(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 741 729 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
13.05.2026 Bulletin 2026/20

(21) Application number: **24212277.8**

(22) Date of filing: **12.11.2024**

(51) International Patent Classification (IPC):
F24H 4/04 *(2006.01)* ***F24H 15/152*** *(2022.01)*
F24H 15/168 *(2022.01)* ***F24H 15/172*** *(2022.01)*

(52) Cooperative Patent Classification (CPC):
F24H 4/04; F24H 15/152; F24H 15/168; F24H 15/172

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
GE KH MA MD TN

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(54) HEAT PUMP WATER HEATER SCHEDULING WITH DYNAMIC TARIFFS

(57) An implementation of the disclosed technology provides a method of controlling a hot water system that includes a heat pump and a hot water tank. The method includes estimating the hot water usage over a past time period based on the heat production of the heat pump during the past time period, without relying on data from sensors measuring actual usage of hot water or hot water taken from the hot water tank. The method further includes estimating hot water usage over a future time period based on the estimated hot water usage over the past time period, accessing energy tariff data for the future time period, generating a schedule for operating the heat pump to optimize energy costs based on the estimated hot water usage over the future time period and the energy tariff data, and operating the hot water system according to the schedule.

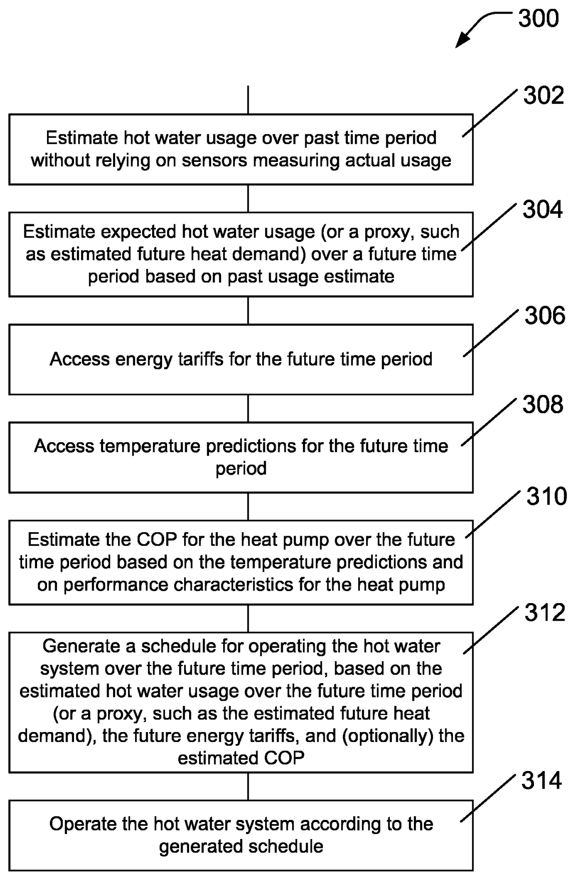

FIG. 3

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Description

TECHNICAL FIELD

[0001] The disclosed technology relates to heat pump water systems for use in production of hot water and/or heating systems, and in particular to control of such a heat pump water heating system to operate on a schedule to optimize energy costs based on dynamic energy tariff information.

BACKGROUND

[0002] Water heating systems are means of producing hot water for heating applications, in particular central heating with, e.g., radiators, underfloor heating or other heating means, water heating systems may alternatively or additionally be used in the production of domestic and/or sanitary hot water, also referred to as tap water. It will be understood that while much of the discussion here will center on heat pump water heaters that are used for the production of domestic hot water (DHW), similar systems may be used for other heating and/or cooling applications, and the discussion of heat pump water heaters is intended merely to **illustrate** the technology. Similar systems and methods may be applied to a wide range of applications in which water or other liquids are heated and/or cooled for use in a wide range of heating and/or cooling applications.

[0003] A heat pump water heater is a water heater with at least one heat pump as a water heating element. A heat pump water heater may have other associated heating means such as an electric resistive element or heat exchangers associated with a hot water circuit or, more generally, with other suitable refrigerant fluids. Supplementary heating, such as a gas-powered boiler, pellet boiler, thermal solar panel, and/or other heating systems may also be used.

[0004] Heat pump water heaters need an available energy/heat source to transfer heat to the water to be heated. Different sources can be used. The type of source can be used to differentiate and designate different types of heat pump water heaters. For example, ambient air heat pump water heaters use ambient air as an energy source. Ambient air entering and leaving the heat pump is drawn in and returned to the volume of air available at the installation site. The place of installation is often an unheated, frost-free room such as a utility room in a building (e.g., a cellar, garage, attic, etc.), though controlled temperature rooms may also be used. Ambient air heat pumps provide a simplified product compared to other heat pump types. This is because, e.g., the ambient air used has a limited and positive temperature range. In addition, the pressure losses in the air flow are low as the air is pulled in and discharged in the same space as the product location.

[0005] Ducted air heat pump water heaters use outside air as an energy source - i.e., air that is drawn in and/or discharged from and/or to the outside. This type of heat pump water heater offers greater flexibility in installation modes and allows the user to choose a configuration that provides for comfort throughout the year. For example, it is possible to choose to discharge the air from the heat pump to the outside when the outside temperature is below the comfort temperature of the room. Alternatively, one can choose to recirculate the air from the heat pump at the installation site when this provides comfort. This type of heat pump water heater may be susceptible to significant pressure drops due to lengths, bends, and height differences in the ducts. A heat pump system could also be split, with an outside portion (e.g., an outdoor unit (ODU) with a mono-block or split-block heat pump) and an indoor portion (e.g., an indoor unit (IDU) with the tank or heating/cooling circuit).

[0006] Extracted air heat pump water heaters use air extracted from a ventilation network of the installation building as an energy source. This air has a relatively constant and high temperature, as it comes from living areas of a dwelling. In general, this air may be particularly humid and can contain significant levels of dust or other debris, because it may come from damp rooms, such as bathrooms or kitchens. Heat pumps using this type of air must be able to operate with a relatively low air flow rate (that of the building's ventilation system). A fan may be included in the heat pump water heater. Alternatively, the fan of the ventilation system of the installation building may be used, removing the need for a fan in the heat pump water heater.

[0007] Water or ground source heat pump water heaters use an open (e.g., for underground water pumping) or closed (e.g., for soil) water circuit as an energy source. The water circuit may be the return of a heating circuit, a geothermal circuit or any other closed or open water circuit.

[0008] For all above-mentioned heat pump water heater types, the heat pump includes at least one closed refrigerant circuit. The refrigerant circuit includes a first heat exchanger with the source medium (an evaporator), a compressor, a second heat exchanger with the destination medium (a condenser), in particular water or other liquids (e.g., for use in heating and/or cooling applications, and/or domestic hot water), and an expansion device.

[0009] Control of heat pump water heating and/or cooling systems can present a number of challenges. Because it can take some time to heat or cool water using a heat pump, it may be difficult to ensure that there is sufficient hot or cool water to meet demands. For example, when the demand for hot water becomes greater than can be readily supplied, systems may fall back on other heat sources, such as electric resistive heating or a backup gas boiler. While these sources may be faster at producing hot water than a heat pump, they may be less energy efficient and/or more expensive or environmentally harmful to operate.

[0010] Environmental conditions can also cause control challenges. For example, heat pump water heating systems may be more efficient when the source medium (e.g., outside air, ambient air) is warm than when it is cold. In systems that use outside air, the heat pump may not be able to operate when the outside air temperature is too cold. As with meeting demands for hot and/or cool water, the energy efficiency of heat pumps will vary with environmental conditions, and the use of other heat sources, such as electric resistive heating or a backup gas boiler may make sense, depending on environmental conditions.

[0011] Additionally, users of such heating systems may wish to reduce or control their energy costs. Energy costs may vary over time, with prices or price forecasts being available ahead of the time that the energy is used. Thus, the times at which the heat pump is operated may affect the cost of providing hot water to meet demands, as may the timing of the demands, and the ability to efficiently store heated water for later use.

[0012] Control systems for heat pump water heating systems, therefore, may take into account environmental conditions (e.g., outdoor temperatures, solar production forecasts, etc.), anticipated hot water demand, energy consumption, defrost cycles, dynamic energy prices and other factors to deliver a desired level of comfort and a reasonable level of energy usage and cost.

[0013] While some of these factors, such as forecasted environmental conditions and dynamic energy prices, may be available, e.g., over the Internet from external sources, other factors, such as anticipated hot water demand, may vary with each individual user or household. Typically, anticipated hot water demand is determined on past usage patterns, which are typically measures using sensors that measure usage of hot water. Such sensors may be costly to purchase and install, may add significantly to the cost of a hot water system and/or may not always function correctly so that false sensor results or no sensor results are given. Additionally, in many existing systems, such usage sensors are not present and cannot be easily installed or added to the system. Controllers for such legacy systems, while possibly upgradable to improve the energy efficiency of the system, will not have access sensor-based measurements of hot water usage that would provide the data that is typically used to determine the anticipated hot water demand.

SUMMARY

[0014] Based on the above, it is an object to provide a controller for a hot water system, particularly a hot water system using a heat pump as a primary heat source, that is able to optimize energy costs using information such as forecasted environmental conditions, forecasted energy tariffs, and anticipated hot water demand. Because these factors may vary over time, it is a further object for the controller to generate a schedule for operating a heat pump water heating system that optimizes energy costs based on this information, and to operate the heat pump water heater according to the schedule.

[0015] It is a further object to provide a controller that is able to optimize energy costs using measures of anticipated hot water demand that do not require additional sensors to measure hot water usage. It is, therefore, an object to use sensors and measurements available in existing heat pump water heating systems, without relying on sensors that measure actual usage of hot water to estimate hot water demand.

[0016] For example, a heat pump may have access to information such as temperature and flow volume of water entering the heat pump, and temperature and flow volume of water leaving the heat pump, as well as the temperature of water in the storage tank. These are measurements relevant to the production of hot water and control of the heat pump, but generally do not directly indicate hot water usage. In most systems, hot water from the heat pump will either be delivered to a storage tank or buffer, or will be used in a heat exchanger to heat water in a tank or buffer. Direct measurements of hot water usage would depend on measurements of water (e.g., temperature and flow volume) taken from such a tank or buffer, rather than measurements of heat production by the heat pump or the temperature of the water in the tank. It is an object to avoid adding sensors to the system to directly measure usage, and to instead use other measurements, such as heat production, to estimate hot water usage or demand. By avoiding such additional sensors, the cost of a hot water system may be reduced, and advanced control systems, that are able to optimize energy costs, may be used with existing or legacy hot water systems that do not include sensors that directly measure hot water usage.

[0017] It should be understood that implementations of the present technology each have at least one of the above-mentioned objects and/or aspects, but do not necessarily have all of them. Some aspects of the present technology that have resulted from attempting to attain the above-mentioned objects may not satisfy these objects and/or may satisfy other objects not specifically recited herein.

[0018] It should also be understood that, as used herein, the term "hot water system" may provide hot and/or cool water or other liquids for a variety of applications. For example, a hot water system may provide domestic hot water, hot water for heating applications, such as room heating, and/or cool water for cooling applications, such as room cooling.

[0019] It will be understood that as used herein, "optimize" means only that the system attempts to improve (e.g., reduce) energy costs. There may be instances in which the system is able to improve the costs, but still lower costs would be possible, or cases in which no improvement or reduction actually occurs. It will further be appreciated that an energy "tariff" refers to the amount charged, e.g., by a producer or distributor of energy for a unit of energy at a particular time, while energy "cost" refers to the amount paid by a consumer of energy for the consumer's total usage over a period of time.

[0020] In some implementations, the disclosed technology provides a method of controlling at least a hot water system, the hot water system including a heat pump and a hot water tank. The method includes estimating, by a controller, a hot water usage over a past time period based at least in part on the heat production of the heat pump during the past time period, without relying on data from a sensor measuring actual usage of hot water or hot water taken from the hot water tank. The method further includes estimating, by the controller, hot water usage over a future time period based at least in part on the estimated hot water usage over the past time period. The method further includes accessing, by the controller, energy tariff data for at least a portion of the future time period, and generating, by the controller, a schedule for operating the heat pump to optimize energy costs based at least in part on the estimated hot water usage over the future time period and the energy tariff data for the future time period. The method further includes operating, using the controller, the hot water system according to the schedule.

[0021] In some implementations, the method further includes estimating, by the controller a heat demand over the future time period. Estimating, by the controller, hot water usage over a future time period includes using the estimated heat demand over the future time period as a proxy for the hot water usage. Advantageously, Heat demand can be estimated using information on the production of hot water, and does not require information from a sensor measuring actual usage of hot water or hot water taken from the hot water tank.

[0022] In some implementations, generating a schedule for operating the heat pump includes dividing the estimated heat demand over the future time period into an estimated heat demand for at least two time slots within the future time period. In some implementations, this may include generating a heat production target for each of numerous time slots within the future time period. Dividing the estimated heat demand into two or more time slots facilitates optimizing for a schedule that includes multiple periods of increased usage or demand, such as a high hot water demand during a time period in the morning and during a second time period in the evening. Additionally, energy tariff data may be available for multiple time slots during the future time period, and these changing tariffs can be taken into account by dividing the future time period into two or more time slots.

[0023] In some implementations, operating the hot water system according to the schedule includes using hysteresis control based on a temperature of hot water in the hot water tank. This is achieved by, for each time slot in the future time period: transforming the heat production target for the time slot into a temperature setpoint for the hot water tank, and, in relation to the time slot, setting the hot water tank temperature setpoint based on the transformed heat production target for the time slot; setting, at the start of the time slot, a hot water tank hysteresis value to a value low enough to cause the heat pump to start operating to heat the water in the hot water tank to the hot water tank temperature setpoint; and setting, at the end of the time slot, the hot water tank temperature setpoint and the hysteresis value to values sufficient to stop the heat pump from further heating the water in the hot water tank, and to prevent heating from starting again except according to the schedule. This provides a way to use common hysteresis control of a heat pump based on the water temperature in the hot water tank to more precisely control the heat production of the heat pump in accordance with the schedule. For example, the temperature setpoint and hysteresis values can be adjusted such that the heat pump is running during time slots in the schedule when energy tariffs are low, and is generally not running during time slots when energy tariffs are high.

[0024] In some implementations, the future time period is a 24 hour period that is divided into a predetermined number of time slots based on a number of time slots in the energy tariff data for the future time period. In many areas, future energy tariffs are available for a 24-hour period, and may vary over that time period, e.g., hourly. When future energy tariff information is available with, e.g., greater granularity than hourly, it may be advantageous to optimize for time slots that conform to the granularity of the future energy tariff information.

[0025] In some implementations, the heat pump uses outside air, and the method further includes: accessing, by the controller, air temperature predictions for the future time period; estimating, by the controller, a coefficient of performance (COP) of the heat pump over the future time period based at least in part on the outdoor air temperature predictions and on performance characteristics of the heat pump; and generating the schedule based at least in part on the estimated COP. In some of these implementations, accessing the air temperature predictions comprises accessing weather forecast data from a cloud-based weather service, the weather forecast data including the air temperature predictions or data from which the air temperature predictions can be derived. In systems with heat pumps that use outside air, the efficiency (i.e., COP) of the heat pump depends on the temperature of the outside air. To accurately predict the energy usage of such a heat pump (and the cost of running the heat pump), predictions of the outside air temperature are needed. These predictions, or data on which temperature predictions may be derived, may be available through weather forecasting services, such as cloud-based services, or may be obtained through other sources, such as past outdoor temperature data or models based on past outdoor temperature data.

[0026] In some implementations, the hot water system includes photovoltaic energy generation, and the method further includes: accessing, by the controller, solar irradiance predictions for the future time period; using, by the controller, the solar irradiance predictions to predict an amount of photovoltaic energy available for use by the hot water system over the future time period; and generating the schedule based at least in part on the predicted amount of photovoltaic energy available. For systems that include solar/photovoltaic energy generation, some or all of the available photovoltaic energy may be used to operate the heat pump, reducing the need to buy energy for running the heat pump from the grid. To accurately predict the cost of running the heat pump in such a system, an estimate of the amount of photovoltaic energy that will be available may be used. The estimated amount of photovoltaic energy that will be available in the future depends on solar irradiance predictions for the location where solar/photovoltaic panels are installed.

[0027] In some implementations, the heat production of the heat pump during the past time period is determined based at least in part on the measured temperature and flow volume of liquid into the heat pump and on the measured temperature and flow volume of liquid out of the heat pump. This is information that is often available for heat pumps, without requiring additional sensors. The input and output temperature and flow volume information from the heat pump relate generally to the heat production of the heat pump, and not to the actual hot water usage.

[0028] In some implementations, the heat production of the heat pump during the past time period is determined based at least in part on the energy usage of the heat pump over the past period of time. This information may be available on the heat pump or e.g., on a smart meter, without requiring additional sensors. The energy usage of the heat pump relates generally to the heat production of the heat pump, and not to the actual hot water usage.

[0029] In some implementations, generating a schedule for operating the heat pump to optimize energy costs includes using an optimization algorithm with an objective function based at least on estimated energy usage and the energy tariff data to optimize energy costs. Many such optimization algorithms are known, and may be used to optimize the schedule based on estimated future energy usage and future energy tariff information.

[0030] In some implementations, the disclosed technology further provides a controller configured to operate at least a hot water system, the hot water system including a heat pump and a hot water tank, the controller being arranged to carry out the method described above.

[0031] In some implementations, the disclosed technology further provides a hot water system, including a heat pump and a hot water tank. The hot water system further includes a controller as described above.

[0032] In some implementations, the disclosed technology further provides a computer-readable medium, such as a transient or non-transient computer-readable medium. A transient computer-readable medium may be, e.g., a signal transmitted over a wired or wireless communication medium, such as a bus or network. A non-transient computer-readable medium may be, e.g., a computer-readable storage medium, such as a memory device, an optical storage medium, or a magnetic storage medium. The computer-readable medium carries instructions for operating a hot water system to carry out the method discussed above.

[0033] In the context of the present specification, unless expressly provided otherwise, the words "first", "second", "third", etc. have been used as adjectives only for the purpose of allowing for distinction between the nouns that they modify from one another, and not for the purpose of describing any particular relationship between those nouns.

[0034] In the context of the present specification, unless expressly provided otherwise, directions indicated by terms such as "top", "bottom", "upper", "lower", "above", "below", etc., are used in their usual sense - i.e., relative to a gravitational direction or axis.

[0035] Additional and/or alternative features, aspects and advantages of implementations of the present technology will become apparent from the following description, the accompanying drawings and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0036] In the figures, the subject-matter of the disclosure is schematically shown, wherein identical or similarly acting elements are usually provided with the same reference signs.

FIG. 1 is a block diagram of an example controller that could be used in some implementations of a hot water system.
FIG. 2 is a block diagram of an example hot water system.
FIG. 3 is a block diagram illustrating a method for generating a schedule for operating a heat pump-based hot water system to optimize energy costs.
FIG. 4 shows an objective function and constraints that may be used for optimization of cost, in accordance with the described technology.

DETAILED DESCRIPTION

[0037] The examples and conditional language recited herein are principally intended to aid the reader in understanding the principles of the present technology and not to limit its scope to such specifically recited examples and conditions. It will be appreciated that those skilled in the art may devise various arrangements that, although not explicitly described or shown herein, nonetheless embody the principles of the present technology.

[0038] Furthermore, as an aid to understanding, the following description may describe relatively simplified implementations of the present technology. As persons skilled in the art would understand, various implementations of the present technology may be of a greater complexity.

[0039] In some cases, what are believed to be helpful examples of modifications to the present technology may also be set forth. This is done merely as an aid to understanding, and, again, not to define the scope or set forth the bounds of the present technology. These modifications are not an exhaustive list, and a person skilled in the art may make other modifications while nonetheless remaining within the scope of the present technology. Further, where no examples of modifications have been set forth, it should not be interpreted that no modifications are possible and/or that what is described is the sole manner of implementing that element of the present technology.

[0040] Moreover, all statements herein reciting principles, aspects, and implementations of the present technology, as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof, whether they are currently known or developed in the future. Thus, for example, it will be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative systems embodying the principles of the present technology.

[0041] With these fundamentals in place, we will now consider some non-limiting examples to illustrate various implementations of aspects of the present disclosure.

<u>Controller</u>

[0042] FIG. 1 depicts an example controller 100, which may be any type of computer system or embedded controller. It will be recognized that some or all the components of the controller 100 may be virtualized and/or cloud-based. As depicted, the controller 100 may include one or more processors 102, a memory 110, a storage interface 120, and a communication interface 140. These system components may be interconnected via a bus 150, which may include one or more internal and/or external buses (not shown) (e.g. a PCI bus, universal serial bus, IEEE 1394 "Firewire" bus, SCSI bus, Serial-ATA bus, etc.), to which these various hardware components may be electronically coupled.

[0043] The memory 110, which may be a random-access memory or any other type of memory, may contain data 112, an optional operating system 114 (it will be understood that not all controllers require an operating system), and a program 116. The data 112 may be any data that serves as input to or output from any program in the controller 100. The operating system 114, which is optional, since not all control applications require use of an operating system, may be an operating system such as MICROSOFT WINDOWS, FreeRTOS, an operating system based on the LINUX kernel (e.g., UBUNTU, DEBIAN, FEDORA, ARCH, SUSE, etc.), or any other operating system suitable for use on a computer system or microcontroller. The program 116 may be any program or set of programs that include program instructions that may be executed by the processor to control actions taken by the controller 100. In particular, the program 116 may include program instructions that, when executed by the processor, cause the processor to carry out one or more of the methods described below.

[0044] The storage interface 120 may be used to connect storage devices, such as the depicted storage device 125, to the controller 100. The storage device 125 may be a solid-state drive using an integrated circuit assembly to store data persistently. Alternatively, the storage device 125 may be a hard drive using any of a variety of types of magnetic storage media to store and retrieve digital data. As another alternative, the storage device 125 may be an optical drive, or a card reader that receives a removable non-volatile semiconductor memory card. As still another alternative, the storage interface 120 may provide a universal serial bus connection to which the storage device 125 may be hot-pluggable, and the storage device 125 may be a flash memory device (e.g., a USB thumb drive). In some implementations, in which storage of data is not necessary, the storage interface 120 and storage device 125 may optionally be omitted.

[0045] In some implementations, the controller 100 may use well-known virtual memory addressing techniques that allow the programs of the controller 100 to behave as if they have access to a large, contiguous address space instead of access to multiple, smaller storage spaces, such as the memory 110 and the storage device 125. Therefore, while the data 112, the optional operating system 114, and the programs 116 are depicted as residing in the memory 110, those skilled in the art will recognize that these items may not necessarily be wholly contained in the memory 110 at the same time.

[0046] The one or more processors 102 may include one or more microprocessors and/or other integrated circuits able to execute program instructions stored in the memory 110. When the controller 100 starts up, the processor(s) 102 may initially execute program instructions of a boot routine and/or the program instructions that make up the operating system 114.

[0047] The communication interface 140 may be used to communicatively connect the controller 100 to other controllers, computer systems, or still other devices (not shown) via a communication channel 160. The communication channel 160 may be a serial or parallel connection, a wired, wireless, mesh or cellular network, or any other type of communication channel or combination of channels. Data and/or program instructions may be sent to the controller 100 as signals via the communication channel. The communication interface 140 may include a combination of hardware and software that enables communications on the communication channel 160. The software in the communication interface 140 may include software that uses one or more communication protocols to communicate over the communication channel 160, including and not limited to, network protocols such as TCP/IP (Transmission Control Protocol/Internet

Protocol) or Modbus.

[0048] It will be understood that the depicted controller 100 is merely an example, and that the technology disclosed herein may be used with a wide variety of other controllers or computer systems, or still other computing devices having different configurations.

Hot Water System

[0049] FIG. 2 depicts an example hot water system 200. The hot water system 200 is generally used to provide domestic hot water to a domestic hot water installation, such as is used in a residential dwelling, but may be used in other heating and/or cooling applications, such as room heating or room cooling. However, it will be understood that the hot water system 200 may be used in other types of buildings, such as apartment buildings or other multi-dwelling buildings, office buildings, or any other type of building at which hot water systems are installed and/or controlled. It will also be understood that although referred to as a "hot water system", the hot water system 200 may also be used in cooling applications, in which the water is cooled, e.g., for use in room cooling.

[0050] As depicted, the hot water system 200 is a heat pump-based system with an optional electric resistive heating element providing backup heating. The system includes a heat pump 202 (the construction and operation of such a heat pump being well-known) and a hot water tank 204, which supplies hot water to a domestic hot water output 220, which may include (for example) hot water taps (not shown), showers (not shown), and other outlets or appliances that consume domestic hot water (not shown). The domestic hot water output 220 may mix the hot water from the hot water tank 204 with cold water to produce a range of water temperatures for domestic use.

[0051] A heat exchanger 206 in the hot water tank 204 transfers heat from primary water (or other heating fluids, such as a water-glycol mixture) warmed by the heat pump 202 to the sanitary domestic hot water in the hot water tank 204. An electric resistive heating element 208 may optionally be included in the primary water lines from the heat pump 202 to the hot water tank 204 (as shown) or may be included directly in the hot water tank 204 to serve as backup heating, during periods in which the heat pump 202 may be unable to provide sufficient heating to meet the demand for domestic hot water. Other backup systems, such as electric, oil, hydrogen, wood, and/or gas-powered boilers, solar thermal systems, additional heat pumps, and/or other known heating systems may optionally be used in addition to the heat pump 202 to heat the primary water (or other heating fluids) that heat the domestic hot water in the hot water tank 204. These additional heat sources may be referred to herein as hydraulic heat sources or hydraulic backup heat sources.

[0052] A controller 210, which may be similar to the example controller 100, described above, controls the heat pump 202, the optional electric resistive heating element 208, any optional hydraulic heat sources (not shown), and/or other devices and actuators that control the flow and mixing of domestic hot water through the hot water system 200. The controller 210 may be connected to various sensors (not shown) that provide information on, e.g., temperatures and flow volumes of the primary water circulating in the heat pump 202, a water temperature in the hot water tank 204, ambient air temperature, and other measurements that may be used (as described below) to control the hot water system 200. The controller 210 may also be connected to a cloud-based system 250, which may provide access to databases, updates, commands from users, remote commands or information, external services, cloud-based storage, or other information sources and services that may be accessed, e.g., over the Internet. For example, the cloud-based system 250 may be used by the controller 210 to access weather predictions and tariff information that may be used by the controller 210. In some implementations, most of the control of the hot water system 200 may be carried out in the cloud-based system 250, with the controller 210 serving primarily to communicate commands to the hot water system 200, and as a backup controller if there are communication problems that prevent communications between the cloud-based system 250 and the controller 210.

[0053] The controller 210 may communicate with various system components in a variety of ways. For example, the controller 210 may communicate wirelessly with sensors, actuators, hydraulic heat sources, and/or other system components using a wireless communication protocol, such as WIFI, Bluetooth, or Zigbee. In some implementations, they may communicate over a wired bus, using protocols such as OpenTherm. Some devices, such as sensors, may be directly connected to the controller 210. For some devices, including older boilers, etc., the controller 210 may be limited to controlling the device using on/off signals. In some implementations, the controller 210 may use numerous types of communication, depending on the devices that are being controlled.

[0054] In some implementations, the heat pump 202 may be built within a single housing (not shown) that also houses the hot water tank 204, the controller 210, and the optional electric resistive heating element 208, to provide a self-contained water heating appliance. In some implementations, such a self-contained water heating appliance may also include an optional backup hydraulic heat source, such as a boiler within the single housing or as an attachment to the housing. In some implementations, the heat pump 202 may more directly heat the domestic hot water in the hot water tank 204, without use of primary water or the heat exchanger 206 (e.g., the water in the hot water tank 204 is heated through heat exchange with the refrigerant circuit of the heat pump 202).

[0055] It will be understood that although the example hot water system 200 shown in FIG. 2 is configured to provide domestic hot water, other configurations could be used to provide hot water for heating and/or cooling applications (e.g., through radiators, underfloor or ceiling heating or cooling loops, etc.). Such systems may include, e.g., various load circuits and pumps, to provide hot or cool water to heating or cooling zones in a house. Other hot water systems 200 may provide hot water for both heating/cooling and domestic hot water uses. Such systems may include load circuits that include domestic heating, such as through radiators, and at least one load circuit that includes a hot water tank for domestic hot water, such as is shown in FIG. 2. While the technology is discussed primarily in terms of control for providing domestic hot water, it will be understood that similar optimization techniques could be used in domestic heating systems, and/or in systems that provide both domestic heating/cooling and domestic hot water.

Control

[0056] The hot water system 200 may be controlled by the controller 210 and/or a cloud-based control system to provide enough hot water at the right times to provide adequate comfort for users of the system, while reducing energy costs to provide that hot water. In some implementations, the controller 210 and/or a cloud-based control system will base this control on time-dependent information, such as anticipated hot water usage at various times of days, electricity tariffs at various times of the day, and weather conditions, such as outdoor temperatures at various times of the day. Due to the time dependence of these factors that affect the operation and cost of operating the hot water system 200, in some implementations, the controller 210 and/or a cloud-based control system may generate a schedule for operating the hot water system 200 that attempts to optimize costs while maintaining comfort. Once such a schedule is generated, it may be used to operate the hot water system 200.

[0057] FIG. 3 shows a block diagram of a method 300 for generating a schedule for operating a heat pump-based hot water system, such as the hot water system 200, to optimize energy costs while providing enough hot water to meet estimated user demands. This is done without relying on data from sensors measuring actual usage of hot water (i.e., usage by a human consumer or central heating system - not usage/intake by the hot water tank 204) or hot water taken from or in the tank (e.g., the hot water tank 204). The method described with reference to FIG. 3 may be operated as a program on the controller 210 shown in FIG. 2, may be operated on the cloud-based system 250, may be operated on separate controllers, which may be hardware-based, virtual, or cloud-based (not shown in FIG. 2), or may be distributed between any combination of these.

[0058] In block 302, the controller estimates the hot water usage over a past time period based (HWU_PTP) at least in part on the heat production of the heat pump 202 (HP) during a past time period (HP_HEAT_PROD_PTP). This is done without relying on data from sensors measuring actual usage of hot water or hot water taken from the hot water tank 204 or hot water in the hot water tank 204.

[0059] This may be achieved in some implementations by assessing the heat produced by the heat pump 202 over the past time period, such as the previous two-week period. The heat production may be determined based on sensors that are associated with the heat pump 202, such as the flow volume and temperature of water or other fluids entering the heat pump, and the flow volume and temperature of water or other fluids that have been heated by the heat pump 202. By knowing the volume of water or other fluids, and the temperature increase, the heat produced by the heat pump 202 may be determined. It should be clear that the flow volumes and temperatures of water or other fluids entering the heat pump and leaving the heat pump are information related to production of heat by the heat pump, and are not measures of actual usage of hot water.

[0060] Alternatively, the electricity usage of the heat pump 202 may be measured (e.g., by a smart meter). This electricity usage, combined with information on environmental temperatures (to determine the coefficient of performance (COP) of the heat pump), may be used to determine the amount of heat produced by the heat pump 202. Again, this is a measure of energy usage - not a measure of actual hot water usage.

[0061] The heat production of the heat pump 202, while it does not provide a precise measurement of hot water usage, does provide information on the amount of energy that was delivered to the hot water tank 204 to provide adequate comfort to the user. In accordance with some implementations, this may be used as a proxy for estimating hot water usage.

[0062] In block 304, the estimated past hot water usage (EST_HW_USE_PTP) is used to estimate the expected hot water usage over a future time period (EST_HW_USE_FTP), such as the following day. In some implementations, this may involve removing outliers from the heat production measurements that were discussed above, such as by removing any daily heat production above the 95th percentile. Once outliers have been removed, the maximum heat production over a predetermined past time period may be used to estimate the amount of energy that needs to be delivered to the hot water tank 204 by the heat pump 202 (i.e., an estimated future heat demand by the hot water system). For example, the maximum (non-outlier) heat production for a day over the past two weeks could be used. This estimated future heat demand (EST_HD_FTP) may be used as a proxy for the estimated hot water usage over the future time period, such as the next day. Use of the maximum heat production may increase the potential cost, but will reduce the risk of there being too little hot water production to satisfy needs (which could lead to increased cost if, for example, an electric resistive heating element is used to quickly heat water to handle the shortage). While using the maximum heat production may produce excess heating in the short-term, excess heat production will be effectively carried over to future time periods (less, e.g., heat losses from the tank), so that the maximum heat production over a past period will tend toward the heat production needed to meet actual demand. It should be noted that the future time period may be a period of a day, or a period of time either shorter or longer than a day. In general, the future period over which heat demand is estimated and costs are to be optimized may depend on the period of time into the future over which future tariff information is available.

[0063] It will be understood that other methods of estimating future hot water usage could also be used. For example, an average or median heat production could be used, instead of the maximum, though this would increase the risk of producing too little hot water. Additionally, the daily heat production over other past time periods could be used. For example, the average, median, or maximum heat production over the past month or six months could be used instead of over the past two weeks. Parameters such as whether to use the maximum, average, median, and the past time period to use for estimating future heat production may be either built-in to the control system, controllable by the system provider, or selected by the user. Additionally, it will be understood that data other than past heat production may be used to estimate hot water demand or heat demand in some implementations, depending on the sensors and other information available to the system.

[0064] In block 306, the system accesses the energy tariffs for a future time period (ETRF_FTP). For example, it is common for electricity tariffs to be available hourly over the next 24-hour period. For example, for some regions, such dynamic tariff information may be available from the EPEX Spot market, via an API. Such dynamic tariff or pricing systems will typically depend on the market for electricity in a given market or location, generally providing lower tariffs for electricity during periods of relatively low demand, and higher tariffs during high demand periods.

[0065] In some implementations, the controller 210 may access the information directly through an API associated with the energy market. In some implementations, a system provider, such as the provider of the controller or heating system may make the future pricing data available through a cloud-based service or API. Depending on the source of the tariff information, information for the next day may be made available at a predetermined time once per day, or may be available at other intervals.

[0066] In block 308, in heat pump systems that include an outdoor unit or that otherwise use outdoor air as a source of heat, the system accesses outdoor temperature predictions (TEMP_FTP) for the future time period, such as hourly temperature predictions for the next 24-hour period. The COP of the heat pump for such air source heat pumps will be dependent on the outdoor temperature, so predicting how much electricity/energy will be needed for heat production will be based at least in part on outdoor air temperatures for the location at which the heat pump is installed, as well as on characteristics of the heat pump. In general, for each model of heat pump, there will be data on the COP dependent on the air temperature. While this COP may vary slightly from unit to unit, it is typically sufficient for the controller to have access to the COP data for the heat pump model that is being used.

[0067] In some implementations, outdoor temperature predictions can be accessed from, e.g., a weather service. In some implementations, a weather model or machine learning algorithm may be used to predict future temperatures. In some implementations, the controller 210 may access the weather predictions directly through an API associated with, e.g., a weather service. In some implementations, a system provider, such as the provider of the controller or heating system may make weather prediction data available through a cloud-based service or API.

[0068] In block 310, the system estimates the COP of the heat pump for the future time period (EST_COP_FTP), based at least in part on the predicted outdoor air temperature for the location of the heat pump (i.e., TEMP_FTP), and on the performance characteristics for the heat pump (PERF _HP). As discussed above, the performance characteristics will vary from unit to unit, but data on the performance characteristics of the model of the heat pump will generally be sufficient to provide an estimate of the COP for a given external air temperature. Similarly, while the actual temperature may vary slightly from the predicted outdoor air temperature, the predictions are usually sufficient for estimating the COP.

[0069] In block 312, the system generates a schedule for operating the hot water system (and, in particular, the heat pump) over the future time period (SCHED_FTP), based at least in part on the estimated hot water usage over the future time period (i.e., the estimated future demand for heat production), and the future energy tariffs (and, in some implementations, estimated COP). In some implementations, due to the lack of sensors that provide information on the timing of actual usage of hot water, the system may split its estimate or proxy for hot water usage into time slots based on predetermined timing strategies either built into the controller, provided by the user, pre-programmed by an installer, or provided by the system or controller manufacturer or provider. For example, in some implementations, the heat demand may be split evenly between two time slots - one occurring in the morning, and one in the evening. This may represent, e.g., the potentially high demand for hot water in the morning, for showers, etc., and the potentially high demand in the evening, for cleaning, dish washing, washing before bed, etc. Of course, this usage pattern may not apply in all households or to all users of hot water, so in some implementations, other schedules may be used to divide the heat demand and to assign it to particular times in a schedule.

[0070] Once the heat demand has been assigned to particular times in the schedule, then the task of the controller in generating the schedule is to meet the heat demand by the assigned time, at a reduced cost, based on the energy tariffs at particular times, and on the predicted COP values (based, e.g., on weather predictions). An optimization method for generating the schedule is described in greater detail below. In general, once the heat production targets and times are determined, and the estimated COPS and future energy tariffs for each future time slot are known, numerous known optimization techniques may be used to determine the schedule for operating the heat pump 202.

[0071] As will be discussed below, the optimization is subject to a number of constraints. For example, for each time slot during the future time period (e.g., for each hour of the next 24-hour period), the amount of energy used by the heat pump cannot be higher than a maximum energy that the heat pump can use during the time slot. Similarly, during any time slot, the system cannot store more energy in the hot water tank (e.g., in terms of volume and temperature) than the hot water tank can hold.

[0072] In some implementations, the schedule for operating the heat pump 202 will result in a heat production target for each time slot in the future time period. For example, the schedule may result in a heat production target for each hour over the next 24 hours. This heat production target gives the estimated heat production that should be achieved by the heating system, and the time (i.e., the end of the time slot) by which the heat production target should be reached.

[0073] At block 314, the system operates the hot water system, and particularly the heat pump, according to the generated schedule (i.e., SCHED_FTP). In some implementations, this may be done using hysteresis control. For hot water systems with hysteresis control, given a setpoint x and a hysteresis y, the heat pump will start operation when the temperature inside the tank drops below *x-y.* Using such control, the system does not start the heat pump for very small increments of temperature, but waits until the temperature has dropped more inside the tank. In such a system, at the start of each time slot (e.g., at the start of each hour), the heat production target calculated by the optimization is transformed into a temperature setpoint for the hot water tank. The system may then set the hysteresis value low (e.g., 2° C) to cause the heat pump to start operating. Once the setpoint is reached in the hot water tank, the setpoint will be maintained (within the small hysteresis value) until the end of the time slot. At the end of the time slot (e.g., at the end of the hour), the system will set the setpoint to a low value (e.g, 40° C) and hysteresis to a high value (e.g., 20° C) to stop the heating and to prevent it starting again unless the system needs it to do so according to the generated schedule. It should be noted that this larger hysteresis band outside of the operation times of the heat pump may permit the temperature in the hot water tank to drop to a lower temperature while still maintaining comfort. Because the heat pump is more efficient when heating water at lower temperatures, this may result in lower energy consumption for providing substantially the same amount of comfort to the end user.

[0074] It will be understood that there may be many variations on the method described above, depending on the details of the hot water system, and the availability of information on future tariffs and weather conditions. For example, some hot water systems may include the ability to use electricity generated by photovoltaic solar generation. In such systems, it may be desirable to take the photovoltaic generation into account in the optimization. This can be done, e.g., by assigning a value to the photovoltaic electricity used based on the value at which it could have been sold back to the grid had it not been used in heat production. Performing tariff optimization in such a system may require estimates of photovoltaic generation, which will depend on solar irradiance, as well as temperature. Since predictions of solar irradiance at a particular location are generally less certain than air temperature predictions, it may be desirable to update the predictions and the generated schedule more often in systems that use photovoltaic energy generation in the hot water system.

[0075] Other variations will include variations in the number of time slots, the future period over which the schedule is generated, the past time period that is used for estimating heat demand or other proxies for hot water usage, the way in which estimated heat demand is divided over the future time period, etc. Generally, these parameters may be built into the control system, or may be adjusted by an installer, user, or by the provider of the control system.

[0076] In some implementations, the method described above for generating a schedule for control of the hot water system may be run periodically. For example, the method may be run once during each 24-hour period to generate a schedule for the next 24 hours. In some implementations, the method may run each day shortly after the hourly energy tariffs for the next 24 hours are made available. It will, of course, be understood that other time periods and timing for running the method could also be used, depending on the system and the availability of future tariffs and weather predictions. For example, as discussed above, it may be desirable to update the generated schedule more often for systems that use energy from photovoltaic generation in the hot water system.

[0077] FIG. 4 shows an objective function 402 and constraints 404 that may be used for optimization of cost in the method discussed above with reference to FIG. 3. It will be understood that the objective function and constraints can be used with any of a number of known optimization techniques or algorithms, such as genetic algorithms, simulated annealing, particle swarm optimization, or other known heuristic or other optimization techniques.

[0078] It will also be understood that in the objective function 402 and constraints 404, the variables are vectors of a length that corresponds to the number of time slots in the future time period. For example, for a system that is attempting to generate a schedule for each hour of a 24-hour period, the variables will be vectors of length 24.

[0079] The example objective function 402 shown in FIG. 4 includes terms related to photovoltaic generation of energy that may be used in providing energy to a heat pump. This photovoltaic energy will be referred to as a PV surplus. It should be noted that in systems without photovoltaic generation, the terms related to the PV surplus simply drop out of the function (e.g., E_{togrid}, $E_{pvsurplus\_used}$, and $E_{pvsurplus\_total}$ will all be 0 - i.e., vectors containing all 0 values).

[0080] The objective function to be minimized through known optimization techniques is shown as objective function 402:

$$Cost_{total} = E_{fromgrid} \cdot Price_{energy\_buy} - E_{togrid} \cdot Price_{energy\_sell}$$

where:

$$E_{fromgrid} = x - E_{pvsurplus\_used}$$

$$E_{togrid} = E_{pvsurplus\_total} - E_{pvsurplus\_used}$$

and x is the energy consumption of the heat pump.

[0081] It will be understood that: $Cost_{total}$ is the total cost, which is being optimized; $E_{fmmgrid}$ is the energy/electricity bought from the grid (a vector containing the energy for each time slot); $Price_{energy\_buy}$ is the energy/electricity tariff or price per unit (a vector with the price for each time slot in the future time period); E_{togrid} is the energy/electricity sold back to the grid (a vector containing the amount of energy for each time slot); $Price_{enregy\_sell}$ is the price at which energy/electricity may be sold to the grid (a vector containing a price for each time slot); $E_{pvsurplus\_total}$ is the total amount of PV surplus available (a vector containing the predicted PV surplus for each time slot in the future time period); and $E_{pvsurplus\_used}$ is the amount of the PV surplus used for the heat pump (a vector with the amount of PV surplus used for each time slot).

[0082] The constraints 404 for the optimization are as follows:

$$(1)\ 0 \leq x \leq E_{hp\_consumption\_max}$$

$$(2)\ 0 \leq E_{inside\_tank} \leq E_{tank\_max}$$

$$(3)\ \sum_1^n x * COP(t) \geq \sum_1^n E_{demand}$$

where x is the energy consumption of the heat pump.

[0083] It will be understood that these constraints are as follows: (1) for each time slot, the amount of energy used by the heat pump cannot be higher than the maximum amount of energy that the heat pump can use during that time slot; (2) during any given time slot, the amount of energy stored in the water in the hot water tank (in terms of both volume and temperature) cannot be higher than the maximum amount that the hot water tank can hold; and (3) the sum of the energy we use for each time slot times the COP for each time slot must be greater than or equal to the heat demand that was estimated - this is a constraint on the heat to be produced over the future time period (divided into n time slots - so n=24 for a one hour time slot with a 24 hour future time period).

[0084] It will be understood that, although the embodiments and/or implementations presented herein have been described with reference to specific features and structures, various modifications and combinations may be made without departing from the disclosure. For example, it is contemplated that in some implementations, the features described above may be used in different arrangements, or in other combinations. The specification and drawings are, accordingly, to be regarded simply as an illustration of the discussed implementations or embodiments and their principles as defined by the appended claims, and are contemplated to cover any and all modifications, variations, combinations or equivalents that fall within the scope of the present disclosure.

REFERENCE SIGNS

[0085]

100	controller
102	processors
110	memory
112	data
114	operating system
116	program
120	storage interface
125	storage device

140	communication interface
150	bus
160	communication channel
200	hot water system
202	heat pump
204	hot water tank
206	heat exchanger
208	electric resistive heating element
210	controller
220	hot water output
250	cloud-based system
300	method
302-314	method blocks
402	objective function
404	constraints

Claims

1. A method (300) of controlling at least a hot water system (200), the hot water system comprising a heat pump (202) and a hot water tank (204), wherein the method (300) comprises:

   estimating (302), by a controller (100, 210), a hot water usage over a past time period based at least in part on a heat production of the heat pump (202) during the past time period, without relying on data from a sensor measuring actual usage of hot water or hot water taken from the hot water tank (204);
   estimating (304), by the controller (100, 210), hot water usage over a future time period based at least in part on the estimated hot water usage over the past time period;
   accessing (306), by the controller (100, 210), energy tariff data for at least a portion of the future time period;
   generating (312), by the controller (100, 210), a schedule for operating the heat pump (202) to optimize energy costs based at least in part on the estimated hot water usage over the future time period and the energy tariff data for the future time period; and
   operating (314), using the controller (100, 210), the hot water system (200) according to the schedule.

2. The method (300) of claim 1, further comprising:

   estimating, by the controller (100, 210), a heat demand over the future time period;
   wherein estimating (304), by the controller (100, 210), hot water usage over a future time period comprises using the estimated heat demand over the future time period as a proxy for the hot water usage.

3. The method (300) of claim 2, wherein generating (312), by the controller (100, 210), a schedule for operating the heat pump (202) comprises dividing the estimated heat demand over the future time period into an estimated heat demand for at least two time slots within the future time period.

4. The method (300) of claim 2 or claim 3, wherein generating (312), by the controller (100, 210), a schedule for operating the heat pump (202) to optimize energy costs comprises generating a heat production target for a plurality of time slots within the future time period, the heat production target specifying an estimated heat production to be achieved by the heat pump by an end of the time slot associated with the heat production target.

5. The method (300) of claim 4, wherein operating (314), using the controller (100, 210), the hot water system (200) according to the schedule comprises using hysteresis control based on a temperature of hot water in the hot water tank (204) by, for each time slot in the future time period:

   transforming the heat production target for the time slot into a temperature setpoint for the hot water tank (204), and, in relation to the time slot, setting the hot water tank temperature setpoint based on the transformed heat production target for the time slot;
   setting, at the start of the time slot, a hot water tank hysteresis value to a value low enough to cause the heat pump (202) to start operating to heat the water in the hot water tank (204) to the hot water tank temperature setpoint; and
   setting, at the end of the time slot, the hot water tank temperature setpoint and the hysteresis value to values sufficient to stop the heat pump (202) from further heating the water in the hot water tank (204), and to prevent

heating from starting again except in accordance with the schedule.

6. The method (300) of any one of the preceding claims, wherein the future time period comprises a 24 hour period that is divided into a predetermined number of time slots based on a number of time slots in the energy tariff data for the future time period.

7. The method (300) of any one of the preceding claims, wherein the heat pump (202) uses outdoor air, and wherein the method (300) further comprises:

accessing (308), by the controller (100, 210), outdoor air temperature predictions for the future time period;
estimating (310), by the controller, a coefficient of performance (COP) of the heat pump (202) over the future time period based at least in part on the outdoor air temperature predictions and on performance characteristics of the heat pump (202); and
generating (312) the schedule based at least in part on the estimated COP.

8. The method (300) of claim 7, wherein accessing the air temperature predictions comprises accessing weather forecast data from a cloud-based weather service, the weather forecast data comprising the air temperature predictions or data from which the air temperature predictions can be derived.

9. The method (300) of any one of the preceding claims, wherein the hot water system (200) includes photovoltaic energy generation, and wherein the method further comprises:

accessing, by the controller (100, 210), solar irradiance predictions for the future time period;
using, by the controller (100, 210), the solar irradiance predictions to predict an amount of photovoltaic energy available for use by the hot water system (200) over the future time period; and
generating (312) the schedule based at least in part on the predicted amount of photovoltaic energy available.

10. The method (300) of any one of the preceding claims, wherein heat production of the heat pump (202) during the past time period is determined based at least in part on a measured temperature and a flow volume of liquid into the heat pump (202) and on a measured temperature and a flow volume of liquid out of the heat pump (202).

11. The method (300) of any one of the preceding claims, wherein the heat production of the heat pump (202) during the past time period is determined based at least in part on energy usage of the heat pump (202) over the past period of time.

12. The method (300) of any one of the preceding claims, wherein generating, by the controller (100, 210), a schedule for operating the heat pump (202) to optimize energy costs comprises using an optimization algorithm with an objective function (402) based at least on estimated energy usage and the energy tariff data to optimize energy costs.

13. A controller (100, 210) configured to operate at least a hot water system (200), the hot water system (200) comprising a heat pump (202) and a hot water tank (204), the controller (100, 210) being arranged to carry out the method (300) of any one of claims 1 to 12.

14. A hot water system (200), comprising a heat pump (202) and a hot water tank (204), the hot water system (202) **characterized in that** the hot water system further comprises a controller (100, 210) according to claim 13.

15. A computer-readable medium (110, 125) carrying instructions for operating a hot water system (200) to carry out the method (300) of any one of claims 1 to 12.

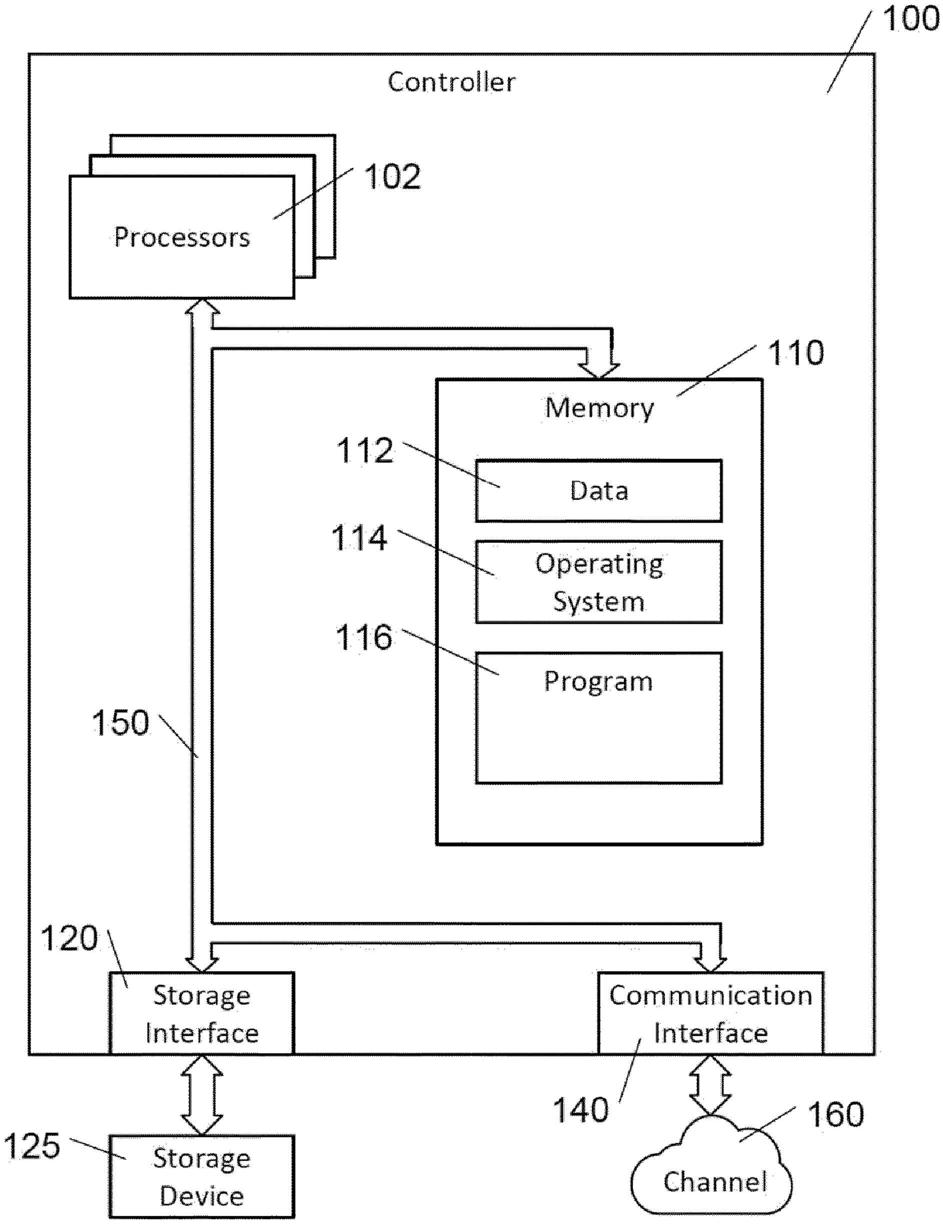
100
Controller
102
Processors
110
Memory
112
Data
114
Operating System
116
Program
150
120
Storage Interface
Communication Interface
140
160
125
Storage Device
Channel

FIG. 1

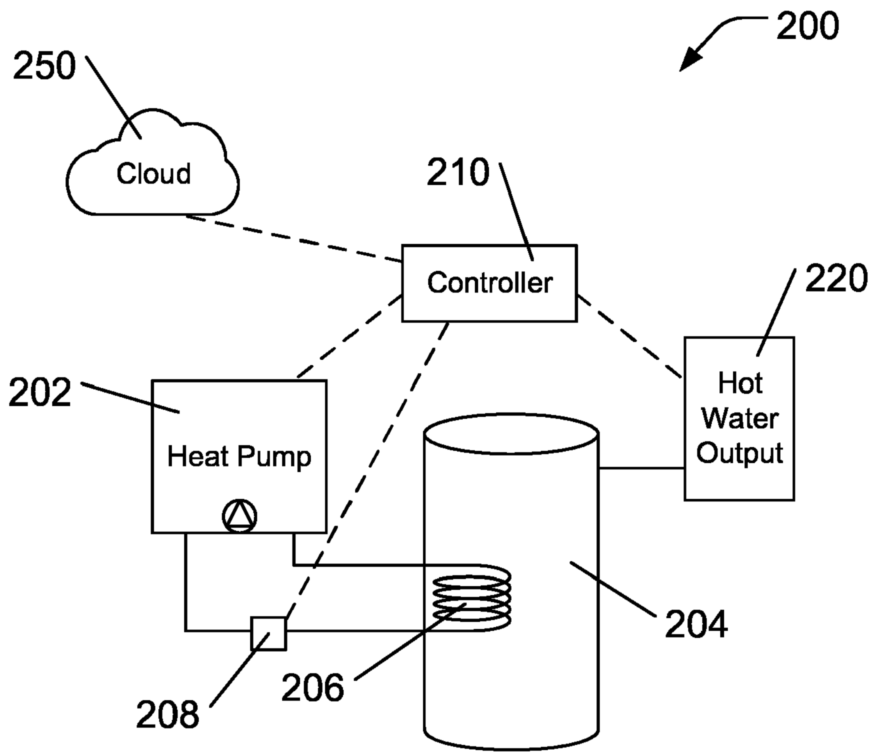
200
250
Cloud
210
Controller
220
Hot
Water
Output
202
Heat Pump
204
206
208

FIG. 2

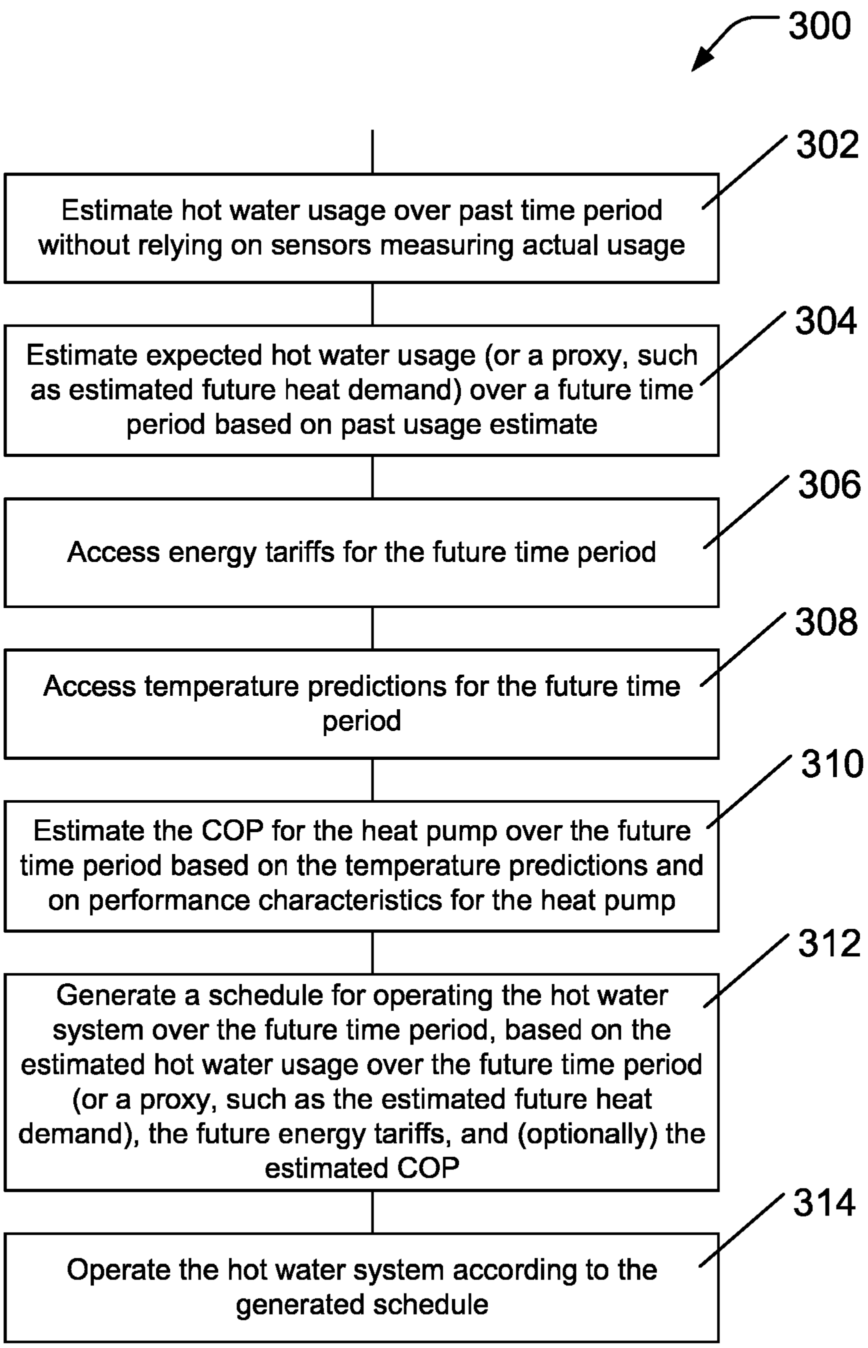
300
302
Estimate hot water usage over past time period without relying on sensors measuring actual usage
304
Estimate expected hot water usage (or a proxy, such as estimated future heat demand) over a future time period based on past usage estimate
306
Access energy tariffs for the future time period
308
Access temperature predictions for the future time period
310
Estimate the COP for the heat pump over the future time period based on the temperature predictions and on performance characteristics for the heat pump
312
Generate a schedule for operating the hot water system over the future time period, based on the estimated hot water usage over the future time period (or a proxy, such as the estimated future heat demand), the future energy tariffs, and (optionally) the estimated COP
314
Operate the hot water system according to the generated schedule

FIG. 3

402

Objective Function:

$$Cost_{total} = E_{fromgrid} \cdot Price_{energy\_buy} - E_{togrid} \cdot Price_{energy\_sell}$$

where:

$$E_{fromgrid} = x - E_{pvsurplus\_used}$$

$$E_{togrid} = E_{pvsurplus\_total} - E_{pvsurplus\_used}$$

and x is the energy consumption of the heat pump.

404

Constraints:

$$0 \leq x \leq E_{hp\_consumption\_max}$$

$$0 \leq E_{inside\_tank} \leq E_{tank\_max}$$

$$\sum_{1}^{n} x * COP(t) \geq \sum_{1}^{n} E_{demand}$$

FIG. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 24 21 2277

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y	US 2023/011737 A1 (BRANECKY BRIAN T [US]) 12 January 2023 (2023-01-12) * paragraph [0029] - paragraph [0071]; figures 1-11 * -----	1-4,6, 10-15 5,7-9	INV. F24H4/04 F24H15/152 F24H15/168 F24H15/172
Y	WO 2023/285772 A1 (FARRELL CHRISTOPHER CHARLES [GB]) 19 January 2023 (2023-01-19) * page 3 - page 5 * -----	5	
Y	WO 2023/161988 A1 (MITSUBISHI ELECTRIC CORP [JP]) 31 August 2023 (2023-08-31) * paragraph [0030] - paragraph [0032]; figure 4 * -----	7,8	
Y	US 2018/252417 A1 (KOMATSU MASAYUKI [JP] ET AL) 6 September 2018 (2018-09-06) * paragraph [0067] - paragraph [0071]; claims 1-7; figures 7A-F, 9A * -----	9	
A	OLYMPIOS ANDREAS V. ET AL: "Operational optimisation of an air-source heat pump system with thermal energy storage for domestic applications", ENERGY CONVERSION AND MANAGEMENT, vol. 273, 1 December 2022 (2022-12-01), page 116426, XP093191972, GB ISSN: 0196-8904, DOI: 10.1016/j.enconman.2022.116426 * the whole document * ----- -/--	1-15	TECHNICAL FIELDS SEARCHED (IPC) F24H

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	2 April 2025	Riesen, Jörg

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
O : non-written disclosure
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

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European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 24 21 2277

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	LYDEN ANDREW ET AL: "Planning level sizing of heat pumps and hot water tanks incorporating model predictive control and future electricity tariffs", ENERGY, ELSEVIER, AMSTERDAM, NL, vol. 238, 11 August 2021 (2021-08-11), XP086855750, ISSN: 0360-5442, DOI: 10.1016/J.ENERGY.2021.121731 [retrieved on 2021-08-11] * the whole document * -----	1-15	

TECHNICAL FIELDS SEARCHED (IPC)

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	2 April 2025	Riesen, Jörg

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