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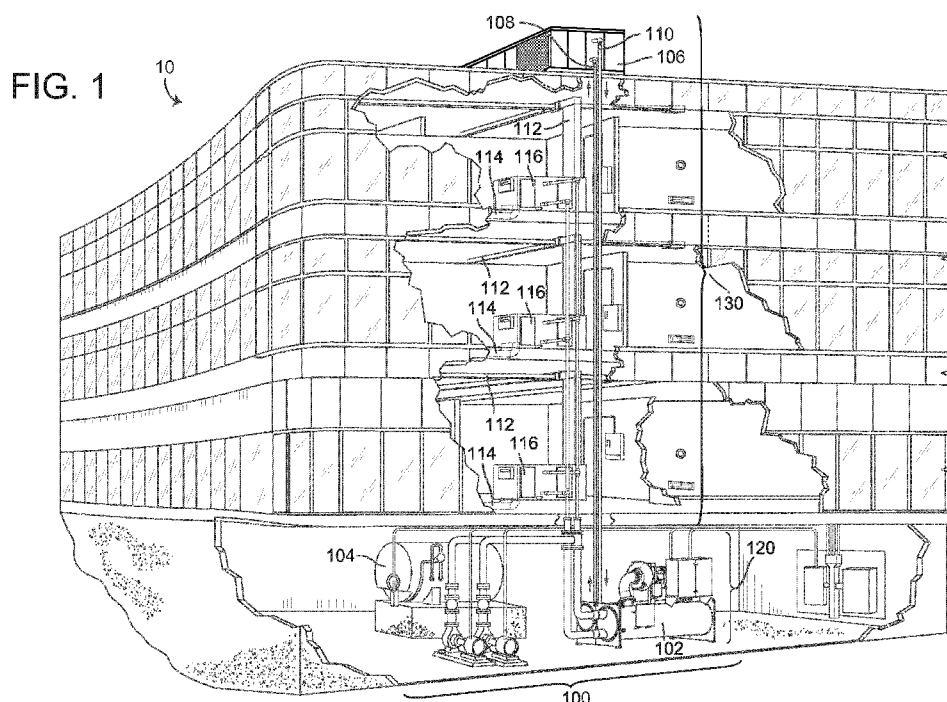
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(57) Abstract: A method of monitoring the performance of a chiller system includes receiving a temperature sensor reading from a temperature sensor on an input channels at an analog-to-digital (A/D) converter interface. The temperature sensor reading is converted into a first value and then converted into an equivalent resistance value using a set of calibration parameters. A first set of configuration parameters are applied to the resistance value to compensate for inaccuracies in the conversion. The resistance value is adjusted based on an internal temperature parameter. A second set of configuration parameters is applied to the resistance value to account for sensor drift over time. A set of coefficient values related to the characteristics of the sensor are received and used to convert the adjusted resistance value into a temperature value. The resistance value and temperature value are transmitted to an external system for monitoring the chiller system.

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## MULTI-CHANNEL MONITORING SYSTEM FOR BUILDING MANAGEMENT SYSTEM

### BACKGROUND

[0001] The present disclosure relates generally to a monitoring or control device for a building management system. A building management system (BMS) is, in general, a system of devices configured to control, monitor, and manage equipment in or around a building or building area. A BMS can include, for example, a heating, ventilation, and air conditioning (HVAC) system, a security system, a lighting system, a fire alerting system, any other system that is capable of managing building functions or devices, or any combination thereof.

[0002] As one example of a BMS sub-system, a HVAC system may control the temperature in a building area. The HVAC system may generally include a controller configured to receive sensor data relating to the temperature in the building area, and to adjust a setpoint temperature accordingly. The HVAC system may include a chiller plant configured to cool a working fluid of the HVAC system, eventually allowing the HVAC system to provide heated or cooled air to the building area. One challenge is monitoring the chiller plant efficiency, particularly to ensure that the operation of the chiller plant consumes the minimum amount of energy required for proper operation. Accordingly, it would be desirable to have systems and methods for monitoring the performance of the chiller plant using various integrated and durable devices.

### SUMMARY

[0003] One implementation of the present disclosure relates to a method of monitoring the performance of a chiller system. The method includes receiving, at a monitoring system, a temperature sensor reading from a temperature sensor on an input channel at an analog-to-digital (A/D) converter interface. The method further includes converting the temperature sensor reading into a first value via an A/D conversion. The method further includes converting the first value into an equivalent resistance value using a set of calibration parameters. The method further includes applying a first set of configuration parameters to the resistance value to compensate for inaccuracies in the conversion. The method further includes adjusting the resistance value based on an internal temperature parameter relating to the internal temperature of the housing of the sensor. The method further includes applying a

second set of configuration parameters to the resistance value to account for installation specific inaccuracies. The method further includes receiving a set of coefficient values related to the characteristics of the sensor. The method further includes using the set of coefficient values to convert the adjusted resistance value into a temperature value. The method further includes transmitting the resistance value and temperature value to an external system for monitoring the performance of the chiller system.

**[0004]** Another implementation of the present disclosure relates to a monitoring system for a chiller plant. The monitoring system includes a plurality of analog-to-digital (A/D) converter interfaces, each A/D converter interface corresponding with an input channel for receiving data from a temperature sensor located within the chiller plant. The monitoring system further includes a temperature module. The temperature module is configured to convert the received data into a first value via an A/D conversion. The temperature module is further configured to convert the first value into an equivalent resistance value using a set of calibration parameters. The temperature module is further configured to apply a first set of configuration parameters to the resistance value to compensate for inaccuracies in the conversion. The temperature module is further configured to adjust the resistance value based on an internal temperature parameter relating to the internal temperature of the housing of the sensor. The temperature module is further configured to apply a second set of configuration parameters to the resistance value to account for installation specific inaccuracies. The temperature module is further configured to receive a set of coefficient values to convert the adjusted resistance value into a temperature value. The temperature module is further configured to use the set of coefficient values to convert the adjusted resistance value into a temperature value. The monitoring system further includes an internal temperature sensor configured to determine the internal temperature parameter within the circuitry of the monitoring system. The monitoring system further includes a communications module configured to transmit the resistance value and temperature value to an external system for monitoring the performance of the chiller system.

**[0005]** Another implementation of the present disclosure relates to a method of monitoring the performance of a chiller system. The method includes monitoring a temperature value associated with the chiller system and storing temperature value data. The method further includes receiving, at a monitoring system, an indication of a tampering event from a tamper sensor. The method further includes logging tampering data relating to the tampering event.

The method further includes transmitting the tampering data to an external system for review. The method further includes determining a change in operation of the monitoring system.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 is a drawing of a building equipped with a building management system (BMS) and a HVAC system, according to some embodiments.

[0007] FIG. 2 is a schematic of a waterside system which can be used as part of the HVAC system of FIG. 1, according to some embodiments.

[0008] FIG. 3 is a block diagram illustrating an airside system which can be used as part of the HVAC system of FIG. 1, according to some embodiments.

[0009] FIG. 4 is a block diagram illustrating a BMS which can be used in the building of FIG. 1, according to some embodiments.

[0010] FIG. 5 is a block diagram of a controller for monitoring a chilled system of the BMS, according to some embodiments.

[0011] FIG. 6 is a detailed flow chart of a process for monitoring a chilled system of the BMS, according to some embodiments.

[0012] FIG. 7 is a block diagram illustrating the process of the controller receiving input from a plurality of temperature sensors, according to some embodiments.

[0013] FIG. 8 is a detailed block diagram of the process of FIG. 7, according to some embodiments.

[0014] FIG. 9 is a flow chart of a process for monitoring a chilled system, according to some embodiments.

### DETAILED DESCRIPTION

[0015] Referring generally to the figures, a monitoring device configured to monitor the performance of a chiller system or chiller plant in a HVAC system is shown, according to an exemplary embodiment. The monitoring device may generally receive input from a plurality of temperature sensors placed in various points throughout the piping within the chiller system. The monitoring device may then apply a plurality of calibration parameters, configuration parameters, and equations to calculate a temperature of the chilled fluid within

the chiller system. The monitoring device may account for possible tampering with any component therein, and may lower the need for calibration for any of the sensors or the monitoring device itself. For example, various configuration parameters used to calculate a temperature value can be adjusted based on calibration parameters received by the monitoring device, the calibration parameters relating to the environment around the sensor providing the input signals. The sensors, monitoring device, chiller system, and other components as described in the present disclosure may be integrated with one another.

[0016] The monitoring device determines the temperature of the chilled fluid, and provides the temperature and other data to an external monitoring system or device. For example, the data may be transmitted to an external data collection device, such as a government monitoring system, at which the data can be analyzed. The external system may then determine if the operation of the chiller system meets standards, if the operation of the chiller system is operating at a required efficiency, and the like. In other embodiments, the external data collection device may be associated with a BMS or other Building Automation System (BAS) for allowing for detailed data collection related to one or more parameters associated with the chiller system. As described in the present disclosure, the monitoring device transmits the data, but in other embodiments, the monitoring device may be in communication with any number of other devices or systems within the BMS, and may relay the data to other devices or systems as well. It should be understood that the systems and methods are described as being implemented in a stand-alone monitoring device; however in other embodiments the monitoring device may be integrated with other BMS controllers, devices, or systems.

[0017] The systems and methods described herein allow for increased accuracy of the temperature values. For example, the systems and methods described herein may be able to accurately determine temperature values to within  $\pm 0.03^{\circ}\text{C}$ . Additionally, the systems and methods described herein allow for compatibility with industry standard temperature sensors or probes, such as 10K $\Omega$  NTC sensors, 100 $\Omega$  PT sensors, and/or 1K $\Omega$  PT sensors). The systems and methods may be compatible with any type of BMS or other building system. The monitoring system may achieve highly stable measurements throughout an operating temperature range, compensating for ambient temperature effects. The monitoring system may provide stable measurements over time, reducing the need for future calibrations of the

system. The monitoring system may provide stable measurements independent of the accuracy and stability of reference voltage.

### **Building Management System and HVAC System**

[0018] Referring now to FIGS. 1–4, an exemplary building management system (BMS) and a heating, ventilation, and air conditioning (HVAC) system in which the systems and methods of the present disclosure can be implemented are shown, according to an exemplary embodiment. Referring particularly to FIG. 1, a perspective view of a building 10 is shown. Building 10 is served by a BMS. A BMS is, in general, a system of devices configured to control, monitor, and manage equipment in or around a building or building area. A BMS can include, for example, a HVAC system, a security system, a lighting system, a fire alerting system, any other system that is capable of managing building functions or devices, or any combination thereof.

[0019] The BMS that serves building 10 includes an HVAC system 100. HVAC system 100 can include a plurality of HVAC devices (e.g., heaters, chillers, air handling units, pumps, fans, thermal energy storage, etc.) configured to provide heating, cooling, ventilation, or other services for building 10. For example, HVAC system 100 is shown to include a waterside system 120 and an airside system 130. Waterside system 120 can provide a heated or chilled fluid to an air handling unit of airside system 130. Airside system 130 can use the heated or chilled fluid to heat or cool an airflow provided to building 10. An exemplary waterside system and airside system which can be used in HVAC system 100 are described in greater detail with reference to FIGS. 2-3.

[0020] HVAC system 100 is shown to include a chiller 102, a boiler 104, and a rooftop air handling unit (AHU) 106. Waterside system 120 can use boiler 104 and chiller 102 to heat or cool a working fluid (e.g., water, glycol, etc.) and can circulate the working fluid to AHU 106. In various embodiments, the HVAC devices of waterside system 120 can be located in or around building 10 (as shown in FIG. 1) or at an offsite location such as a central plant (e.g., a chiller plant, a steam plant, a heat plant, etc.). The working fluid can be heated in boiler 104 or cooled in chiller 102, depending on whether heating or cooling is required in building 10. Boiler 104 can add heat to the circulated fluid, for example, by burning a combustible material (e.g., natural gas) or using an electric heating element. Chiller 102 can place the circulated fluid in a heat exchange relationship with another fluid (e.g., a

refrigerant) in a heat exchanger (e.g., an evaporator) to absorb heat from the circulated fluid. The working fluid from chiller 102 and/or boiler 104 can be transported to AHU 106 via piping 108.

**[0021]** AHU 106 can place the working fluid in a heat exchange relationship with an airflow passing through AHU 106 (e.g., via one or more stages of cooling coils and/or heating coils). The airflow can be, for example, outside air, return air from within building 10, or a combination of both. AHU 106 can transfer heat between the airflow and the working fluid to provide heating or cooling for the airflow. For example, AHU 106 can include one or more fans or blowers configured to pass the airflow over or through a heat exchanger containing the working fluid. The working fluid can then return to chiller 102 or boiler 104 via piping 110.

**[0022]** Airside system 130 can deliver the airflow supplied by AHU 106 (i.e., the supply airflow) to building 10 via air supply ducts 112 and can provide return air from building 10 to AHU 106 via air return ducts 114. In some embodiments, airside system 130 includes multiple variable air volume (VAV) units 116. For example, airside system 130 is shown to include a separate VAV unit 116 on each floor or zone of building 10. VAV units 116 can include dampers or other flow control elements that can be operated to control an amount of the supply airflow provided to individual zones of building 10. In other embodiments, airside system 130 delivers the supply airflow into one or more zones of building 10 (e.g., via supply ducts 112) without using intermediate VAV units 116 or other flow control elements. AHU 106 can include various sensors (e.g., temperature sensors, pressure sensors, etc.) configured to measure attributes of the supply airflow. AHU 106 can receive input from sensors located within AHU 106 and/or within the building zone and can adjust the flow rate, temperature, or other attributes of the supply airflow through AHU 106 to achieve set-point conditions for the building zone.

**[0023]** Referring now to FIG. 2, a block diagram of a waterside system 200 is shown, according to an exemplary embodiment. In various embodiments, waterside system 200 can supplement or replace waterside system 120 in HVAC system 100 or can be implemented separate from HVAC system 100. When implemented in HVAC system 100, waterside system 200 can include a subset of the HVAC devices in HVAC system 100 (e.g., boiler 104, chiller 102, pumps, valves, etc.) and can operate to supply a heated or chilled fluid to AHU

106. The HVAC devices of waterside system 200 can be located within building 10 (e.g., as components of waterside system 120) or at an offsite location such as a central plant.

**[0024]** In FIG. 2, waterside system 200 is shown as a central plant having a plurality of subplants 202–212. Subplants 202–212 are shown to include a heater subplant 202, a heat recovery chiller subplant 204, a chiller subplant 206, a cooling tower subplant 208, a hot thermal energy storage (TES) subplant 210, and a cold thermal energy storage (TES) subplant 212. Subplants 202–212 consume resources (e.g., water, natural gas, electricity, etc.) from utilities to serve the thermal energy loads (e.g., hot water, cold water, heating, cooling, etc.) of a building or campus. For example, heater subplant 202 can be configured to heat water in a hot water loop 214 that circulates the hot water between heater subplant 202 and building 10. Chiller subplant 206 can be configured to chill water in a cold water loop 216 that circulates the cold water between chiller subplant 206 and the building 10. Heat recovery chiller subplant 204 can be configured to transfer heat from cold water loop 216 to hot water loop 214 to provide additional heating for the hot water and additional cooling for the cold water. Condenser water loop 218 can absorb heat from the cold water in chiller subplant 206 and reject the absorbed heat in cooling tower subplant 208 or transfer the absorbed heat to hot water loop 214. Hot TES subplant 210 and cold TES subplant 212 can store hot and cold thermal energy, respectively, for subsequent use.

**[0025]** Hot water loop 214 and cold water loop 216 can deliver the heated and/or chilled water to air handlers located on the rooftop of building 10 (e.g., AHU 106) or to individual floors or zones of building 10 (e.g., VAV units 116). The air handlers push air past heat exchangers (e.g., heating coils or cooling coils) through which the water flows to provide heating or cooling for the air. The heated or cooled air can be delivered to individual zones of building 10 to serve the thermal energy loads of building 10. The water then returns to subplants 202–212 to receive further heating or cooling.

**[0026]** Although subplants 202–212 are shown and described as heating and cooling water for circulation to a building, it is understood that any other type of working fluid (e.g., glycol, CO<sub>2</sub>, etc.) can be used in place of or in addition to water to serve the thermal energy loads. In other embodiments, subplants 202–212 can provide heating and/or cooling directly to the building or campus without requiring an intermediate heat transfer fluid. These and other variations to waterside system 200 are within the teachings of the present invention.

**[0027]** Each of subplants 202–212 can include a variety of equipment configured to facilitate the functions of the subplant. For example, heater subplant 202 is shown to include a plurality of heating elements 220 (e.g., boilers, electric heaters, etc.) configured to add heat to the hot water in hot water loop 214. Heater subplant 202 is also shown to include several pumps 222 and 224 configured to circulate the hot water in hot water loop 214 and to control the flow rate of the hot water through individual heating elements 220. Chiller subplant 206 is shown to include a plurality of chillers 232 configured to remove heat from the cold water in cold water loop 216. Chiller subplant 206 is also shown to include several pumps 234 and 236 configured to circulate the cold water in cold water loop 216 and to control the flow rate of the cold water through individual chillers 232.

**[0028]** Heat recovery chiller subplant 204 is shown to include a plurality of heat recovery heat exchangers 226 (e.g., refrigeration circuits) configured to transfer heat from cold water loop 216 to hot water loop 214. Heat recovery chiller subplant 204 is also shown to include several pumps 228 and 230 configured to circulate the hot water and/or cold water through heat recovery heat exchangers 226 and to control the flow rate of the water through individual heat recovery heat exchangers 226. Cooling tower subplant 208 is shown to include a plurality of cooling towers 238 configured to remove heat from the condenser water in condenser water loop 218. Cooling tower subplant 208 is also shown to include several pumps 240 configured to circulate the condenser water in condenser water loop 218 and to control the flow rate of the condenser water through individual cooling towers 238.

**[0029]** Hot TES subplant 210 is shown to include a hot TES tank 242 configured to store the hot water for later use. Hot TES subplant 210 can also include one or more pumps or valves configured to control the flow rate of the hot water into or out of hot TES tank 242. Cold TES subplant 212 is shown to include cold TES tanks 244 configured to store the cold water for later use. Cold TES subplant 212 can also include one or more pumps or valves configured to control the flow rate of the cold water into or out of cold TES tanks 244.

**[0030]** In some embodiments, one or more of the pumps in waterside system 200 (e.g., pumps 222, 224, 228, 230, 234, 236, and/or 240) or pipelines in waterside system 200 include an isolation valve associated therewith. Isolation valves can be integrated with the pumps or positioned upstream or downstream of the pumps to control the fluid flows in waterside system 200. In various embodiments, waterside system 200 can include more, fewer, or

different types of devices and/or subplants based on the particular configuration of waterside system 200 and the types of loads served by waterside system 200.

**[0031]** Referring now to FIG. 3, a block diagram of an airside system 300 is shown, according to an exemplary embodiment. In various embodiments, airside system 300 can supplement or replace airside system 130 in HVAC system 100 or can be implemented separate from HVAC system 100. When implemented in HVAC system 100, airside system 300 can include a subset of the HVAC devices in HVAC system 100 (e.g., AHU 106, VAV units 116, ducts 112–114, fans, dampers, etc.) and can be located in or around building 10. Airside system 300 can operate to heat or cool an airflow provided to building 10 using a heated or chilled fluid provided by waterside system 200.

**[0032]** In FIG. 3, airside system 300 is shown to include an economizer-type air handling unit (AHU) 302. Economizer-type AHUs vary the amount of outside air and return air used by the air handling unit for heating or cooling. For example, AHU 302 can receive return air 304 from building zone 306 via return air duct 308 and can deliver supply air 310 to building zone 306 via supply air duct 312. In some embodiments, AHU 302 is a rooftop unit located on the roof of building 10 (e.g., AHU 106 as shown in FIG. 1) or otherwise positioned to receive return air 304 and outside air 314. AHU 302 can be configured to operate an exhaust air damper 316, mixing damper 318, and outside air damper 320 to control an amount of outside air 314 and return air 304 that combine to form supply air 310. Any return air 304 that does not pass through mixing damper 318 can be exhausted from AHU 302 through exhaust damper 316 as exhaust air 322.

**[0033]** Each of dampers 316–320 can be operated by an actuator. For example, exhaust air damper 316 can be operated by actuator 324, mixing damper 318 can be operated by actuator 326, and outside air damper 320 can be operated by actuator 328. Actuators 324–328 can communicate with an AHU controller 330 via a communications link 332. Actuators 324–328 can receive control signals from AHU controller 330 and can provide feedback signals to AHU controller 330. Feedback signals can include, for example, an indication of a current actuator or damper position, an amount of torque or force exerted by the actuator, diagnostic information (e.g., results of diagnostic tests performed by actuators 324–328), status information, commissioning information, configuration settings, calibration data, and/or other types of information or data that can be collected, stored, or used by actuators 324–328. AHU controller 330 can be an economizer controller configured to use one or more control

algorithms (e.g., state-based algorithms, extremum seeking control (ESC) algorithms, proportional-integral (PI) control algorithms, proportional-integral-derivative (PID) control algorithms, model predictive control (MPC) algorithms, feedback control algorithms, etc.) to control actuators 324–328.

**[0034]** Still referring to FIG. 3, AHU 302 is shown to include a cooling coil 334, a heating coil 336, and a fan 338 positioned within supply air duct 312. Fan 338 can be configured to force supply air 310 through cooling coil 334 and/or heating coil 336 and provide supply air 310 to building zone 306. AHU controller 330 can communicate with fan 338 via communications link 340 to control a flow rate of supply air 310. In some embodiments, AHU controller 330 controls an amount of heating or cooling applied to supply air 310 by modulating a speed of fan 338.

**[0035]** Cooling coil 334 can receive a chilled fluid from waterside system 200 (e.g., from cold water loop 216) via piping 342 and can return the chilled fluid to waterside system 200 via piping 344. Valve 346 can be positioned along piping 342 or piping 344 to control a flow rate of the chilled fluid through cooling coil 334. In some embodiments, cooling coil 334 includes multiple stages of cooling coils that can be independently activated and deactivated (e.g., by AHU controller 330, by BMS controller 366, etc.) to modulate an amount of cooling applied to supply air 310.

**[0036]** Heating coil 336 can receive a heated fluid from waterside system 200 (e.g., from hot water loop 214) via piping 348 and can return the heated fluid to waterside system 200 via piping 350. Valve 352 can be positioned along piping 348 or piping 350 to control a flow rate of the heated fluid through heating coil 336. In some embodiments, heating coil 336 includes multiple stages of heating coils that can be independently activated and deactivated (e.g., by AHU controller 330, by BMS controller 366, etc.) to modulate an amount of heating applied to supply air 310.

**[0037]** Each of valves 346 and 352 can be controlled by an actuator. For example, valve 346 can be controlled by actuator 354 and valve 352 can be controlled by actuator 356. Actuators 354–356 can communicate with AHU controller 330 via communications links 358–360. Actuators 354–356 can receive control signals from AHU controller 330 and can provide feedback signals to controller 330. In some embodiments, AHU controller 330 receives a measurement of the supply air temperature from a temperature sensor 362

positioned in supply air duct 312 (e.g., downstream of cooling coil 334 and/or heating coil 336). AHU controller 330 can also receive a measurement of the temperature of building zone 306 from a temperature sensor 364 located in building zone 306.

**[0038]** In some embodiments, AHU controller 330 operates valves 346 and 352 via actuators 354–356 to modulate an amount of heating or cooling provided to supply air 310 (e.g., to achieve a set-point temperature for supply air 310 or to maintain the temperature of supply air 310 within a set-point temperature range). The positions of valves 346 and 352 affect the amount of heating or cooling provided to supply air 310 by cooling coil 334 or heating coil 336 and may correlate with the amount of energy consumed to achieve a desired supply air temperature. AHU controller 330 can control the temperature of supply air 310 and/or building zone 306 by activating or deactivating coils 334–336, adjusting a speed of fan 338, or a combination thereof.

**[0039]** Still referring to FIG. 3, airside system 300 is shown to include a building management system (BMS) controller 366 and a client device 368. BMS controller 366 can include one or more computer systems (e.g., servers, supervisory controllers, subsystem controllers, etc.) that serve as system level controllers, application or data servers, head nodes, or master controllers for airside system 300, waterside system 200, HVAC system 100, and/or other controllable systems that serve building 10. BMS controller 366 can communicate with multiple downstream building systems or subsystems (e.g., HVAC system 100, a security system, a lighting system, waterside system 200, etc.) via a communications link 370 according to like or disparate protocols (e.g., LON, BACnet, etc.). In various embodiments, AHU controller 330 and BMS controller 366 can be separate (as shown in FIG. 3) or integrated. In an integrated implementation, AHU controller 330 can be a software module configured for execution by a processor of BMS controller 366.

**[0040]** In some embodiments, AHU controller 330 receives information from BMS controller 366 (e.g., commands, setpoints, operating boundaries, etc.) and provides information to BMS controller 366 (e.g., temperature measurements, valve or actuator positions, operating statuses, diagnostics, etc.). For example, AHU controller 330 can provide BMS controller 366 with temperature measurements from temperature sensors 362–364, equipment on/off states, equipment operating capacities, and/or any other information that can be used by BMS controller 366 to monitor or control a variable state or condition within building zone 306.

**[0041]** Client device 368 can include one or more human-machine interfaces or client interfaces (e.g., graphical user interfaces, reporting interfaces, text-based computer interfaces, client-facing web services, web servers that provide pages to web clients, etc.) for controlling, viewing, or otherwise interacting with HVAC system 100, its subsystems, and/or devices. Client device 368 can be a computer workstation, a client terminal, a remote or local interface, or any other type of user interface device. Client device 368 can be a stationary terminal or a mobile device. For example, client device 368 can be a desktop computer, a computer server with a user interface, a laptop computer, a tablet, a smartphone, a PDA, or any other type of mobile or non-mobile device. Client device 368 can communicate with BMS controller 366 and/or AHU controller 330 via communications link 372.

**[0042]** Referring now to FIG. 4, a block diagram of a building management system (BMS) 400 is shown, according to an exemplary embodiment. BMS 400 can be implemented in building 10 to automatically monitor and control various building functions. BMS 400 is shown to include BMS controller 366 and a plurality of building subsystems 428. Building subsystems 428 are shown to include a building electrical subsystem 434, an information communication technology (ICT) subsystem 436, a security subsystem 438, a HVAC subsystem 440, a lighting subsystem 442, a lift/escalators subsystem 432, and a fire safety subsystem 430. In various embodiments, building subsystems 428 can include fewer, additional, or alternative subsystems. For example, building subsystems 428 can also or alternatively include a refrigeration subsystem, an advertising or signage subsystem, a cooking subsystem, a vending subsystem, a printer or copy service subsystem, or any other type of building subsystem that uses controllable equipment and/or sensors to monitor or control building 10. In some embodiments, building subsystems 428 include waterside system 200 and/or airside system 300, as described with reference to FIGS. 2–3.

**[0043]** Each of building subsystems 428 can include any number of devices, controllers, and connections for completing its individual functions and control activities. HVAC subsystem 440 can include many of the same components as HVAC system 100, as described with reference to FIGS. 1–3. For example, HVAC subsystem 440 can include a chiller, a boiler, any number of air handling units, economizers, field controllers, supervisory controllers, actuators, temperature sensors, and other devices for controlling the temperature, humidity, airflow, or other variable conditions within building 10. Lighting subsystem 442 can include any number of light fixtures, ballasts, lighting sensors, dimmers, or other devices

configured to controllably adjust the amount of light provided to a building space. Security subsystem 438 can include occupancy sensors, video surveillance cameras, digital video recorders, video processing servers, intrusion detection devices, access control devices (e.g., card access, etc.) and servers, or other security-related devices.

**[0044]** Still referring to FIG. 4, BMS controller 366 is shown to include a communications interface 407 and a BMS interface 409. Interface 407 can facilitate communications between BMS controller 366 and external applications (e.g., monitoring and reporting applications 422, enterprise control applications 426, remote systems and applications 444, applications residing on client devices 448, etc.) for allowing user control, monitoring, and adjustment to BMS controller 366 and/or subsystems 428. Interface 407 can also facilitate communications between BMS controller 366 and client devices 448. BMS interface 409 can facilitate communications between BMS controller 366 and building subsystems 428 (e.g., HVAC, lighting security, lifts, power distribution, business, etc.).

**[0045]** Interfaces 407, 409 can be or include wired or wireless communications interfaces (e.g., jacks, antennas, transmitters, receivers, transceivers, wire terminals, etc.) for conducting data communications with building subsystems 428 or other external systems or devices. In various embodiments, communications via interfaces 407, 409 can be direct (e.g., locally wired or wireless communications) or via a communications network 446 (e.g., a WAN, the Internet, a cellular network, etc.). For example, interfaces 407, 409 can include an Ethernet card and port for sending and receiving data via an Ethernet-based communications link or network. In another example, the interfaces 407, 409 can include a Wi-Fi transceiver for communicating via a wireless communications network. In another example, one or more of interfaces 407, 409 can include cellular or mobile phone communications transceivers. In one embodiment, communications interface 407 is a power line communications interface and BMS interface 409 is an Ethernet interface. In other embodiments, communications interface 407 and BMS interface 409 are Ethernet interfaces or are the same Ethernet interface.

**[0046]** Still referring to FIG. 4, BMS controller 366 is shown to include a processing circuit 404 including a processor 406 and memory 408. Processing circuit 404 can be communicably connected to BMS interface 409 and/or communications interface 407 such that processing circuit 404 and the various components thereof can send and receive data via interfaces 407, 409. Processor 406 can be implemented as a general purpose processor, an

application specific integrated circuit (ASIC), one or more field programmable gate arrays (FPGAs), a group of processing components, or other suitable electronic processing components.

**[0047]** Memory 408 (e.g., memory, memory unit, storage device, etc.) can include one or more devices (e.g., RAM, ROM, Flash memory, hard disk storage, etc.) for storing data and/or computer code for completing or facilitating the various processes, layers and modules described in the present application. Memory 408 can be or include volatile memory or non-volatile memory. Memory 408 can include database components, object code components, script components, or any other type of information structure for supporting the various activities and information structures described in the present application. According to an exemplary embodiment, memory 408 is communicably connected to processor 406 via processing circuit 404 and includes computer code for executing (e.g., by processing circuit 404 and/or processor 406) one or more processes described herein.

**[0048]** In some embodiments, BMS controller 366 is implemented within a single computer (e.g., one server, one housing, etc.). In various other embodiments BMS controller 366 can be distributed across multiple servers or computers (e.g., that can exist in distributed locations). Further, while FIG. 4 shows applications 422 and 426 as existing outside of BMS controller 366, in some embodiments, applications 422 and 426 can be hosted within BMS controller 366 (e.g., within memory 408).

**[0049]** Still referring to FIG. 4, memory 408 is shown to include an enterprise integration layer 410, an automated measurement and validation (AM&V) layer 412, a demand response (DR) layer 414, a fault detection and diagnostics (FDD) layer 416, an integrated control layer 418, and a building subsystem integration later 420. Layers 410–420 can be configured to receive inputs from building subsystems 428 and other data sources, determine optimal control actions for building subsystems 428 based on the inputs, generate control signals based on the optimal control actions, and provide the generated control signals to building subsystems 428. The following paragraphs describe some of the general functions performed by each of layers 410–420 in BMS 400.

**[0050]** Enterprise integration layer 410 can be configured to serve clients or local applications with information and services to support a variety of enterprise-level applications. For example, enterprise control applications 426 can be configured to provide

subsystem-spanning control to a graphical user interface (GUI) or to any number of enterprise-level business applications (e.g., accounting systems, user identification systems, etc.). Enterprise control applications 426 can also or alternatively be configured to provide configuration GUIs for configuring BMS controller 366. In yet other embodiments, enterprise control applications 426 can work with layers 410–420 to optimize building performance (e.g., efficiency, energy use, comfort, or safety) based on inputs received at interface 407 and/or BMS interface 409.

**[0051]** Building subsystem integration layer 420 can be configured to manage communications between BMS controller 366 and building subsystems 428. For example, building subsystem integration layer 420 can receive sensor data and input signals from building subsystems 428 and provide output data and control signals to building subsystems 428. Building subsystem integration layer 420 can also be configured to manage communications between building subsystems 428. Building subsystem integration layer 420 translate communications (e.g., sensor data, input signals, output signals, etc.) across a plurality of multi-vendor/multi-protocol systems.

**[0052]** Demand response layer 414 can be configured to optimize resource usage (e.g., electricity use, natural gas use, water use, etc.) and/or the monetary cost of such resource usage in response to satisfy the demand of building 10. The optimization can be based on time-of-use prices, curtailment signals, energy availability, or other data received from utility providers, distributed energy generation systems 424, from energy storage 427 (e.g., hot TES 242, cold TES 244, etc.), or from other sources. Demand response layer 414 can receive inputs from other layers of BMS controller 366 (e.g., building subsystem integration layer 420, integrated control layer 418, etc.). The inputs received from other layers can include environmental or sensor inputs such as temperature, carbon dioxide levels, relative humidity levels, air quality sensor outputs, occupancy sensor outputs, room schedules, and the like. The inputs can also include inputs such as electrical use (e.g., expressed in kWh), thermal load measurements, pricing information, projected pricing, smoothed pricing, curtailment signals from utilities, and the like.

**[0053]** According to an exemplary embodiment, demand response layer 414 includes control logic for responding to the data and signals it receives. These responses can include communicating with the control algorithms in integrated control layer 418, changing control strategies, changing setpoints, or activating/deactivating building equipment or subsystems in

a controlled manner. Demand response layer 414 can also include control logic configured to determine when to utilize stored energy. For example, demand response layer 414 can determine to begin using energy from energy storage 427 just prior to the beginning of a peak use hour.

**[0054]** In some embodiments, demand response layer 414 includes a control module configured to actively initiate control actions (e.g., automatically changing setpoints) which minimize energy costs based on one or more inputs representative of or based on demand (e.g., price, a curtailment signal, a demand level, etc.). In some embodiments, demand response layer 414 uses equipment models to determine an optimal set of control actions. The equipment models can include, for example, thermodynamic models describing the inputs, outputs, and/or functions performed by various sets of building equipment. Equipment models can represent collections of building equipment (e.g., subplants, chiller arrays, etc.) or individual devices (e.g., individual chillers, heaters, pumps, etc.).

**[0055]** Demand response layer 414 can further include or draw upon one or more demand response policy definitions (e.g., databases, XML files, etc.). The policy definitions can be edited or adjusted by a user (e.g., via a graphical user interface) so that the control actions initiated in response to demand inputs can be tailored for the user's application, desired comfort level, particular building equipment, or based on other concerns. For example, the demand response policy definitions can specify which equipment can be turned on or off in response to particular demand inputs, how long a system or piece of equipment should be turned off, what setpoints can be changed, what the allowable set point adjustment range is, how long to hold a high demand set-point before returning to a normally scheduled set-point, how close to approach capacity limits, which equipment modes to utilize, the energy transfer rates (e.g., the maximum rate, an alarm rate, other rate boundary information, etc.) into and out of energy storage devices (e.g., thermal storage tanks, battery banks, etc.), and when to dispatch on-site generation of energy (e.g., via fuel cells, a motor generator set, etc.).

**[0056]** Integrated control layer 418 can be configured to use the data input or output of building subsystem integration layer 420 and/or demand response layer 414 to make control decisions. Due to the subsystem integration provided by building subsystem integration layer 420, integrated control layer 418 can integrate control activities of the subsystems 428 such that the subsystems 428 behave as a single integrated supersystem. In an exemplary embodiment, integrated control layer 418 includes control logic that uses inputs and outputs

from a plurality of building subsystems to provide greater comfort and energy savings relative to the comfort and energy savings that separate subsystems could provide alone. For example, integrated control layer 418 can be configured to use an input from a first subsystem to make an energy-saving control decision for a second subsystem. Results of these decisions can be communicated back to building subsystem integration layer 420.

**[0057]** Integrated control layer 418 is shown to be logically below demand response layer 414. Integrated control layer 418 can be configured to enhance the effectiveness of demand response layer 414 by enabling building subsystems 428 and their respective control loops to be controlled in coordination with demand response layer 414. This configuration may advantageously reduce disruptive demand response behavior relative to conventional systems. For example, integrated control layer 418 can be configured to assure that a demand response-driven upward adjustment to the set-point for chilled water temperature (or another component that directly or indirectly affects temperature) does not result in an increase in fan energy (or other energy used to cool a space) that would result in greater total building energy use than was saved at the chiller.

**[0058]** Integrated control layer 418 can be configured to provide feedback to demand response layer 414 so that demand response layer 414 checks that constraints (e.g., temperature, lighting levels, etc.) are properly maintained even while demanded load shedding is in progress. The constraints can also include set-point or sensed boundaries relating to safety, equipment operating limits and performance, comfort, fire codes, electrical codes, energy codes, and the like. Integrated control layer 418 is also logically below fault detection and diagnostics layer 416 and automated measurement and validation layer 412. Integrated control layer 418 can be configured to provide calculated inputs (e.g., aggregations) to these higher levels based on outputs from more than one building subsystem.

**[0059]** Automated measurement and validation (AM&V) layer 412 can be configured to verify that control strategies commanded by integrated control layer 418 or demand response layer 414 are working properly (e.g., using data aggregated by AM&V layer 412, integrated control layer 418, building subsystem integration layer 420, FDD layer 416, or otherwise). The calculations made by AM&V layer 412 can be based on building system energy models and/or equipment models for individual BMS devices or subsystems. For example, AM&V layer 412 can compare a model-predicted output with an actual output from building subsystems 428 to determine an accuracy of the model.

**[0060]** Fault detection and diagnostics (FDD) layer 416 can be configured to provide on-going fault detection for building subsystems 428, building subsystem devices (i.e., building equipment), and control algorithms used by demand response layer 414 and integrated control layer 418. FDD layer 416 can receive data inputs from integrated control layer 418, directly from one or more building subsystems or devices, or from another data source. FDD layer 416 can automatically diagnose and respond to detected faults. The responses to detected or diagnosed faults can include providing an alert message to a user, a maintenance scheduling system, or a control algorithm configured to attempt to repair the fault or to work-around the fault.

**[0061]** FDD layer 416 can be configured to output a specific identification of the faulty component or cause of the fault (e.g., loose damper linkage) using detailed subsystem inputs available at building subsystem integration layer 420. In other exemplary embodiments, FDD layer 416 is configured to provide “fault” events to integrated control layer 418 which executes control strategies and policies in response to the received fault events. According to an exemplary embodiment, FDD layer 416 (or a policy executed by an integrated control engine or business rules engine) can shut-down systems or direct control activities around faulty devices or systems to reduce energy waste, extend equipment life, or ensure proper control response.

**[0062]** FDD layer 416 can be configured to store or access a variety of different system data stores (or data points for live data). FDD layer 416 can use some content of the data stores to identify faults at the equipment level (e.g., specific chiller, specific AHU, specific terminal unit, etc.) and other content to identify faults at component or subsystem levels. For example, building subsystems 428 can generate temporal (i.e., time-series) data indicating the performance of BMS 400 and the various components thereof. The data generated by building subsystems 428 can include measured or calculated values that exhibit statistical characteristics and provide information about how the corresponding system or process (e.g., a temperature control process, a flow control process, etc.) is performing in terms of error from its set-point. These processes can be examined by FDD layer 416 to expose when the system begins to degrade in performance and alert a user to repair the fault before it becomes more severe.

### Chiller System Monitoring System

[0063] Referring now to FIG. 5, a block diagram of a monitoring system 500 for monitoring a chiller system (e.g., the waterside system of FIG. 2) is shown, according to an exemplary embodiment. Monitoring system 500 may generally be configured to determine a temperature value based on multiple sensor inputs. Monitoring system 500, in some embodiments, is installed or located within the waterside system of the HVAC system, and may be integrated with any number of other systems and/or controllers of a BMS.

[0064] Monitoring system 500 is shown to receive a plurality of temperature sensor readings from a plurality of temperature sensors 510. As shown in FIG. 5, four temperature sensors 510 may be connected to monitoring system 500; in other embodiments any number of temperature sensors may be used. Temperature sensors 510 are placed in various areas throughout the piping within the chiller system. Temperature sensors 510 may be of any type. In some embodiments, temperature sensors 510 are resistance thermometers or resistance temperature detectors. Temperature sensors 510 may be made of any suitable material, such as platinum, copper, or nickel. In some embodiments, temperature sensors 510 are negative temperature coefficient (NTC) type thermistors. It should be understood that while the present disclosure provides platinum type sensors and NTC type thermistors as examples of temperature sensors, in other embodiments any type of temperature sensing unit may be used with the monitoring system of the present disclosure.

[0065] Monitoring system 500 includes a plurality of A/D converters 512 configured to receive input from a temperature sensor 510. In some embodiments, each temperature sensor 510 has a designated communications channel with an A/D converter 512. In some embodiments, each A/D converter 512 has an assigned temperature sensor 510. Temperature sensor 510 and A/D converter 512 can establish any type of wired or wireless connection for communicating with one another.

[0066] Monitoring system 500 may include one or more tamper resistant devices. For example, monitoring system 500 is shown to include a tamper sensor 520. Tamper sensor 520 can determine if the components or circuitry of monitoring system 500 has been tampered with by a user. Tampering may generally include the user opening the housing 526 of one or more portions of the monitoring system 500, thereby providing access to some or all of the components of monitoring system 500. Tamper sensor 520 may further determine

if the user has connected or disconnected a temperature sensor 510 or temperature probe, or if the communication between monitoring system 500 and other systems has been disconnected. A tampering module 544 (described below) may use an input from tamper sensor 520 to determine if a tampering event has occurred and an impact of the tampering event. In some embodiments, the tampering module 544 may record a tampering event to provide historical record that a tampering event occurred. In other embodiments, the tampering module 522 may generate a message or alert which may be transmitted to one or more external devices. For example, the tampering module 522 may transmit a message to one or more controllers in the BMS.

**[0067]** In some embodiments, case tamper sensor 520 is a Hall Effect sensor which can determine if housing 526 (either in whole or in part) has been removed, or if housing 526 has been opened. For example, the Hall Effect sensor may produce a signal when the distance between two parts of housing 526 varies beyond a certain, predefined amount, indicating that the housing has been opened or removed. Case tamper sensor 520 may also be other types of sensors, such as a proximity sensor, an IR sensor, a light sensor, or other applicable sensor type. In other embodiments, case tamper sensor 520 may be a simple physical device which indicates tampering, such as a tamper resistant seal which is broken when an attempt is made to access case housing 526. In some embodiments, the monitoring system 500 may be configured to contain no user-adjustable components in the analog input circuit design. For example, all resistors may be fixed (i.e. no potentiometers). This can prevent components from being adjusted by a user, or other unauthorized party.

**[0068]** Monitoring system 500 is shown to include an internal power supply 522. In various embodiments, monitoring system 500 may have a wired connection with a power source. In other embodiments, the internal power supply may be a battery, or other energy storage device. In still other embodiments, the internal power supply may be a combination of a wired connection with a power source and one or more energy storage devices. In some embodiments, an external power supply to monitoring system 500 may be interrupted, and power supply 522 may provide a temporary power supply to the various components of monitoring system 500.

**[0069]** Monitoring system 500 is shown to include a communications module 524. After determining a temperature value (described in greater detail below), communications module 524 may transmit the temperature value and other relevant information to an external system,

such as an external data collection device. The external system may be, for example, a system for monitoring the performance of the chiller system against various regulations. For example, the external system may be a governmental monitoring system. Further, in some embodiments, the temperature value may be provided to a controller of the BMS configured to control the operation of a HVAC system (e.g., a chiller plant controller). Communications module 524 may be one or both of a wired interface or wireless interface, and may communicate with other devices and systems via any protocol. For example, communications module 524 may transmit data wirelessly via a local area network, may transmit data within the BMS via a wired connection (e.g., a power line connection), or via any other type of protocol. In some embodiments, communications module 524 may be a wireless interface such as cellular, Wi-Fi, Zigbee, Bluetooth, RF, LoRa, etc., or a wired interface such as USB, Firewire, Lightning Connectors, CAT5 (wired internet), etc. In some embodiments, communications module 524 may communicate with a BMS or a component thereof via a network connection, such as a BACnet network connection (e.g., a data communication protocol for equipment and controllers within a BMS in a building, for managing the exchange of data between the equipment and the system specifically).

**[0070]** Monitoring system 500 is shown to include a processing circuit 532 including a processor 534 and memory 536. Processor 534 can be a general purpose or specific purpose processor, an application specific integrated circuit (ASIC), one or more field programmable gate arrays (FPGAs), a group of processing components, or other suitable processing components. Processor 534 is configured to execute computer code or instructions stored in memory 536 or received from other computer readable media (e.g., CDROM, network storage, a remote server, etc.). Memory 536 can include one or more devices (e.g., memory units, memory devices, storage devices, etc.) for storing data and/or computer code for completing and/or facilitating the various processes described in the present disclosure. Memory 536 can include random access memory (RAM), read-only memory (ROM), hard drive storage, temporary storage, non-volatile memory, flash memory, optical memory, or any other suitable memory for storing software objects and/or computer instructions. Memory 536 can include database components, object code components, script components, or any other type of information structure for supporting the various activities and information structures described in the present disclosure. Memory 536 can be communicably connected to processor 534 via processing circuit 532 and can include

computer code for executing (e.g., by processor 534) one or more processes described herein. When processor 534 executes instructions stored in memory 536, processor 534 generally configures monitoring system 500 (and more particularly processing circuit 532) to complete such activities.

**[0071]** Memory 536 is shown to include a temperature compensation module 540.

Temperature compensation module 540 may generally be configured to determine possible external effects on the plurality of temperature sensor readings and to apply one or more adjustments to account for the effects. Temperature compensation module 540 may further convert, using various calibration parameters, input from the sensors into an equivalent resistance value. For example, temperature compensation module 540 may determine or retrieve one or more calibration parameters (e.g., from database 548). The calibration parameters may include, for example, a reference resistance value that can be used to convert a signal from a temperature sensor into an equivalent resistance value. As another example, temperature compensation module 540 may apply configuration parameters to the value to compensate for inaccuracies in the conversion of the received value into an equivalent resistance value. As another example, temperature compensation module 540 may adjust the value based on an internal temperature sensor reading of a sensor within monitoring system 500. As another example, temperature compensation module 540 may apply configuration parameters to account for sensor drift over time of the plurality of temperature sensors 510. As another example, temperature compensation module 540 may apply configuration parameters to account for installation specific inaccuracies. As another example, temperature compensation module 540 may account for possible inaccuracies related to the communications channel between temperature sensors 510 and A/D converters 512. In other words, temperature compensation module 540 may generally account for various external factors that can result in an inaccurate temperature value being determined by monitoring system 500.

**[0072]** Memory 536 is shown to include a temperature measurement module 542.

Temperature measurement module 542 may generally be configured to convert a resistance value created and adjusted by temperature compensation module 540 into an equivalent temperature value. Temperature measurement module 542 may be configured to determine the type of sensors that provided the temperature sensor readings, and to select one or more coefficient values relating to the type of sensor. Temperature measurement module 542 may

further select one of a plurality of equations to use with the coefficient values and resistance value to calculate the temperature value. An example of a possible calculation is described in greater detail in FIG. 6.

**[0073]** Memory 536 is shown to include a tampering module 544. Tampering module 544 may determine whether monitoring system 500 has been compromised in any way. For example, tamper detection module 544 may detect if housing 526 has been removed or tampered with, whether a temperature sensor has been added or removed, or whether the user has made any modification to the data produced by monitoring system 500. Tampering module 544 may generally receive an indication of a tampering event (from tamper sensor 520 or another module), log tampering data relating to the tampering event, transmit the tampering data to an external system (via communications module 524), and determine a change in operation of monitoring system 500.

**[0074]** In some embodiments, the tampering event may be a user or an authorized party opening housing 526 and changing settings on one more components within housing 526. In one embodiment, the tampering event may be detected by the tamper sensor 520, described above. In other examples, the tampering event may be detected by, for example, the removal or modification of a sticker placed on the housing to seal the housing.

**[0075]** In some embodiments, the tampering event may be the disconnection of a temperature sensor and the installation of a fixed resistor, or the installation of a fixed resistor in parallel with the temperature sensor. The installation of a fixed resistor in parallel with the temperature sensor may result in the data collected by the fixed resistor to be unreliable. For example, a parallel resistor may result in the chiller system registering a temperature of a fluid in the chiller system that is higher or lower than the actual temperature. In one embodiment, the disconnection of a temperature sensor and/or the installation of a fixed resistor may be detected by the tamper sensor 520. In some examples, the tampering module 544 may evaluate one or more parameters, such as an indication of the housing being opened or removed (e.g. via tamper sensor 520), and a subsequent variation in resistance within the monitoring system 500. In one example, the tampering module 544 may detect a temperature probe disconnection by detecting a high resistance on a channel, indicating that the temperature probe has been disconnected. Having detected that a temperature probe has, or may have been disconnected, the tampering module 544 may determine whether to mark the temperature values calculated by monitoring system 500 as unreliable. Further, tampering

module 544 may cause the reporting of an alarm or warning via any method (e.g., a text alert, the flashing of one or more LED lights, etc.). In one embodiment, an LED light associated with a channel experiencing a tampering event may provide an indication that the channel is unreliable. For example, the LED light may turn on, turn off, or flash to indicate that the channel is unreliable. In one embodiment, the monitoring system 500 may continue to monitor the unreliable channel, but will provide an indication that the data collected may be unreliable.

**[0076]** In a further embodiment, the tampering event may be the installation of a parallel fixed resistance in parallel with the temperature probe, without disconnecting the temperature probe during the installation. Where a resistor is installed in parallel with the temperature probe without the disconnection of the temperature probe, the tampering module may detect the addition of the parallel resistors by detecting a step-function change in the collected data. In some examples, the tampering module 544 may be configured to detect a step-function change in the input (e.g. the temperature probe). Where the tampering module 544 detects a step-function change indicating the installation of a fixed resistor, the tampering module 544 may indicate that the channel or channels is unreliable, as described above.

**[0077]** In some embodiments, the tampering event may be a power supply for monitoring system 500 being turned off (e.g., during connection or disconnection of a temperature sensor or fixed resistor). Tampering module 544 may activate a backup power supply (e.g., a super-capacitor, battery, etc.) and generally provide power management for monitoring system 500. In some embodiments, the backup power supply can provide power to the monitoring system 500 for a number of days (e.g. two). However, different backup power supplies can provide power to the monitoring system 500 for more or less time. This can prevent a user or other unauthorized actor from disconnecting temperature probes and/or installing fixed resistors when the power is removed from the monitoring system 500. In some embodiments, the tampering module 544 may generate one or more signals to indicate that the monitoring system is operating using backup power. This can provide an indication to the BMS that the primary power supply to the monitoring system 500 is not functioning.

**[0078]** In some embodiments, the tampering event may be a disconnection of monitoring system 500 from the network. Monitoring system 500 may indicate that the device was off-line for a period of time, and may flag the data collected during the off-line period. For example, the monitoring system 500 may determine that it has been disconnected from the

network where a heartbeat signal is not received by the monitoring system 500. In some embodiments, the tampering event may be a change of address which may change the communications protocol of monitoring system 500. Where the address is changed, the BMS may log the monitoring system as “off line,” and all data received from that monitoring device will be indicated as such.

**[0079]** In some embodiments, the tampering event may be a user modifying a measured or calculated temperature value. Tampering module 544 may be configured to mark some or all data as read-only, or may be allowed to override the edits. Tampering module 544 may further mark edited data as altered, may indicate a user who modified the data, and the like. In some embodiments, the tampering event may be a user modifying a configuration parameter or coefficient value. Similarly, tampering module 544 may prevent the user from modifying the values, or may mark the resulting temperature values as modified. Further, the monitoring system 500 may be configured to have a single user account, thereby allowing only a single authorized user to modify the temperature values. In other embodiments, any changes to the temperature, or other, values is monitored and associated with a user based on the user ID associated with the user making the modifications. This allows for any changes to be traceable back to an individual user for follow-up verification.

**[0080]** In further embodiments, the tampering event may be a user modifying one or more coefficient values within an equation used by the monitoring system 500. For example, the tampering event may be an attempted modification of one or more coefficient values of the Steinhart-Hart equation, described above. The tampering module 544 may be configured to set up user accounts for each user such that only specified users may have access to write or override the coefficient values. Further, the tampering module 544 may be configured to report any change of value of the coefficients to the BMS or BAS, to allow the tampering event to be recorded and noted.

**[0081]** Memory 536 is shown to include a data logging module 546. After determining a plurality of temperature values, data logging module 546 may be configured to store the temperature values and equivalent resistance values in a data store within monitoring system 500.

**[0082]** Memory 536 is shown to include a database 548 which may store calibration parameters, configuration parameters, and coefficient values. As described in the present

disclosure, both temperature compensation module 540 and temperature measurement module 542 may use one or more calibration parameters or configuration parameters to calculate an equivalent resistance value or temperature value. In some implementations, some values may be stored within database 548 and retrieved by modules 540, 542 when needed. The values may be pre-set values provided by an external system relating to the hardware or software of controller 500. For example, coefficient values may be based on the type of material of the sensor or the controller, configuration parameters may be based on operating parameters of the components of monitoring system 500, and the like. Further, some values may be provided by a user, or may be based on exact calibration data from each individual temperature sensor 510. For example, the one or more temperature sensors 510 may be calibrated by a third party service, which can then provide all necessary calibration parameters which can be input into the monitoring system 500 to ensure the temperature readings are accurate, as will be described in more detail below.

**[0083]** Referring now to FIG. 6, a detailed flow chart of a process 600 for monitoring a chiller system is shown, according to some embodiments. Process 600 may be executed by, for example, temperature compensation module 540 and temperature measurement module 542 of monitoring system 500. Process 600 may be executed for a single temperature sensor signal from a single temperature sensor. For example, process 600 may be executed for each single temperature sensor 510. In some embodiments, process 600 may be executed for each temperature sensor reading received by monitoring system 500, and then each sensed temperature may be transmitted by monitoring system 500. In other embodiments, process 600 may include one or more steps for combining temperature sensor readings from multiple sensors or from a single sensor, or monitoring system 500 may combine multiple calculated temperature values once the values are computed by monitoring system 500. It should be understood that all such variations are within the scope of the present disclosure.

**[0084]** Based on a user defined frequency, monitoring system 500 and more particularly temperature compensation module 540 reads raw data from a temperature sensor 510 via A/D converter 512 (shown in FIG. 6 as ADC value 602). The value is passed through a low pass filter 620 and then converted into an equivalent resistance value at 622. At 622, calibration parameters 604 may be applied to the value. In some embodiments, calibration parameters 604 may include a reference resistance value which may generally correspond to a resistance value associated with the temperature sensor and A/D converter (i.e., any impact of the actual

devices involved with the temperature sensing on the value produced by the temperature sensor).

**[0085]** After the temperature sensor data is converted into an equivalent resistance value, additional parameters 606, 608 may be applied to the value at factory calibration block 624. Parameters 606, 608 may generally be factory calibration parameters related to possible inaccuracies associated with the circuitry of the A/D converter and the conversion of the value into an equivalent resistance value. The parameters may be applied as one or both of a gain or offset to the value (both are shown in the embodiment of FIG. 6 for illustrative purposes). For example, parameters 606, 608 may help compensate for any potential inaccuracies associated with the analog input channel on which the sensor data was transmitted. Inaccuracies in the analog signal transmitted via the analog input channel may result in the conversion due to the presence of noise in the channel. Parameters 606, 608 may be stored parameters or generated by controller 500 based on the conditions detected.

**[0086]** Process 600 includes a temperature compensation block 626 at which the internal temperature of monitoring system 500 is used to adjust the resistance value. As described above, the internal temperature within housing 526 may impact the data received at monitoring system 500. At block 626, an internal temperature parameter 610 relating to the internal temperature is applied to the resistance value.

**[0087]** Process 600 includes applying a set of field calibration parameters 612, 614 (at field calibration 628) to the resistance value. Field calibration parameters 612, 614 may generally relate to the sensor drift over time. For example, the output signal of a sensor may gradually change over time, independent of the conditions that the sensor is measuring. Field calibration parameters 612, 614 may generally represent the impact of the drift that distorts the signal sent by the sensors to monitoring system 500. Field calibration parameters 612, 614 may also generally relate to installation specific inaccuracies. Installation specific inaccuracies may be inaccuracies associated with the installation of the monitoring system 500, and may account for inaccuracies related to sensor placement, wire lengths, wiring layouts, field component values, etc. Field calibration parameters 612, 614 may be applied as one or both of a gain or offset to the value (both are shown in the embodiment of FIG. 6 for illustrative purposes). Field calibration parameters 612, 614 are applied to a second set of configuration parameters retrieved by monitoring system 500.

**[0088]** At block 630, the adjusted resistance value is converted into a temperature value. The type of equation used, and the coefficient values used in the equation, may vary based on the type of sensor and other related factors. For example, at block 630, controller 500 may determine a sensor specific parameter vector 616 and a sensor type 618, which may govern which equation controller 500 uses and the value of specific coefficients within each equation. The temperature values may then be provided to a user. For example, the temperature values may be transmitted via the communications module 524.

**[0089]** As one example, if the sensor is a platinum type sensor, a Callendar-Van Dusen equation may be used to convert the resistance value to a temperature value. The values of the various coefficients of the equation may vary based on the temperature range. For example, for a temperature range from 0°C to 850°C, the following equation may be used:

$$R_t = R_0(1 + At + Bt^2)$$

**[0090]** For a temperature range from -200°C to 0°C, the following equation may be used:

$$R_t = R_0(1 + At + Bt^2 + C(t - 100^\circ\text{C})t^3)$$

**[0091]**  $R_0$ ,  $A$ ,  $B$ , and  $C$  are sensor specific coefficients (i.e., identified by sensor specific parameter vectors 616), and  $R_t$  is a resistance value in  $\Omega$  at a temperature  $t$  (in °C). For example,  $A$ ,  $B$ , and  $C$  may be derived from experimentally determined parameters using resistance measurements made at different temperatures (e.g., 0°C, 100°C, and 260°C). In other words, coefficients  $A$ ,  $B$ , and  $C$  relate to the sensor performance at different temperatures, and are weighted based on the approximate temperature of the environment surrounding the sensor.

**[0092]** As another example, if the sensor is a negative temperature coefficient (NTC) type thermistor, a Steinhart-Hart equation may be used to convert the resistance value to a temperature value:

$$\frac{1}{T} = A + B(\ln(R)) + C(\ln(R))^3$$

**[0093]**  $A$ ,  $B$ , and  $C$  are sensor specific coefficients (i.e., identified by sensor specific parameter vectors 616), and  $R$  is a resistance value in the sensor in  $\Omega$  at a temperature  $T$  (in Kelvin). For example,  $A$ ,  $B$ , and  $C$  are coefficients that vary based on the type and model of the thermistor and the temperature range of the temperature being measured. In some embodiments, these coefficients may be provided or defined by the manufacturer of the

thermistor. In other embodiments, the coefficients may be derived by measuring resistance at different precise temperatures, then solving three simultaneous equations with A, B, and C as the three variables, with the equations based on the measured resistance.

**[0094]** Process 600 includes transmitting the measured resistance value and temperature value (blocks 632, 634). For example, the values may be transmitted to an external system for monitoring the performance of the chilled system. The values may be in any format (e.g., a standard change-of-value message may be created and transmitted by monitoring system 500).

**[0095]** Referring generally to FIGS. 7-8, the process of the controller receiving input from a plurality of temperature sensors is shown in greater detail. More particularly, the process of A/D converter 512 receiving temperature sensor data is shown in greater detail. As described above, each temperature sensor may be associated with a particular communications channel on which a sensor input 702 is provided as an analog input 704 to A/D converter 512. It should be understood that in various embodiments, monitoring system 500 may include any number of analog inputs 704 configured to receive input signals from one or more sensors 702.

**[0096]** Referring more specifically to FIG. 8, each analog input is received at monitoring system 500 from each temperature sensor. The analog input is passed through an amplifier 802 of the A/D converter 512 (shown separate in FIG. 8). In some embodiments, monitoring system 500 includes a sensor excitation source 804 configured to enhance the analog input for processing. The amplified analog input is provided to A/D converters 512 and converted into a digital value usable by processing circuit 532 and more particularly modules 540, 542. The values may be transmitted to processing circuit 532 from A/D converter 512 via a designated serial communication bus within controller 500.

**[0097]** Processing circuit 532 may further receive temperature sensor data from an internal temperature sensor 810 of monitoring system 500. Since the internal temperature may impact the analog signal received at the controller, the internal temperature readings may be used as a calibration or configuration parameter by processing circuit 532.

**[0098]** Referring now to FIG. 9, a flow chart of a process 900 for monitoring a chilled system is shown, according to an exemplary embodiment. Process 900 may be executed by, for example, monitoring system 500.

**[0099]** Process 900 includes receiving, at the monitoring system, a temperature sensor reading from a temperature sensor at 902. The temperature sensor reading may be provided on an input channel and received at an A/D converter interface. The temperature sensor reading is an analog input. Process 900 further includes converting the temperature sensor reading into a first value at 904. The first value is a digital value derived from the analog input.

**[0100]** Process 900 includes converting the first value into an equivalent resistance value at 906. The first value may be converted using a set of calibration parameters. Further, the process 900 may generally include passing the first value through a low pass filter and applying the calibration parameters at 906. The calibration parameters may relate to a reference resistance value, or to inaccuracies associated with the input channel.

**[0101]** Process 900 includes applying a first set of configuration parameters to the resistance value at 908. The first set of configuration parameters may be used to compensate for inaccuracies in the circuitry of the sensor. Process 900 includes adjusting the resistance value based on an internal temperature parameter related to an internal temperature of the housing of the sensor at 910. For example, the internal temperature may impact the signal being sent from the sensor to the monitoring system. Process 900 further includes applying a second set of configuration parameters to the resistance value to account for installation specific inaccuracies at 912.

**[0102]** Process 900 includes receiving a set of coefficient values related to the characteristics of the sensor at 914. For example, at 914, the monitoring system may determine the type of temperature sensor, and may select the appropriate coefficient values. Process 900 includes using the set of coefficient values to convert the adjusted resistance value into a temperature value at 916. The resistance value can be converted into a temperature value via an equation, in some embodiments. In one example, the temperature sensor is a platinum temperature sensor, and the equation used is a Callendar-Van Dusen equation. In another example, the temperature sensor is a NTC type thermistor, and the equation used is a Steinhart-Hart equation.

**[0103]** Process 900 includes transmitting the resistance value and temperature value at 918. In some embodiments, the values are transmitted to an external system or controller for

monitoring the chiller system. In some embodiments, the values are transmitted to a chiller controller for controlling the operation of the chiller.

**[0104]** The construction and arrangement of the systems and methods as shown in the various exemplary embodiments are illustrative only. Although only a few embodiments have been described in detail in this disclosure, many modifications are possible (e.g., variations in sizes, dimensions, structures, shapes and proportions of the various elements, values of parameters, mounting arrangements, use of materials, colors, orientations, etc.). For example, the position of elements may be reversed or otherwise varied and the nature or number of discrete elements or positions may be altered or varied. Accordingly, all such modifications are intended to be included within the scope of the present disclosure. The order or sequence of any process or method steps may be varied or re-sequenced according to alternative embodiments. Other substitutions, modifications, changes, and omissions may be made in the design, operating conditions and arrangement of the exemplary embodiments without departing from the scope of the present disclosure.

**[0105]** The present disclosure contemplates methods, systems and program products on any machine-readable media for accomplishing various operations. The embodiments of the present disclosure may be implemented using existing computer processors, or by a special purpose computer processor for an appropriate system, incorporated for this or another purpose, or by a hardwired system. Embodiments within the scope of the present disclosure include program products comprising machine-readable media for carrying or having machine-executable instructions or data structures stored thereon. Such machine-readable media can be any available media that can be accessed by a general purpose or special purpose computer or other machine with a processor. By way of example, such machine-readable media can include RAM, ROM, EPROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to carry or store desired program code in the form of machine-executable instructions or data structures and which can be accessed by a general purpose or special purpose computer or other machine with a processor. Combinations of the above are also included within the scope of machine-readable media. Machine-executable instructions include, for example, instructions and data which cause a general purpose computer, special purpose computer, or special purpose processing machines to perform a certain function or group of functions.

[0106] Although the figures show a specific order of method steps, the order of the steps may differ from what is depicted. Also two or more steps may be performed concurrently or with partial concurrence. Such variation will depend on the software and hardware systems chosen and on designer choice. All such variations are within the scope of the disclosure. Likewise, software implementations could be accomplished with standard programming techniques with rule based logic and other logic to accomplish the various connection steps, processing steps, comparison steps and decision steps.

**WHAT IS CLAIMED IS:**

1. A method of monitoring the performance of a chiller system, comprising:
  - receiving, at a monitoring system, a temperature sensor reading from a temperature sensor on an input channel at an analog-to-digital (A/D) converter interface;
  - converting the temperature sensor reading into a first value via an A/D conversion;
  - converting the first value into an equivalent resistance value using a set of calibration parameters;
  - applying a first set of configuration parameters to the resistance value to compensate for inaccuracies in the conversion of the first value into an equivalent resistance value;
  - adjusting the resistance value based on an internal temperature parameter relating to the internal temperature within the housing of the sensor;
  - applying a second set of configuration parameters to the resistance value to account for installation specific inaccuracies;
  - receiving a set of coefficient values related to the characteristics of the sensor;
  - using the set of coefficient values to convert the adjusted resistance value into a temperature value; and
  - transmitting the resistance value and temperature value to an external system for monitoring the performance of the chiller system.
2. The method of claim 1, wherein converting the first value into an equivalent resistance value using a set of calibration parameters comprises:
  - passing the first value through a low pass filter; and
  - applying the set of calibration parameters to the first value, wherein the first set of calibration parameters comprise a reference resistance value.
3. The method of claim 1, wherein the first set of calibration parameters at least partially comprise a parameter relating to inaccuracies associated with the plurality of input channels.
4. The method of claim 1, wherein the circuitry of the monitoring system includes an internal temperature sensor housed within the circuitry of the monitoring system, and wherein the internal temperature parameter is based on an output of the internal temperature.

5. The method of claim 1, wherein the set of coefficient values are based on the type of temperature sensor providing the temperature sensor reading.
6. The method of claim 5, wherein the temperature sensor is a platinum temperature sensor, and wherein converting the adjusted resistance value into a temperature value comprises applying the set of coefficient values using a Callendar-Van Dusen equation.
7. The method of claim 5, wherein the temperature sensor is a negative temperature coefficient (NTC) type thermistor, and wherein converting the adjusted resistance value into a temperature value comprises applying the set of coefficient values using a Steinhart-Hart equation.
8. The method of claim 1, further comprising transmitting the temperature value to a heating, venting, and air conditioning (HVAC) system of a building management system; wherein the temperature value is used to monitor the performance of the chiller system.
9. A monitoring system for a chiller plant, comprising:
  - a plurality of analog-to-digital (A/D) converter interfaces, each A/D converter interface corresponding with an input channel for receiving data from a temperature sensor located within the chiller plant;
  - a temperature module configured to:
    - convert the received data into a first value via an A/D conversion;
    - convert the first value into an equivalent resistance value using a set of calibration parameters;
    - apply a first set of configuration parameters to the resistance value to compensate for inaccuracies in the conversion of the first value into an equivalent resistance value;
    - adjust the resistance value based on an internal temperature parameter relating to the internal temperature within the housing of the sensor;
    - apply a second set of configuration parameters to the resistance value to account for installation specific inaccuracies;
    - receive a set of coefficient values to convert the adjusted resistance value into

a temperature value; and

use the set of coefficient values to convert the adjusted resistance value into a temperature value;

an internal temperature sensor configured to determine the internal temperature parameter within the circuitry of the monitoring system; and

a communications module configured to transmit the resistance value and temperature value to an external system for monitoring the performance of the chiller system.

10. The system of claim 9, the monitoring system further comprising:

a tamper sensor configured to detect a tampering event within the monitoring system; and

a tamper detection module configured to determine the impact of the tampering event within the monitoring system, and to determine a change in operation of the monitoring system in response.

11. The system of claim 9, wherein the communications module is further configured to transmit the temperature value to a heating, venting, and air conditioning (HVAC) system of a building management system;

wherein the temperature value is used to adjust a temperature setpoint of the building management system.

12. The system of claim 9, wherein converting the first value into an equivalent resistance value comprises:

passing the received data through a low pass filter; and

applying the set of calibration parameters to the first value, wherein the set of calibration parameters comprise a reference resistance value.

13. The system of claim 9, wherein the first set of calibration parameters at least partially comprise one or more parameters relating to inaccuracies associated with one or more of the plurality of input channels.

14. The system of claim 9, wherein the temperature sensor is a platinum temperature sensor and the set of coefficient values are related to one or more properties of the platinum

temperature sensor; and

wherein converting the adjusted resistance value into a temperature value comprises applying the set of coefficient values using a Callendar-Van Dusen equation.

15. The system of claim 9, wherein the temperature sensor is a negative temperature coefficient (NTC) type thermistor and the set of coefficient values are related to one or more properties of the NTC type thermistor; and

wherein converting the adjusted resistance value into a temperature value comprises applying the set of coefficient values using a Steinhart-Hart equation.

16. The system of claim 9, further comprising

a data logging module configured to store the resistance value and temperature value in a memory; and

a parameter database configured to store at least one of the calibration parameters, first set of configuration parameters, set of coefficient values, and second set of configuration parameters.

17. A method of monitoring the performance of a chiller system, comprising:

monitoring a temperature value associated with the chiller system and storing temperature value data;

receiving, at a monitoring system, an indication of a tampering event from a tamper sensor,

logging tampering data relating to the tampering event;

transmitting the tampering data to an external system for review; and

determining a change in operation of the monitoring system.

18. The method of claim 17, wherein the tampering event comprises at least one of:

a user opening a housing that houses the circuitry of the monitoring system;

a user disconnecting a temperature sensor connected with the monitoring system;

a user modifying a connection between the monitoring system and other systems in a building management system;

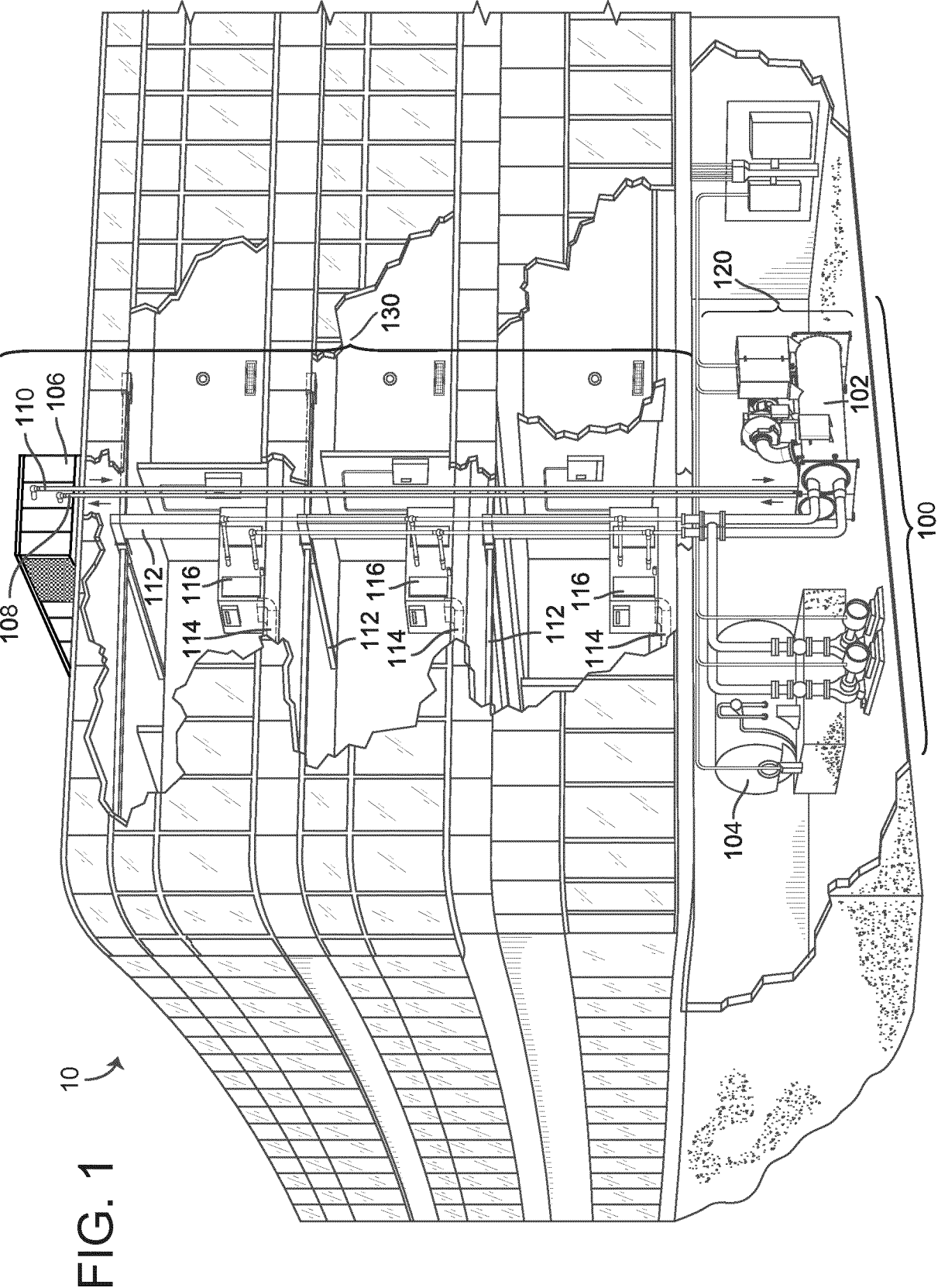
a user modifying one or more coefficient values, configuration parameters, or

calibration parameters related to the calculation of the temperature value;  
a user modifying temperature value data logged by the monitoring system;  
a user connecting an external device in parallel to or in place of a temperature sensor connected to the monitoring system; and  
a power supply outage.

19. The method of claim 17, wherein the change in operation of the monitoring system comprises at least one of:

generating an alarm to be transmitted to one or more users or systems;  
marking the tampering data as one of altered or unreliable;  
adjusting monitoring system operation to reduce operating power; and  
allowing or denying user access to the temperature value data, or allowing or denying a user to modify the temperature value data.

20. The method of claim 17, further comprising transmitting the temperature value data to the external system for review.



2/9

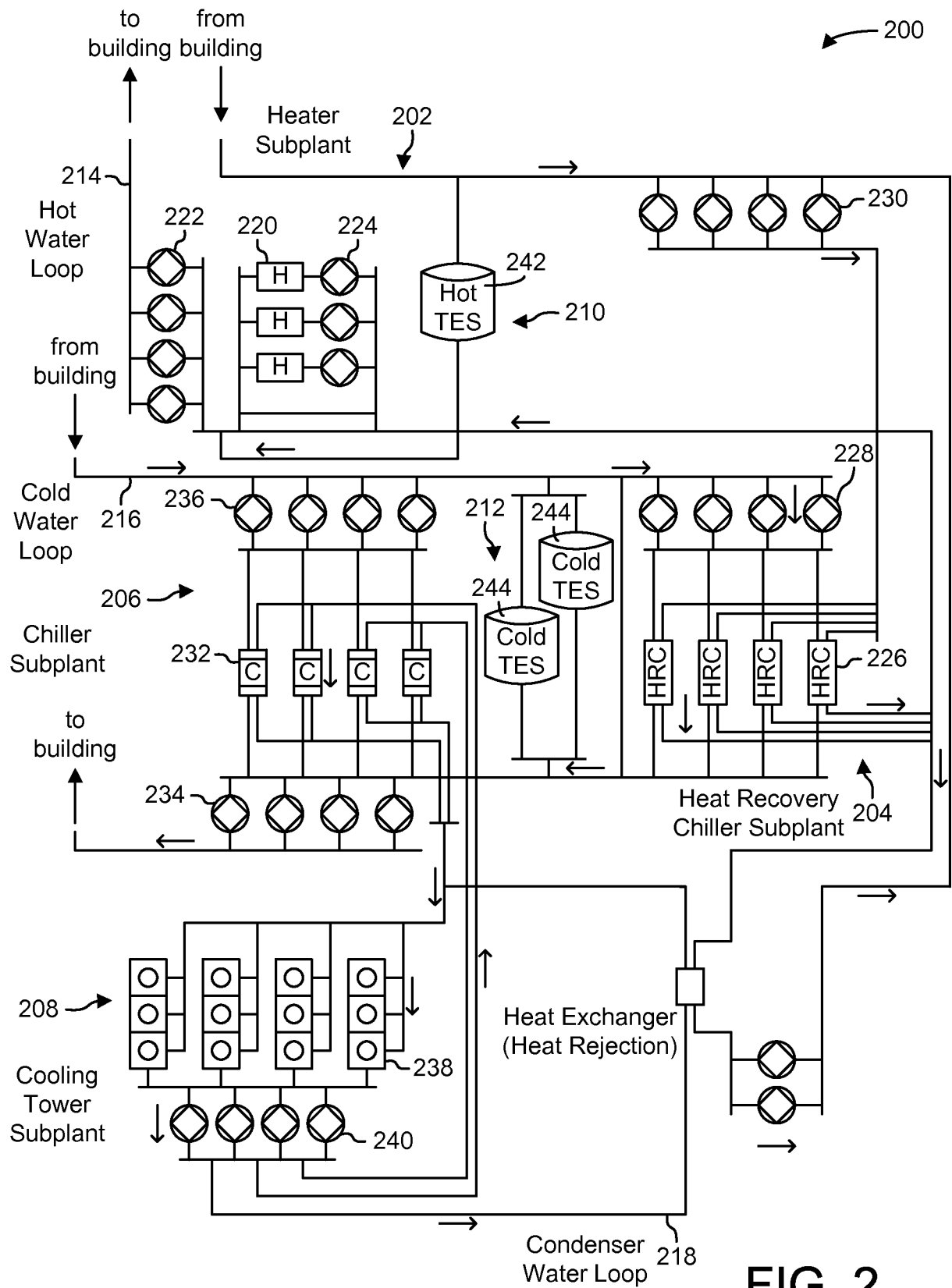


FIG. 2

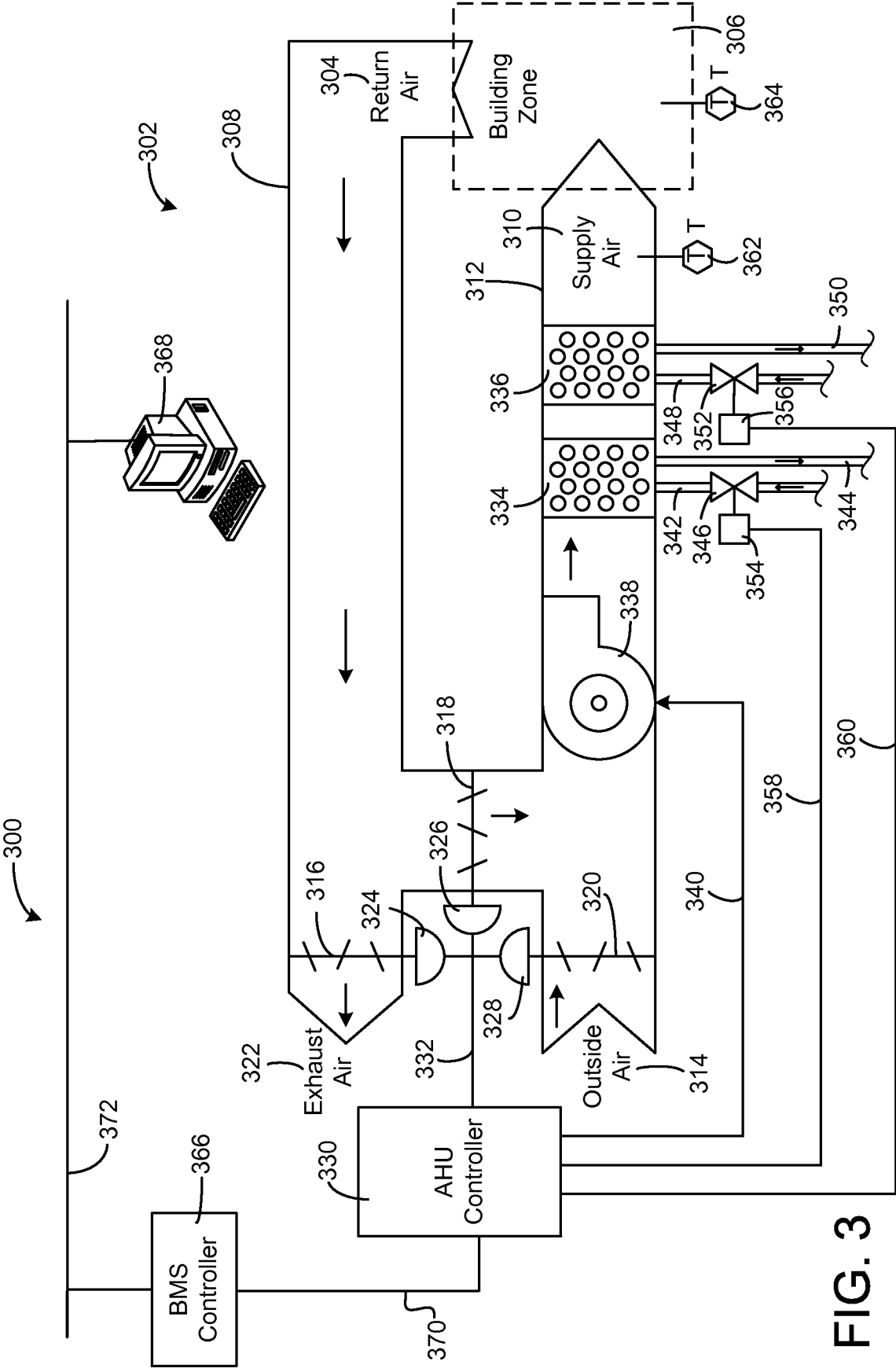


FIG. 3

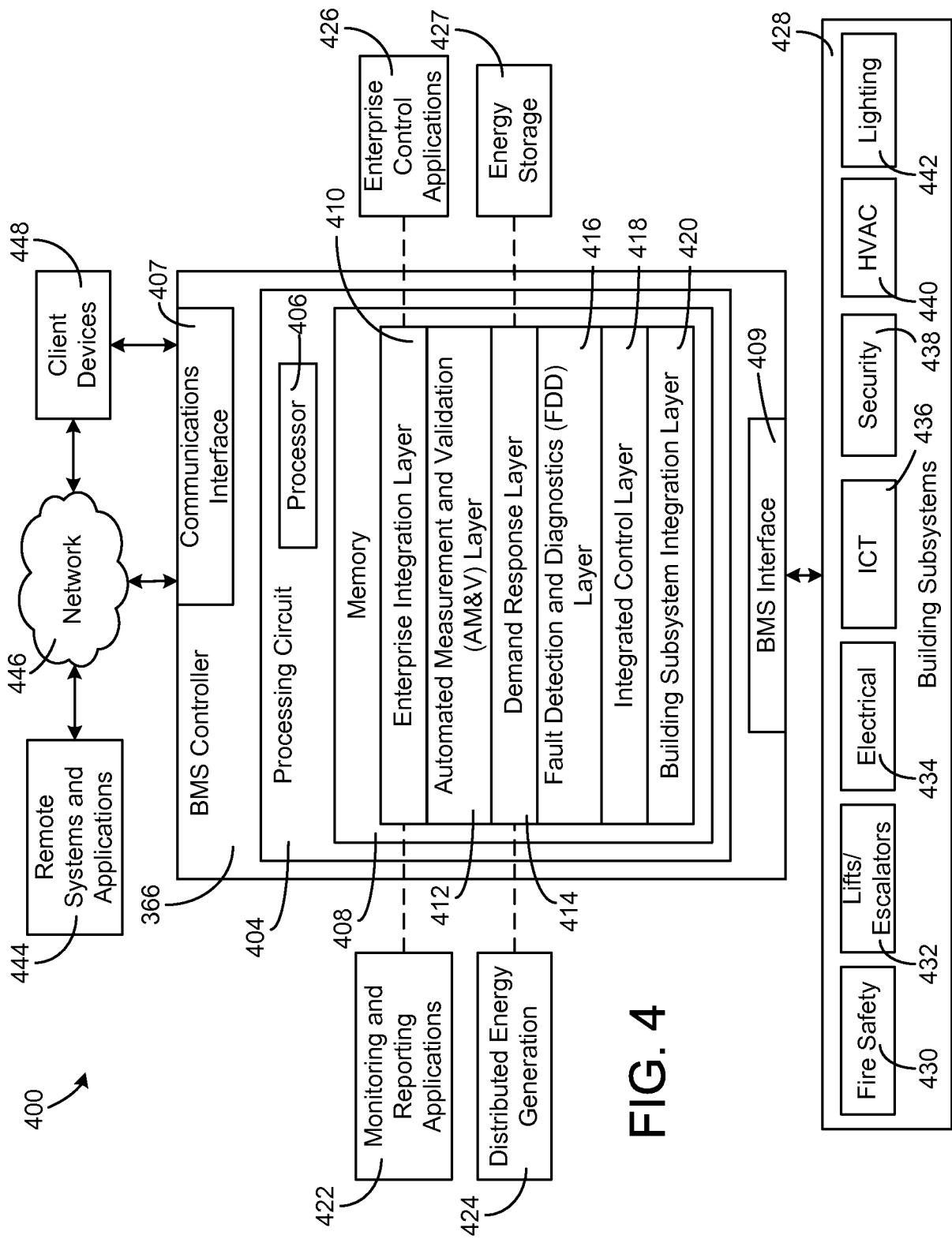


FIG. 4

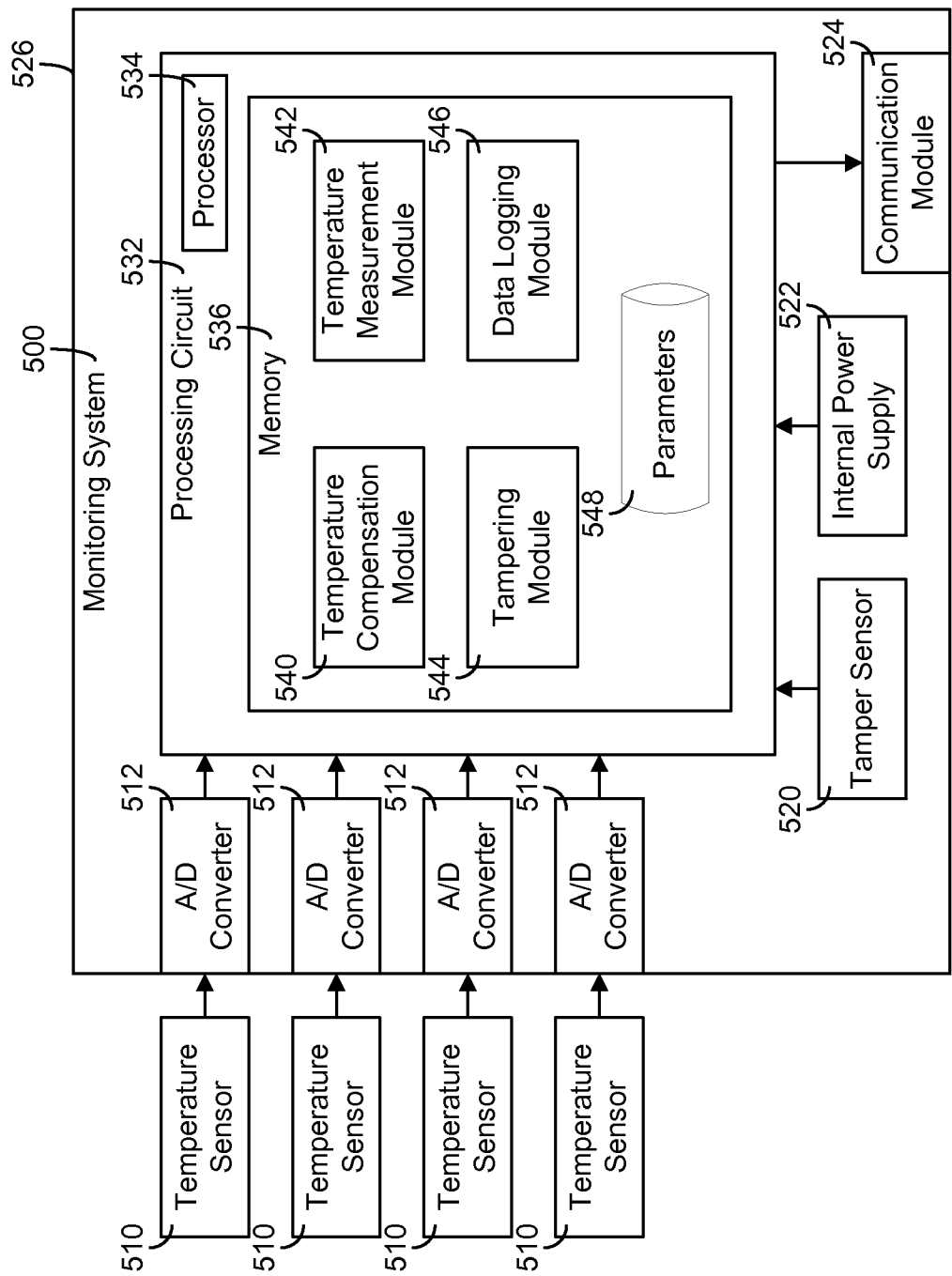


FIG. 5

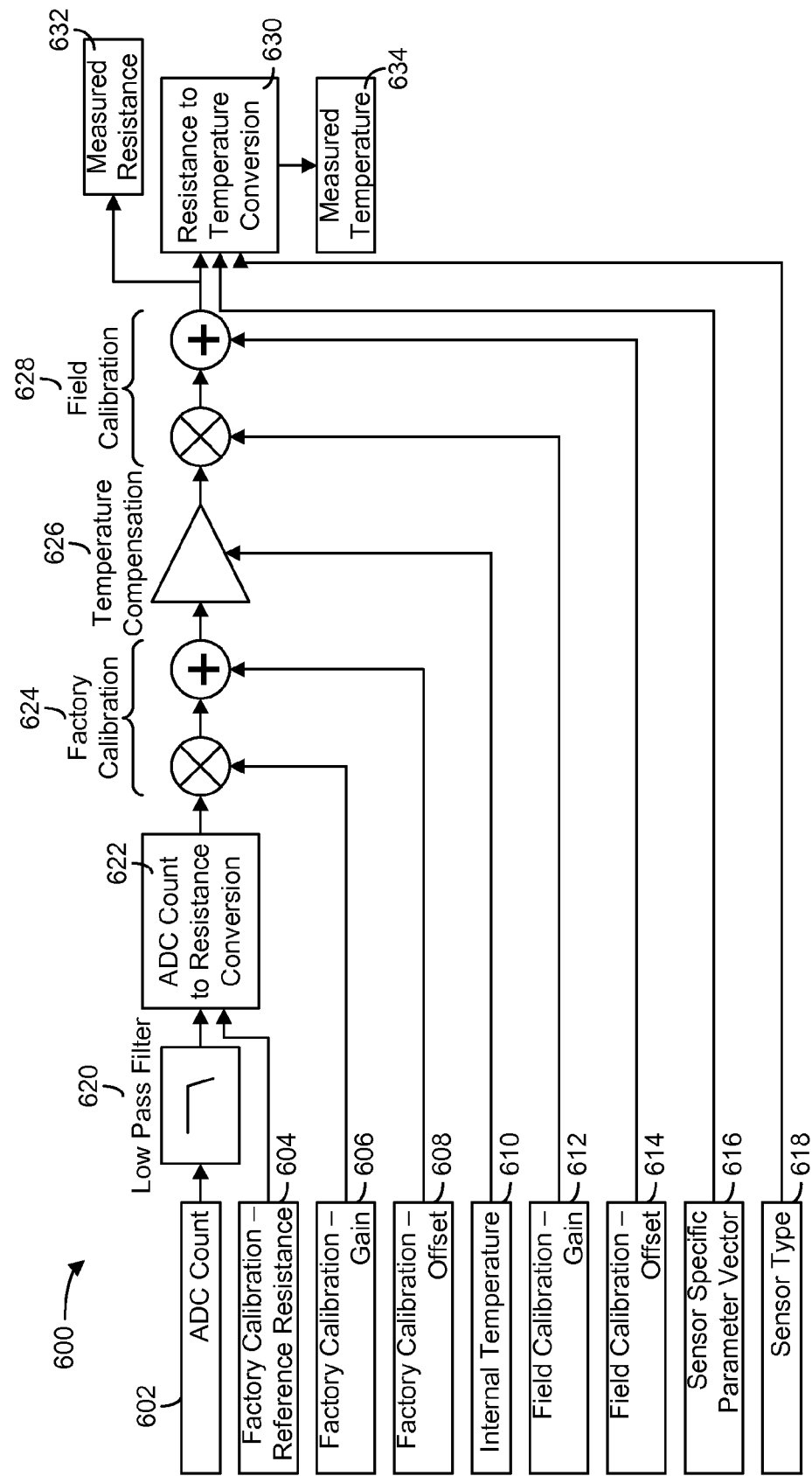


FIG. 6

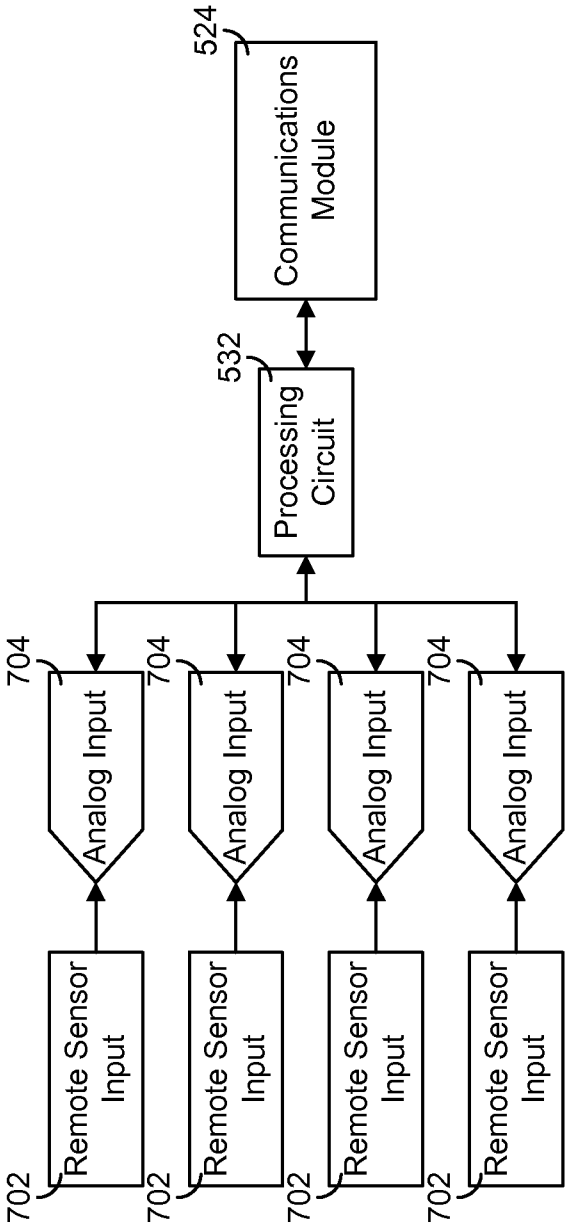


FIG. 7

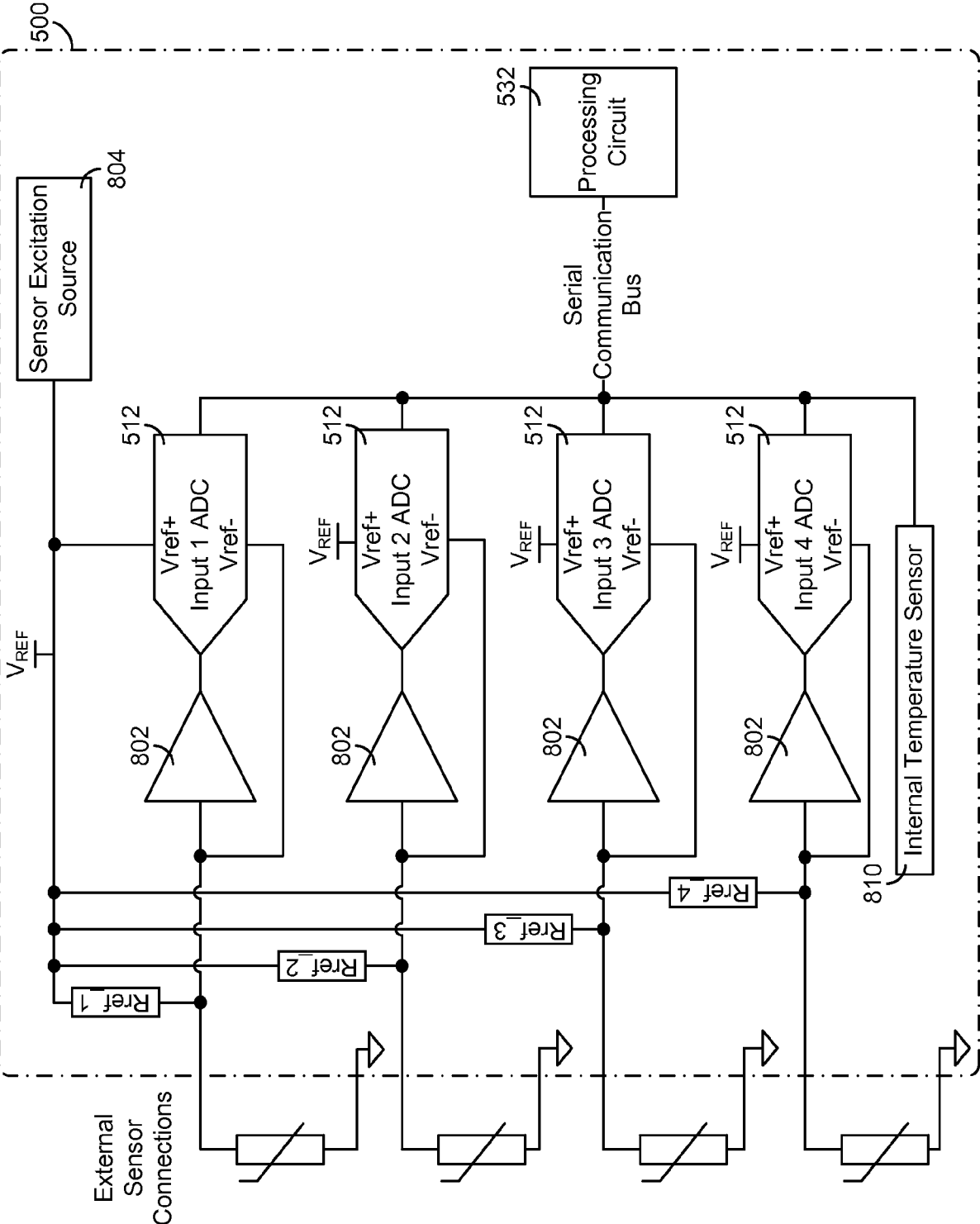
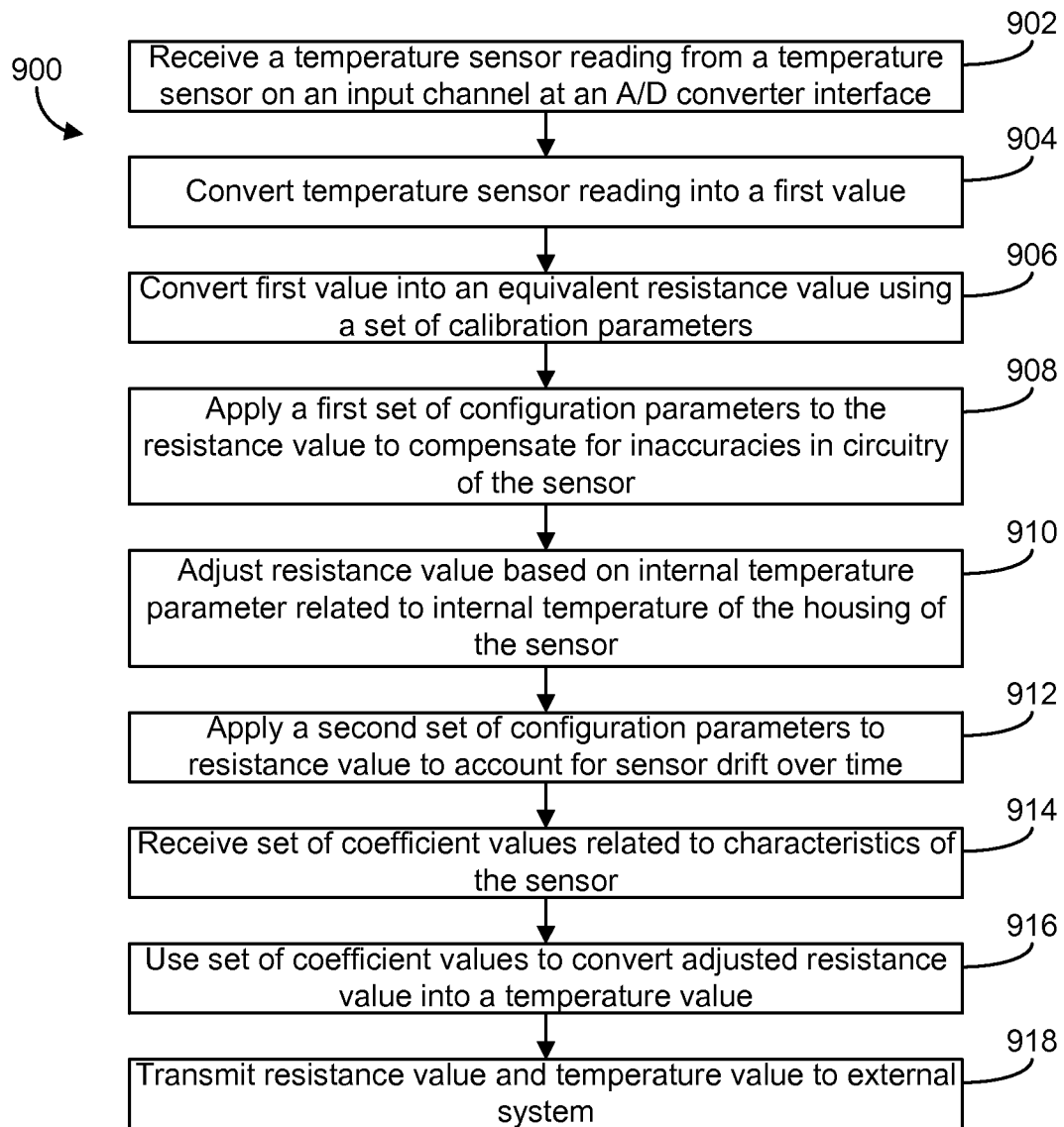


FIG. 8

**9/9****FIG. 9**

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2017/019183

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01K 15/00; G01D 3/028; G01K 1/00; G05D 23/19 (2017.01)

CPC - G01K 15/005; G01D 3/028; G01K 1/00; G01K 15/00; G01K 15/002; G05D 23/19 (2017.02)

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

USPC - 62/125; 62/129; 62/130; 236/94 (keyword delimited)

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. |
|-----------|------------------------------------------------------------------------------------|-----------------------|
| Y         | EP 0670481 B1 (BECTON DICKINSON CO) 18 September 2002 (18.09.2002) entire document | 1-16                  |
| Y         | US 5,381,954 A (TOKIZAKI) 17 January 1995 (17.01.1995) entire document             | 1-16                  |
| Y         | US 3,754,442 A (ARNETT) 28 August 1973 (28.08.1973) entire document                | 6, 14                 |
| Y         | US 2008/0212643 A1 (MCGAHHEY et al) 04 September 2008 (04.09.2008) entire document | 7, 15                 |
| Y         | US 5,646,858 A (SCHROCK et al) 08 July 1997 (08.07.1997) entire document           | 10                    |
| A         | US 5,301,513 A (DUFF et al) 12 April 1994 (12.04.1994) entire document             | 1-16                  |

☐ 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

"&amp;" document member of the same patent family

Date of the actual completion of the international search

19 June 2017

Date of mailing of the international search report

06 JUL 2017

Name and mailing address of the ISA/US

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Blaine R. Copenheaver

PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2017/019183

## Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:  
See extra sheet(s).

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:  
1-16

### Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2017/019183

Continued from Box No. III Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-16, drawn to a method of monitoring the performance of a chiller system

Group II, claims 17-20, drawn to a method of monitoring the performance of a chiller system

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention: applying a first set of configuration parameters to the resistance value to compensate for inaccuracies in the conversion of the first value into an equivalent resistance value as claimed therein is not present in the invention of Group II. The special technical feature of the Group II invention: receiving, at a monitoring system, an indication of a tampering event from a tamper logging tampering data relating to the tampering event as claimed therein is not present in the invention of Group I.

Groups I and II lack unity of invention because even though the inventions of these groups require the technical feature of a method of monitoring the performance of a chiller system, comprising receiving, at a monitoring system, a temperature sensor reading, this technical feature is not a special technical feature as it does not make a contribution over the prior art.

Specifically, US 5,301,513 A to Duff et al., April 12, 1994 teaches a method of monitoring the performance of a chiller system, comprising receiving, at a monitoring system, a temperature sensor reading (each unit controller monitors the temperature of the chilled water in a line 18a, 18b, or 18c. The system controller finally receives a chilled water supply temperature reading from a chilled water supply sensor 38. See col. 2, lines 57-59, col. 3, lines 12-16).

Since none of the special technical features of the Group I or II inventions are found in more than one of the inventions, unity of invention is lacking.