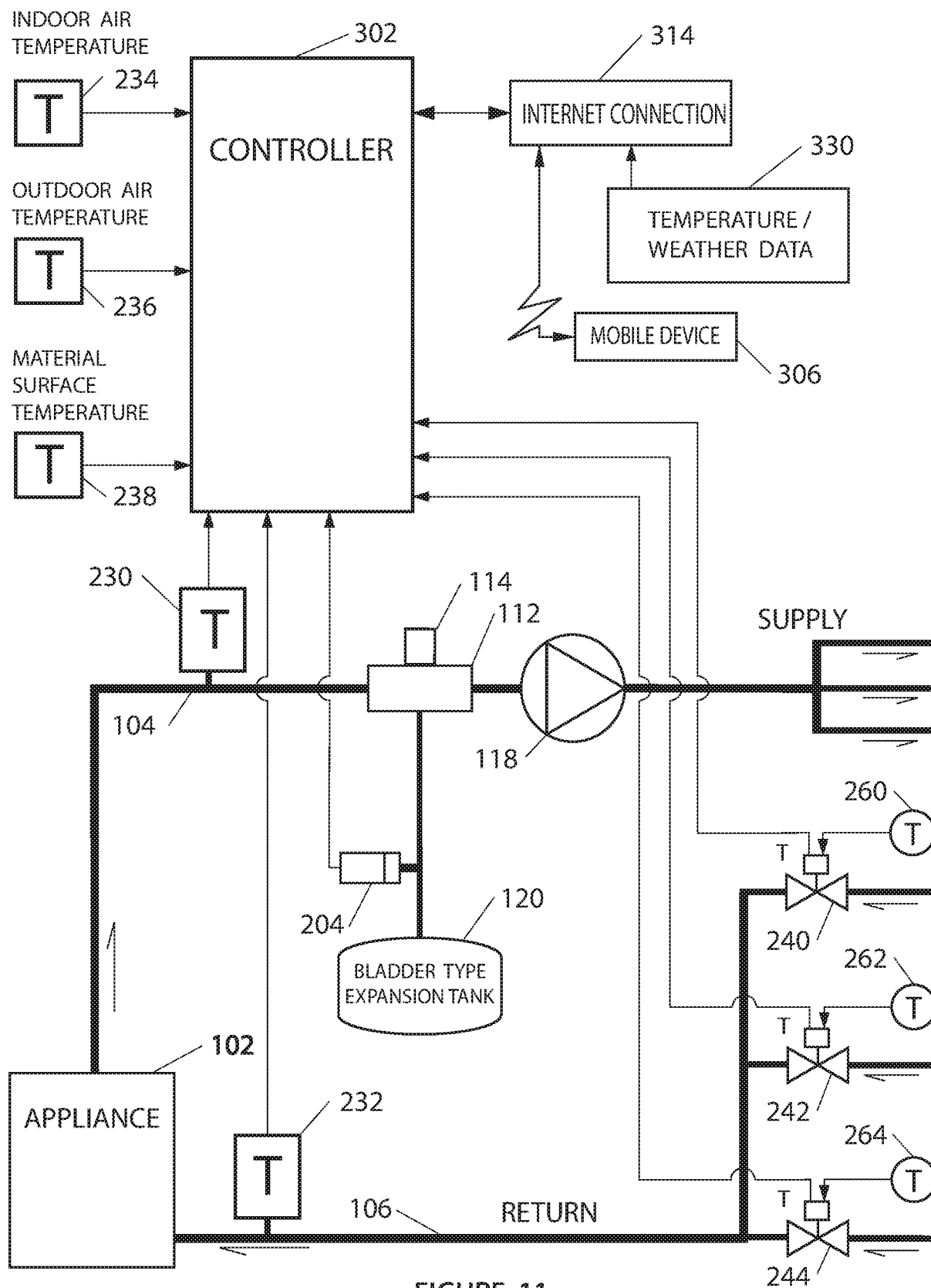


FIGURE 11

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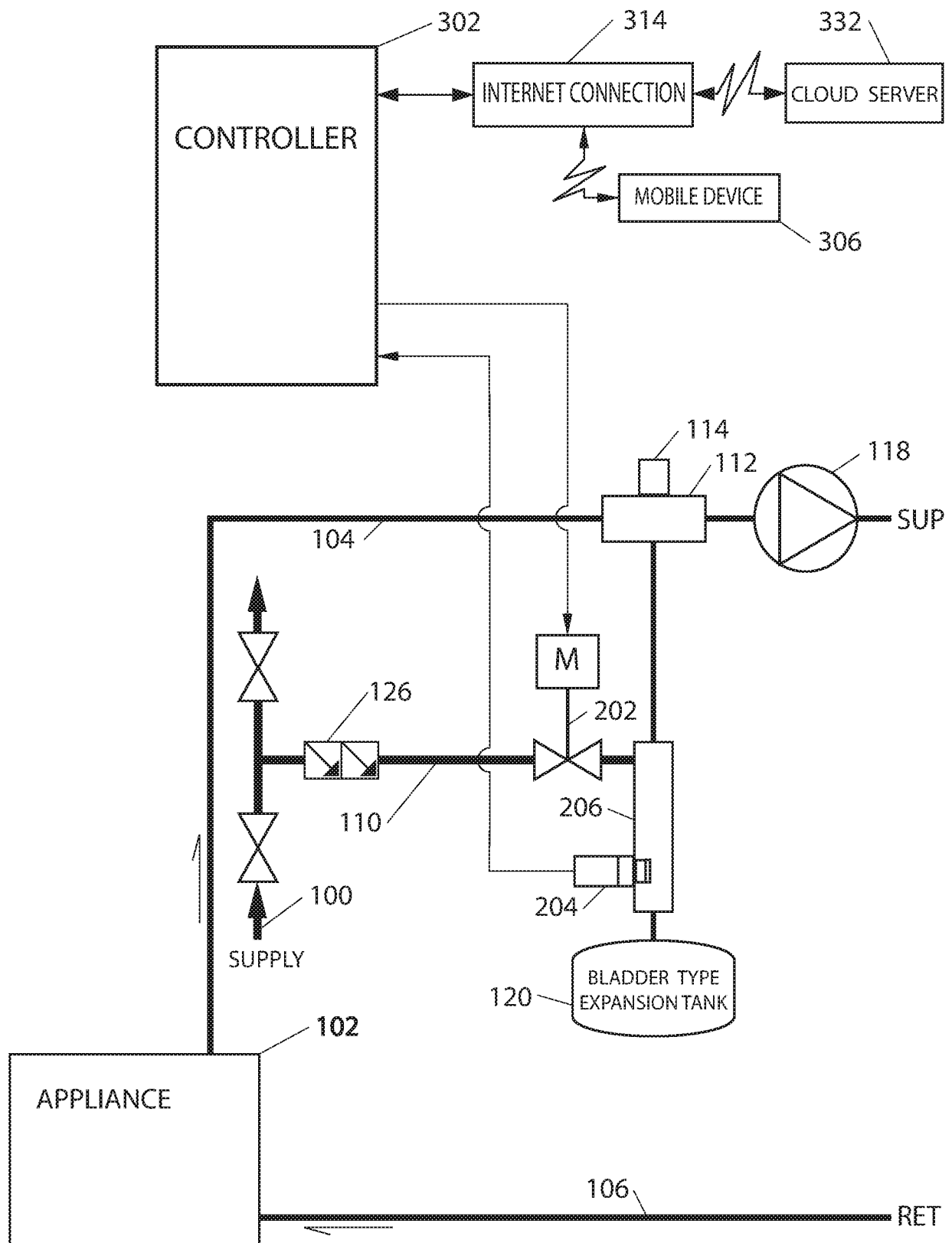


FIGURE 12

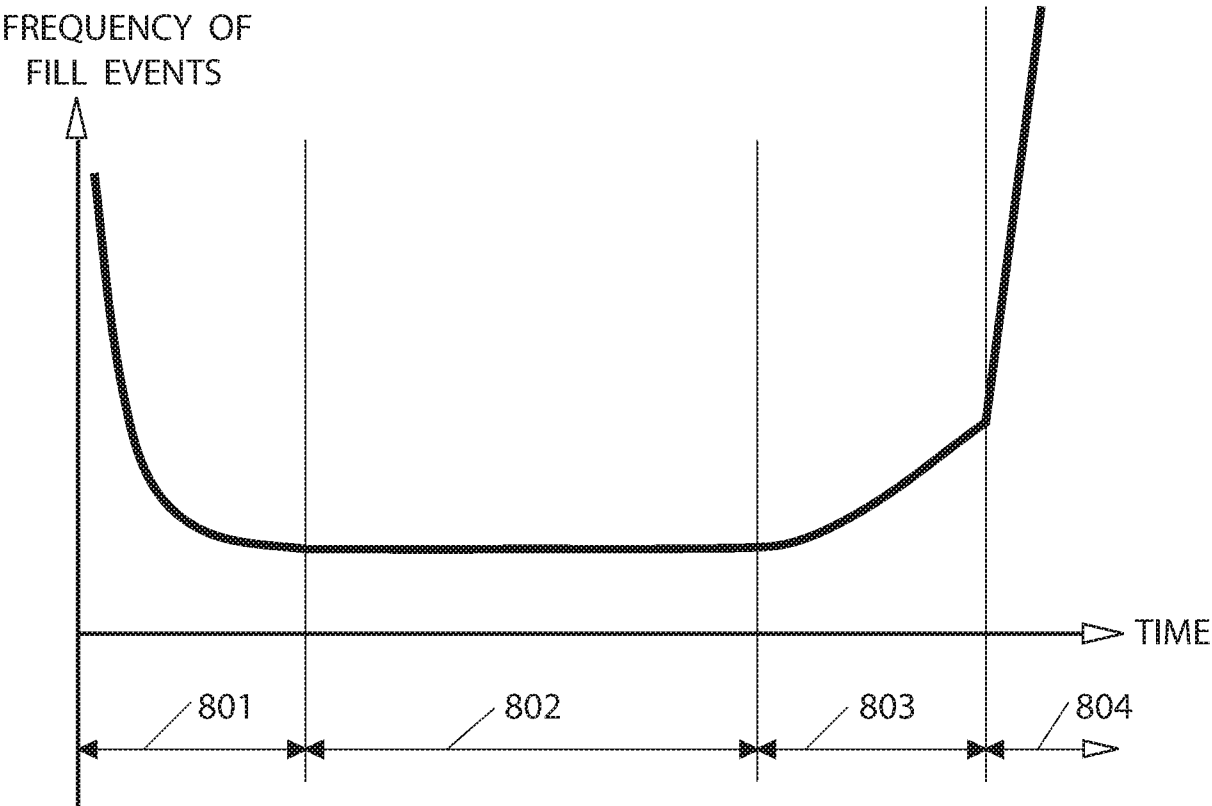


FIGURE 13

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 19/30669

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01L 7/08; F24D 3/02; F24D 3/04 (2019.01)

CPC - G01L 7/08; E03B 7/071; F24D 11/00; F24D 19/1009; F24D 3/04; F24D 3/06; F24D 3/08; F24D 3/10; F24D 3/12; F24H 9/165; G05D 16/2013; F24D 3/105; F24D 3/1058; F24D 3/1066; F24D 3/1083; F24D 11/001; F24D 11/002

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History Document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History Document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2011/0112814 A1 (Clark) 12 May 2011 (12.05.2011), para [0046]-[0048], [0055]-[0058].	1-10
A	US 2017/0074747 A1 (Emerson Climate Technologies Inc.) 16 March 2017 (16.03.2017), para [0024]-[0025], [0040].	1-10
A	US 2007/0205293 A1 (Kwak) 06 September 2007 (06.09.2007), entire document.	1-10
A	US 2014/0048244 A1 (Wallace) 20 February 2014 (20.02.2014), entire document.	1-10
A	WO 2016/085829 A1 (Zhadanovsky Igor) 02 June 2016 (02.06.2016), entire document.	1-10

☐ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

24 June 2019

Date of mailing of the international search report

19 JUL 2019

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