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(54) **HOT WATER SUPPLY SYSTEM****Publication Classification**(71) Applicant: **DAIKIN INDUSTRIES, LTD.**, Osaka (JP)(51) **Int. Cl.**
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Dec. 28, 2020 (JP) 2020-218484

(57) **ABSTRACT**

A hot water supply system includes a hot water supply apparatus, a plurality of supply paths, and an estimation unit. The hot water supply apparatus includes a heating apparatus configured to heat water, a tank configured to store the water heated by the heating apparatus, and a water circuit configured to circulate the water in the tank. Each supply path is coupled to a corresponding one of a plurality of hot water supply targets and is configured to supply the water from the tank. The estimation unit is configured to predict a total amount of hot water supply demand, based on time-series data of a first index that indicates an amount of heat of water used in each of the plurality of hot water supply targets.

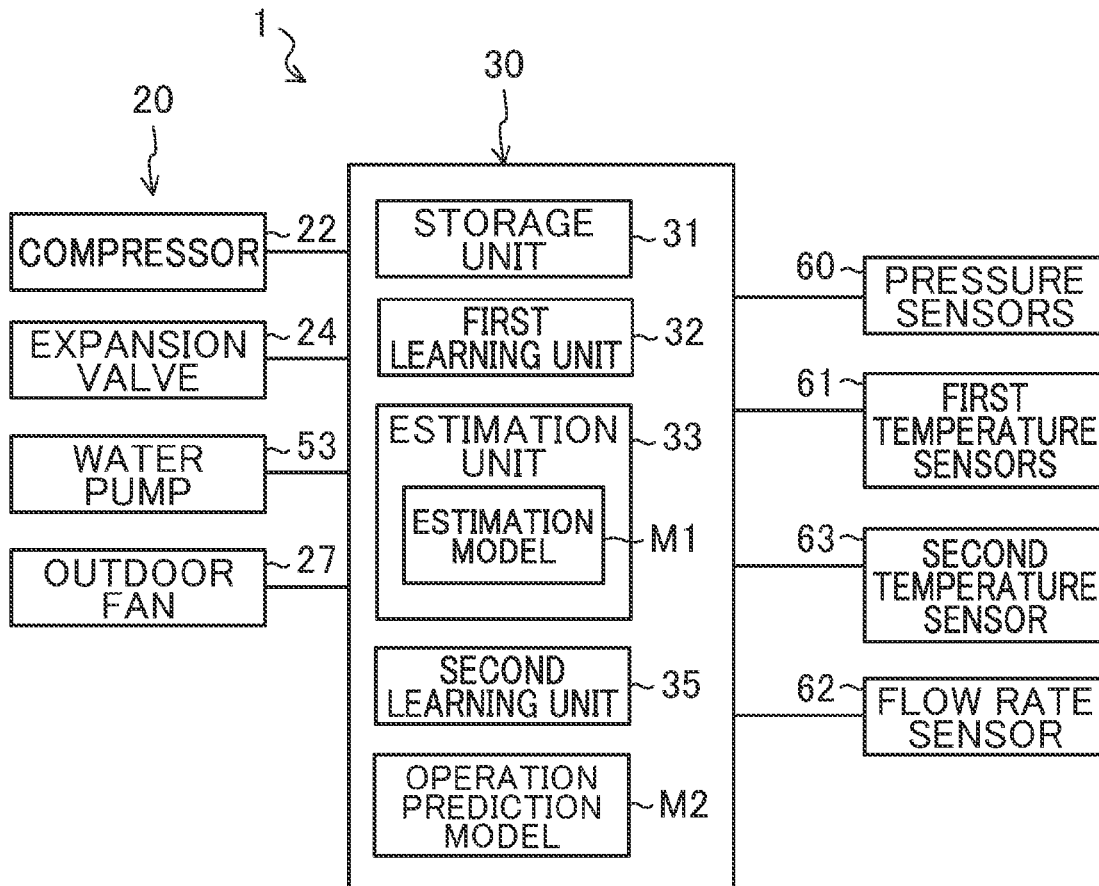


FIG.1

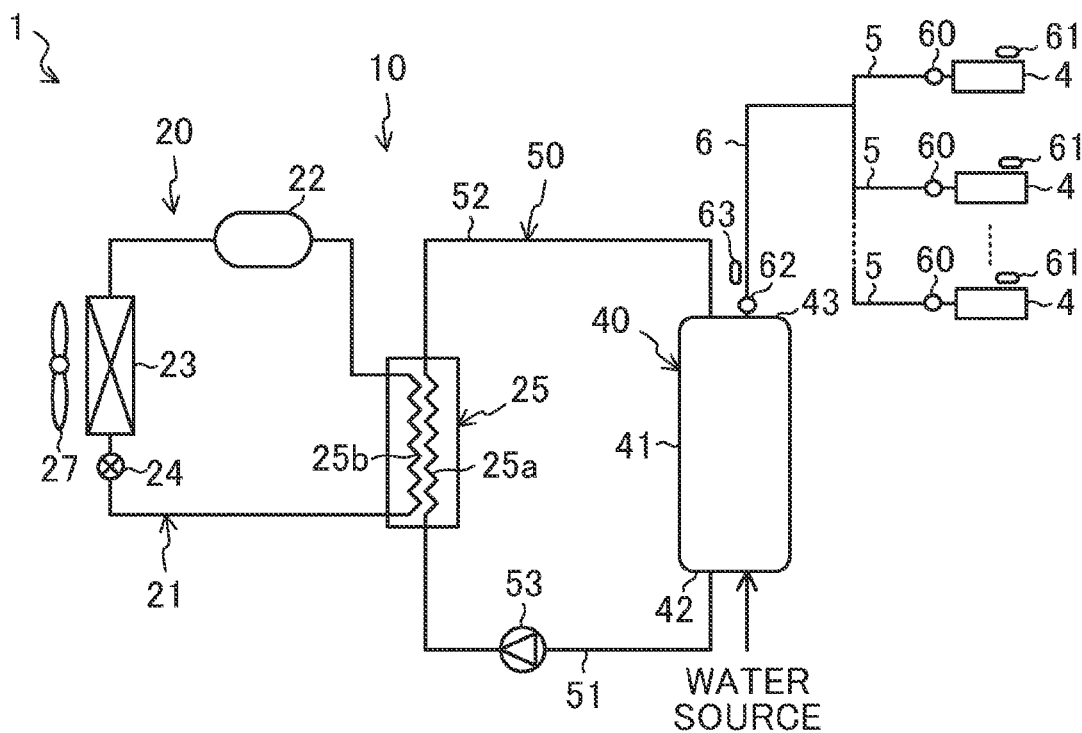


FIG.2

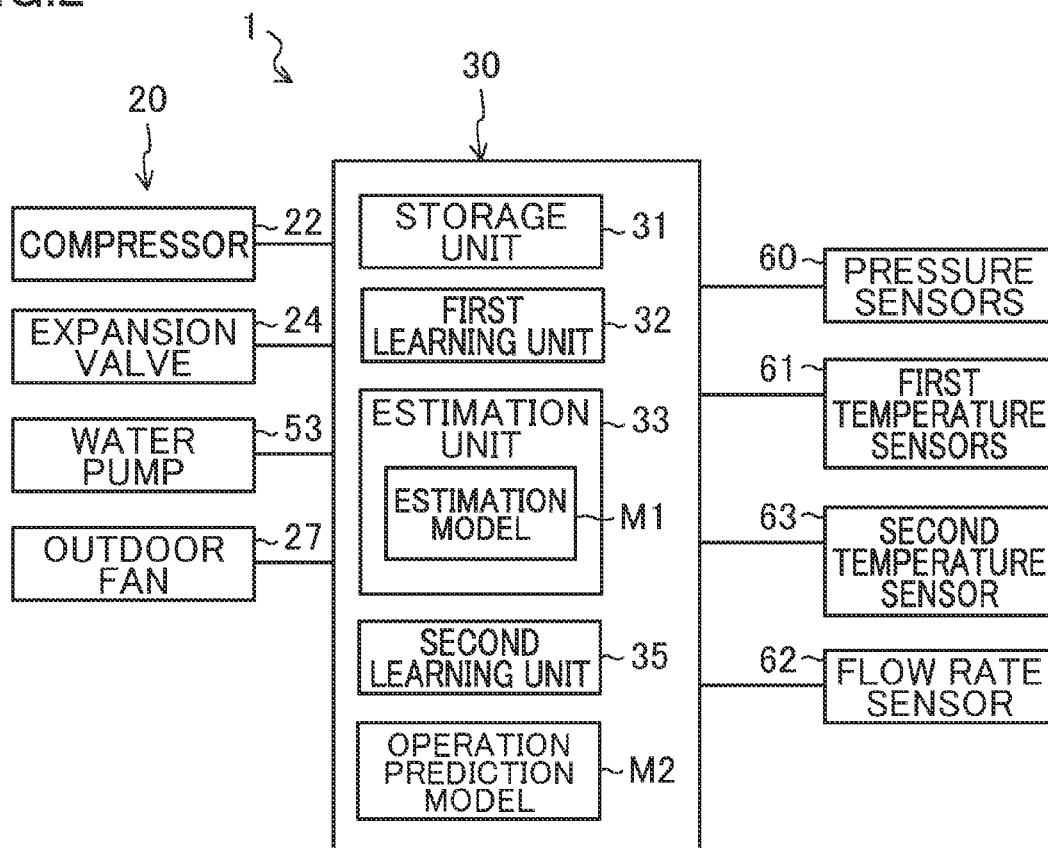


FIG.3

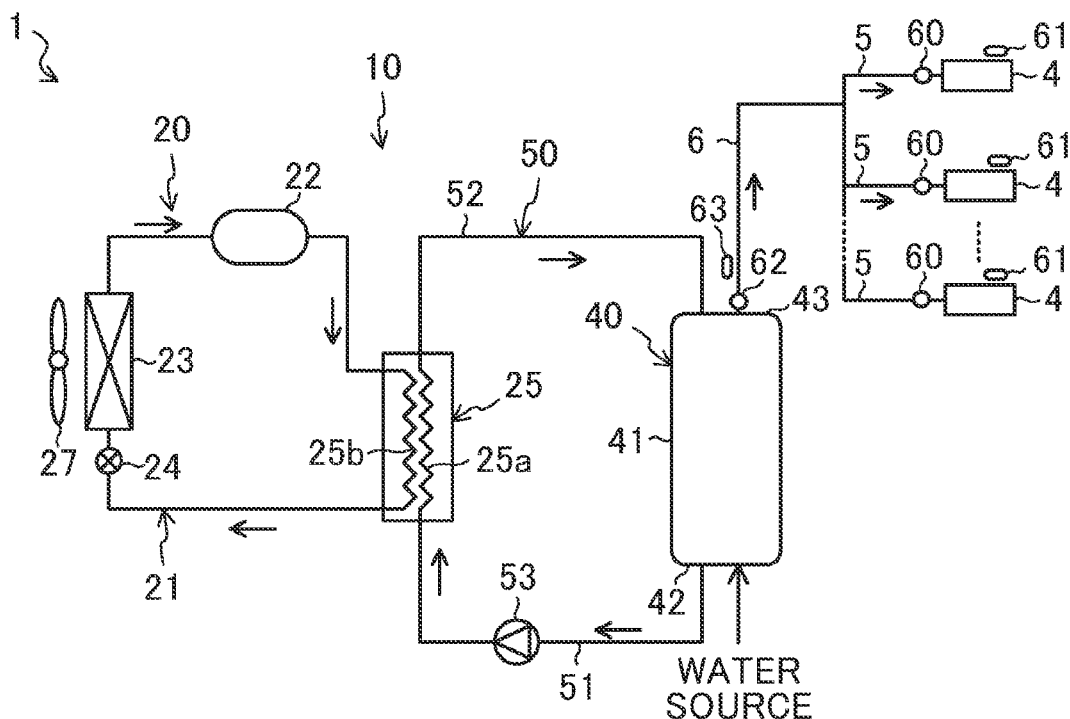


FIG.4

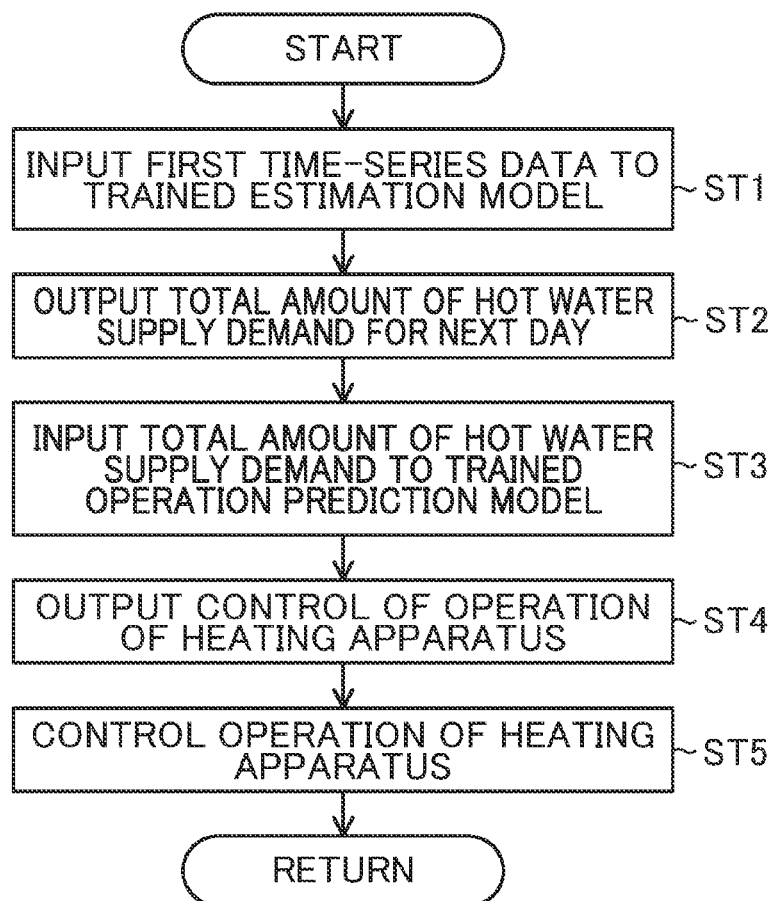


FIG.5

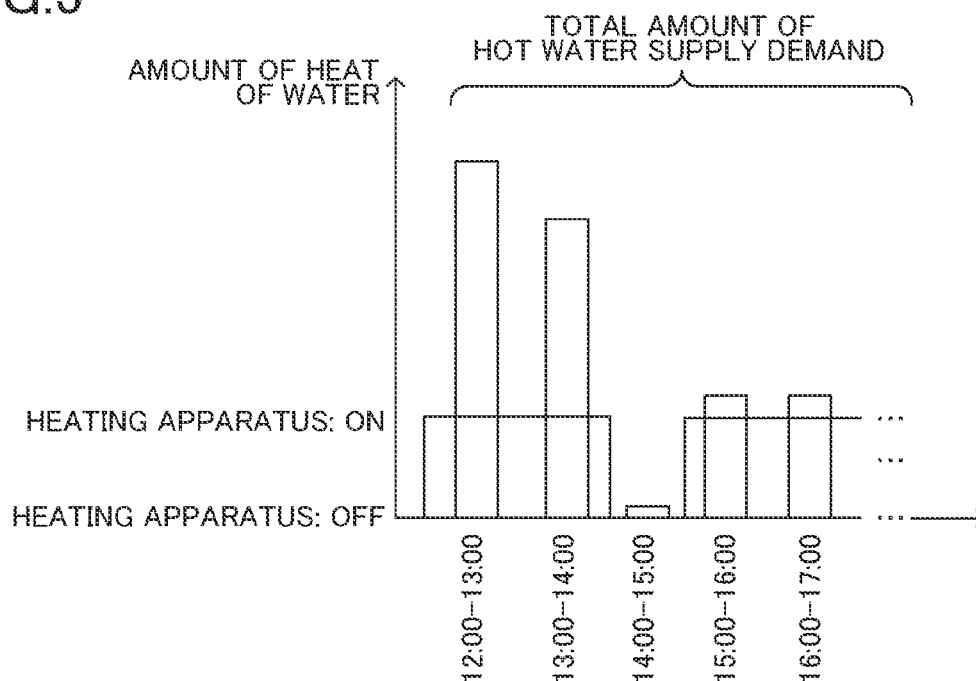


FIG.6

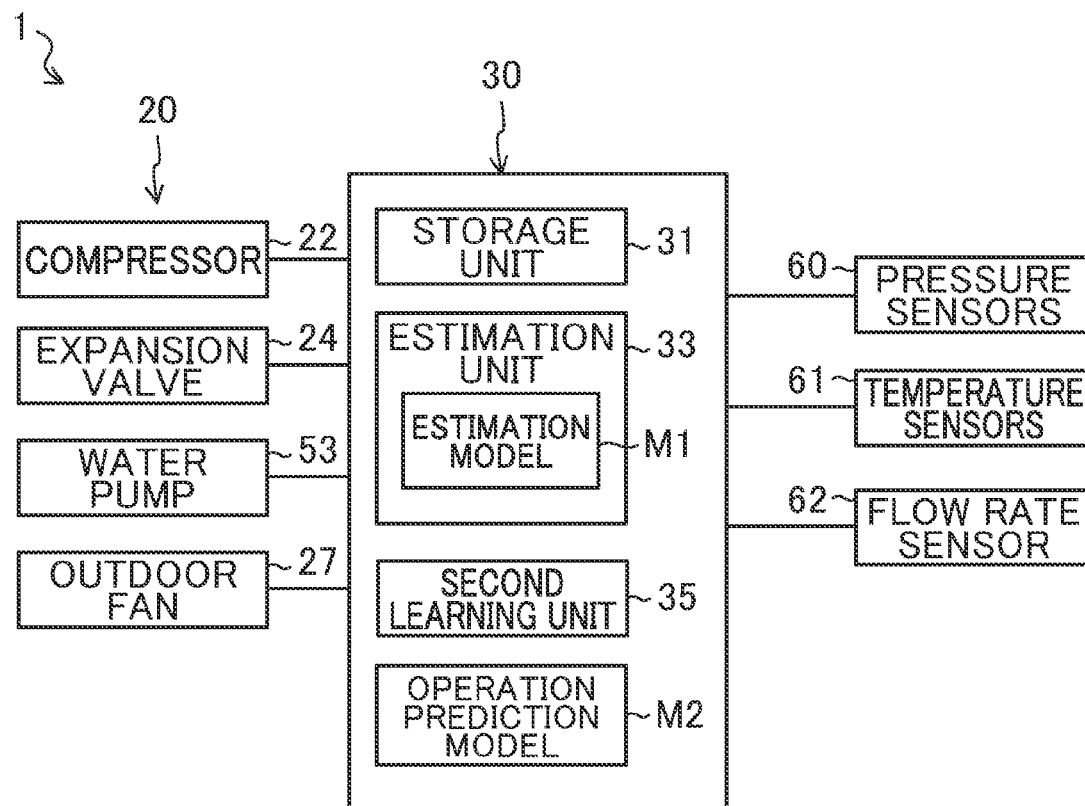


FIG. 7

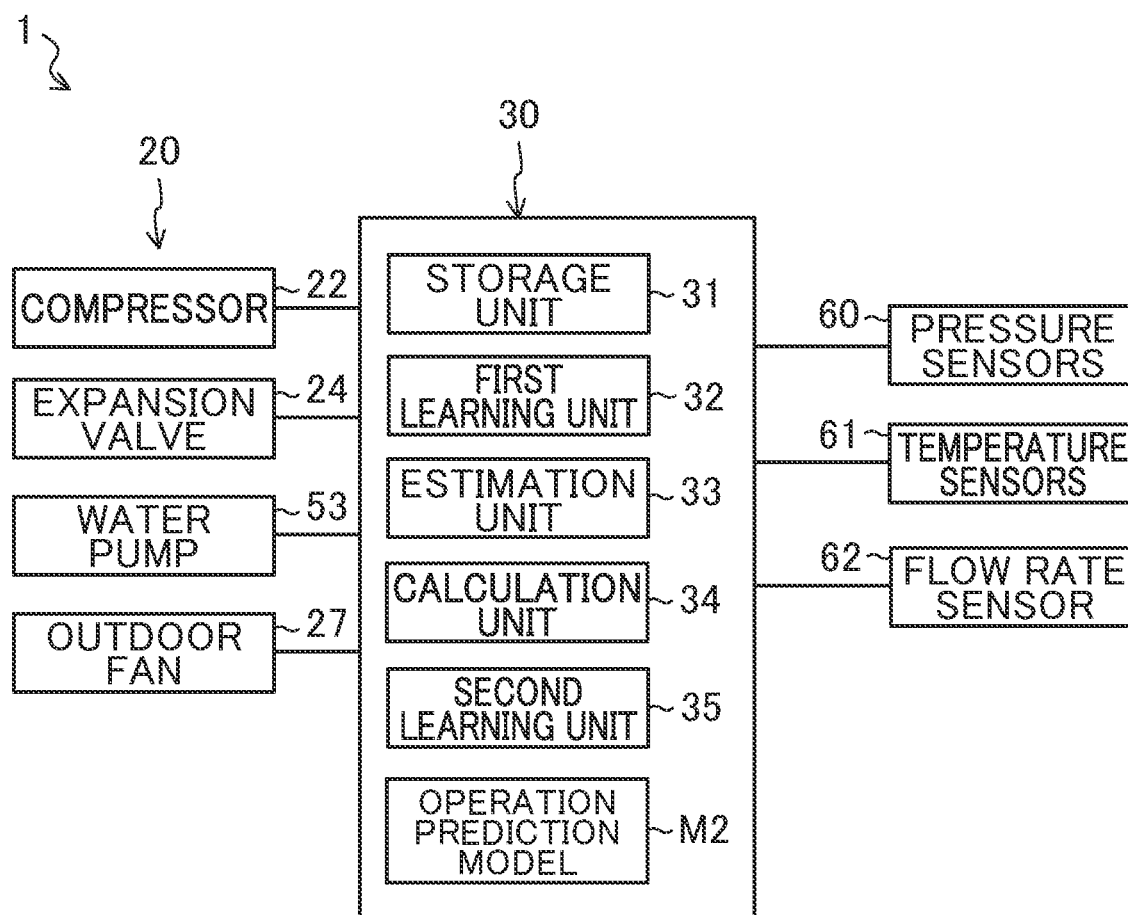


FIG.8

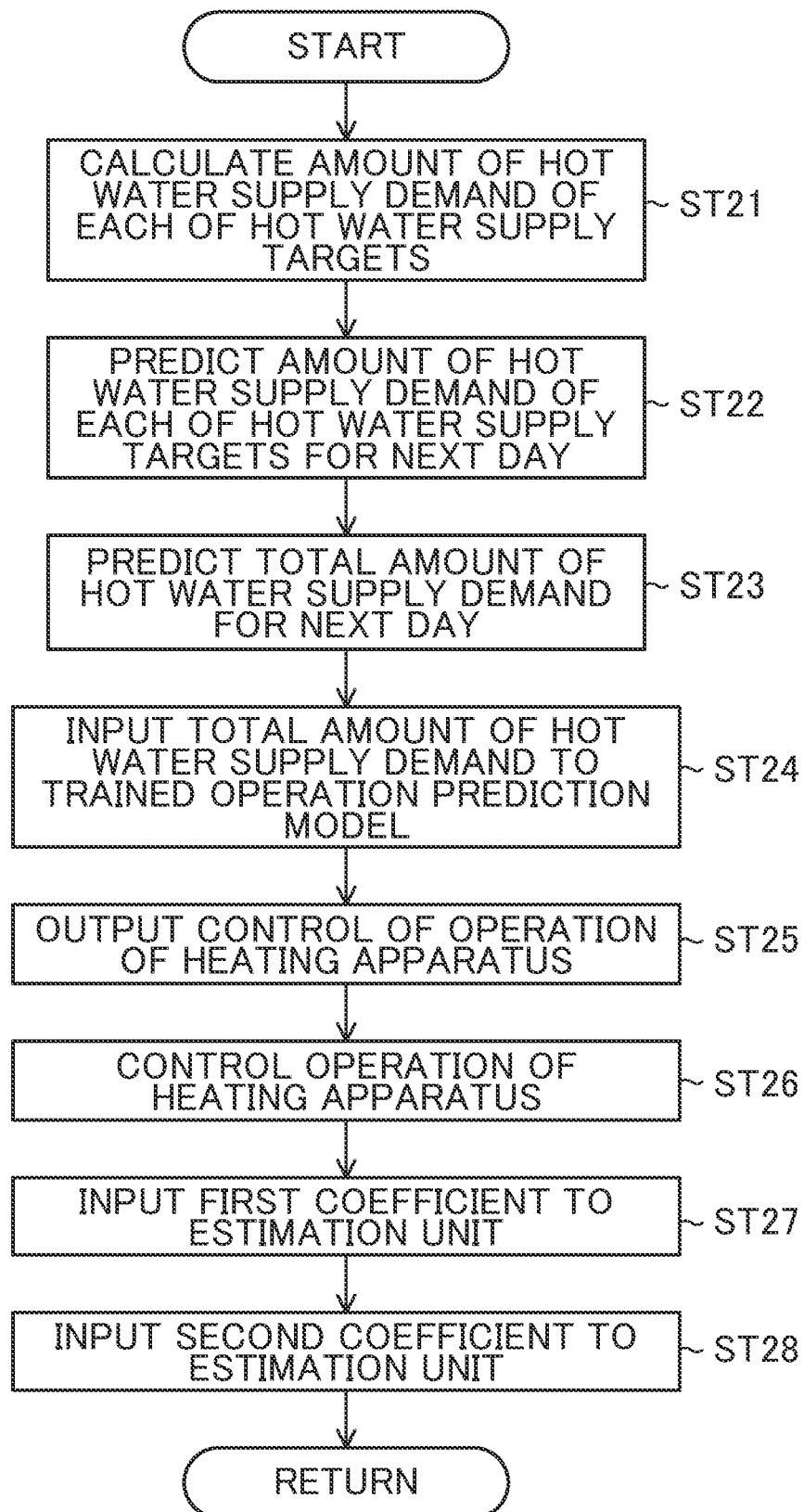


FIG.9

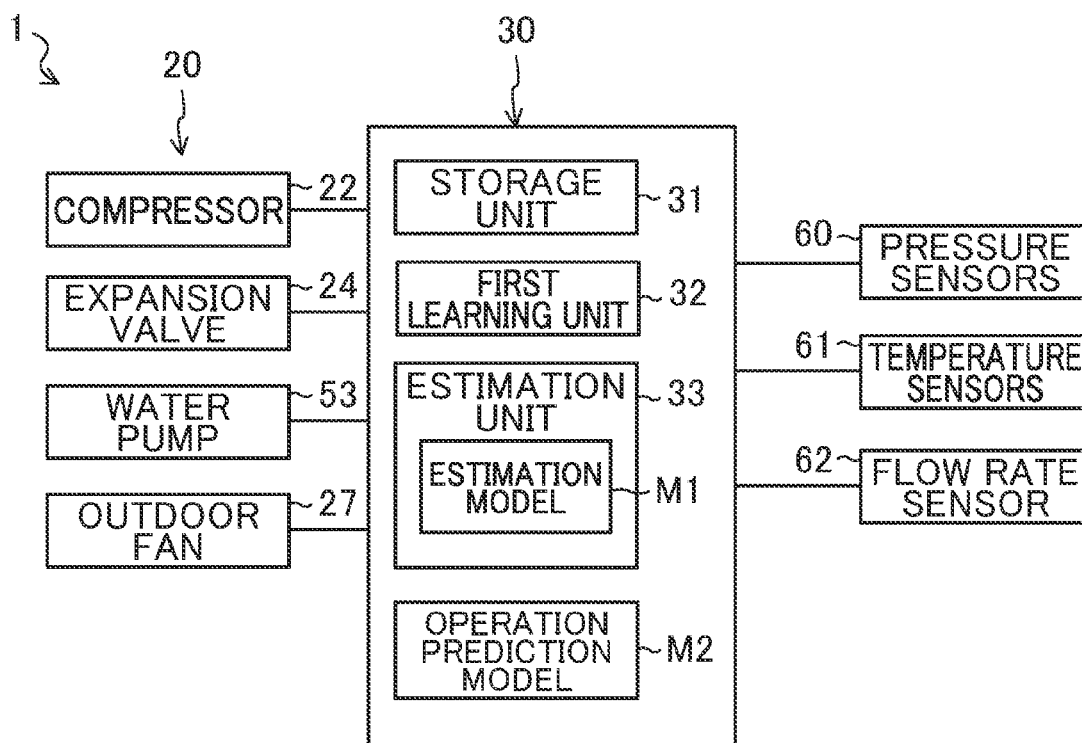


FIG.10

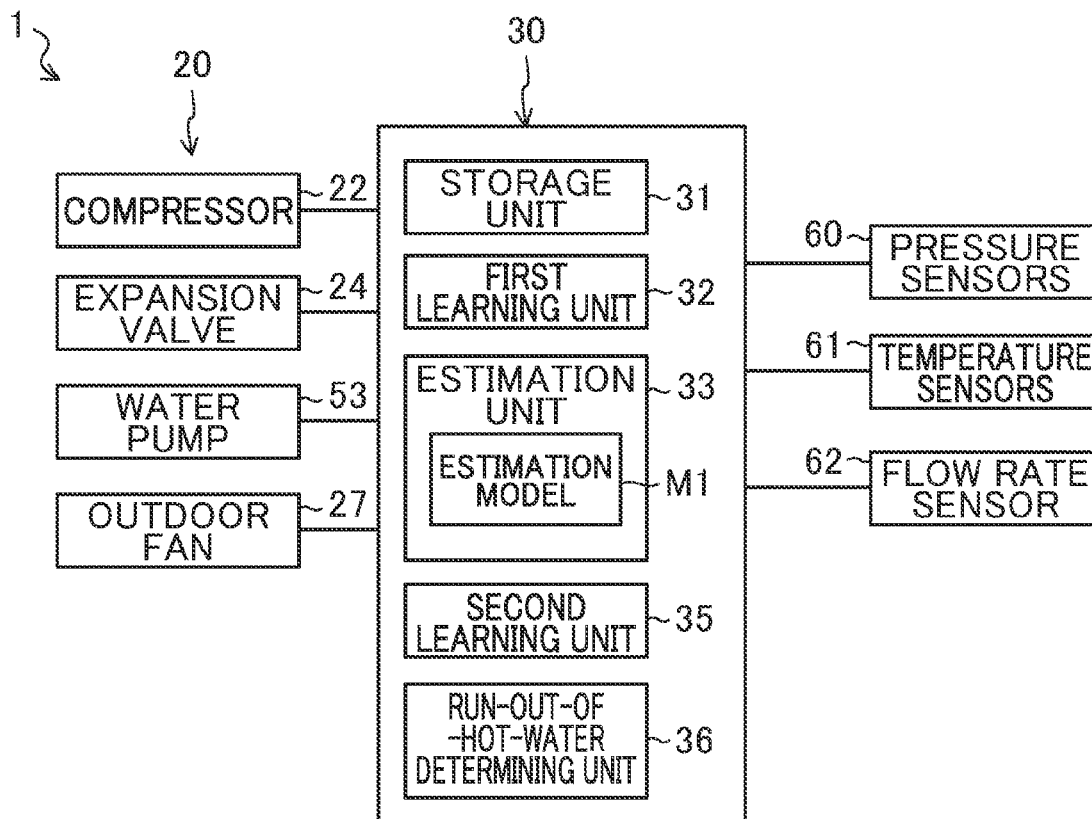
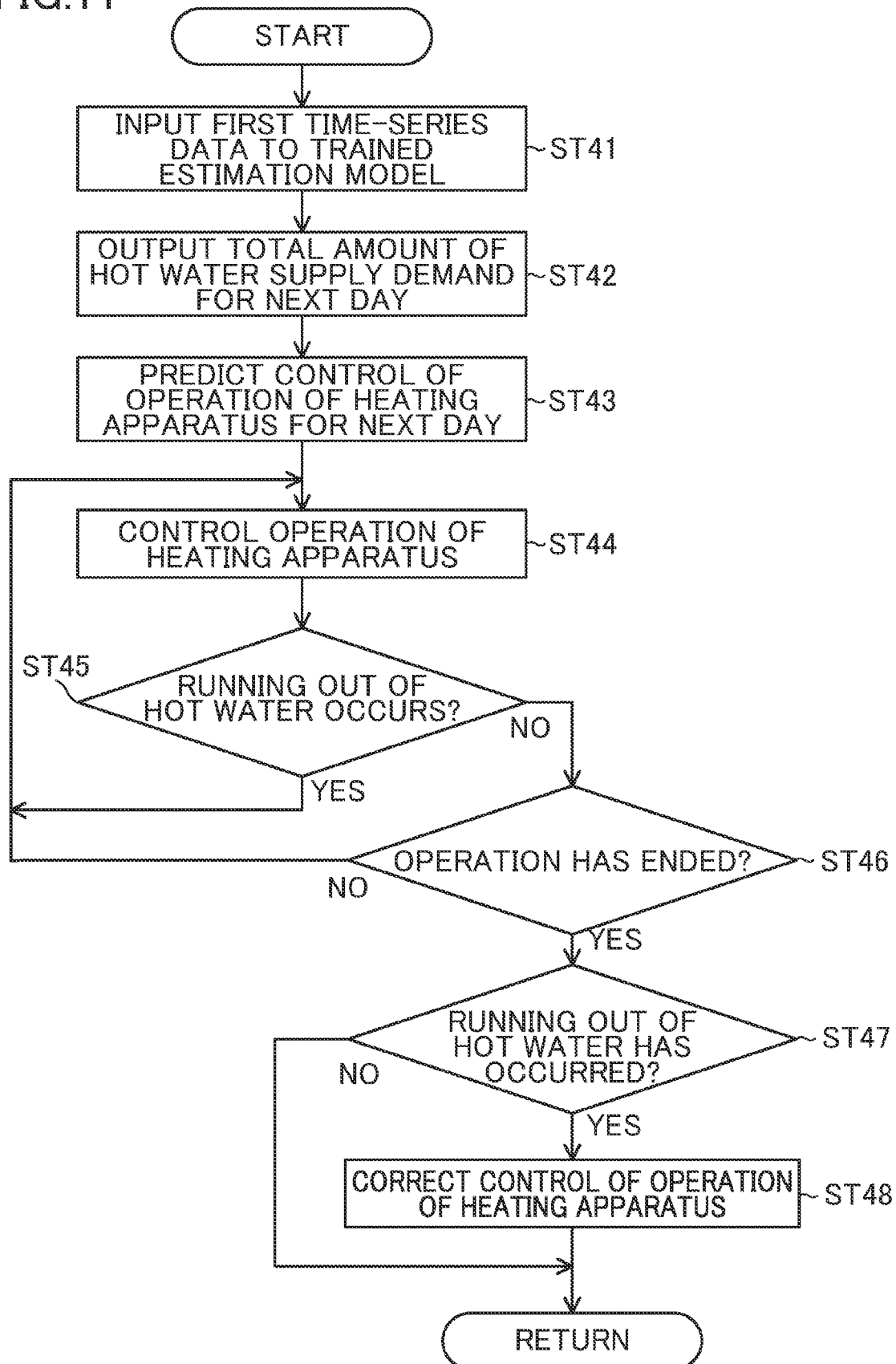


FIG.11



HOT WATER SUPPLY SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This is a continuation of International Application No. PCT/JP2021/047399 filed on Dec. 21, 2021, which claims priority to Japanese Patent Application No. 2020-218484, filed on Dec. 28, 2020. The entire disclosures of these applications are incorporated by reference herein.

BACKGROUND

Technical Field

[0002] The present disclosure relates to a hot water supply system.

Background Art

[0003] Japanese Unexamined Patent Application Publication No. 2006-183947 discloses a hot water supply system including a hot water generation means such as a fuel cell or a gas engine, and a hot water storage tank that utilizes discharged heat of the hot water generation means. This hot water supply system provides an optimum operation plan of the fuel cell by learning a pattern of hot water supply demand.

SUMMARY

[0004] A first aspect is a hot water supply system that includes a hot water supply apparatus, a plurality of supply paths, and an estimation unit. The hot water supply apparatus includes a heating apparatus configured to heat water, a tank configured to store the water heated by the heating apparatus, and a water circuit configured to circulate the water in the tank. Each supply path is coupled to a corresponding one of a plurality of hot water supply targets and is configured to supply the water from the tank. The estimation unit is configured to predict a total amount of hot water supply demand, based on time-series data of a first index that indicates an amount of heat of water used in each of the plurality of hot water supply targets.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is an overall configuration diagram of a hot water supply system according to an embodiment.

[0006] FIG. 2 is a block diagram of the hot water supply system.

[0007] FIG. 3 is a diagram illustrating a flow of refrigerant when the heating apparatus is in an operating state.

[0008] FIG. 4 is a flowchart illustrating an operation of the hot water supply system.

[0009] FIG. 5 is a graph illustrating a relationship between a total amount of hot water supply demand and control of an operation of the heating apparatus.

[0010] FIG. 6 is a block diagram of a hot water supply system according to a first modification of the embodiment.

[0011] FIG. 7 is a block diagram of a hot water supply system according to a second modification of the embodiment.

[0012] FIG. 8 is a flowchart illustrating an operation of the hot water supply system.

[0013] FIG. 9 is a block diagram of a hot water supply system according to a third modification of the embodiment.

[0014] FIG. 10 is a block diagram of a hot water supply system according to a fourth modification of the embodiment.

[0015] FIG. 11 is a flowchart illustrating an operation of the hot water supply system.

DETAILED DESCRIPTION OF EMBODIMENT(S)

[0016] An embodiment will be described below with reference to the drawings. Note that the embodiment below is a preferable example in essence and does not intend to limit the scope of the present invention and of the applications or uses thereof.

Embodiment

[0017] As illustrated in FIG. 1, the present disclosure presents a hot water supply system (1). The hot water supply system (1) heats water supplied from a water source and stores the heated water in a tank (40). Hot water stored in the tank (40) is supplied to a plurality of hot water supply targets (4). The water source includes a water supply. The hot water supply targets (4) include a bathtub, a shower, a faucet, and so on.

[0018] The hot water supply system (1) includes a heating apparatus (20), the tank (40), a water circuit (50), supply paths (5), a first pipe (6), pressure sensors (60), temperature sensors (61, 63), and a control unit (30).

Heating Apparatus

[0019] The heating apparatus (20) according to the present embodiment is of a heat pump type. The heating apparatus (20) generates heat for heating water. The heating apparatus (20) is of a vapor compression type. The heating apparatus (20) includes a refrigerant circuit (21). The refrigerant circuit (21) is filled with refrigerant. The refrigerant circuit (21) includes a compressor (22), a heat-source-side heat exchanger (23), an expansion valve (24), and a utilization-side heat exchanger (25).

[0020] The compressor (22) compresses refrigerant suctioned thereto and discharges the compressed refrigerant.

[0021] The heat-source-side heat exchanger (23) is an air-cooled heat exchanger. The heat-source-side heat exchanger (23) is disposed outdoors. The heating apparatus (20) includes an outdoor fan (27). The outdoor fan (27) is disposed in the vicinity of the heat-source-side heat exchanger (23). The heat-source-side heat exchanger (23) allows air transported by the outdoor fan (27) and the refrigerant to exchange heat.

[0022] The expansion valve (24) is a decompression mechanism that decompresses the refrigerant. The expansion valve (24) is provided between a liquid-side end of the utilization-side heat exchanger (25) and a liquid-side end of the heat-source-side heat exchanger (23). The decompression mechanism is not limited to the expansion valve, and may be a capillary tube, an expander, or the like. The expander recovers energy of the refrigerant as power.

[0023] The utilization-side heat exchanger (25) is a liquid-cooled heat exchanger. The utilization-side heat exchanger (25) includes a first flow path (25a) and a second flow path (25b). The second flow path (25b) is coupled to the refrigerant circuit (21). The first flow path (25a) is coupled to the

water circuit (50). The utilization-side heat exchanger (25) allows water flowing through the first flow path (25a) and the refrigerant flowing through the second flow path (25b) to exchange heat.

[0024] In the utilization-side heat exchanger (25), the first flow path (25a) is formed along the second flow path (25b). In the present embodiment, in a heating operation described in detail below, a direction of the refrigerant flowing through the second flow path (25b) is substantially opposite to a direction of the water flowing through the first flow path (25a). That is, during the heating operation, the utilization-side heat exchanger (25) functions as a counter-current heat exchanger.

Tank and Water Circuit

[0025] The tank (40) is a container that stores water. The tank (40) has a vertically long cylindrical shape. The tank (40) includes a body portion (41) that has a cylindrical shape, a bottom portion (42) that closes a lower end of the body portion (41), and a top portion (43) that closes an upper end of the body portion (41).

[0026] Water in the tank (40) circulates through the water circuit (50). The first flow path (25a) of the utilization-side heat exchanger (25) is coupled to the water circuit (50). The water circuit (50) includes an upstream flow path (51) and a downstream flow path (52).

[0027] An inflow end of the upstream flow path (51) is coupled to the bottom portion (42) of the tank (40). An outflow end of the upstream flow path (51) is coupled to an inflow end of the first flow path (25a).

[0028] An inflow end of the downstream flow path (52) is coupled to an outflow end of the first flow path (25a). An outflow end of the downstream flow path (52) is coupled to the top portion (43) of the tank (40).

[0029] The water circuit (50) includes a water pump (53). The water pump (53) causes water to circulate through the water circuit (50). The water pump (53) transports water in the tank (40) to send the water to the first flow path (25a) of the utilization-side heat exchanger (25). The water pump (53) further transports the water to the first flow path (25a) to send the water to the tank (40).

First Pipe and Supply Paths

[0030] An inflow end of the first pipe (6) is coupled to the tank (40). An outflow end of the first pipe (6) is coupled to an inflow end of each of the plurality of supply paths (5). An outflow end of each of the supply paths (5) is coupled to a corresponding one of the hot water supply targets (4).

Pressure Sensors

[0031] The pressure sensors (60) are coupled to the respective supply paths (5). The pressure sensors (60) each detect a pressure of water in a corresponding one of the supply paths (5). That is, the pressure sensors (60) each detect a pressure of water to be supplied to a corresponding one of the hot water supply targets (4).

Temperature Sensors

[0032] The hot water supply system (1) includes the first temperature sensors (61) and the second temperature sensor (63). The first temperature sensors (61) are provided at the

respective hot water supply targets (4). The first temperature sensors (61) each detect a temperature of water used in a corresponding one of the hot water supply targets (4). The second temperature sensor (63) is provided at the inflow end of the first pipe (6). The second temperature sensor (63) detects a temperature of water flowing into the first pipe (6) from the tank (40).

Flow Rate Sensor

[0033] A flow rate sensor (62) is provided at the inflow end of the first pipe (6). The flow rate sensor (62) detects an amount of water flowing into the first pipe (6) from the tank (40).

Control Unit

[0034] The control unit (30) illustrated in FIG. 2 includes a microcomputer and a memory device (specifically, a semiconductor memory) that stores software that causes the microcomputer to operate. The control unit (30) is connected to various devices and sensors of a hot water supply apparatus (10) with cables or wirelessly. The control unit (30) controls devices of the heating apparatus (20) and the water circuit (50). The devices of the water circuit (50) include the water pump (53).

[0035] The control unit (30) includes a storage unit (31), a first learning unit (32), an estimation unit (33), and a second learning unit (35).

[0036] The storage unit (31) stores time-series data of a first index. The first index indicates an amount of heat of water used in each of the hot water supply targets (4). Specifically, the first index includes a temperature of water used in each of the hot water supply targets (4) and a pressure of water in each of the supply paths (5). Hereinafter, the time-series data of the first index is referred to as first time-series data. The first time-series data is time-series data in the present disclosure.

[0037] A total amount of hot water supply demand means an amount of heat of water used by the entire hot water supply apparatus (10) in a predetermined time. The total amount of hot water supply demand corresponds to a sum of amounts of heat of water used in the respective hot water supply targets (4).

[0038] The storage unit (31) stores an actual total amount of hot water supply demand as time-series data. The actual total amount of hot water supply demand is determined by measuring, with a detection means, an amount of heat of water flowing out from the tank (40) to the first pipe (6). Specifically, the total amount of hot water supply demand is determined based on values obtained by the flow rate sensor (62) and the second temperature sensor (63). The time-series data of the total amount of hot water supply demand stored in the storage unit (31) is referred to as second time-series data.

[0039] The first learning unit (32) learns the first time-series data of a predetermined period stored in the storage unit (31) and the second time-series data of the same time period as that of the first time-series data in association with each other. The first learning unit (32) performs learning through machine learning.

[0040] The estimation unit (33) predicts an amount of hot water supply demand, based on the first time-series data. Specifically, the estimation unit (33) predicts the total amount of hot water supply demand, based on a result of

learning performed by the first learning unit (32). More specifically, the estimation unit (33) predicts the total amount of hot water supply demand by using a trained estimation model (M1) that has learned, through machine learning, the first time-series data and the second time-series data stored in the storage unit (31) in association with each other. The estimation unit (33) predicts, for example, the total amount of hot water supply demand for the next day which is a predetermined time. As illustrated in FIG. 5, the total amount of hot water supply demand predicted by the estimation unit (33) may be time-series data that changes on a certain time (for example, hourly) basis.

[0041] The estimation model (M1) is included in the estimation unit (33). The estimation model (M1) is generated to predict, based on the first time-series data, the total amount of hot water supply demand. The estimation model (M1) is constructed as a multilayer neural network that has acquired a prediction capability through machine learning. The estimation model (M1) in the present embodiment is generated through “supervised learning”. The neural network for generating the estimation model (M1) performs learning using learning data and a discriminant function. The learning data is a set of pairs of input data and training data corresponding to the input data.

[0042] The input data is the first time-series data of a predetermined period stored in the storage unit (31). Specifically, the input data is time-series data of the pressure of water in each of the supply paths (5) in a predetermined period and time-series data of the temperature of water used in the hot water supply target (4) connected to the supply path (5). The training data is the second time-series data in the same period as that of the input data. The neural network is caused to perform “supervised learning” using the learning data described above, so that the trained estimation model (M1) is generated as a result of learning.

[0043] In this way, the estimation unit (33) predicts the total amount of hot water supply demand by using the trained estimation model (M1). The estimation unit (33) inputs, to the trained estimation model (M1), the first time-series data of a predetermined period (for example, one week up to the previous day) stored in the storage unit (31), to output the total amount of hot water supply demand. In this way, the estimation unit (33) predicts the total amount of hot water supply demand.

[0044] The second learning unit (35) learns the total amount of hot water supply demand and the operation state of the heating apparatus (20) in association with each other. The second learning unit (35) performs learning through machine learning. The control unit (30) controls the operation of the heating apparatus (20), based on a result of learning performed by the second learning unit (35). Specifically, the control unit (30) controls the operation of the heating apparatus (20) by using an operation prediction model (M2).

[0045] The control unit (30) includes the operation prediction model (M2). The operation prediction model (M2) is generated through machine learning to predict, based on the total amount of hot water supply demand, control of the operation of the heating apparatus (20). The control unit (30) controls the operation of the heating apparatus (20) by using such a trained operation prediction model (M2).

[0046] The operation prediction model (M2) is generated through “reinforcement learning”. Specifically, the second

learning unit (35) sets electricity cost per day as a reward and sets the operation state of the heating apparatus (20) as a state variable. The operation state of the heating apparatus (20) refers to, for example, an ON state or an OFF state of the heating apparatus (20). The second learning unit (35) inputs, as input data, the second time-series data of a predetermined period to the operation prediction model (M2). Thus, the second learning unit (35) performs learning such that the electricity cost for the operation of the heating apparatus (20) for one day is minimized. The total amount of hot water supply demand predicted by the estimation unit (33) is input to the trained operation prediction model (M2) thus generated, so that the operation of the heating apparatus (20) is controlled such that the power is minimized.

Heating Operation

[0047] As illustrated in FIG. 3, the control unit (30) controls the heating apparatus (20) to perform a heating operation. Specifically, the control unit (30) causes the compressor (22) and the outdoor fan (27) to operate. The control unit (30) appropriately adjusts an opening degree of the expansion valve (24). The control unit (30) causes the water pump (53) to operate.

[0048] The refrigerant compressed by the compressor (22) flows through the second flow path (25b) of the utilization-side heat exchanger (25). In the utilization-side heat exchanger (25), the refrigerant in the second flow path (25b) dissipates heat to water in the first flow path (25a). The pressure of the refrigerant that has dissipated heat or has condensed in the second flow path (25b) is reduced by the expansion valve (24). The refrigerant then flows through the heat-source-side heat exchanger (23). In the heat-source-side heat exchanger (23), the refrigerant absorbs heat from outdoor air to evaporate. The refrigerant that has evaporated in the heat-source-side heat exchanger (23) is suctioned by the compressor (22).

[0049] In the water circuit (50), the water in the tank (40) flows out to the upstream flow path (51). The water in the upstream flow path (51) flows through the first flow path (25a) of the utilization-side heat exchanger (25). The water in the first flow path (25a) is heated by the refrigerant in the heating apparatus (20).

[0050] The heated water in the tank (40) flows through the predetermined supply path (5) through the first pipe (6). The water flowing through the supply path (5) flows out to outside from the hot water supply target (4) coupled to the supply path (5).

Operation of Hot Water Supply System

[0051] An example of an operation of the hot water supply system (1) of the present embodiment will be described next with reference to FIG. 4.

[0052] In step ST1, the control unit (30) inputs the first time-series data of one week up to the previous day to the trained estimation model (M1).

[0053] In step ST2, the control unit (30) outputs the total amount of hot water supply demand for the next day (future) from the trained estimation model (M1). The total amount of hot water supply demand output at this time is time-series data that changes on an hourly basis for the next day.

[0054] In step ST3, the control unit (30) inputs the total amount of hot water supply demand for the next day output in step ST2 to the trained operation prediction model (M2).

[0055] In step ST4, the control unit (30) outputs control of the operation of the heating apparatus (20) for the next day from the trained operation prediction model (M2). The control of the operation output at this time is, for example, an operation plan for setting the heating apparatus (20) in an ON state or an OFF state on an hourly basis for the next day as illustrated in FIG. 5. Based on this operation plan, the control unit (30) controls the heating operation of the heating apparatus (20). The heating apparatus (20) boils the water in the tank (40) so that an amount of hot water needed in each time period can be supplied to the hot water supply targets (4) based on the predicted total amount of hot water supply demand.

[0056] In step ST5, the control unit (30) controls the heating operation of the heating apparatus (20), based on the control of the operation of the heating apparatus (20) output in step ST4. For example, in the operation plan of FIG. 5, the control unit (30) controls the heating operation of the heating apparatus (20) to boil the water in the tank (40) from 13:00 to 14:00 so that a necessary amount of hot water can be supplied to the hot water supply targets (4). On the other hand, the control unit (30) controls the heating apparatus (20) so that the heating operation is not performed from 14:00 to 15:00. This is because, in this operation plan, it is determined, based on the amount of hot water necessary from 14:00 to 15:00 and an amount of hot water remaining in the tank (40), that not performing the heating operation from 14:00 to 15:00 is more efficient. Then, the control unit (30) controls the heating operation of the heating apparatus (20) to boil the water in the tank (40) in accordance with the necessary amount of hot water in each time period after 15:00.

[0057] The hot water supply system (1) of the present embodiment includes the estimation unit (33) that predicts the total amount of hot water supply demand, based on the time-series data (first time-series data) of the first index that indicates the amount of heat of water used in each of the plurality of hot water supply targets (4). Thus, since the total amount of hot water supply demand is estimated based on the first index of each of the hot water supply targets (4), the prediction accuracy of the total amount of hot water supply demand can be improved as compared with a case where the total amount of hot water supply demand is estimated based only on the hot water supply target (4) (for example, a shower or bathtub) having a relatively large amount of hot water supply.

[0058] For example, even in a house such as an apartment house in which a plurality of households are in a single building, the prediction accuracy of the total amount of hot water supply demand of the house can be improved. Specifically, in the apartment housing, the amount of hot water supply of each of the hot water supply targets (4) to be used varies from household to household. Thus, for example, if the amount of hot water supply for a shower or a bathtub used in a household A is larger than the amount of hot water supply for the other households, the predicted value of the amount of hot water supply for the household A affects the predicted value of the entire apartment housing. As a result, the prediction accuracy of the amount of hot water supply for the other households may decrease. However, the hot water supply system (1) of the present embodiment estimates the total amount of hot water supply demand of the entire apartment housing, based on the time-series data of the first index of each of the hot water supply targets

(4) of each household in the apartment housing. Thus, the prediction accuracy of the total amount of hot water supply demand of the entire apartment housing can be improved, and consequently the prediction accuracy of the total amount of hot water supply demand of each household can be improved.

[0059] The hot water supply system (1) of the embodiment includes the first learning unit (32) that learns the first time-series data and the second time-series data (the total amount of hot water supply demand) in association with each other. The estimation unit (33) predicts the total amount of hot water supply demand, based on a result of the learning performed by the first learning unit (32). Thus, the total amount of hot water supply demand can be predicted based on the result of the learning performed by the first learning unit (32).

[0060] In the hot water supply system (1) of the embodiment, the first learning unit (32) performs the learning through machine learning. Thus, the total amount of hot water supply demand can be predicted based on a result of the learning obtained through machine learning.

[0061] In the hot water supply system (1) of the embodiment, the estimation unit (33) includes the estimation model (M1) generated through machine learning to predict, based on the first time-series data, the total amount of hot water supply demand, and predicts the total amount of hot water supply demand by using the estimation model (M1). In the present embodiment, the trained estimation model (M1) based on the first time-series data of a predetermined period is generated through supervised learning. By using such a trained estimation model (M1), the prediction accuracy of the total amount of hot water supply demand can be improved for sure.

[0062] The trained estimation model (M1) is updated through sequential learning. Thus, as the number of times of the use of the hot water supply system (1) increases, the number of times of the update of the trained estimation model (M1) also increases. As a result, the prediction accuracy of the total amount of hot water supply demand output from the trained estimation model (M1) can be improved.

[0063] In the hot water supply system (1) of the embodiment, the first index includes the temperature of the water used in each of the plurality of hot water supply targets (4) and the pressure of the water in each of the supply paths (5). The trained estimation model (M1) can be generated through supervised learning by using, as input data, the time-series data of the temperature of the water used in each of the hot water supply targets (4) and the time-series data of the pressure of the water in the supply path (5) connected to the hot water supply target (4) and by using, as training data, the second time-series data.

[0064] The hot water supply system (1) of the embodiment includes the control unit (30) that controls the operation of the heating apparatus (20), based on the total amount of hot water supply demand. Thus, for example, the heating apparatus (20) can perform the operation according to the amount of heat of water needed by the hot water supply targets (4) in each time period of the next day.

[0065] The hot water supply system (1) of the embodiment includes the second learning unit (35) that learns the total amount of hot water supply demand and the operation state of the heating apparatus (20) in association with each other. The control unit (30) controls the operation of the heating apparatus (20), based on a result of the learning per-

formed by the second learning unit (35). Thus, the operation of the heating apparatus (20) can be controlled based on the result of the learning performed by the second learning unit (35).

[0066] In the hot water supply system (1) of the embodiment, the second learning unit (35) performs the learning through machine learning. Thus, the control of the operation of the heating apparatus (20) can be predicted based on a result of the learning obtained through machine learning.

[0067] In the hot water supply system (1) of the embodiment, the control unit (30) includes the operation prediction model (M2) generated through machine learning to predict, based on the total amount of hot water supply demand, control of the operation of the heating apparatus (20), and controls the operation of the heating apparatus (20) by using the operation prediction model (M2). In the present embodiment, by using the operation prediction model (M2) trained through machine learning, the heating apparatus (20) can be operated with high efficiency and the operation of the heating apparatus (20) can be controlled so that the electricity cost per day is minimized as compared with past electricity cost. Since the operation of the heating apparatus (20) can be controlled in accordance with the total amount of hot water supply demand, running out of hot water in the tank (40) can be suppressed while hot water is being supplied.

[0068] The trained operation prediction model (M2) is updated through sequential learning. Thus, as the number of times of the use of the hot water supply system (1) increases, the number of times of the update of the trained operation prediction model (M2) also increases. As a result, control of the operation that achieves reduced electricity cost can be predicted. Thus, as the number of times of the use of the hot water supply system (1) of the present embodiment increases, the electricity cost per day can be made low.

[0069] In the hot water supply system (1) according to the embodiment, the heating apparatus (20) is of a heat pump type. Thus, even in a heat pump having a relatively small start-up capacity, the risk of running out of hot water can be reduced and a highly efficient operation can be performed.

First Modification

[0070] In the hot water supply system (1) of the present modification, the estimation unit (33) includes the trained estimation model (M1) that has performed learning in advance. A configuration different from that of the above-described embodiment will be described below.

[0071] As illustrated in FIG. 6, the control unit (30) does not include the first learning unit (32). The estimation model (M1) of the present modification is generated in advance to predict, based on the first time-series data, the total amount of hot water supply demand before the hot water supply system (1) is used by a user (before shipment of the hot water supply system (1)).

[0072] The estimation model (M1) of the present modification is also generated through “supervised learning”. Predetermined learning data stored in a data server is input to the estimation model (M1). Specifically, the input data includes nationwide user information (the number of family members, the age and gender of each family member, and residential area), information on the hot water supply targets (4) owned by each user (the number of hot water supply targets, types of the hot water supply targets (4), and faucet

information), the time-series data of the pressure of the water in the supply path (5) coupled to each of the hot water supply targets (4) of the hot water supply system (1) owned by each user, and the time-series data of the temperature of the water used in the hot water supply target. The training data is the second time-series data stored in the data server. The data server stores time-series data of past several years.

[0073] The neural network is caused to perform “supervised learning” by using such learning data. The trained estimation model (M1) of the present modification is generated as a result of learning. The estimation unit (33) predicts the total amount of hot water supply demand by using the trained estimation model (M1).

[0074] The storage unit (31) stores user data. The user data includes information such as a family structure (such as the number of family members and the age and gender of each family member) and a residential area.

[0075] As described above, the hot water supply system (1) of the present modification also predicts the total amount of hot water supply demand, based on the first time-series data of each hot water supply target, and thus can improve the prediction accuracy of the total amount of hot water supply demand. In particular, the trained estimation model (M1) of the present modification is generated by using the first time-series data of nationwide users stored in the data server. Thus, by inputting the information such as the residential area and the family structure of the user and the first time-series data to the trained estimation model (M1), the total amount of hot water supply demand according to the user can be obtained with a higher prediction accuracy than in the case of inputting the first time-series data alone.

[0076] In addition, since the hot water supply system (1) already includes the trained estimation model (M1) at the time of shipment, the user can use the hot water supply system (1) having a high prediction accuracy of the total amount of hot water supply demand from the start of use.

Second Modification

[0077] The hot water supply system (1) of the present modification predicts the total amount of hot water supply demand by using a predetermined logical expression.

[0078] An amount of hot water supply demand means an amount of heat of water for each of the hot water supply targets (4) used in a predetermined period. The amount of hot water supply demand corresponds to a total amount of heat of water used in each of the hot water supply targets (4).

[0079] The hot water supply system (1) of the present modification predicts the amount of hot water supply demand of each of the hot water supply targets (4), based on time-series data of an amount of heat of water used in the hot water supply target (4) in a predetermined period. The hot water supply system (1) then predicts the total amount of hot water supply demand, based on the predicted amounts of hot water supply demand of the respective hot water supply targets (4). A configuration different from those of the above-described embodiment and first modification will be described below.

[0080] As illustrated in FIG. 7, in the hot water supply system (1) of the present modification, the control unit (30) includes a calculation unit (34). The control unit (30) of the present modification does not include the estimation

model (M1). The first learning unit (32) does not perform machine learning.

[0081] The calculation unit (34) determines time-series data of the amount of hot water supply demand of each of the hot water supply targets (4) in a predetermined period, based on the first time-series data stored in the storage unit (31).

[0082] The estimation unit (33) predicts the amount of hot water supply demand of each of the hot water supply targets (4), based on the amount of hot water supply demand of the hot water supply target (4) in the predetermined period determined by the calculation unit (34). The amount of hot water supply demand of each of the hot water supply targets (4) is predicted by using a predetermined logical expression and a first coefficient. The total amount of hot water supply demand predicted by the estimation unit (33) may be time-series data that changes on a certain time (for example, hourly) basis for the next day. The estimation unit (33) predicts the total amount of hot water supply demand, based on the predicted amounts of hot water supply demand of the respective hot water supply targets (4). The total amount of hot water supply demand is predicted by using a predetermined logical expression and a second coefficient. The first learning unit (32) inputs the first coefficient and the second coefficient to the estimation unit (33).

[0083] The first learning unit (32) adjusts the first coefficient to reduce a residual between the amount of hot water supply demand in a predetermined period predicted by the estimation unit (33) for each of the hot water supply targets (4) and the amount of hot water supply demand actually used in the predetermined period. The first learning unit (32) inputs the adjusted first coefficient to the estimation unit (33). The first learning unit (32) adjusts the second coefficient to reduce a residual between the total amount of hot water supply demand in a predetermined period predicted by the estimation unit (33) and the total amount of hot water supply demand actually used in the predetermined period. The first learning unit (32) inputs the second coefficient to the estimation unit (33). Operation of Hot Water Supply System

[0084] An example of an operation of the hot water supply system (1) of the present modification will be described next with reference to FIG. 8. Since steps ST24 to ST26 are the same as steps ST3 to ST5 of the above-described embodiment, respectively, description thereof is omitted.

[0085] In step ST21, the control unit (30) determines, based on the first time-series data of a predetermined period (for example, one week up to the previous day) stored in the storage unit (31), time-series data of the amount of hot water supply demand of each of the hot water supply targets (4) in the period.

[0086] In step ST22, the control unit (30) predicts, by using the predetermined logical expression and the first coefficient, the amount of hot water supply demand of each of the hot water supply targets (4) for the next day, from the time-series data of the amount of hot water supply demand determined in step ST21.

[0087] In step ST23, the control unit (30) predicts the total amount of hot water supply demand for the next day from the amounts of hot water supply demand of the respective hot water supply targets (4) for the next day predicted in step ST22.

[0088] In step ST27, the control unit (30) adjusts the first coefficient to reduce a prediction error, based on the residual

between the amount of hot water supply demand of each of the hot water supply targets (4) predicted in step ST22 and the amount of hot water supply demand of the hot water supply target (4) actually used. The control unit (30) inputs the adjusted first coefficient to the estimation unit (33).

[0089] In step ST28, the control unit (30) adjusts the predetermined second coefficient to reduce a prediction error, based on the residual between the total amount of hot water supply demand predicted in step ST23 and the total amount of hot water supply demand actually used. The control unit (30) inputs the adjusted second coefficient to the estimation unit (33).

[0090] According to the present modification, by repeating the adjustment of input of the first coefficient for prediction of the amount of hot water supply demand of each of the hot water supply targets (4), the residual between the predicted amount of hot water supply demand of each of the hot water supply targets (4) and the amount of hot water supply demand of the hot water supply target (4) actually used can be reduced. Further, by repeating the adjustment of input of the second coefficient, the residual between the predicted amount of hot water supply demand and the hot water supply demand actually used can be reduced, and consequently the prediction accuracy of the total amount of hot water supply demand can be improved.

Third Modification

[0091] In the hot water supply system (1) of the present modification, the control unit (30) includes the trained operation prediction model (M2) that has performed learning in advance. A configuration different from those of the above-described embodiment and modifications will be described below.

[0092] As illustrated in FIG. 9, the control unit (30) of the present modification does not include the second learning unit (35). The operation prediction model (M2) of the present modification is generated in advance to predict control of the operation based on the total amount of hot water supply demand before the hot water supply system (1) is used by a user (before shipment of the hot water supply system (1)).

[0093] The operation prediction model (M2) of the present modification is also generated through “reinforcement learning”. The input data (such as nationwide user information (the number of family members, the age and gender of each family member, and residential area), information on the hot water supply targets (4) owned by each user (the number of hot water supply targets, type of the hot water supply targets, and faucet information), and the total amount of hot water supply demand of each user) stored in the data server of the above-described embodiment is input to the operation prediction model (M2). The electricity cost per day is set as the reward and the operation state of the heating apparatus (20) is set as the state variable, so that the trained operation prediction model (M2) that has performed learning to minimize the electricity cost for the operation of the heating apparatus (20) per day is generated. Thus, in response to input of the total amount of hot water supply demand to the trained operation prediction model (M2), control of the operation of the heating apparatus (20) to minimize the electric power is output.

[0094] As described above, also in the present modification, by using the operation prediction model (M2) trained

through machine learning, the heating apparatus (20) can be controlled so that the electricity cost per day is minimized as compared with the past electricity cost. In particular, the trained operation prediction model (M2) of the present modification is generated by using the total amount of hot water supply demand of nationwide users stored in the data server. Thus, by inputting the information such as the residential area and the family structure of the user and the total amount of hot water supply demand to the trained estimation model (M1), control of the operation of the heating apparatus (20) can be predicted which reduces the electricity cost more according to the user than in the case of inputting the total amount of hot water supply demand alone.

[0095] In addition, since the hot water supply system (1) already includes the trained operation prediction model (M2) at the time of shipment, the user can use the hot water supply system (1) that can control the operation of the heating apparatus (20) to reduce the electricity cost per day from the start of use.

Fourth Modification

[0096] The hot water supply system (1) of the present modification predicts control of the operation of the heating apparatus (20) from the total amount of hot water supply demand based on predetermined control. A configuration different from those of the above-described embodiment and modifications will be described below.

[0097] As illustrated in FIG. 10, in the hot water supply system (1) of the present modification, the control unit (30) includes a run-out-of-hot-water determining unit (36). The control unit (30) does not include the operation prediction model (M2).

[0098] If a detected value of the flow rate sensor (62) becomes zero while the heating apparatus (20) is ON, the run-out-of-hot-water determining unit (36) determines that there is no water in the tank (40) (hot water has run out).

[0099] The second learning unit (35) learns control of the operation of the heating apparatus (20) for reducing a risk of running out of hot water, based on the total amount of hot water supply demand. Specifically, if there is a time when hot water has run out as a result of controlling the operation state of the heating apparatus (20) based on the total amount of hot water supply demand predicted by the estimation unit (33), the second learning unit (35) corrects the control of the operation of the heating apparatus (20) performed on that day. Based on such a feedback, the second learning unit (35) corrects the control of the operation of the heating apparatus (20) and predicts control of the operation of the heating apparatus (20) for the next day.

Operation of Hot Water Supply System

[0100] An example of an operation of the hot water supply system (1) of the present modification will be described next with reference to FIG. 11. Since steps ST41 and ST42 are the same as steps ST1 and ST2 of the above-described embodiment, respectively, description thereof is omitted.

[0101] In step ST43, the control unit (30) predicts control of the operation of the heating apparatus (20), based on the total amount of hot water supply demand estimated by the estimation unit (33).

[0102] In step ST44, the control unit (30) controls the heating apparatus (20) to perform control of the operation predicted in step ST43.

[0103] In step ST45, the control unit (30) determines whether running out of hot water occurs while hot water is being supplied to the hot water supply target(s) (4). If running out of hot water occurs (YES in step ST45), the control unit (30) controls the heating apparatus (20) to boil the water supplied to the tank (40) (step ST44). If running out of hot water does not occur (NO in step ST45), step ST46 is performed.

[0104] In step ST46, the control unit (30) determines whether the operation of the heating apparatus (20) for one day has ended. If the operation has ended (YES in step ST46), step ST47 is performed. If the operation has not ended (NO in step ST46), step ST44 is performed again.

[0105] In step ST47, the control unit (30) determines whether running out of hot water has occurred in the operation of the heating apparatus (20) for the day. If running out of hot water has occurred (YES in step ST47), step ST48 is performed.

[0106] In step ST48, the control unit (30) corrects the control of the operation, based on the occurrence time of running out of hot water, the amount of water that has been boiled, the boiling temperature, and so on.

[0107] According to the present modification, the control unit (30) corrects the control of the operation of the heating apparatus (20) at each occurrence of running out of hot water. By predicting control of the operation, based on such a correction, the risk of running out of hot water on the next day can be reduced.

Other Embodiments

[0108] The above-described embodiment and modifications may be configured as follows.

[0109] The first index may be a temperature of water used in each of the hot water supply targets (4) and an amount of water in the supply path (5) connected to the hot water supply target (4). In this case, each of the supply paths (5) is provided with a flow rate sensor (not illustrated) that measures a flow rate of water. The flow rate sensor is connected to the control unit (30) with a cable or wirelessly.

[0110] The first index may be an amount of heat of water used in each of the hot water supply targets (4). The time-series data of the amount of heat of water used in each of the hot water supply targets (4) may be determined based on time-series data of the temperature of water used in the hot water supply target (4) and time-series data of a pressure of water in the supply path (5) coupled to the hot water supply target (4). The time-series data of the amount of heat of water used in each of the hot water supply targets (4) may be determined based on time-series data of the temperature of water used in the hot water supply target (4) and time-series data of an amount of water in the supply path (5) coupled to the hot water supply target (4). The time-series data of the amount of heat of water used in each of the hot water supply targets (4) is input to the estimation model (M1) as input data.

[0111] In reinforcement learning of the operation prediction model (M2), the operation state of the heating apparatus (20), which is set as the state variable, may be a rotation speed of the compressor (22), a condensation temperature of the utilization-side heat exchanger (25), an opening degree of the expansion valve (24), or the like. For example, the control unit (30) increases the rotation speed of the compressor (22) to heat water in the tank (40), or decreases the

opening degree of the expansion valve (24) to suppress an increase in the condensation temperature of the utilization-side heat exchanger (25) and thus to suppress heating of the water in the tank (40).

[0112] The hot water supply system (1) may include a predetermined sensor (not illustrated) capable of directly detecting an amount of heat of water used in each of the hot water supply targets (4). In this case, the time-series data of the amount of heat of water used in each of the hot water supply targets (4) detected not by the calculation unit (34) but by the sensor is input to the estimation model (M1).

[0113] The input data input to the estimation model (M1) may include at least one of the number of hot water supply targets (4), types of the hot water supply targets (4), and specifications of faucets of the hot water supply targets (4). As described above, by using, as input data, the information on each of the hot water supply targets (4) in addition to the first time-series data, the total amount of hot water supply demand can be predicted based on the hot water supply target (4) whose type is specified and the first time-series data of the hot water supply target (4). For example, if the hot water supply targets (4) are a bathtub and a shower, the bathtub (filling the bathtub with hot water) and the shower are often used at the same time or in relatively close time periods (before and during bathing). Thus, the first learning unit (32) can learn the total amount of hot water supply demand in consideration of the amount of hot water supply demand of the shower, based on the first time-series data of the bathtub, and can also learn the total amount of hot water supply demand in consideration of the amount of hot water supply demand of the bathtub, based on the first time-series data of the shower. By using the trained estimation model (M1) that has been trained in this way, the risk of running out of hot water can be reduced.

[0114] The total amount of hot water supply demand predicted by the estimation unit (33) may be an amount of heat of water to be used by the hot water supply apparatus (10) only in a predetermined time period (for example, one hour from a certain time on the next day).

[0115] In the above-described embodiment, the second time-series data may be determined based on a change in the temperature of hot water stored in the tank (40). In this case, a stored hot water temperature sensor (not illustrated) is provided in the tank (40). The stored hot water temperature sensor is connected to the control unit (30) with a cable or wirelessly. For example, when a temperature value obtained by the stored hot water temperature sensor decreases, the decrease indicates that hot water is supplied from the tank (40) and water is supplied to the tank (40). The amount of heat of water that has flowed out from the tank (40) can be determined based on how much the temperature detected by the stored hot water temperature sensor has decreased.

[0116] The estimation unit (33) may estimate the total amount of hot water supply demand, based on an amount (amounts) of used hot water in a selected one (selected ones) of the hot water supply targets (4). Thus, the prediction accuracy of the total amount of hot water supply demand can be improved by omitting a noise-like hot water supply target that decreases the prediction accuracy.

[0117] The estimation model (M1) can also be generated through “unsupervised learning”. In this case, the neural network repeats a learning operation of grouping a plurality of pieces of input data into a plurality of classifications by

clustering so that pieces of input data (total amounts of hot water supply demand) similar to one another are classified into the same classification. Thus, the trained estimation model (M1) can be generated without using training data. The estimation model (M1) may be generated through “reinforcement learning”.

[0118] The storage unit (31) does not have to be provided in the control unit (30). The storage unit (31) may be provided in a predetermined server that can communicate with the control unit (30).

[0119] In the above-described embodiment and modifications, the operation prediction model (M2) may be generated through “supervised learning” or “unsupervised learning”.

[0120] The first learning unit (32) may perform learning by using a learning method other than those used in the above-described embodiment and modifications. The second learning unit (35) may perform learning by using a learning method other than those used in the above-described embodiment and modifications.

[0121] While the embodiment and modifications have been described above, it should be understood that various modifications can be made on the configurations and details without departing from the gist and the scope of the claims. The embodiment and modifications described above may be combined or replaced as appropriate unless the functionality of the target of the present disclosure is reduced. The words “first” and “second” mentioned above are used to distinguish the terms to which these words are assigned, and do not limit the number or order of the terms.

[0122] As described above, the present disclosure is useful for a hot water supply system.

1. A hot water supply system comprising:
 - a hot water supply apparatus including
 - a heating apparatus configured to heat water,
 - a tank configured to store the water heated by the heating apparatus, and
 - a water circuit configured to circulate the water in the tank;
 - a plurality of supply paths, each supply path
 - being coupled to a corresponding one of a plurality of hot water supply targets and
 - being configured to supply the water from the tank; and
 - an estimation unit configured to predict a total amount of hot water supply demand, based on time-series data of a first index that indicates an amount of heat of water used in each of the plurality of hot water supply targets.
2. The hot water supply system according to claim 1, further comprising:
 - a first learning unit configured to learn the time-series data and the total amount of hot water supply demand in association with each other,
 - the estimation unit being configured to predict the total amount of hot water supply demand, based on a result of the learning performed by the first learning unit.
3. The hot water supply system according to claim 2, wherein
 - the first learning unit is configured to perform the learning through machine learning.
4. The hot water supply system according to claim 1, wherein
 - the estimation unit includes an estimation model generated through machine learning to predict, based on the time-series data, the total amount of hot water supply demand, and

the estimation unit is configured to predict the total amount of hot water supply demand by using the estimation model.

5. The hot water supply system according to claim 3, wherein

the estimation unit includes an estimation model generated through the machine learning to predict, based on the time-series data, the total amount of hot water supply demand, and

the estimation unit is configured to predict the total amount of hot water supply demand by using the estimation model.

6. The hot water supply system according to claim 1, wherein

the first index includes a temperature and an amount of the water used in each of the plurality of hot water supply targets.

7. The hot water supply system according to claim 1, wherein

the first index includes a temperature of the water used in each of the plurality of hot water supply targets and a pressure of the water in each of the supply paths.

8. The hot water supply system according to claim 1, wherein

the estimation unit is configured to predict the total amount of hot water supply demand, based on the time-series data and at least one of

a number of the hot water supply targets, types of the hot water supply targets, and specifications of faucets of the hot water supply targets.

9. The hot water supply system according to claim 1, wherein

the estimation unit is configured to predict the total amount of hot water supply demand, based on the time-series data for a selected one of the hot water supply targets.

10. The hot water supply system according to claim 1, further comprising:

a control unit configured to control an operation of the heating apparatus, based on the total amount of hot water supply demand.

11. The hot water supply system according to claim 10, further comprising:

a second learning unit configured to learn the total amount of hot water supply demand and an operation state of the heating apparatus in association with each other,

the control unit being configured to control the operation of the heating apparatus, based on a result of the learning performed by the second learning unit.

12. The hot water supply system according to claim 11, wherein

the second learning unit is configured to perform the learning through machine learning.

13. The hot water supply system according to claim 10, wherein

the control unit includes an operation prediction model generated through machine learning to predict, based on the total amount of hot water supply demand, control of the operation of the heating apparatus, and

the control unit is configured to control the operation of the heating apparatus by using the operation prediction model.

14. The hot water supply system according to claim 12, wherein

the control unit includes an operation prediction model generated through the machine learning to predict, based on the total amount of hot water supply demand, control of the operation of the heating apparatus, and

the control unit is configured to control the operation of the heating apparatus by using the operation prediction model.

15. The hot water supply system according to claim 1, wherein

the heating apparatus is a heat pump.

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