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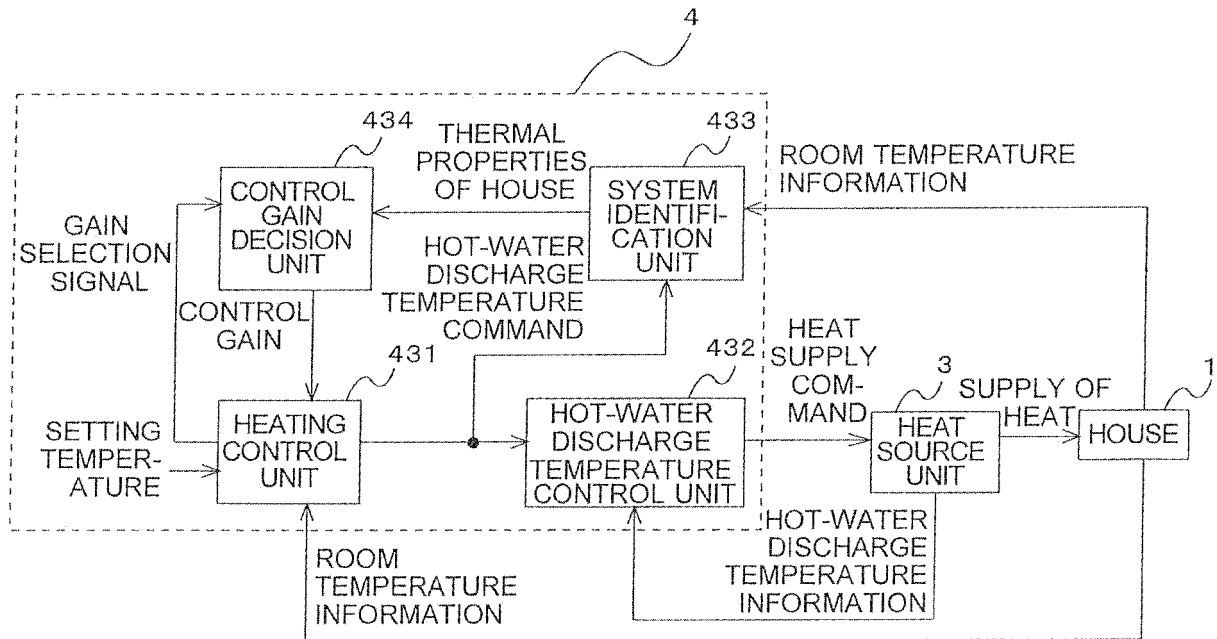
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(54) **HOT-WATER HEATING SYSTEM, CONTROL DEVICE, AND CONTROL METHOD**

(57) A hot water heating system includes a room temperature sensor that detects room temperature information of a building; a heat source unit that generates hot water; an indoor unit that rejects heat of hot water generated by the heat source unit and heats the building; and a controller that controls the heat source unit. The controller includes a control gain determination unit that calculates a first gain and a second gain based on thermal properties of the building, a heating control unit that updates a hot-water discharge temperature command corresponding to a target value of a temperature of water at an outlet of a refrigerant-water heat exchanger by using the first gain and the second gain, and a hot-water discharge temperature control unit that, in a case of air-conditioning ON in which the indoor unit supplies heat to the building, outputs a heat supply command to the heat source unit based on the hot-water discharge temperature command updated by the heating control unit. The

first gain is designed so that the hot-water discharge temperature command that results in intended room temperature response in the case of air-conditioning ON is obtained, and the second gain is designed so that the hot-water discharge temperature command reflecting a change in room temperature in a case of air-conditioning OFF in which the indoor unit does not supply heat to the building is obtained. The heating control unit updates, in the case of air-conditioning ON, the hot-water discharge temperature command by using a setting temperature for room temperature, the room temperature information, and the first gain, and updates, in the case of air-conditioning OFF, the hot-water discharge temperature command by using the setting temperature, the room temperature information, and the second gain.

FIG. 4



**Description**Technical Field

5 **[0001]** The present invention relates to a hot water heating system that heats space in a building, and relates to a controller and a control method for the hot water heating system.

Background Art

10 **[0002]** In related art, there is a hot water heating system that circulates hot water heated by heat generated in a heat source unit using a heat pump to perform heating. In control of the hot water heating system, for energy conservation, for example, the heat source unit is repeatedly stopped and driven in accordance with a room temperature, for example. Specifically, when a setting temperature is lower than a room temperature, or when an air conditioning load is so low that the quantity of heat that is necessary is below a minimum value in operating the heat source unit, the heat source unit is stopped. Then, after the stopping of the heat source unit, for example, when the room temperature falls with the passage of time under the influence of outside air, for example, and falls below the setting temperature, the operation of the heat source unit is resumed. For example, Patent Literature 1 discloses a hot water heating apparatus that detects a hot water temperature on a supply path side to perform feedback control in accordance with a preset target temperature. In the hot water heating apparatus disclosed in Patent Literature 1, when a hot water temperature on the supply path side rises to a predetermined temperature at which fire is extinguished, the operation of a heat source unit is stopped, and when a hot water temperature on the supply path side falls to a predetermined temperature at which ignition is restarted that is lower than the target temperature, the operation of the heat source unit is resumed.

Citation List

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Patent Literature

**[0003]** Patent Literature 1 Japanese Unexamined Patent Application Publication No. 2013-217604 (See Claim 1)

30 Summary of Invention

Technical Problem

35 **[0004]** In control performed so that a hot-water discharge temperature in a hot water heating apparatus, such as a radiator or a floor heating appliance, agrees with a setting temperature, when the quantity of heat that is necessary reaches or falls below a minimum quantity of heat generated by a heat source unit, the operation of the heat source unit has to be stopped, and, when the hot-water discharge temperature falls below the setting temperature, the operation of the heat source unit has to be resumed. Here, in an existing hot water heating apparatus, in the resumption of the operation of a heat source unit, the heat source unit is controlled by a preset heat supply command in which no consideration is given to thermal properties of an actual building. In this case, when the preset heat supply command is excessive for the quantity of heat essentially necessary for the building, a hot-water discharge temperature may exceed an upper limit to bring the heat source unit to a stop again, and thus the operation and stopping of the heat source unit are repeated in a short time period in some cases. As a result, there is a possibility that the durability of an actuator will decrease and energy conservation performance will diminish. When the preset heat supply command indicates less than the quantity of heat that is essentially necessary, the hot-water discharge temperature does not rise sufficiently, and a room temperature is thus less likely to rise, thereby reducing comfort.

40 **[0005]** Furthermore, for energy conservation, while the occupant is out, or at night, a setting temperature for heating is reduced to stop the supply of heat from the heat source unit in some cases. If a room temperature falls below the setting temperature, the setting temperature for heating is raised when the occupant returns home, or early in the morning, for example, and the heat source unit resumes the supply of heat. At this time, when the supply of heat is resumed by a hot-water discharge temperature command of a predetermined temperature set in advance, hot-water discharge temperature command information adjusted through heating control until just before the supply of heat is stopped is not made use of, and feedback control thus starts from the beginning. As a result, the heating control becomes discontinuous, thereby increasing the time taken to stabilize the room temperature. In a highly-airtight/well-insulated house, in particular, if a setting temperature is raised before a room temperature falls below the setting temperature, it takes time before the room temperature reaches the setting temperature due to discontinuity of the heating control, thereby reducing comfort.

55 **[0006]** The present invention has been made to overcome such drawbacks and provides a hot water heating system, a controller, and a control method that each achieve energy conservation without reducing comfort.

Solution to Problem

**[0007]** A hot water heating system according to an embodiment of the present invention includes: a room temperature sensor configured to detect room temperature information of a building; a heat source unit configured to generate hot water; an indoor unit configured to reject heat of hot water generated by the heat source unit and heat the building; and a controller configured to control the heat source unit, wherein the heat source unit includes a compressor configured to compress refrigerant, a refrigerant-water heat exchanger configured to exchange heat between the refrigerant and water, and a circulation pump configured to circulate the hot water between the refrigerant-water heat exchanger and the indoor unit, wherein the controller includes a control gain determination unit configured to calculate a first gain and a second gain based on thermal properties of the building, a heating control unit configured to update a hot-water discharge temperature command corresponding to a target value of a temperature of water at an outlet of the refrigerant-water heat exchanger by using the first gain and the second gain, and a hot-water discharge temperature control unit configured to, in a case of air-conditioning ON in which the indoor unit supplies heat to the building, output a heat supply command to the heat source unit based on the hot-water discharge temperature command updated by the heating control unit, wherein the first gain is designed so that the hot-water discharge temperature command that results in intended room temperature response in the case of air-conditioning ON is obtained, wherein the second gain is designed so that the hot-water discharge temperature command reflecting a change in room temperature in a case of air-conditioning OFF in which the indoor unit does not supply heat to the building is obtained, and wherein the heating control unit is configured to update, in the case of air-conditioning ON, the hot-water discharge temperature command by using a setting temperature for room temperature, the room temperature information, and the first gain, and update, in the case of air-conditioning OFF, the hot-water discharge temperature command by using the setting temperature, the room temperature information, and the second gain.

Advantageous Effects of Invention

**[0008]** In the hot water heating system according to the embodiment of the present invention, in the case of air-conditioning OFF as well, the hot-water discharge temperature command is updated by using the setting temperature, the room temperature information, and the second gain. Thus, operation is resumed based on the updated hot-water discharge temperature command, thereby enabling a hot-water discharge temperature to be continuous from the air-conditioning OFF to the air-conditioning ON. For this reason, a state before the air-conditioning OFF can be continued, thereby making it possible to obtain energy conservation effects without reducing room temperature comfort.

Brief Description of Drawings**[0009]**

- FIG. 1 is a schematic configuration diagram of a hot water heating system in Embodiment 1 of the present invention.
- FIG. 2 is a schematic configuration diagram of a hot water circulation circuit in Embodiment 1 of the present invention.
- FIG. 3 is a functional block diagram of a controller in Embodiment 1 of the present invention.
- FIG. 4 illustrates a flow of heating control performed by a heating control unit, a hot-water discharge temperature control unit, a system identification unit, and a control gain determination unit in Embodiment 1 of the present invention.
- FIG. 5 is a flowchart illustrating a flow of a system identification process in Embodiment 1 of the present invention.
- FIG. 6 illustrates an example of sampling performed in the system identification unit according to Embodiment 1 of the present invention.
- FIG. 7 is a block diagram of the heating control unit in Embodiment 1 of the present invention.
- FIG. 8 is a flowchart illustrating a flow of a heating control process in Embodiment 1 of the present invention.
- FIG. 9 illustrates an example of a simulation result in the hot water heating system in Embodiment 1 of the present invention.
- FIG. 10 illustrates a flow of heating control performed by the heating control unit, the hot-water discharge temperature control unit, the system identification unit, and the control gain determination unit in Embodiment 2 of the present invention.
- FIG. 11 is a block diagram of the heating control unit in Embodiment 2 of the present invention.
- FIG. 12(a) illustrates a thermal network model to be controlled,
- FIG. 12(b) illustrates a thermal network model in the case where a heat quantity is supplied from an indoor unit,
- FIG. 12(c) illustrates a thermal network model in the case where no heat quantity is supplied from the indoor unit.

- FIG. 13 is a schematic configuration diagram of a hot water circulation circuit in Embodiment 3 of the present invention.
- FIG. 14 is a functional block diagram of the controller in Embodiment 3 of the present invention.
- FIG. 15 illustrates a flow of heating control performed by the heating control unit, the hot-water discharge temperature control unit, the system identification unit, and the control gain determination unit in Embodiment 3 of the present invention.
- FIG. 16 illustrates an example of how to determine on a gain selection signal in Embodiment 3 of the present invention.
- FIG. 17 is a flowchart illustrating a flow of a system identification process (during air-conditioning OFF) in Embodiment 3 of the present invention.
- FIG. 18 is a flowchart illustrating a flow of a heating control process in Embodiment 3 of the present invention.
- FIG. 19 illustrates a flow of heating control using return temperature information performed by the heating control unit, the hot-water discharge temperature control unit, the system identification unit, and the control gain determination unit in Embodiment 3 of the present invention.

### Description of Embodiments

**[0010]** Embodiments of a hot water heating system in the present invention will be described in detail below with reference to the drawings.

#### Embodiment 1

**[0011]** FIG. 1 is a schematic configuration diagram of a hot water heating system 100 in Embodiment 1 of the present invention. The hot water heating system 100 comprises a room temperature sensor 2 that measures a room temperature of a house 1 that is a building to be heated, a heat source unit 3 that generates hot water used for heating, a controller 4 that outputs a heat supply command to the heat source unit 3 so that a room temperature detected by the room temperature sensor 2 agrees with a setting temperature, and an indoor unit 5 that rejects heat of hot water supplied from the heat source unit 3 to heat a room.

**[0012]** FIG. 2 is a schematic configuration diagram of a hot water circulation circuit in Embodiment 1. The hot water circulation circuit is constituted by the heat source unit 3 having a heat pump cycle, and an indoor heat exchanger 51 provided to the indoor unit 5 that are connected. As illustrated in FIG. 2, the heat source unit 3 includes a compressor 31, an outdoor heat exchanger 32, a fan 33, a refrigerant flow rate regulation device 34, a refrigerant-water heat exchanger 35, and a circulation pump 36. The heat source unit 3 further includes a heat source unit control unit 37 that controls each component of the heat source unit 3.

**[0013]** As illustrated in FIG. 2, the compressor 31, the outdoor heat exchanger 32, the refrigerant flow rate regulation device 34, and the refrigerant-water heat exchanger 35 are connected in series by a heat source side flow passage 30. Refrigerant for conveying heat is circulated through the heat source side flow passage 30. The refrigerant-water heat exchanger 35, the indoor heat exchanger 51, and the circulation pump 36 are connected in series by a use side flow passage 50. As a heat medium for conveying heat, water is circulated through the use side flow passage 50. The compressor 31 compresses refrigerant sucked from a suction side into high-temperature high-pressure gas refrigerant and discharges the gas refrigerant from a discharge side. The outdoor heat exchanger 32 serves as an evaporator of refrigerant during heating operation and exchanges heat between outside air and refrigerant to receive heat from the outside air. The fan 33 sends air to the outdoor heat exchanger 32 to adjust reception of heat in the outdoor heat exchanger 32. The refrigerant flow rate regulation device 34 is an electronic expansion valve, for example, and regulates a flow rate of refrigerant that flows through the refrigerant-water heat exchanger 35.

**[0014]** The refrigerant-water heat exchanger 35 serves as a condenser of refrigerant during heating operation and exchanges heat between refrigerant circulating through the heat source side flow passage 30 and water circulating through the use side flow passage 50. Thus, the heat source side flow passage 30 and the use side flow passage 50 that are independent from each other are thermally connected to each other in terms of flow passage. As a heat medium to be circulated through the use side flow passage 50, antifreeze, or a liquid mixture of water and antifreeze, for example, may be used in place of water. The circulation pump 36 regulates a flow rate of hot water heated via the refrigerant-water heat exchanger 35. Hot water circulating the use side flow passage 50 rejects heat by using the indoor heat exchanger 51 and is heated via the refrigerant-water heat exchanger 35 again.

**[0015]** In the use side flow passage 50, the heat source unit 3 further includes a hot-water discharge temperature sensor 21 that is provided on an outlet side of the refrigerant-water heat exchanger 35 and that detects a hot-water discharge temperature, a return temperature sensor 22 that is provided on an inlet side of the refrigerant-water heat exchanger 35 and that detects a return temperature of water having circulated through the indoor heat exchanger 51, and a flow rate sensor 23 that detects a flow rate of water that circulates through the use side flow passage 50. Pieces

of Information detected by these sensors are transmitted to the heat source unit control unit 37 via analog communication or digital communication. The heat source unit control unit 37 controls, based on a heat supply command from the controller 4 and information from each sensor, the operating capacity of the compressor 31, the air volume of the fan 33, the opening degree of the refrigerant flow rate regulation device 34, and the flow rate in the circulation pump 36, for example.

**[0016]** FIG. 3 is a functional block diagram of the controller 4 in Embodiment 1. As illustrated in FIG. 3, the controller 4 includes an input-output unit 41 that exchanges information with the room temperature sensor 2, the heat source unit 3, and the indoor unit 5, a storage unit 42 that stores various pieces of information and programs, and a control unit 43 that controls each unit.

**[0017]** The input-output unit 41 includes a digital input unit 411, an AD conversion unit 412, a serial communication unit 413, and a display unit 414. The digital input unit 411 receives, in the form of a digital signal, operating information of the indoor unit 5 or the heat source unit 3, switch information of the controller 4, or information from a non-illustrated flow switch, for example. The AD conversion unit 412 converts analog information from the room temperature sensor 2, the hot-water discharge temperature sensor 21, and the return temperature sensor 22 into digital information. The serial communication unit 413 is an interface for exchanging various pieces of setting information or sensor information with the indoor unit 5 or the heat source unit 3 via serial communication. The serial communication unit 413 may also receive room temperature information from a remote control (not illustrated) of the indoor unit 5, for example, via wireless communication. The display unit 414 displays information, such as a setting temperature, a current room temperature, or a hot-water discharge temperature, on a liquid crystal display screen.

**[0018]** The storage unit 42 is composed of a nonvolatile memory, for example. The storage unit 42 stores an initial setting, such as an initial control gain before completion of system identification, various pieces of sensor information from the input-output unit 41, thermal properties of the house 1 calculated by a system identification unit 433, a control gain designed in a control gain determination unit 434, a heat supply command data to the heat source unit 3, and input data input via the input-output unit 41, for example.

**[0019]** The control unit 43 comprises a microcomputer or a DSP (Digital Signal Processor), for example. The control unit 43 includes a heating control unit 431, a hot-water discharge temperature control unit 432, the system identification unit 433, the control gain determination unit 434, a mode determination unit 435, and an output data processing unit 436. Each unit described above is implemented, as a functional unit implemented by software, by a CPU (not illustrated) included in the control unit 43 executing a program stored in a recording medium, such as the storage unit 42. Alternatively, each unit described above may be implemented by an electronic circuit, such as an ASIC (Application Specific IC), an FPGA (Field Programmable Gate Array), or a PLD (Programmable Logic Device).

**[0020]** FIG. 4 illustrates a flow of heating control performed by the heating control unit 431, the hot-water discharge temperature control unit 432, the system identification unit 433, and the control gain determination unit 434 in Embodiment 1. As illustrated in FIG. 4, the system identification unit 433 calculates thermal properties of the house 1 from room temperature information acquired from the room temperature sensor 2 of the house 1 and a hot-water discharge temperature command from the heating control unit 431, and outputs the thermal properties to the control gain determination unit 434. The control gain determination unit 434 calculates a plurality of control gains in the heating control unit 431 based on the thermal properties of the house 1 calculated by the system identification unit 433. The heating control unit 431 generates a gain selection signal based on room temperature information, for example, and outputs the gain selection signal to the control gain determination unit 434. The control gain determination unit 434 determines on a control gain in accordance with the gain selection signal, and outputs the control gain to the heating control unit 431.

**[0021]** The heating control unit 431 generates a hot-water discharge temperature command from the control gain calculated by the control gain determination unit 434, a setting temperature, and room temperature information acquired from the room temperature sensor 2, and outputs the hot-water discharge temperature command to the hot-water discharge temperature control unit 432. The hot-water discharge temperature command corresponds to a target value of a temperature of water flowing through the use side flow passage 50 on the outlet side of the refrigerant-water heat exchanger 35 (hot-water discharge temperature). The hot-water discharge temperature control unit 432 generates a heat supply command to the heat source unit 3 from the hot-water discharge temperature command acquired from the heating control unit 431 and hot-water discharge temperature information acquired by the hot-water discharge temperature sensor 21 of the heat source unit 3. The heat supply command is a control target value in the heat source unit 3. The heat source unit control unit 37 of the heat source unit 3 controls, for example, the operating capacity of the compressor 31 in accordance with the heat supply command from the hot-water discharge temperature control unit 432 and supplies heat to the house 1.

**[0022]** Referring back to FIG. 3, the mode determination unit 435 makes a determination about a mode, such as heating, or hot-water supply, in accordance with input data from the input-output unit 41. The output data processing unit 436 processes output data for the input-output unit 41.

**[0023]** Next, the calculation of thermal properties of the house 1 performed by the system identification unit 433 will be described. Assuming that the thermal properties of the house 1 is a transfer function of a first-order lag system, a

transfer function from a quantity of heat to a room temperature is represented by the following expression (1).  
[Math. 1]

$$y = x = \frac{K_r}{\tau_r s + 1} u \quad \cdot \cdot \cdot (1)$$

**[0024]** In expression (1), s is the Laplace operator, y is an output, x is a state variable,  $K_r$  is a proportionality coefficient of the thermal properties of the house 1,  $\tau_r$  is a time constant of the thermal properties of the house 1, and u is a manipulated variable. Discretizing expression (1) using a backward difference of the following expression (2) yields the following expression (3).  
[Math. 2]

$$s = \frac{z - 1}{T_s z} \quad \cdot \cdot \cdot (2)$$

[Math. 3]

$$x[k] = \frac{\tau_r}{\tau_r + T_s} x[k-1] + \frac{K_r T_s}{\tau_r + T_s} u[k-1] \quad \cdot \cdot \cdot (3)$$

**[0025]** In expressions (2) and (3),  $T_s$  is a sampling period, z is a lead element,  $x[k]$  is a discretized state variable,  $x[k-1]$  is a discretized state variable in an immediately preceding sample, and  $u[k-1]$  is a manipulated variable in the immediately preceding sample. When expression (3) is changed, the following expression (4) is obtained.  
[Math. 4]

$$T_s x[k] = -(x[k] - x[k-1])\tau_r + T_s u[k-1]K_r \quad \cdot \cdot \cdot (4)$$

**[0026]** Expression (4) represents data at a certain point, and the system identification unit 433 acquires state variables x and manipulated variables u at a plurality of points, and thus calculates a proportionality coefficient  $K_r$  of the thermal properties of the house 1 and a time constant  $\tau_r$  of the thermal properties of the house 1. For example, in the case where state variables x and manipulated variables u at four points are taken, the following expression (5) is obtained. With time-series data, assuming that a left-hand side vector is  $\alpha$ , a right-hand side matrix is  $\beta$ , and a right-hand side vector is  $\gamma$ , a proportionality coefficient  $K_r$  of the thermal properties of the house 1 and a time constant  $\tau_r$  of the thermal properties of the house 1 are obtained by the method of least squares using a pseudo inverse matrix from expression (6).  
[Math. 5]

$$\begin{pmatrix} T_s x_1[k] \\ T_s x_2[k] \\ T_s x_3[k] \\ T_s x_4[k] \end{pmatrix} = \begin{pmatrix} -(x_1[k] - x_1[k-1]) & T_s u_1[k-1] \\ -(x_2[k] - x_2[k-1]) & T_s u_2[k-1] \\ -(x_3[k] - x_3[k-1]) & T_s u_3[k-1] \\ -(x_4[k] - x_4[k-1]) & T_s u_4[k-1] \end{pmatrix} \begin{pmatrix} \tau_r \\ K_r \end{pmatrix} \quad \cdot \cdot \cdot (5)$$

[Math. 6]

$$\gamma = (\beta^T \beta)^{-1} \beta^T \alpha \quad \cdot \cdot \cdot (6)$$

**[0027]** In expression (5), subscripts of each discretized state variable  $x[k]$ , each discretized state variable  $x[k-1]$  in the immediately preceding sample, and each manipulated variable  $u[k-1]$  refer to data numbers. In the case where resolution of state variables x or manipulated variables u is high, the accuracy of system identification increases as the number of pieces of data increases. However, in the case where the accuracy or resolution of the microcomputer used in the controller 4 or an AD converter mounted on a control board on which the microcomputer is mounted is low, for

example, in the case where detection resolution of a room temperature equivalent to a state variable  $x$  is about 0.1 degrees C, a data group of the independent expression (4) is not obtained in some cases. In this case, the sampling period  $T_s$  set at a fixed period in expression (5) is replaced by a change sampling period  $T_{sn}$  (where  $n$  is a data number) that is a period of time that elapses before a state variable changes, a manipulated variable  $u$  is also replaced by an integrated value  $U_{n\_sum}$  (where  $n$  is a data number), and a sampling period  $T_s$  for determination of a change is set to about 10 seconds or less. This can compensate for the roughness of the detection resolution. Furthermore, when a value of  $x_n[k] - x_n[k-1]$  is preset, even if a low-priced microcomputer is mounted in the controller 4, the thermal properties of the house 1 can be calculated while performing heating control. In this case, expression (5) is rewritten as expression (7). [Math. 7]

$$\begin{pmatrix} T_{s1}x_1[k] \\ T_{s2}x_2[k] \\ T_{s3}x_3[k] \\ T_{s4}x_4[k] \end{pmatrix} = \begin{pmatrix} -(x_1[k] - x_1[k-1]) & T_{s1}u_{1\_sum} \\ -(x_2[k] - x_2[k-1]) & T_{s2}u_{2\_sum} \\ -(x_3[k] - x_3[k-1]) & T_{s3}u_{3\_sum} \\ -(x_4[k] - x_4[k-1]) & T_{s4}u_{4\_sum} \end{pmatrix} \begin{pmatrix} \tau_r \\ K_r \end{pmatrix} \quad \cdot \cdot \cdot (7)$$

**[0028]** In the case where room temperature information from the room temperature sensor 2 is received not via wired communication but via wireless communication from a wireless device, such as a remote control, a period of wireless communication is increased because of a battery life problem. In this case, when information about an elapsed time is received together with the room temperature information, even if the period of wireless communication is 10 seconds or more, a determination of a change in room temperature can be made in the controller 4, thereby enabling an increase in the accuracy of system identification.

**[0029]** FIG. 5 is a flowchart illustrating a flow of a system identification process in Embodiment 1. FIG. 5 illustrates an example where, assuming that a value of  $x_n[k] - x_n[k-1]$  is 0.5, thermal properties of the house 1 are calculated based on pieces of time-series data at four points. The value of  $x_n[k] - x_n[k-1]$  and the number of pieces of time-series data are not limited to these. As illustrated in FIG. 5, in this process, first, a state variable  $x$  and a manipulated variable  $u$  at the start of system identification are acquired as initial data and stored in the storage unit 42 (S1). Then, the heating control unit 431 performs heating control by using an initial control gain stored in the storage unit 42 (S2). The initial control gain may be preset based on data of a test facility. Alternatively, in the case where building data, such as the thermal insulation or heat capacity of an individual house 1, is obtained, the initial control gain may be preset with reference to the value of the building data. In Embodiment 1, system identification is performed by the system identification unit 433 while heating control using the initial control gain is performed.

**[0030]** Next, it is determined whether pieces of data at four points have been acquired (S3). The data here refers to a state variable  $x_n$ , an integrated value  $u_{n\_sum}$  of a manipulated variable  $u$ , and a change sampling period  $T_{sn}$  that are used for calculating the thermal properties of the house 1. Then, when pieces of data at four points have not been acquired (S3: NO), it is determined whether a room temperature has risen by 0.5 degrees C or more from a previously stored room temperature (S4). Then, when the room temperature has not risen by 0.5 degrees C or more from the previously stored room temperature (S4: NO), a sample count  $cnt$  is incremented by one (S5), and a summation of manipulated variables  $u$  is performed (S6). Then, the process flow returns to step S2, and the processes of step S2 and the subsequent steps are repeated.

**[0031]** On the other hand, when the room temperature has risen by 0.5 degrees C or more from the previously stored room temperature (S4: YES), a state variable  $x_n$ , an integrated value  $u_{n\_sum}$  of the manipulated variable  $u$ , and a change sampling period  $T_{sn}$  are stored (S7). The state variable  $x_n$  is a room temperature detected by the room temperature sensor 2, and the integrated value  $u_{n\_sum}$  of the manipulated variable  $u$  is an integrated value of a hot-water discharge temperature command generated by the heating control unit 431. Here, the heating control unit 431 generates a hot-water discharge temperature command by using a setting temperature, a room temperature, and the initial control gain. The change sampling period  $T_{sn}$  is obtained from the following expression (8) by using a sample count  $cnt$  and a sampling period  $T_s$ . [Math. 8]

$$T_{sn} = T_s * cnt \quad \cdot \cdot \cdot (8)$$

**[0032]** Subsequently, the sample count  $cnt$  is reset (S8), the process flow returns to step S2, and the processes of step S2 and the subsequent steps are repeated. Then, when pieces of data at four points that are different from the initial data at the start of system identification have been acquired (S3: YES), a time constant  $\tau_r$  and a proportionality

coefficient  $K_r$  of the thermal properties of the house 1 are calculated based on the acquired data (S9).

**[0033]** Fig. 6 illustrates an example of sampling performed in the system identification unit 433 according to Embodiment 1. Fig. 6 illustrates an example of sampling performed in the case where a state variable  $x$  is a room temperature and a manipulated variable  $u$  is a hot-water discharge temperature command. Assume that  $P_0$  is a room temperature at the start of system identification and that a room temperature having risen by 0.5 degrees C with respect to this room temperature is  $P_1$ . In this case, a change sampling period  $T_{s1}$  and an integrated value  $u_{1\_sum}$  of the hot-water discharge temperature command are as illustrated in Fig. 6. Furthermore,  $P_1$  is equivalent to room temperatures of  $x_2[k-1]$  and  $x_1[k]$ . Assuming that a room temperature having risen by another 0.5 degrees C from the room temperature  $P_1$  is  $P_2$ , a change sampling period  $TS2$  that elapses before the room temperature changes from  $P_1$  to  $P_2$  and an integrated value  $u_{2\_sum}$  of the hot-water discharge temperature command are as illustrated in Fig. 6. The same applies to  $P_3$  and  $P_4$ . Although the manipulated variable  $u$  is a hot-water discharge temperature command in the heating control unit 431 in Embodiment 1, the manipulated variable  $u$  may be a hot-water discharge temperature detected in the hot-water discharge temperature sensor 21. In the case where a hot-water discharge temperature is used, however, noise control for hot-water discharge temperature information is necessary. Furthermore, in the case where a hot-water discharge temperature is used, response of a control system of the hot-water discharge temperature control unit 432 is not taken into consideration, and it is thus desirable that a hot-water discharge temperature command be used as the manipulated variable  $u$ .

**[0034]** Next, how the control gain determination unit 434 determines on a control gain will be described. In the following, the heating control unit 431 includes a PI controller (not illustrated) and performs PI control based on a room temperature and a setting temperature. The case where the PI controller is designed to be executable of pole-zero cancellation will be described. The control gain determination unit 434 calculates a control gain in PI control performed by the heating control unit 431 based on a proportionality coefficient  $K_r$  of the thermal properties of the house 1 and a time constant  $\tau_r$  of the thermal properties of the house 1 that have been calculated by the system identification unit 433. Furthermore, the control gain determination unit 434 calculates a compressor ON gain in the case where the compressor 31 of the heat source unit 3 is operating and a compressor OFF gain in the case where the compressor 31 is stopped. The compressor ON gain corresponds to "first gain" of the present invention, and the compressor OFF gain corresponds to "second gain" of the present invention.

**[0035]** Specifically, the PI controller of the heating control unit 431 designed as a continuous system is represented by the following expression (9). In expression (9),  $\tau_c$  is a design time constant of the PI controller, and  $s$  is the Laplace operator.

[Math. 9]

$$\frac{\tau_r s + 1}{\tau_c K_r s} \quad \cdot \cdot \cdot (9)$$

**[0036]** By using a proportional gain  $K_p$ , an integral gain  $K_i$ , and the Laplace operator  $s$ , the PI controller is represented by the following expression (10).

[Math. 10]

$$K_p + K_i \frac{1}{s} \quad \cdot \cdot \cdot (10)$$

**[0037]** Assuming that a design time constant of a PI controller gain in the case where the compressor 31 is operating is  $\tau_{c\_ON}$ , a proportional gain  $K_{p\_ON}$  and an integral gain  $K_{i\_ON}$  corresponding to the compressor ON gain are obtained by using the following expressions (11) and (12).

[Math. 11]

$$K_{p\_ON} = \frac{\tau_r}{\tau_{c\_ON} K_r} \quad \cdot \cdot \cdot (11)$$

[Math. 12]

$$K_{i\_ON} = \frac{1}{\tau_{c\_ON} K_r} \quad \cdot \cdot \cdot (12)$$

**[0038]** Assuming that a design time constant of a PI controller gain in the case where the compressor 31 is stopped is  $\tau_{c\_OFF}$ , a proportional gain  $K_{p\_OFF}$  and an integral gain  $K_{i\_OFF}$  corresponding to the compressor OFF gain are obtained by using the following expressions (13) and (14), respectively.  
[Math. 13]

$$K_{p\_OFF} = \frac{\tau_r}{\tau_{c\_OFF} K_r} \quad \cdot \cdot \cdot (13)$$

[Math. 14]

$$K_{i\_OFF} = \frac{1}{\tau_{c\_OFF} K_r} \quad \cdot \cdot \cdot (14)$$

**[0039]** Here, the design time constant  $\tau_{c\_ON}$  of the PI controller gain in the case where the compressor 31 is operating depends on a dead time determined by a total quantity and a flow rate of hot water flowing through the use side flow passage 50, and the dead time is about 10 minutes at the most. For this reason, in the case where the design time constant  $\tau_{c\_ON}$  is set so that a room temperature overshoot does not occur,  $\tau_{c\_ON}$  is set to be 2.6 or more times longer than the dead time. For example, assuming the dead time is 10 minutes,  $\tau_{c\_ON}$  is about 1600 seconds. In the case of FIG. 6, the dead time is obtained by measuring a time period from when the hot-water discharge temperature command rises to when the room temperature starts to rise. The design time constant  $\tau_{c\_OFF}$  of the PI controller gain in the case where the compressor 31 is stopped is a time constant  $\tau_r$  of the thermal properties of the house 1. Note that, in the case where a time constant  $\tau_r$  and a proportionality coefficient  $K_r$  of the thermal properties of the house can be predicted from the thermal insulation of the house 1 at design time and catalogue data of the indoor unit 5, a control gain may be designed by using the predicted values. The control gain determination unit 434 determines between the compressor ON gain and the compressor OFF gain that have been calculated as described above based on a gain selection signal from the heating control unit 431 and outputs a determination to the heating control unit 431.

**[0040]** Next, heating control performed by the heating control unit 431 will be described. The heating control unit 431 determines, from room temperature information from the room temperature sensor 2, for example, which of a compressor ON gain and a compressor OFF gain is to be used. For example, when any one or more of a case where the deviation between a setting temperature and a room temperature is 0 or more, a case where a hot-water discharge temperature command is larger than a lower limit, and a case where a value equivalent to a quantity of heat is larger than a minimum quantity of heat generated by the heat source unit 3 is established, the compressor ON gain is selected. On the other hand, when any one or more of a case where the deviation between the setting temperature and the room temperature is smaller than 0, a case where the hot-water discharge temperature command reaches the lower limit, and a case where the value equivalent to the quantity of heat is smaller than 0 is established, the compressor OFF gain is selected. Then, a gain selection signal based on the result is generated and is output to the control gain determination unit 434.

**[0041]** Furthermore, the heating control unit 431 updates the hot-water discharge temperature command based on the compressor ON gain or the compressor OFF gain determined by the control gain determination unit 434. FIG. 7 is a block diagram of the heating control unit 431 in Embodiment 1. Based on a room temperature deviation obtained by subtracting room temperature information detected by the room temperature sensor 2 from a setting temperature, the heating control unit 431 performs a control operation for each control period  $T_c$  and updates the hot-water discharge temperature command. The control period  $T_c$  is the same value as the sampling period  $T_s$  or is an integral multiple of the sampling period  $T_s$ .

**[0042]** The proportional gain  $K_{p\_ON}$  or  $K_{p\_OFF}$  calculated by the control gain determination unit 434 is input as the proportional gain  $K_p$ , and the integral gain  $K_{i\_ON}$  or  $K_{i\_OFF}$  is input as the integral gain  $K_i$ . The heating control unit 431 further determines whether the hot-water discharge temperature command corresponding to an operation result is input to a limiter, and performs anti-reset windup processing using a difference between the hot-water discharge temperature command before limiter processing and the hot-water discharge temperature command after the limiter processing, and the inverse of the proportional gain  $K_p$ . Through the processing, even when the hot-water discharge temperature command reaches the upper or lower limit, the hot-water discharge temperature command does not remain at the upper or lower limit and changes quickly, thereby preventing a room temperature overshoot to obtain energy conservation effects.

**[0043]** FIG. 8 is a flowchart illustrating a flow of a heating control process in Embodiment 1. In this process, first, the control gain determination unit 434 calculates a compressor ON gain and a compressor OFF gain by using a time constant  $\tau_r$  of the thermal properties of the house 1 and a proportionality coefficient  $K_r$  of the thermal properties of the house 1 that have been obtained by the system identification unit 433 (S21). Then, a gain selection signal is acquired from the heating control unit 431 (S22), and it is determined, based on the acquired gain selection signal, whether the

compressor ON gain is to be selected (S23).

**[0044]** Here, when the compressor ON gain is selected (S23: YES), the compressor ON gain is output to the heating control unit 431. Then, the heating control unit 431 performs a heating control operation by using the compressor ON gain and updates a hot-water discharge temperature command (S24). Subsequently, the updated hot-water discharge temperature command is output to the hot-water discharge temperature control unit 432 (S25). When the compressor ON gain is not selected (S23: NO), that is, when the compressor OFF gain is selected, the compressor OFF gain is output to the heating control unit 431. Then, the heating control unit 431 performs a heating control operation using the compressor OFF gain and updates a hot-water discharge temperature command (S26). In this case, since the compressor 31 is stopped, the hot-water discharge temperature command is not output to the hot-water discharge temperature control unit 432, and only the hot-water discharge temperature command within the heating control unit 431 is updated. Then, a gain selection signal is output from the heating control unit 431 to the control gain determination unit 434 in accordance with room temperature information, for example, and thus the processes from step S22 to step S26 are repeated.

**[0045]** Next, heat supply command generation performed by the hot-water discharge temperature control unit 432 will be described. The hot-water discharge temperature control unit 432 performs PI control to cause the hot-water discharge temperature command from the heating control unit 431 to agree with hot-water discharge temperature information from the hot-water discharge temperature sensor 21, and generates a heat supply command to the heat source unit 3. An expression of the PI control is similar to expression (10). A control gain of the hot-water discharge temperature control unit 432 is calculated through system identification by using a state variable  $x$  and a manipulated variable  $u$  of expression (5) as hot-water discharge temperature information and a heat supply command, respectively.

**[0046]** FIG. 9 illustrates an example of a simulation result in the hot water heating system 100 according to Embodiment 1. FIG. 9(a) illustrates how a hot-water discharge temperature command changes, FIG. 9(b) illustrates a gain selection signal, and FIG. 9(c) illustrates how a room temperature changes. With respect to simulation conditions, a setting temperature while an occupant is at home (16 hours) is 22 degrees C, and a setting temperature while the occupant is out (8 hours) is 20 degrees C. Furthermore, a time constant  $\tau_r$  of the thermal properties of the house 1 is 20000 seconds (about 5.6 hours), a proportionality coefficient  $K_r$  of the thermal properties of the house 1 is 0.6, and a time constant  $\tau_{c\_ON}$  while the compressor is ON is 3600 seconds. In FIG. 9(a), a solid line represents a hot-water discharge temperature command in the hot water heating system 100 according to Embodiment 1, and a dashed line represents a hot-water discharge temperature command in the related art. In FIG. 9(c), a solid line represents a room temperature in the case where the hot water heating system 100 according to Embodiment 1 is used, a dashed line represents a room temperature in the case where a hot water heating system in the related art is used, and a dashed-dotted line represents a setting temperature in each hot water heating system.

**[0047]** As illustrated in Fig. 9(a), in Embodiment 1, when a setting temperature is changed to 20 degrees C while the occupant is out, a gain selection signal is OFF (compressor OFF), and a control gain in the heating control unit 431 is changed to a compressor OFF gain. Thus, a time constant in the heating control unit 431 is the time constant  $\tau_r$  of the thermal properties of the house 1, and a value of a hot-water discharge temperature command when the setting temperature is raised from 20 degrees C to 22 degrees C is a value (about 33 degrees C) reflecting room temperature response of the setting temperature of 20 degrees C. As a result, room temperature response to the setting temperature of 22 degrees C behaves according to design response. On the other hand, in the related art, as a hot-water discharge temperature command value in the case where the compressor 31 is stopped, a predetermined temperature (25 degrees C) set in advance is used, and room temperature response is therefore slower than design response. Thus, in Embodiment 1, in a so-called well-insulated/highly-airtight house in which a time constant of the thermal properties of the house 1 is long relative to a set time period from a command to reduce a setting temperature to a command to raise the setting temperature, the effect of improving the capability of following a setting temperature, in particular, is obtained.

**[0048]** As described above, according to Embodiment 1, when a hot-water discharge temperature command is updated by using a compressor OFF gain even when the compressor 31 is stopped, control can be started by using an appropriate hot-water discharge temperature command in resuming the operation of the compressor 31. A hot-water discharge temperature at the time of resumption of the operation of the compressor 31 is continuous from a hot-water discharge temperature before the stopping of the compressor 31, and a state before the stopping of the compressor 31 can thus be continued, thereby making it possible to obtain energy conservation effects without reducing room temperature comfort. The system identification unit 433 calculates thermal properties of the actual house 1, and thus a room temperature can be comfortably controlled even in the case where indoor units 5 of, for example, a floor heating appliance, a radiator, and a fan coil unit that are different in hot water temperature zone used, are combined with any of houses 1 built of wood, concrete, and, brick, for example, having different thermal properties of the house 1.

**[0049]** Furthermore, the system identification unit 433 calculates a proportionality coefficient  $K_r$  and a time constant  $\tau_r$  of the thermal properties of the house 1, the control gain determination unit 434 calculates a compressor OFF gain by using the time constant  $\tau_r$  of the thermal properties of the house 1 as a design time constant in the heating control unit 431, and a hot-water discharge temperature command thus decreases in accordance with spontaneous heat radiation

characteristics of the house 1. With this configuration, a hot-water discharge temperature at the time of resumption of the operation of the compressor 31 reflects room temperature change conditions and it is possible to improve room temperature controllability.

[0050] Furthermore, the system identification unit 433 calculates the thermal properties of the house 1 by using a hot-water discharge temperature command generated using a setting temperature, room temperature information, and an initial control gain by the heating control unit 431 as an input variable and by using room temperature information of the house 1 as an output variable, and the thermal properties of the house 1 reflecting a delay in a hot-water discharge temperature control system can thus be calculated, thereby increasing the accuracy of system identification. As a result, the comfort of heating control is increased, and a room temperature overshoot is less likely to occur, thereby enabling an improvement in energy conservation performance.

[0051] Furthermore, when the system identification unit 433 calculates the thermal properties of the house 1 based on multiple pieces of time series data that are different in sampling period, a period of time that elapses before the room temperature changes can be included in time series data, and, even if measurement resolution of the room temperature is rough, the roughness can be compensated for by time data. As a result, the accuracy of system identification can be increased.

[0052] Additionally, when the hot-water discharge temperature control unit 432 is provided, variations in heat supply from the heat source unit 3 are controlled by the hot-water discharge temperature control system, and an influence on a higher-level heating control system can be reduced.

## Embodiment 2

[0053] Next, Embodiment 2 of the present invention will be described. Although, in Embodiment 1 described above, system identification is performed by using a hot-water discharge temperature command from the heating control unit 431 and room temperature information from the room temperature sensor 2 as an input variable and an output variable, respectively, Embodiment 2 differs from Embodiment 1 in that a hot-water discharge temperature command from the heating control unit 431 and return temperature information from the return temperature sensor 22 are input variables. The other components of the hot water heating system 100 and each device are the same as those in Embodiment 1 and are denoted by the same reference numerals.

[0054] FIG. 10 illustrates a flow of heating control performed by the heating control unit 431, the hot-water discharge temperature control unit 432, the system identification unit 433, and the control gain determination unit 434 in Embodiment 2. As illustrated in FIG. 10, the system identification unit 433 calculates thermal properties of the house 1 from room temperature information acquired from the room temperature sensor 2 of the house 1, a hot-water discharge temperature command from the heating control unit 431, and return temperature information from the return temperature sensor 22, and outputs the thermal properties to the control gain determination unit 434. Specifically, the system identification unit 433 calculates a time constant  $\tau_r$  and a proportionality coefficient  $K_r$  of the thermal properties of the house 1 by using a difference between a hot-water discharge temperature command and a return temperature as a manipulated variable  $u$ .

[0055] The control gain determination unit 434 calculates a compressor ON gain and a compressor OFF gain in the heating control unit 431 based on the time constant  $\tau_r$  and the proportionality coefficient  $K_r$  of the thermal properties of the house 1 calculated by the system identification unit 433, and outputs a control gain to the heating control unit 431 in accordance with a gain selection signal. The heating control unit 431 generates a hot-water discharge temperature command from the control gain calculated by the control gain determination unit 434, a setting temperature, and room temperature information acquired from the room temperature sensor 2, and outputs the hot-water discharge temperature command to the hot-water discharge temperature control unit 432.

[0056] FIG. 11 is a block diagram of the heating control unit 431 in Embodiment 2. In Embodiment 2, an output of a PI control operation of expression (10) is a difference between a hot-water discharge temperature command and a return temperature command. To convert this into a hot-water discharge temperature command, as illustrated in FIG. 11, a value obtained by adding return temperature information from the return temperature sensor 22 to the output of the PI controller is defined as a hot-water discharge temperature command before the limiter.

[0057] As described above, according to Embodiment 2, the system identification unit 433 can calculate the thermal properties of the house 1 reflecting a delay in the hot-water discharge temperature control system and heat transfer conditions in the indoor heat exchanger 51 by using a hot-water discharge temperature command generated using a setting temperature, room temperature information, and an initial control gain by the heating control unit 431 and a return temperature as input variables and by using room temperature information of the house 1 as an output variable, thereby increasing the accuracy of system identification and improving the capability of following a room temperature in heating control. Thus, comfort is increased, and a room temperature overshoot is also less likely to occur because of an improvement in the capability of following a room temperature, thereby making it possible to achieve an improvement in energy conservation performance as well.

## Embodiment 3

**[0058]** Next, Embodiment 3 of the present invention will be described. Although, in Embodiments 1 and 2 described above, the thermal properties of the house 1 are regarded as a model of a single-input/single-output system as represented by expression (1), Embodiment 3 differs from Embodiments 1 and 2 in that the thermal properties of the house 1 are regarded as a model of a multi-input/single-output system. Furthermore, although, in Embodiments 1 and 2, a control gain in the PI controller of the heating control unit 431 is selected in accordance with an ON/OFF state of the compressor 31, Embodiment 3 differs from Embodiments 1 and 2 in that an ON/OFF state of the circulation pump 36 that circulates hot water through the indoor unit 5 is taken into consideration in addition to an ON/OFF state of the compressor 31. Note that components that are the same as those in Embodiment 1 are denoted by the same reference numerals as those in Embodiment 1.

**[0059]** FIG. 12 illustrates thermal network models in Embodiment 3. FIG. 12(a) illustrates a thermal network model to be controlled in Embodiment 3, FIG. 12(b) illustrates a thermal network model in the case where a heat quantity is supplied from the indoor unit 5, and FIG. 12(c) illustrates a thermal network model in the case where no heat quantity is supplied from the indoor unit 5. In Embodiments 1 and 2 described above, the thermal properties of the house 1 are regarded as a single-input/single-output system model of expression (1), and system identification is performed while the indoor unit 5 is supplying heat. Then, control gains in PI control performed by the heating control unit 431 are calculated using results obtained through the system identification by expressions (11) to (14). On the other hand, in Embodiment 3, the thermal network model of FIG. 12(a) is to be controlled, and control gains (air-conditioning ON gain and air-conditioning OFF gain) in PI control are designed.

**[0060]** In FIGS. 12(a) to 12(c),  $T_o$  denotes an outdoor air temperature,  $T_z$  denotes a room temperature,  $Q_{idu}$  denotes a heat quantity supplied from the indoor unit 5,  $R_{all}$  denotes thermal resistance [K/kW] of the house 1, and  $C_{all}$  denotes heat capacity [kJ/K] of the house 1. By virtue of the application of the principle of superposition, when a transfer function from indoor unit supply heat to a room temperature and a transfer function from an outdoor air temperature to a room temperature are added up by using the thermal network model in the case where a heat quantity is supplied from the indoor unit 5, which is illustrated in FIG. 12(b), and the thermal network model in the case where no heat quantity is supplied, which is illustrated in FIG. 12(c), the thermal network model of FIG. 12(a) is represented by the following expression (15).

[Math. 15]

$$T_z(s) = \frac{R_{all}}{R_{all}C_{all}s + 1} Q_{idu} + \frac{1}{R_{all}C_{all}s + 1} T_o \quad \cdot \cdot \cdot (15)$$

**[0061]** FIG. 13 is a schematic configuration diagram of a hot water circulation circuit in Embodiment 3. The hot water circulation circuit according to Embodiment 3 differs from the hot water circulation circuit according to Embodiment 1 illustrated in FIG. 2 in that an outdoor air temperature sensor 500 is provided. The other configuration of the hot water circulation circuit is the same as that in Embodiment 1. In FIG. 13, although the outdoor air temperature sensor 500 is provided in the heat source unit 3, the configuration is not limited to this and may be any configuration in which outdoor air temperature information is provided to the controller 4. For example, the outdoor air temperature sensor 500 may be provided separately like the room temperature sensor 2 and may be connected to the input-output unit 41 of the controller 4.

**[0062]** FIG. 14 is a functional block diagram of the controller 4 in Embodiment 3. The controller 4 according to Embodiment 3 differs from the controller 4 according to Embodiment 1 illustrated in FIG. 3 in that outdoor air temperature information is stored in the storage unit 42. The other configuration of the controller 4 is the same as that in Embodiment 1. Outside air temperature information is stored in the storage unit 42 from the heat source unit 3 through the input-output unit 41 of the controller 4 and is used in processes performed by the control unit 43. Outside air temperature information is not only acquired from the outdoor air temperature sensor 500, but may also be acquired from weather forecast data by converting it into a form that the controller 4 can read.

**[0063]** FIG. 15 illustrates a flow of heating control performed by the heating control unit 431, the hot-water discharge temperature control unit 432, the system identification unit 433, and the control gain determination unit 434 in Embodiment 3. The flow of heating control in Embodiment 3 differs from the flow of heating control in Embodiment 1 illustrated in FIG. 4 in that outdoor air temperature information is supplied from the heat source unit 3 to the system identification unit 433. The other configuration in the flow of heating control is the same as that in Embodiment 1. Outside air temperature information is used in system identification in the system identification unit 433.

**[0064]** FIG. 16 illustrates an example of how to determine on a gain selection signal in Embodiment 3. Although, in Embodiments 1 and 2, the heating control unit 431 generates a gain selection signal based on an ON/OFF state of the compressor 31, in Embodiment 3, an ON/OFF state of the circulation pump 36 that circulates hot water through the indoor unit 5 is further taken into consideration. Specifically, as illustrated in FIG. 16, based on an ON/OFF state of the

circulation pump 36, that is, based on whether heat has been supplied by the indoor unit 5, an air-conditioning ON gain or an air-conditioning OFF gain is selected. In the example of FIG. 16, when the circulation pump 36 is OFF even if the compressor 31 is ON, the air-conditioning OFF gain is selected. When the circulation pump 36 is ON even if the compressor 31 is OFF, the air-conditioning ON gain is selected. How to determine on a gain selection signal is not limited to the example of FIG. 16. For example, when the compressor 31 is ON and the circulation pump 36 is OFF, such a situation can only happen in a short time in most cases, and the air-conditioning ON gain may thus be selected. The case where the indoor unit 5 supplies heat with the circulation pump 36 being in an ON state and the case where the indoor unit 5 does not supply heat (a state of only spontaneous heat radiation) with the circulation pump 36 being in an OFF state are hereinafter referred to as "air-conditioning ON" and "air-conditioning OFF", respectively. The air-conditioning ON gain corresponds to "first gain" of the present invention, and the air-conditioning OFF gain corresponds to "second gain" of the present invention.

**[0065]** Next, the calculation of thermal properties of the house 1 performed by the system identification unit 433 according to Embodiment 3 will be described. In Embodiment 3, the model of expression (15) is used for the model of system identification, and system identification during air-conditioning ON and system identification during air-conditioning OFF are performed separately. When expression (15) is represented by using the proportionality coefficient  $K_r$  of the thermal properties of the house 1 and the time constant  $\tau_r$  of the thermal properties of the house 1 of expression (1), the following expression (16) is given.

[Math. 16]

$$y = x = \frac{K_r}{\tau_r s + 1} Q_{idu} + \frac{1}{\tau_r s + 1} T_o \quad \cdot \cdot \cdot (16)$$

**[0066]** During air-conditioning ON, system identification is performed during the daytime in cloudy days or during the nighttime, thereby enabling system identification to be performed while inhibiting the influence of changes in outdoor air temperature. A system identification process during air-conditioning ON is the same as that described in Embodiment 1.

**[0067]** During air-conditioning OFF,  $Q_{idu}$  of a first term on the right-hand side of expression (16) is 0, and a transfer function (a second term on the right-hand side) from an outdoor air temperature to a room temperature can thus be obtained. At this time, assume that an initial value of a state variable of the transfer function of the second term on the right-hand side is a room temperature immediately before the air-conditioning OFF. The initial value differs according to discretization methods and is proportional to a room temperature.

**[0068]** FIG. 17 is a flowchart illustrating a flow of a system identification process (during air-conditioning OFF) in Embodiment 3. In this process, first, a state variable  $x$  and a manipulated variable  $u$  at the start of system identification are acquired as initial data and stored in the storage unit 42 (S31). Then, the heating control unit 431 performs heating control by using an initial control gain stored in the storage unit 42 (S32). Here, in the case of air-conditioning OFF, in the heating control, a hot-water discharge temperature command within the heating control unit 431 is updated, and a hot-water discharge temperature command to the hot-water discharge temperature control unit 432 is not updated.

**[0069]** Next, it is determined whether pieces of data at four points have been acquired (S33). The data here refers to a state variable  $x_n$ , an integrated value  $u_{n\_sum}$  of a manipulated variable  $u$ , and a change sampling period  $T_{sn}$  that are used for calculating the thermal properties of the house 1. Then, when pieces of data at four points have not been acquired (S33: NO), it is determined whether a room temperature has decreased by 0.5 degrees C or more from a previously stored room temperature (S34). This is because the room temperature decreases during air-conditioning OFF. Then, when the room temperature has not decreased by 0.5 degrees C or more from the previously stored room temperature (S34: NO), a sample count  $cnt$  is incremented by one (S35), and a summation of manipulated variables  $u$  is performed (S36). Then, the process flow returns to step S32, and the processes of step S32 and the subsequent steps are repeated.

**[0070]** On the other hand, when the room temperature has decreased by 0.5 degrees C or more from the previously stored room temperature (S34: YES), a state variable  $x_n$ , an integrated value  $u_{n\_sum}$  of the manipulated variable  $u$ , and a change sampling period  $T_{sn}$  are stored (S37). The state variable  $x_n$  is a room temperature detected by the room temperature sensor 2, and the integrated value  $u_{n\_sum}$  of the manipulated variable  $u$  corresponds to an outdoor air temperature detected by the outdoor air temperature sensor 500. The change sampling period  $T_{sn}$  is a value obtained by using expression (8) described above. Subsequently, the sample count  $cnt$  is reset (S38), the process flow returns to step S32, and the processes of step S32 and the subsequent steps are repeated. Then, when pieces of data at four points that are different from the initial data at the start of system identification have been acquired (S33: YES), a time constant  $\tau_r$  and a proportionality coefficient  $K_r$  of the thermal properties of the house 1 are calculated based on the acquired data (S39).

**[0071]** Then, an air-conditioning OFF gain that is a control gain of the PI controller during air-conditioning OFF is obtained by using expressions (17) and (18). A design time constant  $\tau_{c\_OFF}$  is a time constant  $\tau_r$  of the thermal properties

of the house 1 as in Embodiments 1 and 2.

[Math. 17]

$$K_{p\_OFF} = \frac{\tau_r}{\tau_{c\_OFF}} = 1 \quad \cdot \cdot \cdot (17)$$

[Math. 18]

$$K_{i\_OFF} = \frac{1}{\tau_{c\_OFF}} = \frac{1}{\tau_r} \quad \cdot \cdot \cdot (18)$$

**[0072]** FIG. 18 is a flowchart illustrating a flow of a heating control process in Embodiment 3. In this process, first, the control gain determination unit 434 calculates an air-conditioning ON gain and an air-conditioning OFF gain during air-conditioning ON and during air-conditioning OFF separately by using a time constant  $\tau_r$  of the thermal properties of the house 1 and a proportionality coefficient  $K_r$  of the thermal properties of the house 1 that have been obtained by the system identification unit 433 (S41). Then, a gain selection signal is acquired from the heating control unit 431 (S42), and it is determined, based on the acquired gain selection signal, whether the air-conditioning ON gain is to be selected (S43). The heating control unit 431 generates the gain selection signal with consideration given not only to an ON/OFF state of the compressor 31 but also to an ON/OFF state of the circulation pump 36.

**[0073]** Here, when the air-conditioning ON gain is selected (S43: YES), the air-conditioning ON gain is output to the heating control unit 431. Then, the heating control unit 431 performs a heating control operation by using the air-conditioning ON gain and updates a hot-water discharge temperature command (S44). Subsequently, the updated hot-water discharge temperature command is output to the hot-water discharge temperature control unit 432 (S45). When the air-conditioning ON gain is not selected (S43: NO), that is, when the air-conditioning OFF gain is selected, the air-conditioning OFF gain is output to the heating control unit 431. Then, the heating control unit 431 performs a heating control operation using the air-conditioning OFF gain and updates a hot-water discharge temperature command (S46). In this case, since air-conditioning is OFF, the hot-water discharge temperature command is not output to the hot-water discharge temperature control unit 432, and only the hot-water discharge temperature command within the heating control unit 431 is updated. Then, a gain selection signal is output from the heating control unit 431 to the control gain determination unit 434 in accordance with room temperature information, for example, and thus the processes from step S42 to step S46 are repeated.

**[0074]** As described above, according to Embodiment 3, in addition to operating conditions on a heat source side flow passage 30 side of the heat source unit 3, operating conditions on a use side flow passage 50 side are reflected, and a gain selection can thus be made with increased accuracy. When system identification is performed during air-conditioning ON and during air-conditioning OFF separately by using the model represented by expression (16) in which the influence of an outdoor air temperature has been taken into consideration, a control gain design of the PI controller is calculated under conditions closer to an actual use environment. Thus, a hot-water discharge temperature command at the time of resumption of air-conditioning ON is appropriately set, and room temperature controllability is improved and becomes comfortable.

**[0075]** Furthermore, FIG. 19 illustrates a flow of heating control performed by the heating control unit 431, the hot-water discharge temperature control unit 432, the system identification unit 433, and the control gain determination unit 434 in the case where return temperature information is used as in Embodiment 2 in Embodiment 3. In Embodiment 3, outdoor air temperature information is added to Embodiment 2, and outdoor air temperature information is used in the system identification unit 433 as in FIG. 15.

#### Embodiment 4

**[0076]** Next, Embodiment 4 of the present invention will be described. Embodiment 4 differs from Embodiment 3 in that the thermal properties of the house 1 during air-conditioning ON and the thermal properties of the house 1 during air-conditioning OFF are different in model. The other components of the hot water heating system 100 and each device are the same as those in Embodiment 3 and are denoted by the same reference numerals.

**[0077]** The calculation of thermal properties of the house 1 performed by the system identification unit 433 according to Embodiment 4 will be described. In Embodiment 4, expression (19) is used as the model of system identification, and system identification during air-conditioning ON and system identification during air-conditioning OFF are performed separately as in Embodiment 3. In Embodiment 4, assuming that the system time constant for air-conditioning ON is different from the system time constant for the air-conditioning, a model is used in which the case where a room tem-

perature does not converge to an outdoor air temperature during air-conditioning OFF has been taken into consideration. Reasons why a room temperature does not converge to an outdoor air temperature during air-conditioning OFF are that there is heat of home appliances and lighting in the house 1, for example, and that there is the influence of solar radiation. In some cases, furniture, walls, a floor, and a ceiling, for example, store heat because of air-conditioning or solar radiation, for example, and exchange heat with air in a room when a room temperature starts to decrease after air-conditioning OFF. In Embodiment 4, to take these into consideration with a low-priced microcomputer, in expression (19), heat except heat supplied by air-conditioning is assumed to be proportional to an outdoor air temperature, and expression (19) serves as a model for designing an air-conditioning OFF gain and an air-conditioning ON gain of the PI controller.

[Math. 19]

$$y = x = \frac{K_r}{\tau_r s + 1} Q_{idu} + \frac{K_{r\_OFF}}{\tau_{r\_OFF} s + 1} T_o \quad \cdot \cdot \cdot (19)$$

**[0078]** In expression (19),  $K_{r\_OFF}$  is a proportionality coefficient of the thermal properties of the house 1 during air-conditioning OFF, and  $\tau_{r\_OFF}$  is a time constant of the thermal properties of the house 1 during air-conditioning OFF. In the case where system identification is performed by using the model of expression (19), a PI control gain during air-conditioning ON is obtained by using expressions (11) and (12) in Embodiment 1. A PI control gain during air-conditioning OFF is obtained using the proportionality coefficient  $K_{r\_OFF}$  and the time constant  $\tau_{r\_OFF}$  of the thermal properties of the house 1 during air-conditioning OFF, and a control design time constant  $\tau_{c\_OFF}$  during air-conditioning OFF by the following expressions (20) and (21).

[Math. 20]

$$K_{p\_OFF} = \frac{\tau_{r\_OFF}}{\tau_{c\_OFF} K_{r\_OFF}} = \frac{1}{K_{r\_OFF}} \quad \cdot \cdot \cdot (20)$$

[Math. 21]

$$K_{i\_OFF} = \frac{1}{\tau_{c\_OFF} K_{r\_OFF}} \quad \cdot \cdot \cdot (21)$$

**[0079]** As described above, according to Embodiment 4, even if a room temperature does not converge to an outdoor air temperature during air-conditioning OFF, a control gain designed for an actual environment can be set, a hot-water discharge temperature command at the time of resumption of air-conditioning ON is appropriately set, and room temperature controllability is improved and becomes comfortable.

**[0080]** Although Embodiments of the present invention have been described above, the present invention is not limited to the configurations in Embodiments described above, and various modifications or combinations can be made within the scope of the technical idea of the present invention. For example, the hot water heating system 100 not only has a heating function, but may also have another function, such as a cooling function. The hot water heating system 100 according to the present invention can be used not only for the house 1 but also for various constructions, such as buildings. Furthermore, a point of measurement of a room temperature is not limited to one point, and an entire building may be controlled by using an average value or a minimum value of a plurality of points of measurement as a point of measurement.

**[0081]** Furthermore, the system identification unit 433 may calculate thermal properties of the house 1 from room temperature information acquired from the room temperature sensor 2 of the house 1, a hot-water discharge temperature command from the heating control unit 431, return temperature information from the return temperature sensor 22, and a flow rate detected by the flow rate sensor 23. Specifically, a value equivalent to heat supply obtained by multiplying a return temperature difference obtained by subtracting return temperature information from hot-water discharge temperature information by a flow rate is defined as a manipulated variable  $u$  in expression (5) or expression (7), and a time constant  $\tau_r$  and a proportionality coefficient  $K_r$  of the thermal properties of the house 1 are calculated. In this case as well, the accuracy of system identification is increased, and the capability of following a room temperature in heating control is improved.

Reference Signs List**[0082]**

|    |     |                                              |
|----|-----|----------------------------------------------|
| 5  | 1   | house                                        |
|    | 2   | room temperature sensor                      |
|    | 3   | heat source unit                             |
|    | 4   | controller                                   |
|    | 5   | indoor unit                                  |
| 10 | 21  | hot-water discharge temperature sensor       |
|    | 22  | return temperature sensor                    |
|    | 23  | flow rate sensor                             |
|    | 30  | heat source side flow passage                |
|    | 31  | compressor                                   |
| 15 | 32  | outdoor heat exchanger                       |
|    | 33  | fan                                          |
|    | 34  | refrigerant flow rate regulation device      |
|    | 35  | refrigerant-water heat exchanger             |
|    | 36  | circulation pump                             |
| 20 | 37  | heat source unit control unit                |
|    | 41  | input-output unit                            |
|    | 42  | storage unit                                 |
|    | 43  | control unit                                 |
|    | 50  | use side flow passage                        |
| 25 | 51  | indoor heat exchanger                        |
|    | 100 | hot water heating system                     |
|    | 411 | digital input unit                           |
|    | 412 | AD conversion unit                           |
|    | 413 | serial communication unit                    |
| 30 | 414 | display unit                                 |
|    | 431 | heating control unit                         |
|    | 432 | hot-water discharge temperature control unit |
|    | 433 | system identification unit                   |
|    | 434 | control gain determination unit              |
| 35 | 435 | mode determination unit                      |
|    | 436 | output data processing unit                  |
|    | 500 | outdoor air temperature sensor               |

**40 Claims****1.** A hot water heating system comprising:

|    |                                                                                                                      |
|----|----------------------------------------------------------------------------------------------------------------------|
|    | a room temperature sensor configured to detect room temperature information of a building;                           |
| 45 | a heat source unit configured to generate hot water;                                                                 |
|    | an indoor unit configured to reject heat of hot water generated by the heat source unit and heat the building; and   |
|    | a controller configured to control the heat source unit,                                                             |
|    | wherein the heat source unit includes                                                                                |
|    | a compressor configured to compress refrigerant,                                                                     |
| 50 | a refrigerant-water heat exchanger configured to exchange heat between the refrigerant and water, and                |
|    | a circulation pump configured to circulate the hot water between the refrigerant-water heat exchanger and the        |
|    | indoor unit,                                                                                                         |
|    | wherein the controller includes                                                                                      |
|    | a control gain determination unit configured to calculate a first gain and a second gain based on thermal properties |
| 55 | of the building,                                                                                                     |
|    | a heating control unit configured to update a hot-water discharge temperature command corresponding to a             |
|    | target value of a temperature of water at an outlet of the refrigerant-water heat exchanger by using the first gain  |
|    | and the second gain, and                                                                                             |

a hot-water discharge temperature control unit configured to, in a case of air-conditioning ON in which the indoor unit supplies heat to the building, output a heat supply command to the heat source unit based on the hot-water discharge temperature command updated by the heating control unit,  
 wherein the first gain is designed so that the hot-water discharge temperature command that results in intended room temperature response in the case of air-conditioning ON is obtained,  
 wherein the second gain is designed so that the hot-water discharge temperature command reflecting a change in room temperature in a case of air-conditioning OFF in which the indoor unit does not supply heat to the building is obtained, and  
 wherein the heating control unit is configured to update, in the case of air-conditioning ON, the hot-water discharge temperature command by using a setting temperature for room temperature, the room temperature information, and the first gain, and update, in the case of air-conditioning OFF, the hot-water discharge temperature command by using the setting temperature, the room temperature information, and the second gain.

2. The hot water heating system of claim 1,  
 wherein the controller further includes a system identification unit configured to calculate the thermal properties of the building,  
 wherein the system identification unit calculates a proportionality coefficient and a time constant of the thermal properties of the building, and  
 wherein the control gain determination unit calculates the second gain by using the time constant of the thermal properties of the building as a design time constant in the heating control unit.
3. The hot water heating system of claim 2, wherein the control gain determination unit obtains a design time constant in the heating control unit from a dead time based on a total quantity and a flow rate of hot water generated by the heat source unit and calculates the first gain.
4. The hot water heating system of claim 2 or 3, further comprising an outdoor air temperature sensor configured to detect an outdoor air temperature,  
 wherein the system identification unit performs system identification in the case of air-conditioning ON and system identification in the case of air-conditioning OFF separately, calculates the thermal properties of the building by using at least the room temperature information in the system identification in the case of air-conditioning ON, and calculates the thermal properties of the building by using an outdoor air temperature detected by the outdoor air temperature sensor in the system identification in the case of air-conditioning OFF.
5. The hot water heating system of any one of claims 2 to 4, wherein the system identification unit is configured to calculate the thermal properties of the building by using a hot-water discharge temperature command generated by the heating control unit using the setting temperature for room temperature, the room temperature information, and a preset initial control gain as an input variable and by using the room temperature information as an output variable.
6. The hot water heating system of any one of claims 2 to 4,  
 wherein the heat source unit further includes a return temperature sensor configured to detect a return temperature of water returning to the refrigerant-water heat exchanger through the indoor unit, and  
 wherein the system identification unit is configured to calculate the thermal properties of the building by using a hot-water discharge temperature command generated by the heating control unit using the setting temperature for room temperature, the room temperature information, and a preset initial control gain and  
 the return temperature as input variables and  
 by using the room temperature information as an output variable.
7. The hot water heating system of any one of claims 2 to 6, wherein the system identification unit calculates the thermal properties of the building based on multiple pieces of time series data that are different in sampling period.
8. The hot water heating system of any one of claims 1 to 7, wherein the room temperature information includes a room temperature and an elapsed time.
9. The hot water heating system of any one of claims 1 to 8, wherein the heating control unit sets upper and lower limits for the hot-water discharge temperature command and has an anti-reset windup processing function.
10. A controller of a hot water heating system including a heat source unit configured to generate hot water, the controller comprising:

a control gain determination unit configured to calculate a first gain and a second gain based on thermal properties of a building to be heated;

a heating control unit configured to update a hot-water discharge temperature command corresponding to a target value of a temperature of water at an outlet of the refrigerant-water heat exchanger by using the first gain and the second gain; and

a hot-water discharge temperature control unit configured to, in a case of air-conditioning ON in which the indoor unit supplies heat to the building, output a heat supply command to the heat source unit based on the hot-water discharge temperature command updated by the heating control unit,

wherein the first gain is designed so that the hot-water discharge temperature command that results in intended room temperature response in the case of air-conditioning ON is obtained,

wherein the second gain is designed so that the hot-water discharge temperature command reflecting a change in room temperature in a case of air-conditioning OFF in which the indoor unit does not supply heat to the building is obtained, and

wherein the heating control unit is configured to update, in the case of air-conditioning ON, the hot-water discharge temperature command by using a setting temperature for room temperature, the room temperature information, and the first gain, and update, in the case of air-conditioning OFF, the hot-water discharge temperature command by using the setting temperature, the room temperature information, and the second gain.

11. A control method for a hot water heating system including a heat source unit configured to generate hot water, the control method comprising:

calculating a first gain and a second gain based on thermal properties of a building to be heated;

updating a hot-water discharge temperature command corresponding to a target value of a temperature of water at an outlet of the refrigerant-water heat exchanger by using the first gain and the second gain; and

in a case of air-conditioning ON in which the indoor unit supplies heat to the building, giving a heat supply command to the heat source unit based on the hot-water discharge temperature command updated in the updating,

wherein the first gain is designed so that the hot-water discharge temperature command that results in intended room temperature response in the case of air-conditioning ON is obtained,

wherein the second gain is designed so that the hot-water discharge temperature command reflecting a change in room temperature in a case of air-conditioning OFF in which the indoor unit does not supply heat to the building is obtained, and

wherein the updating the hot-water discharge temperature command includes updating, in the case of air-conditioning ON, the hot-water discharge temperature command by using a setting temperature for room temperature, the room temperature information, and the first gain, and updating, in the case of air-conditioning OFF, the hot-water discharge temperature command by using the setting temperature, the room temperature information, and the second gain.

FIG. 1

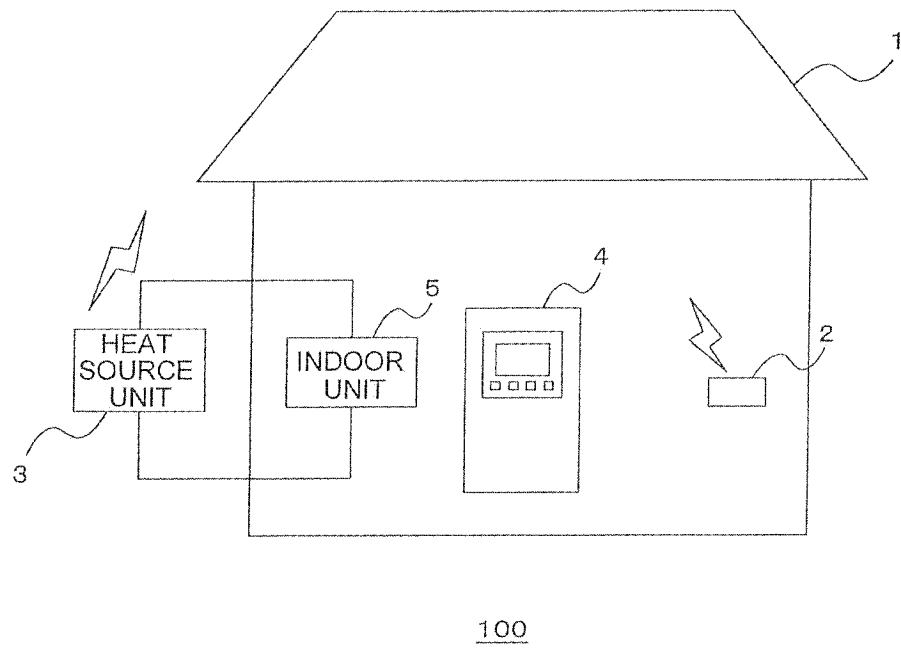


FIG. 2

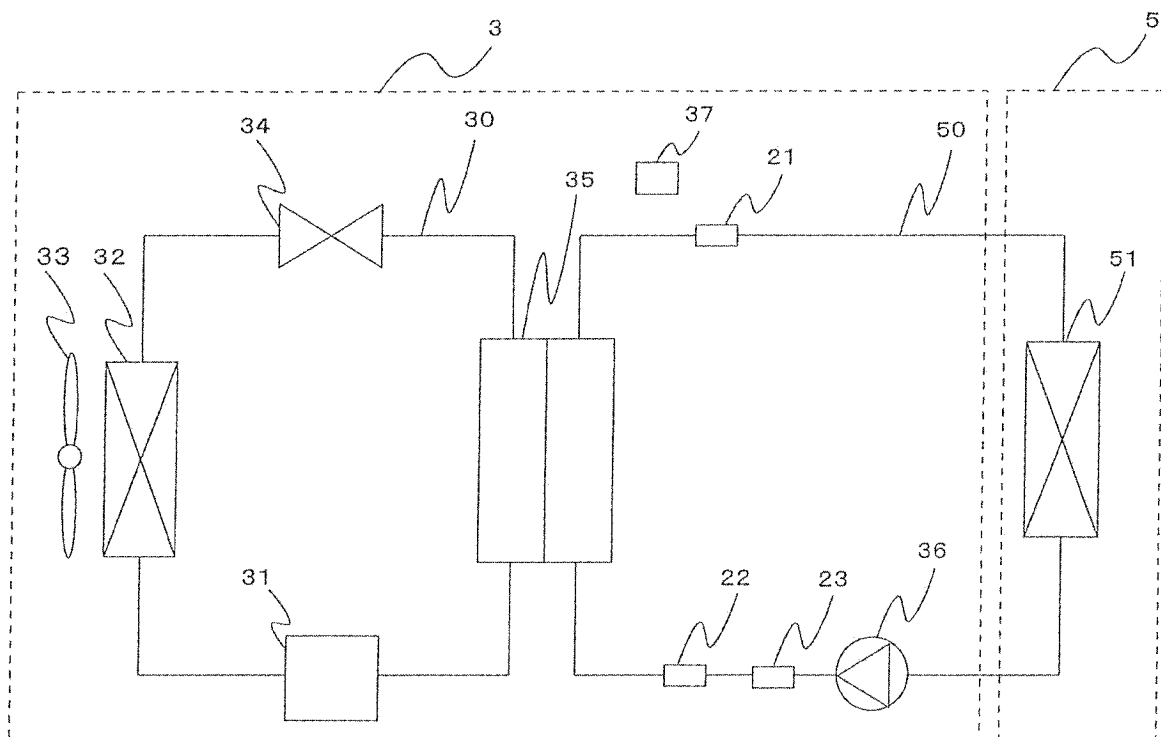


FIG. 3

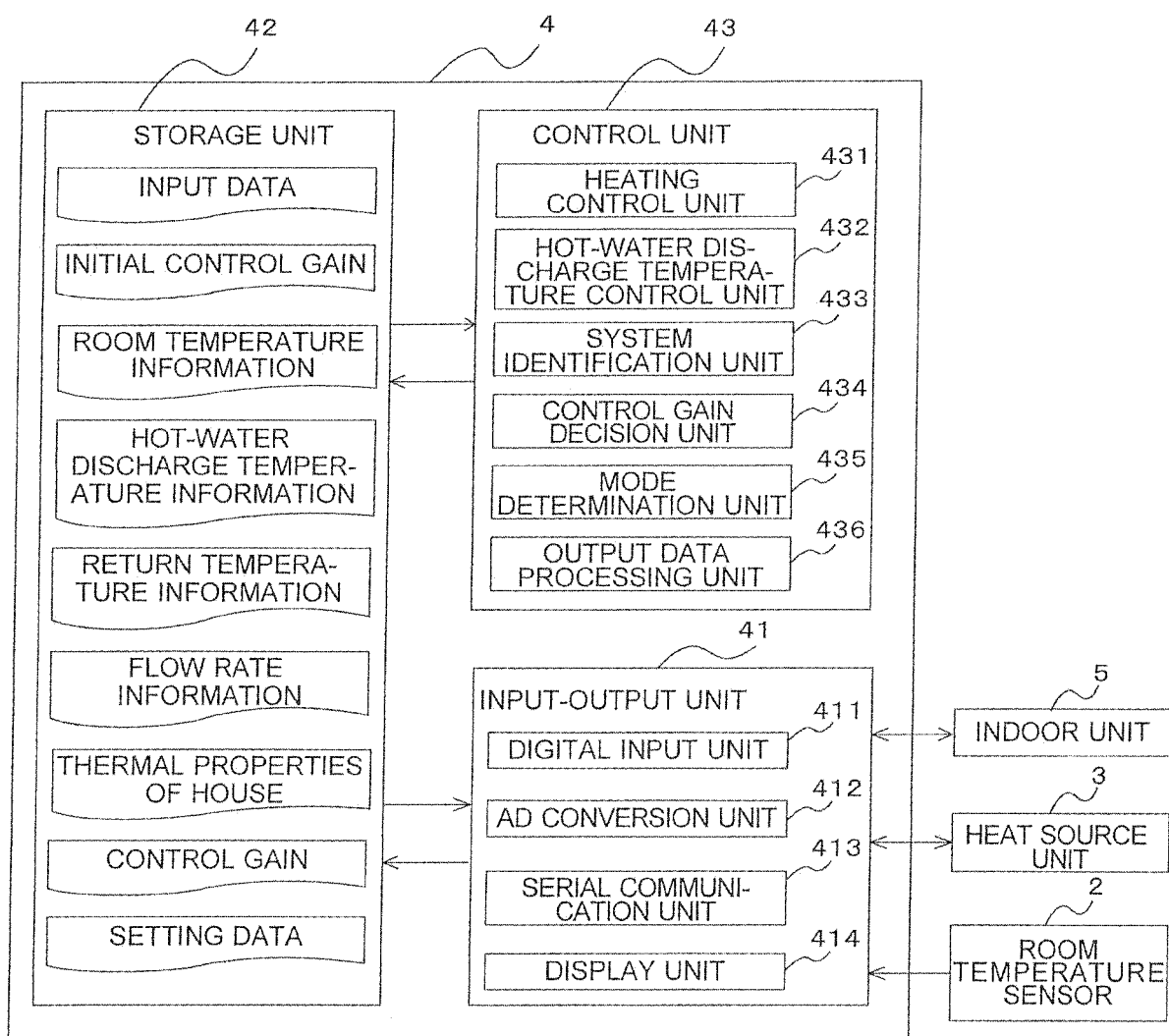


FIG. 4

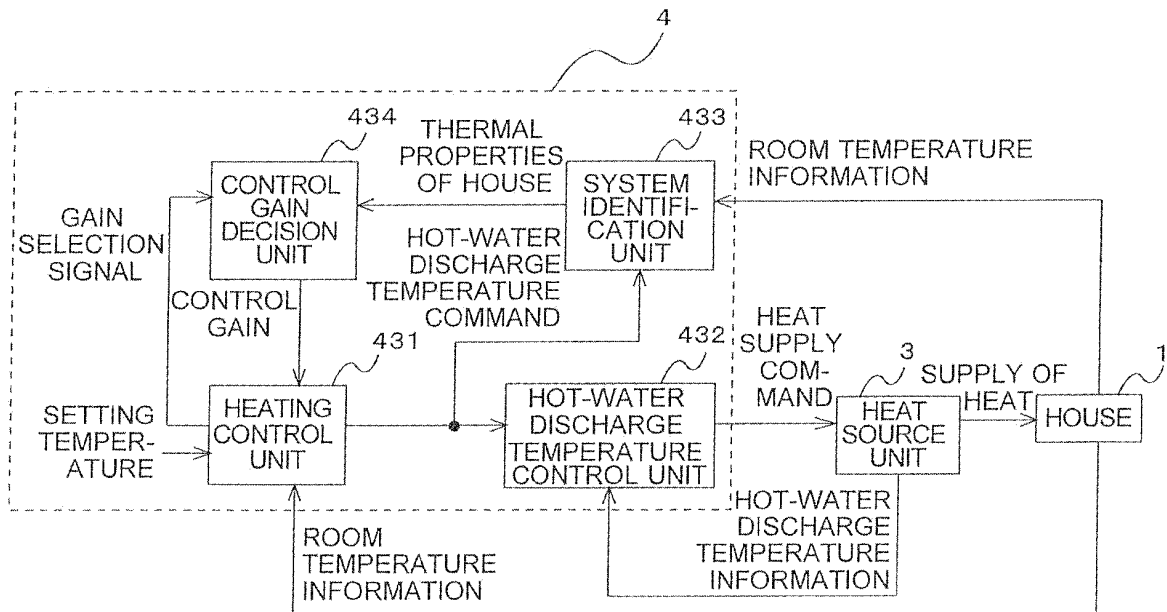


FIG. 5

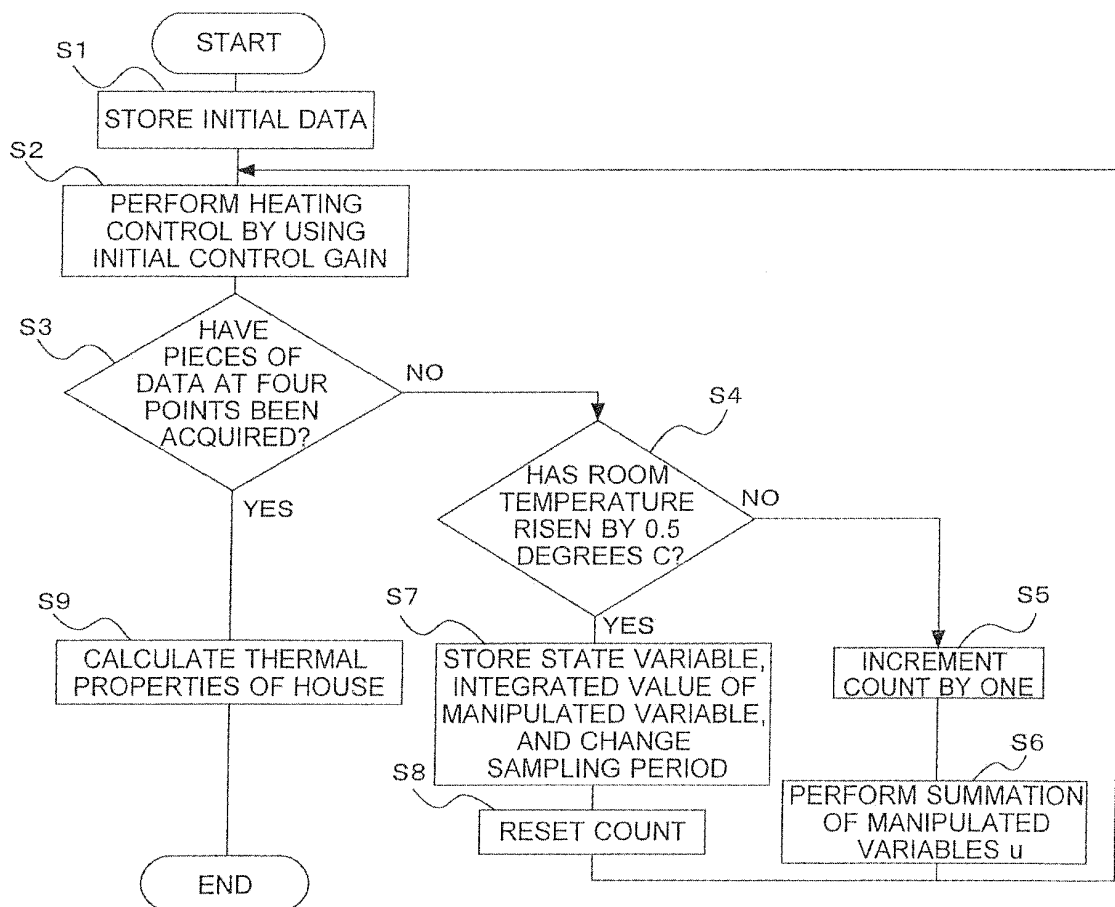


FIG. 6

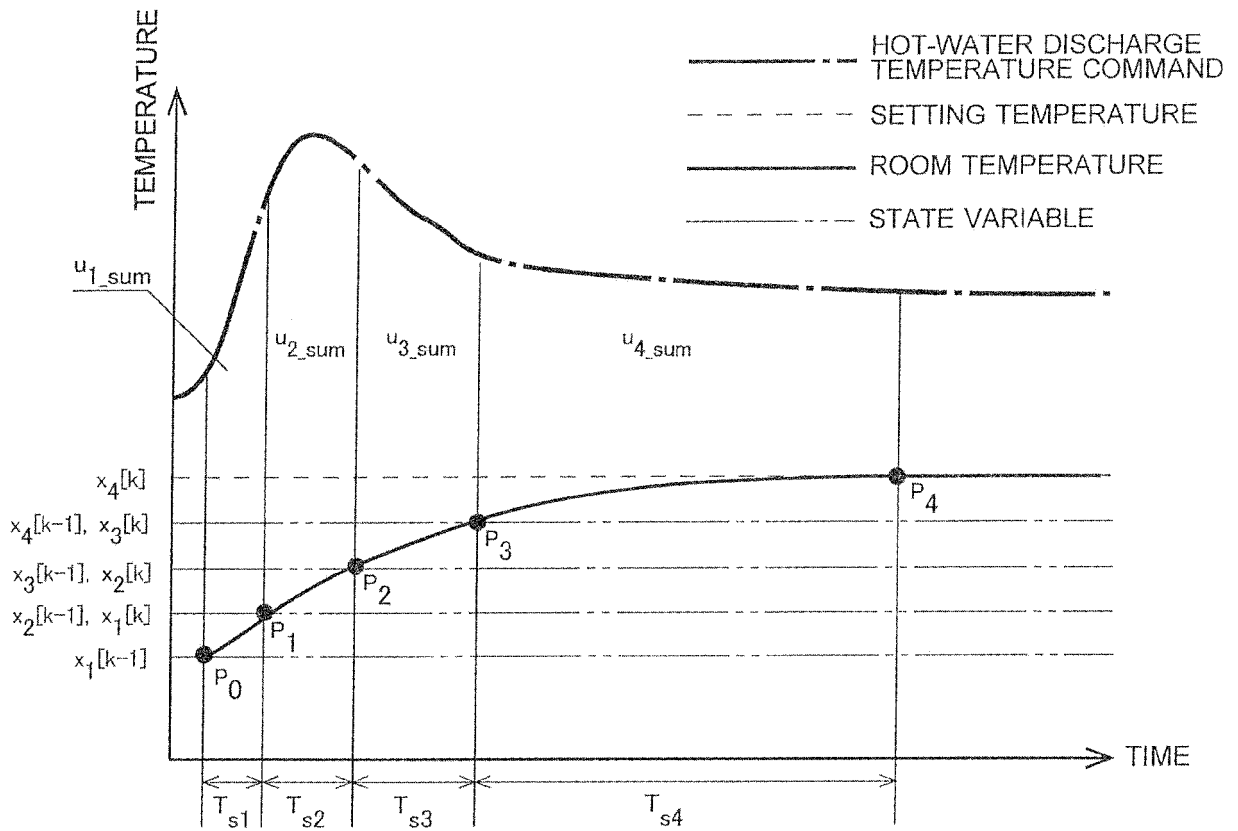


FIG. 7

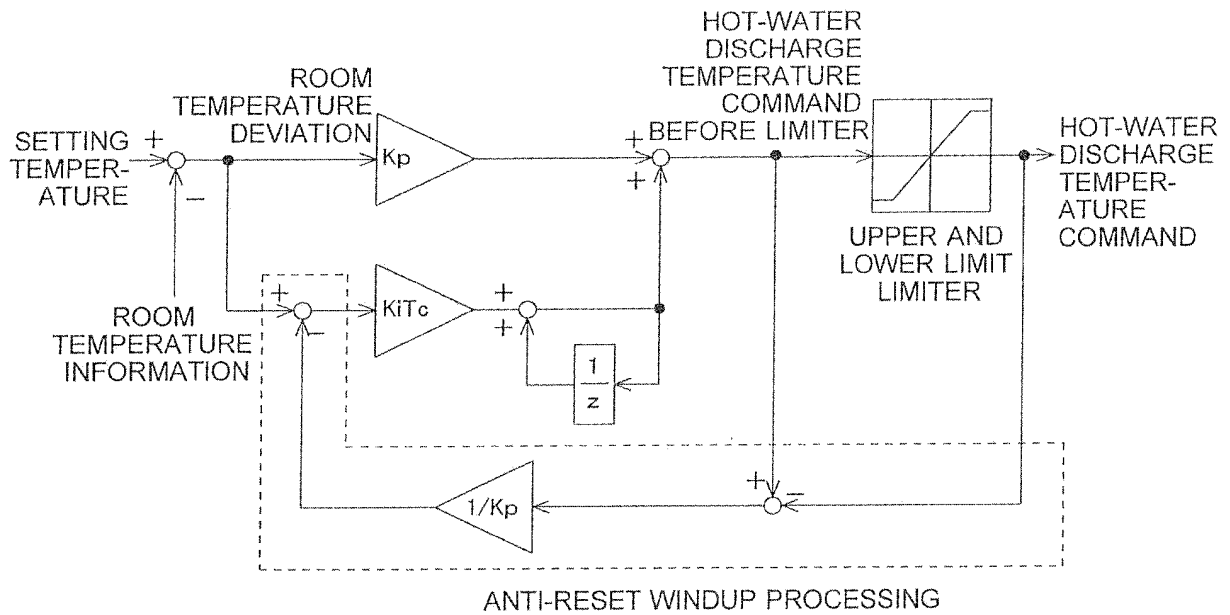


FIG. 8

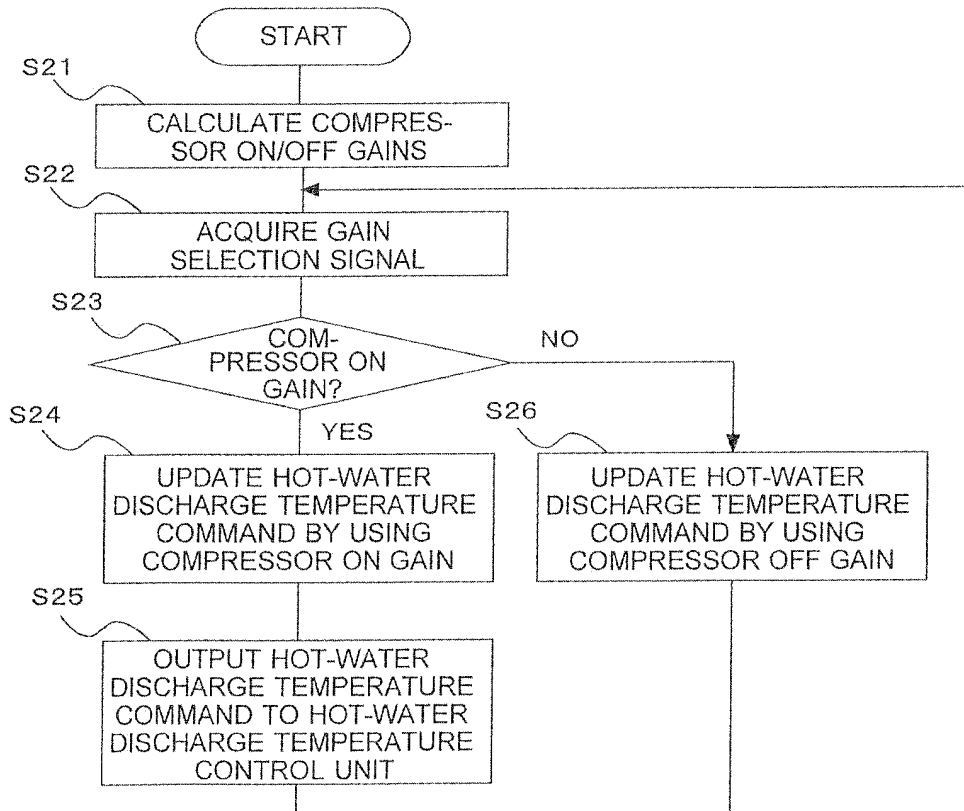


FIG. 9

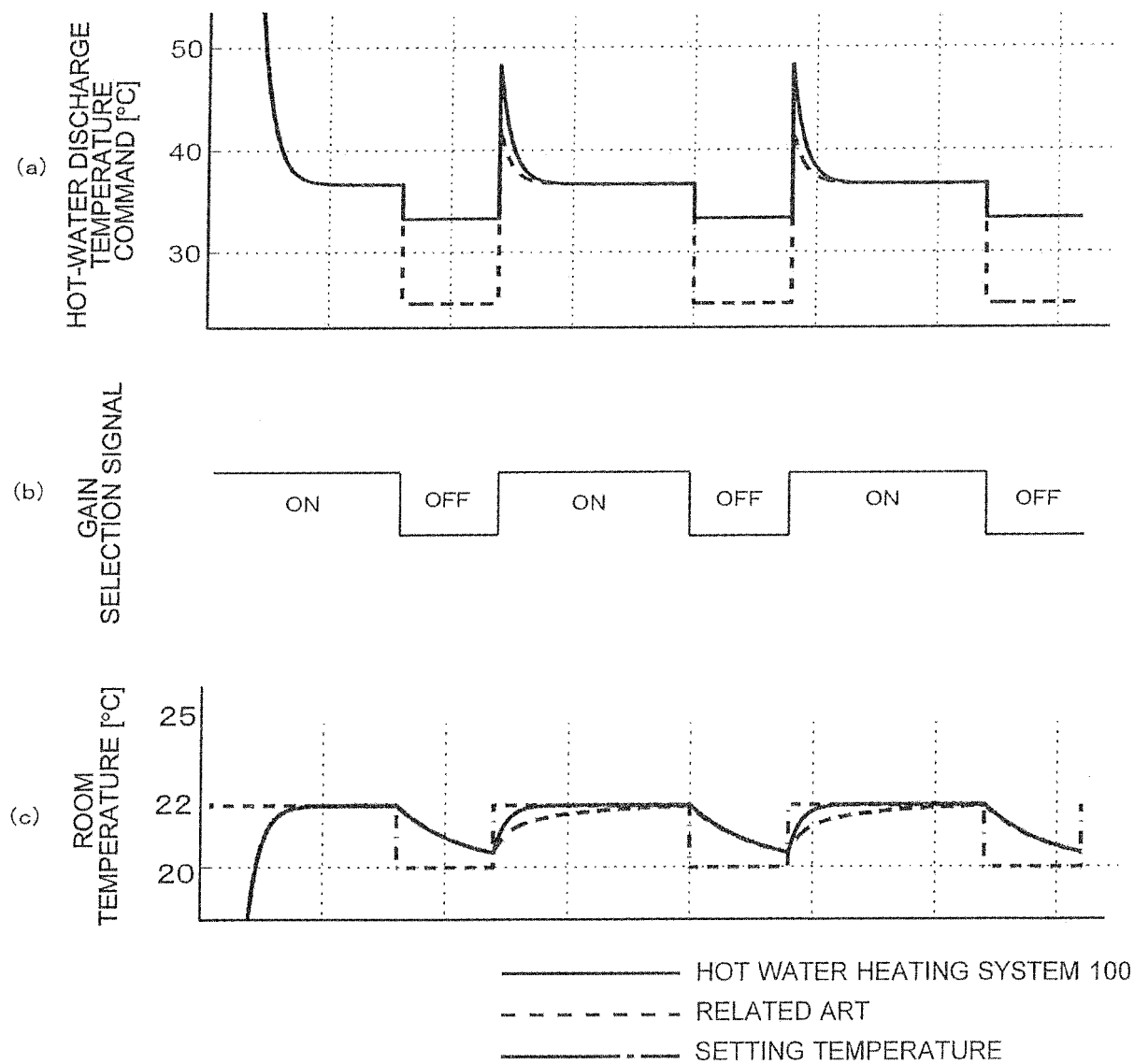


FIG. 10

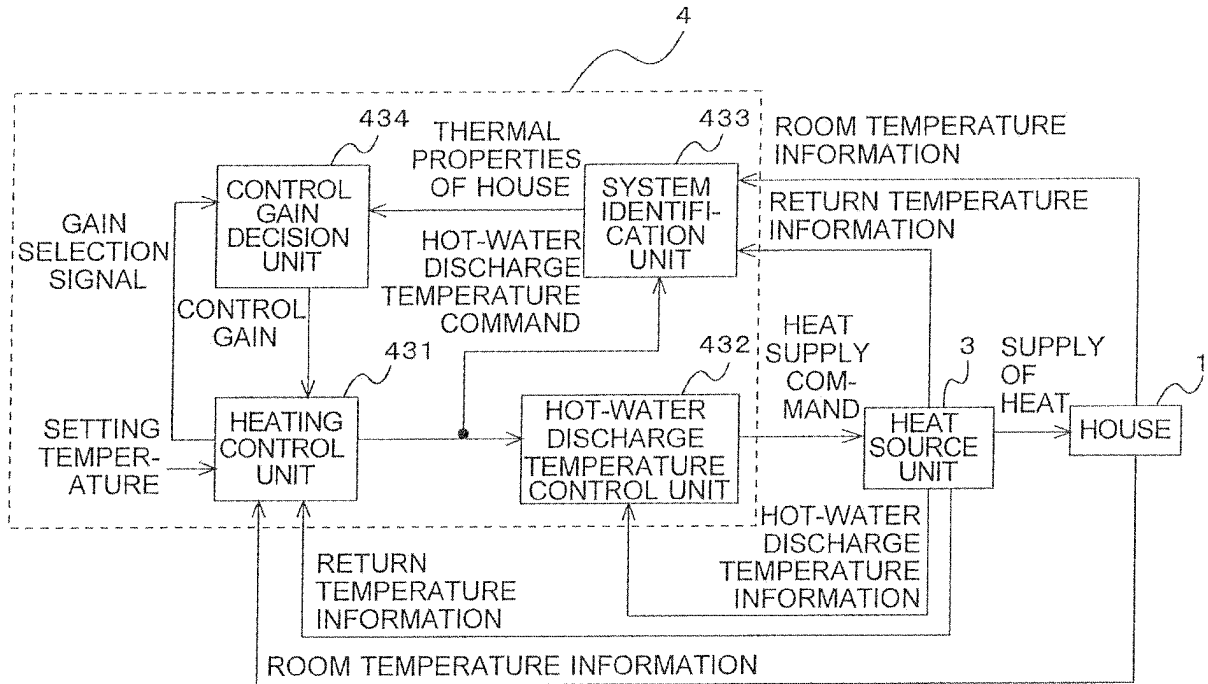


FIG. 11

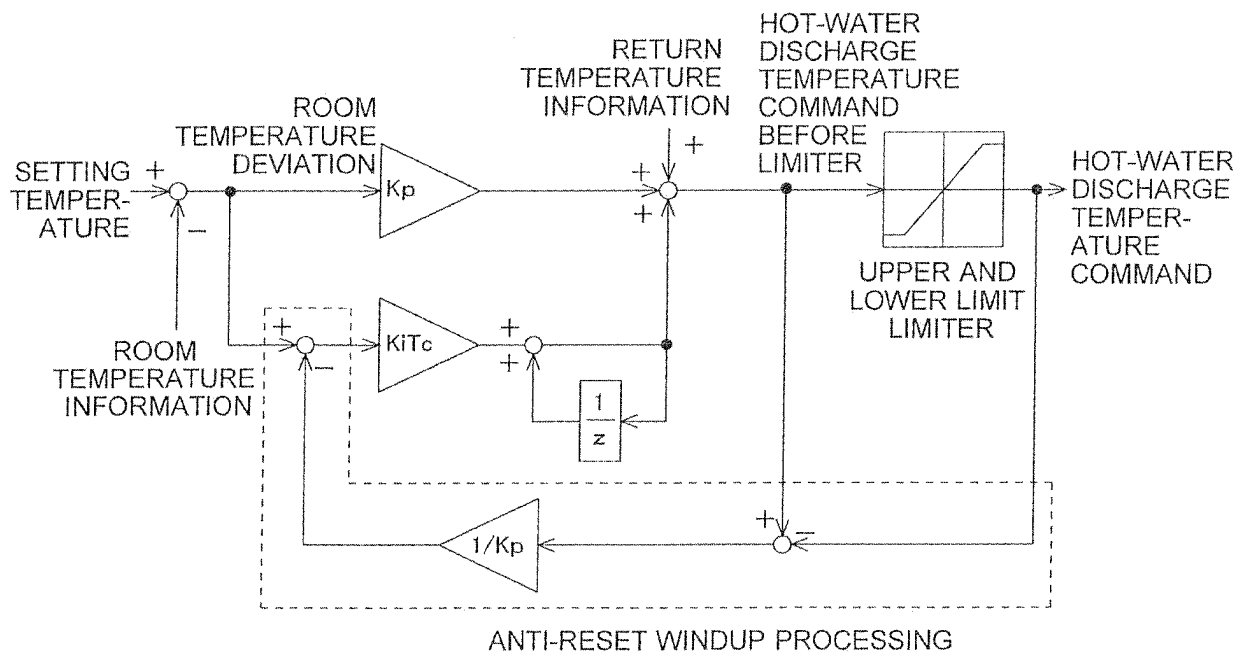


FIG. 12

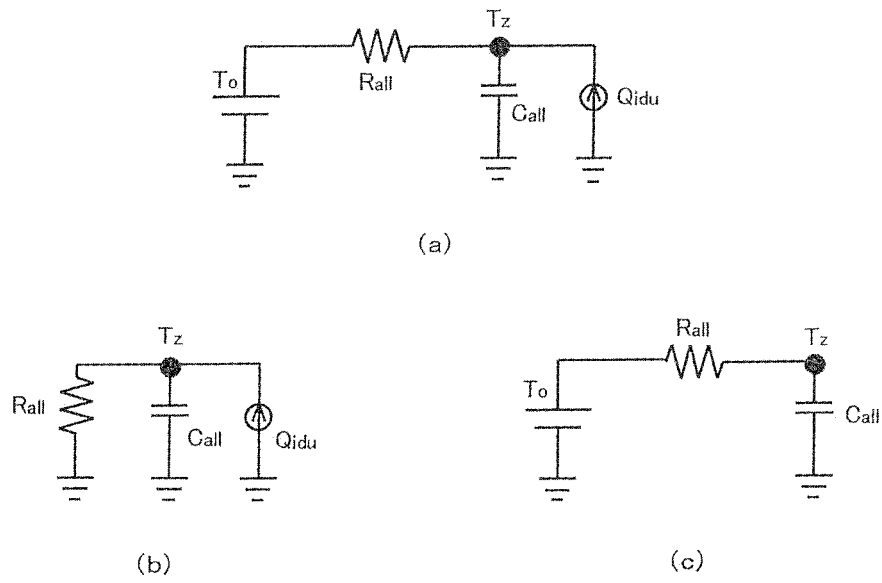


FIG. 13

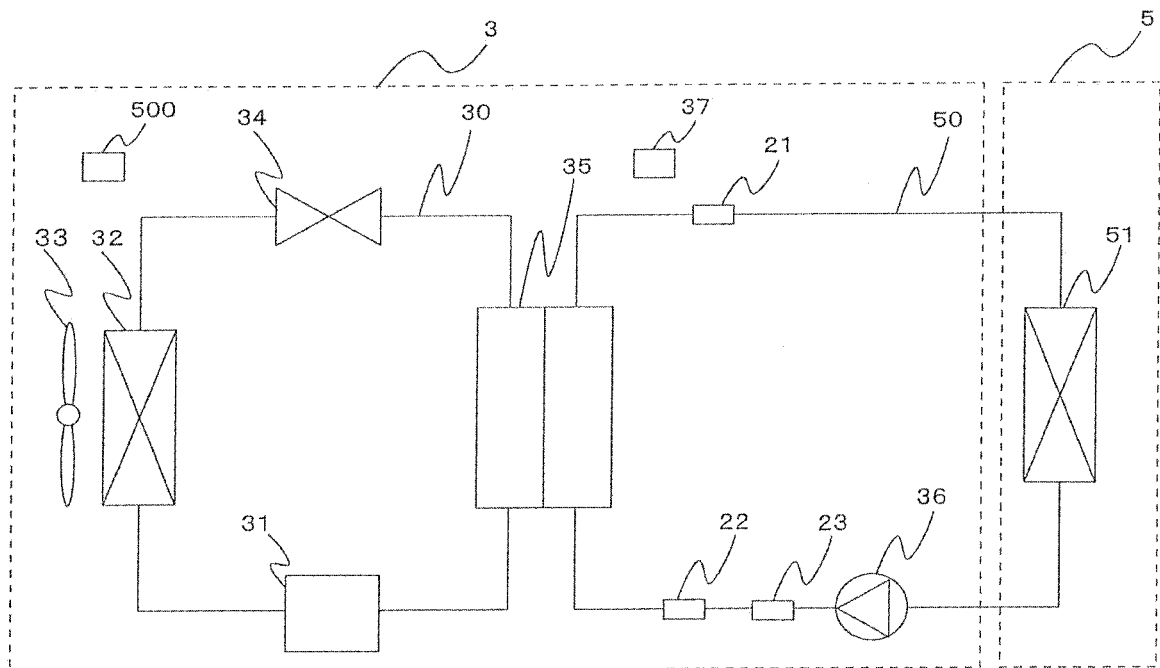


FIG. 14

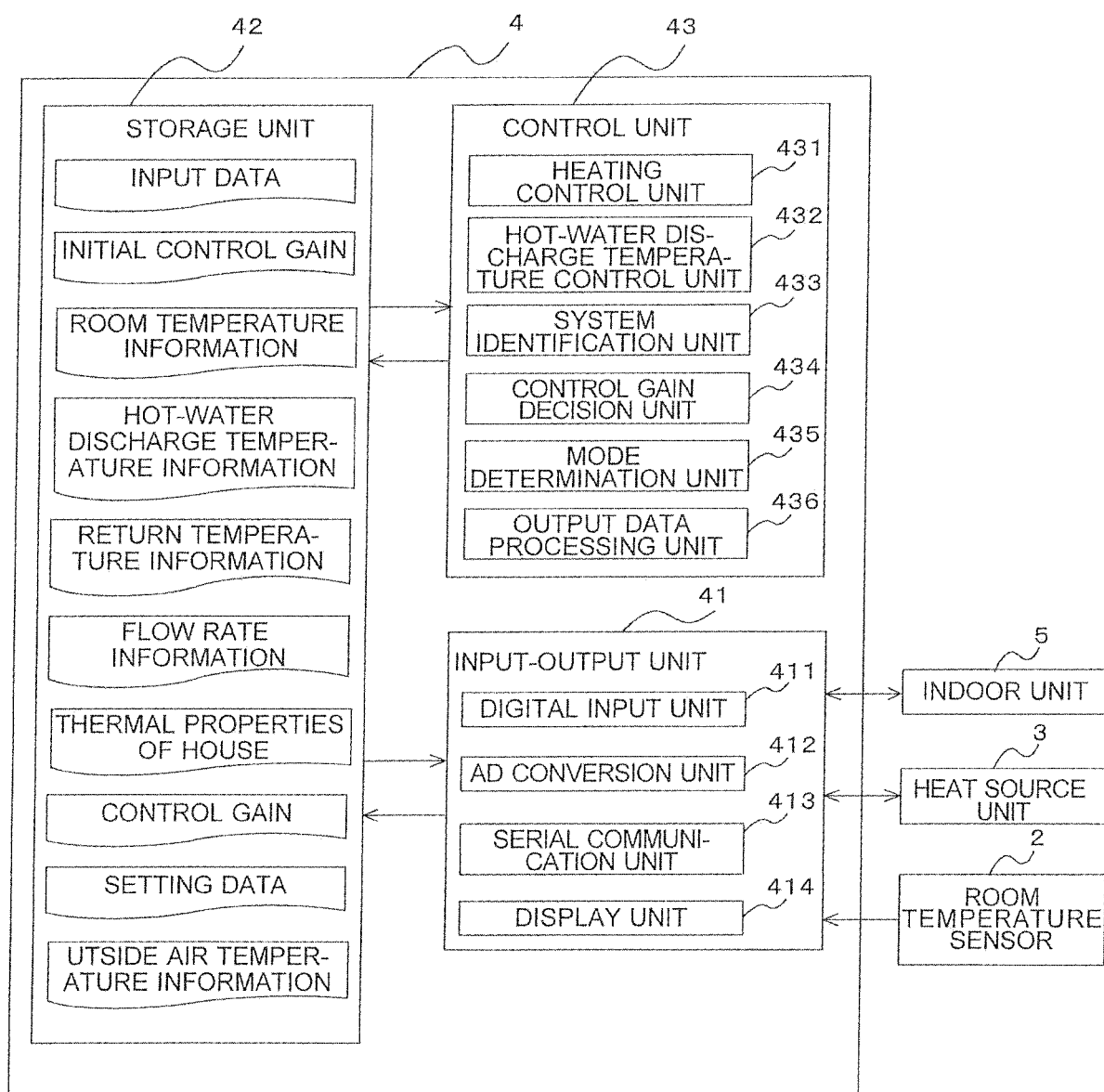


FIG. 15

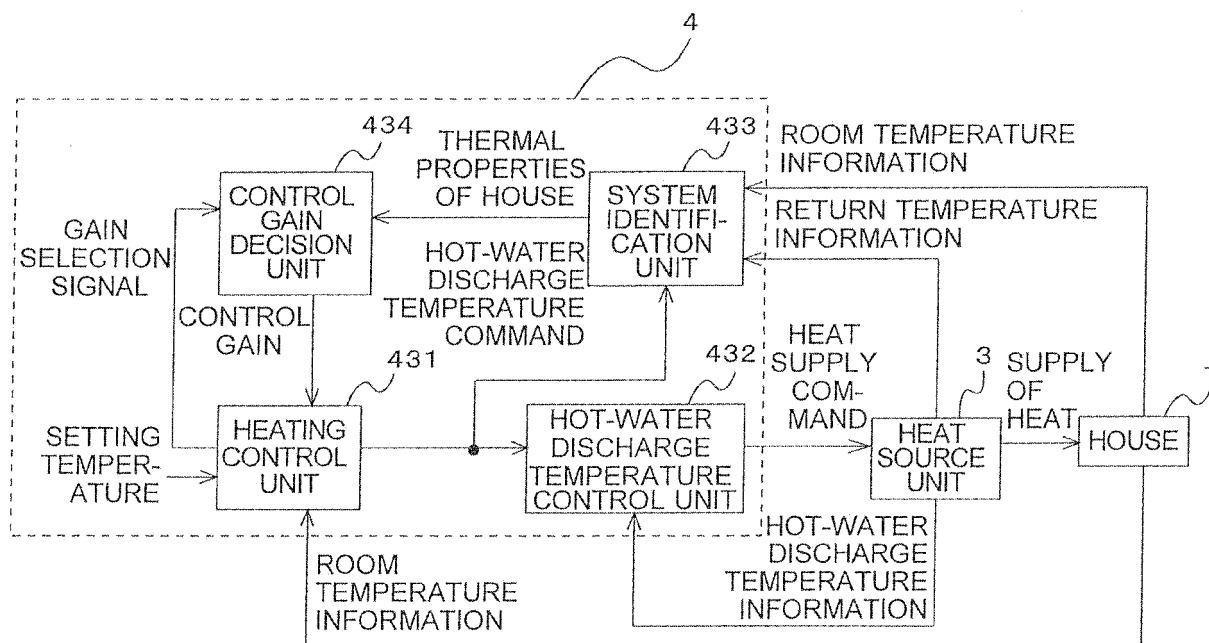


FIG. 16

|                  |     | COMPRESSOR                |                           |
|------------------|-----|---------------------------|---------------------------|
|                  |     | ON                        | OFF                       |
| CIRCULATION PUMP | ON  | AIR-CONDITIONING ON GAIN  | AIR-CONDITIONING ON GAIN  |
|                  | OFF | AIR-CONDITIONING OFF GAIN | AIR-CONDITIONING OFF GAIN |

FIG. 17

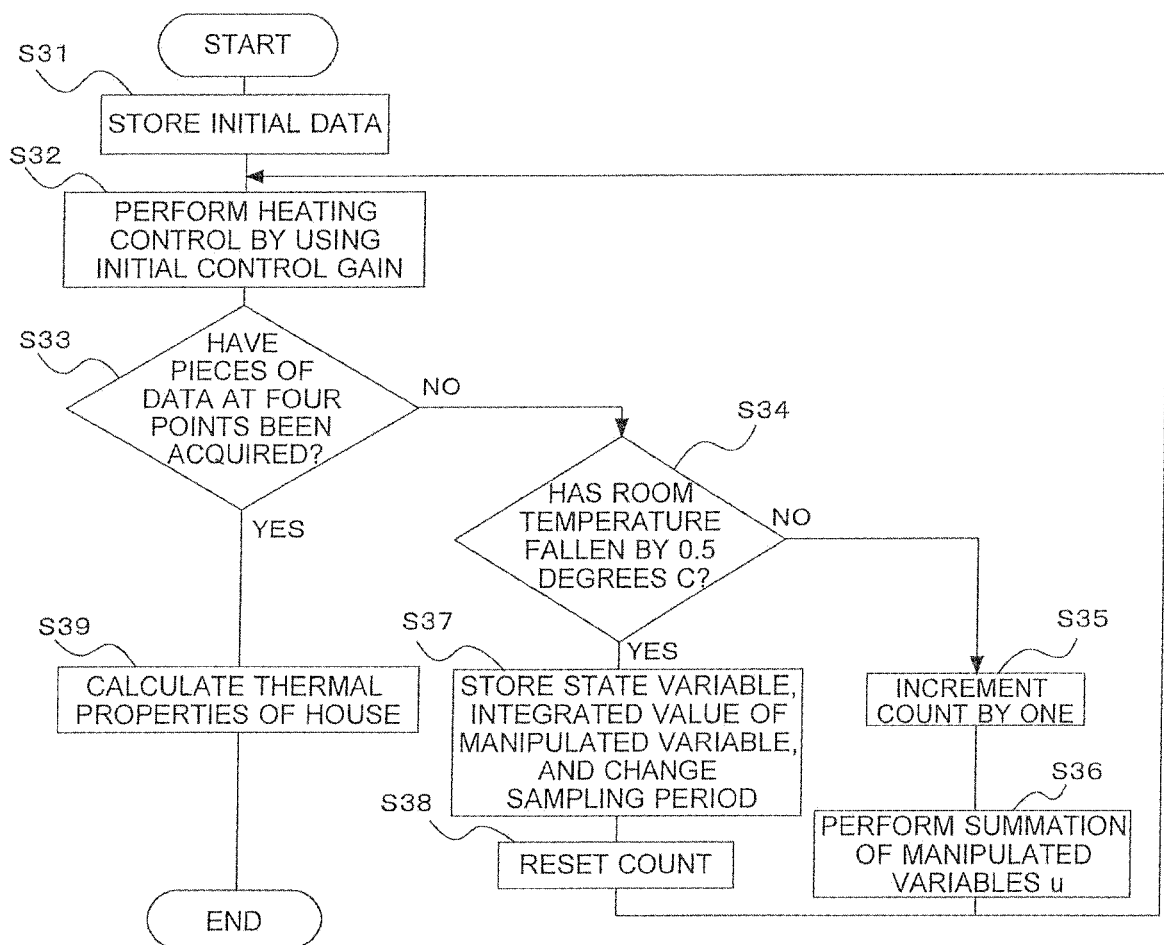


FIG. 18

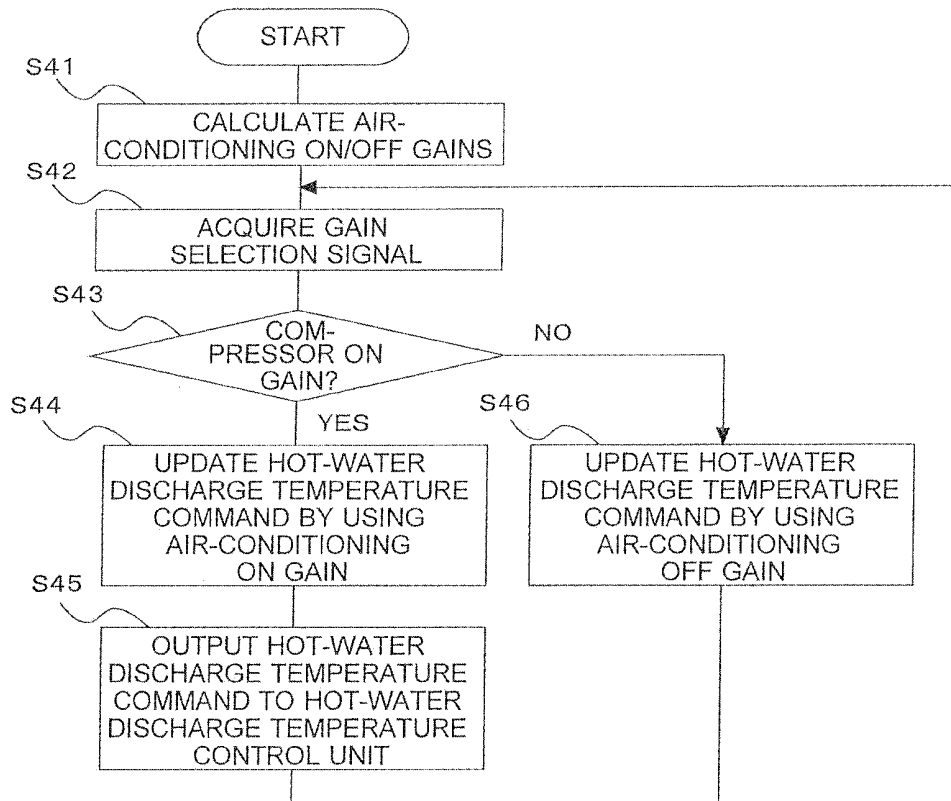
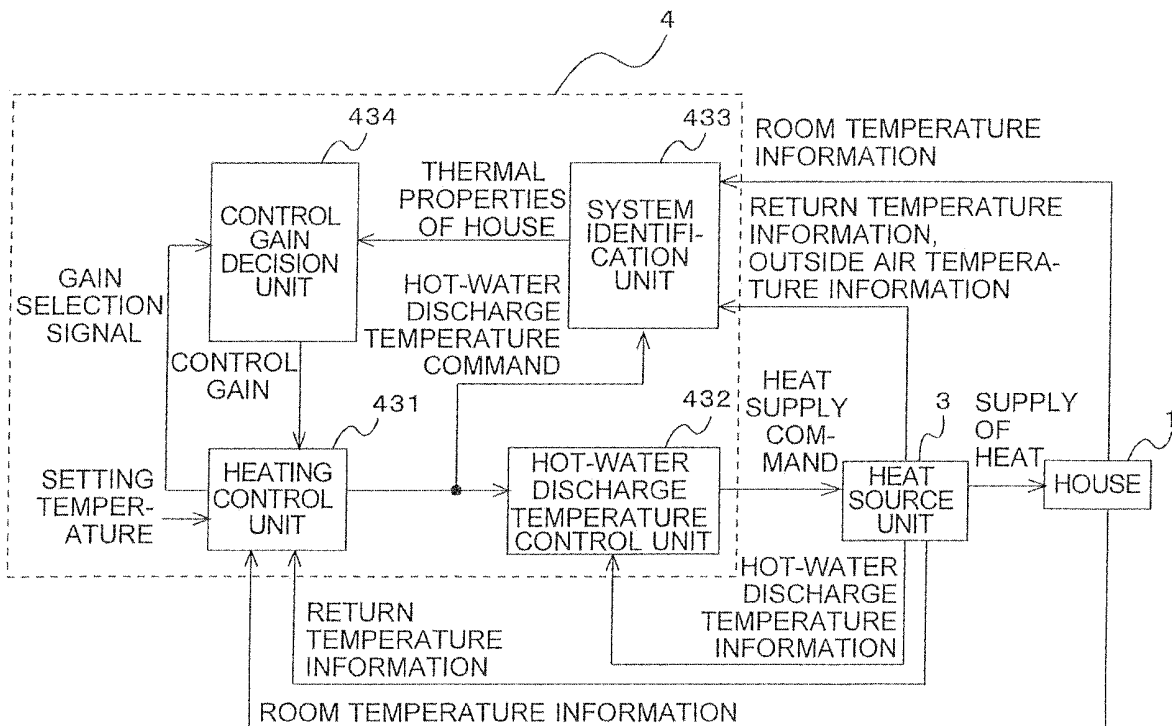


FIG. 19



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/051650

## A. CLASSIFICATION OF SUBJECT MATTER

F24D3/00(2006.01)i, F24D3/18(2006.01)i

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)

F24D3/00, F24D3/18

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

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2016  
 Kokai Jitsuyo Shinan Koho 1971-2016 Toroku Jitsuyo Shinan Koho 1994-2016

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

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                       | Relevant to claim No. |
|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| A         | JP 63-113244 A (Sanyo Electric Co., Ltd.),<br>18 May 1988 (18.05.1988),<br>specification, page 2, upper left column, line<br>11 to page 3, upper right column, line 18; fig.<br>1 to 3<br>(Family: none) | 1-11                  |
| A         | JP 2014-190600 A (Panasonic Corp.),<br>06 October 2014 (06.10.2014),<br>paragraphs [0004] to [0022]<br>(Family: none)                                                                                    | 1-11                  |
| A         | JP 58-106346 A (Yamatake-Honeywell Co., Ltd.),<br>24 June 1983 (24.06.1983),<br>specification, page 5, lower right column, line<br>12 to page 6, upper right column, line 1<br>(Family: none)            | 1-11                  |

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

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Date of the actual completion of the international search  
08 March 2016 (08.03.16)Date of mailing of the international search report  
15 March 2016 (15.03.16)Name and mailing address of the ISA/  
Japan Patent Office  
3-4-3, Kasumigaseki, Chiyoda-ku,  
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

**REFERENCES CITED IN THE DESCRIPTION**

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**Patent documents cited in the description**

- JP 2013217604 A [0003]