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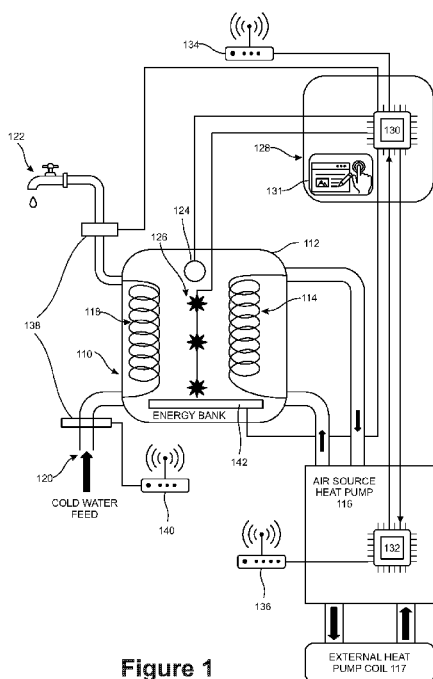


Figure 1

(57) Abstract: Provided is a heating installation including an energy store including a latent heat energy storage medium, and a heat pump having a defrost cycle, the heating installation including a hot water supply system arranged to supply instantaneous heated water and space heating to a building, and a processor to control the installation. The processor being configured to: control the supply of heat from the heat pump to the latent heat energy storage medium to store heat for heating water and to a heating circuit for providing space heating; and estimate a likelihood of a defrost cycle by the heat pump. In anticipation of an impending defrost cycle, the processor further being configured to control operation of the installation to store additional energy by at least one of: heating the latent heat energy storage medium to a higher level than a level set for anticipated water heating demand alone and/or heating the building and/or circulating heating fluid of the installation to a higher level than a level set for desired building heating; to compensate for an absence of heat from the heat pump during the impending defrost cycle.

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Methods and systems and apparatus to support reduced energy and water usage

Technical field

The present disclosure variously relates to methods, systems and apparatus for installations including an in-building hot water supply system including an energy storage arrangement, based on phase change materials, coupled to a heat pump.

Background of the Invention

According to Directive 2012/27/EU buildings represent 40 % of the final energy consumption and 36% of the CO₂ emissions of the European Union. The EU Commission report of 2016 "Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)" concluded that in EU households, heating and hot water alone account for 79% of total final energy use (192.5Mtoe). The EU Commission also report that, "according to 2019 figures from Eurostat, approximately 75% of heating and cooling is still generated from fossil fuels while only 22% is generated from renewable energy". To fulfil the EU's climate and energy goals, the heating and cooling sector must sharply reduce its energy consumption and cut its use of fossil fuels. Heat pumps (with energy drawn from the air, the ground or water) have been identified as potentially significant contributors in addressing this problem.

In many countries, there are policies and pressures to reduce carbon footprint. For example, in the UK in 2020 the UK Government published a whitepaper on a Future Homes Standard, with proposals to reduce carbon emissions from new homes by 75 to 80% compared to existing levels by 2025. In addition, it was announced in early 2019 that there would be a ban on the fitment of gas boilers to new homes from 2025. It is reported that in the UK at the time of filing 78% of the total energy used for the heating of buildings comes from gas, while 12% comes from electricity.

The UK has a large number of small, 2 -3 bedroom or less, properties with gas-fired central heating, and most of these properties use what are known as combination boilers, in which the boiler acts as an instantaneous hot water heater, and as a boiler for central heating. Combination boilers are popular because they combine a small form factor, provide a more or less immediate source of "unlimited" hot water (with 20 to 35kW output), and do not require hot water storage. Such boilers can be purchased from reputable manufactures relatively inexpensively. The small form factor and the ability to do without a hot water storage tank mean that it is generally possible to accommodate such a boiler even in a small flat or house – often wall-mounted in the kitchen, and to install a new boiler with one man day's work. It is therefore possible to get a new combi gas boiler installed inexpensively. With the imminent ban on new gas boilers, alternative heat sources will need to be provided in place of gas combi boilers. In addition, previously fitted combi boilers will eventually need to be replaced with some alternative.

Although heat pumps have been proposed as a potential solution to the need to reduce reliance on fossil fuels and cut CO₂ emissions, they are currently unsuited to the problem of replacing gas fired boilers in smaller domestic (and small commercial) premises or a number of technical, commercial and practical reasons. They are typically very large and need a substantial unit on the outside of the property. Thus, they cannot easily be retrofitted into a property with a typical combi boiler. A unit capable of providing equivalent output to a typical gas boiler would currently be expensive and may require significant electrical demand. Not only do the units themselves cost multiples of the equivalent gas fired equivalent, but also

their size and complexity mean that installation is technically complex and therefore expensive. A storage tank for hot water is also required, and this is a further factor militating against the use of heat pumps in small domestic dwellings. A further technical problem is that heat pumps tend to require a significant time to start producing heat in response to demand, perhaps 30 seconds for self-checking then some time to heat up – so a delay of 1 minute or more between asking for hot water and its delivery. For this reason, attempted renewable solutions using heat pumps and/or solar are typically applicable to large properties with room for a hot water storage tank (with space demands, heat loss and legionella risk).

There therefore exists a need to provide a solution to the problem of finding a suitable technology to replace gas combi boilers, particularly for smaller domestic dwellings.

The present disclosure proposes solutions to this problem, and also addresses issues that may occur during the use of an installation heated by a heat pump.

Summary of the Invention

According to a first aspect, there is provided a method of controlling a heating installation including an energy store including a heat energy storage medium for storing thermal energy, and a heat pump having a defrost cycle, the heating installation arranged to supply instantaneous heated water and space heating to a building, the method including controlling the supply of heat from the heat pump to the heat energy storage medium to thermal energy heat for heating of water and to a heating circuit for providing space heating, the method further including estimating, using a processor of the heating installation, a likelihood of a defrost cycle being performed by the heat pump in anticipation of an impending defrost cycle, under the control of the processor, storing additional thermal energy by at least one of heating the heat energy storage medium to a higher level than a level set for anticipated water heating demand alone and/or heating the building and/or circulating heating fluid of the heating installation to a higher level than a level set for desired building heating to compensate for an absence of heat from the heat pump during the impending defrost cycle, further including using energy from the heat energy storage medium in performing the defrost cycle.

In this way, occupants of the building can continue to use hot water from a hot water system powered by a heat pump, that doesn't need to include a hot water storage tank, without the need to rely on an electric or gas-powered instantaneous water heater during a heat pump defrost cycle, while also benefiting from heat pump powered space heating.

Optionally, the method further comprises using energy from the latent heat energy storage medium in performing the defrost cycle. For example, energy from the latent heat energy store may supplement a heater, such as an electrical heater, built into the heat pump.

Optionally, the heating of the latent heat energy storage medium to a higher level than a level set for anticipated water heating demand alone may include heating the latent heat energy storage medium to a temperature that exceeds the temperature of a phase transition temperature of the medium by at least 5 Celsius: for example in the range 5 to 15 Celsius above the phase transition temperature, optionally in the range 8 to 12 Celsius above, e.g. by at least 10 Celsius above the phase transition temperature. In this way useful extra energy is stored in the form of sensible heat in addition to the energy that is stored as latent heat in the PCM.

Optionally, the heating installation includes a thermostat set to a room temperature maximum in respect of one or more rooms of the building, and heating the building and/or circulating heating fluid of the heating installation to a higher level than a level set for desired building heating may include raising the temperature in the one or more rooms to a level greater than the temperature maximum set by the thermostat. In this way significant extra energy can be stored in the fabric of the building and/or in the circulating fluid in the heating system, by raising room temperature above the normal “set” level determined by a setting of the thermostat.

Optionally, estimating the likelihood of a defrost cycle may include processing with the processor of the installation data from one or more sensors, the data representing exterior temperature, and optionally exterior humidity. The system processor may have its own dedicated external sensors so that it does not need to rely on any such sensors associated with the heat pump.

Optionally, estimating the likelihood of a defrost cycle may include processing data provided by a processor of the heat pump, the processor of the heat pump being distinct from (additional to) the processor of the installation. The heat pump will routinely have its own dedicated temperature sensor to provide signals representing a temperature of the evaporator, and the heat pump’s processor may be configured to share these signals, or status information related to them, with the processor of the system.

Optionally, the storing of additional energy in anticipation of an impending defrost cycle only occurs if the processor of the installation determines that the building is occupied. Energy may be saved by only storing extra energy in the event that the building is occupied.

Optionally, the method further comprises monitoring with the processor of the installation one or more motion sensors within the building. Dedicated or shared motion sensors may be located in the building to provide occupancy information to the system processor, for example for use in determining whether the storage of extra energy prior to a heat pump defrost cycle is worthwhile.

Optionally, the building may include a security monitoring system coupled to the one or more processors of the installation, the method further comprising only storing additional energy in anticipation of an impending defrost cycle if the status of the security monitoring system does not indicate that the building is unoccupied. Such a security monitoring system may be stand-alone or part of a smart building system. In either case, the monitoring system will be able to provide occupancy data, and these data can be shared with the heating system controller – indeed the same controller may control both the smart building/security system and the hot water and heating system – so that occupancy data may be used to inform decisions of the heating (or heating and ventilation) and hot water system. For example, when the security monitoring system is in an “armed away” mode – signifying that the premises are unoccupied, the processor of the installation may be configured not to store additional energy in anticipation of an impending defrost cycle.

Optionally, the heating installation may include a heater within the latent heat energy storage medium, and the heating of the thermal storage medium to a higher level is performed using the heater. In this way, the energy storage medium can be heated, for example under the control of the one or more processors, for example when electricity is cheap or free.

According to a second aspect, there is provided a heating installation including an energy store including a heat energy storage medium for storing thermal energy, and a heat pump having a defrost cycle,

the heating installation including a hot water supply system arranged to supply instantaneous heated water and space heating to a building, and one or more processors to control the heating installation, the one or more processors configured to control the supply of heat from the heat pump to the heat energy storage medium to store thermal energy for heating water and to a heating circuit for providing space heating, estimate a likelihood of a defrost cycle being performed by the heat pump and in anticipation of an impending defrost cycle, control operation of the installation to store additional energy by at least one of heating the heat energy storage medium to a higher level than a level set for anticipated water heating demand alone and/or heating the building and/or circulating heating fluid to a higher level than a level set for desired building heating to compensate for an absence of heat from the heat pump during the impending defrost cycle, wherein the one or more processors is configured to cause the heat pump to use energy from the heat energy storage medium in performing the defrost cycle.

Thus, building occupants can still enjoy hot water, during defrosting of the heat pump, without the need for a hot water storage tank and without reliance of another source of instantaneous water heating. Similarly, despite the inability of the heat pump to provide space heating during the defrost cycle, building occupants may be unlikely to notice any loss of space heating.

Optionally, the one or more processors may be configured to cause the heat pump to use energy from the latent heat energy storage medium in performing the defrost cycle. Although heat pumps generally include a heater of some kind to provide energy for defrosting the heat pump's evaporator, according to aspects of the present disclosure energy from the latent heat energy storage medium may be used for this purpose.

The one or more processors may be so configured that, in heating the latent heat energy storage medium to a higher level than a level set for anticipated water heating demand alone, the latent heat energy storage medium is caused to be heated to a temperature that exceeds the temperature of a phase transition temperature of the medium by at least 5 Celsius. In this way, in addition to storing energy in the energy store as latent heat, additional energy may be stored as sensible heat, increasing the amount of energy available for instantaneous water heating.

The heating installation optionally includes a thermostat set to a temperature maximum in respect of one or more rooms of the building, and the one or more processors may be configured to cause the heating the building and/or circulating heating fluid to a higher level than a level set for desired building heating by increasing the temperature in the one or more rooms to a level greater than the temperature maximum set by the thermostat. Thus, even though the space heating system may set for a maximum normal upper room temperature, the installation is able to increase the room temperature to store energy in the fabric of the building and possibly in a circulating heating fluid (e.g. the liquid inside the radiators and pipework of the space heating system).

In the heating installation of the second aspect, the one or more processors may be configured to estimate the likelihood of a defrost cycle by processing data from one or more sensors, the data representing exterior temperature and optionally humidity.

In the heating installation of the second aspect, the one or more processors may be configured to estimate the likelihood of a defrost cycle by processing data provided by a processor of the heat pump, the processor of the heat pump being distinct from the one or more processors of the installation.

In the heating installation of the second aspect, the one or more processors may be configured to cause the storing of additional energy in anticipation of an impending defrost cycle only if the one or more processors of the installation determines that the building is occupied. Optionally, the one or more processors of the installation is coupled to one or more motion sensors within the building.

The building served by the heating installation of the second aspect may include a security monitoring system coupled to the one or more processors of the installation, and the one or more processors of the installation may be configured not to cause additional energy to be stored in anticipation of an impending defrost cycle if the status of the security monitoring system indicates that the building is unoccupied. For example, when the security monitoring system is in an "armed away" mode – signifying that the premises are unoccupied, the processor of the installation may be configured not to store additional energy in anticipation of an impending defrost cycle.

The heating installation of the second aspect may include a first processor controlling the internal functioning of the heat pump and a second processor associated with the energy store and coupled to sensors in the hot water supply system.

In the heating installation of the second aspect, the latent heat energy storage medium may comprise a mass of phase change material in the energy store, the energy store including a heat exchanger that is coupled between the hot water system and the heat pump. The one or more processors may be configured to provide a signal to the heat pump based on the opening of an outlet of the hot water supply system. Preferably, the mass of phase change material has enough latent heat capacity to heat to a predetermined temperature a predetermined quantity of water in the interval from the opening of an outlet of the hot water supply system until at least the heat pump begins to heat water in the hot water supply system.

The heating installation of the second aspect may include a heater within the thermal storage medium, and the one or more processors of the installation may be configured to activate the heater to heat the latent heat energy storage medium to the higher level.

In the heating installation of the second aspect the one or more processors of the installation may be provided with logic to enable identification of time windows when demand for hot water and or space heating is likely to be such that there is no need for additional energy storage during defrost cycles, and the one or more processors may be configured not to cause additional energy to be stored in anticipation of an impending defrost cycle during such time windows. The one or more processors of the installation may have access to one or more of: a database of past patterns of behaviour of the household, comparables from different or averaged households (for example based on season, current and predicted weather/ climate microclimate), the Internet – for example to receive weather forecasts and energy tariff information.

Brief description of the drawings

Embodiments of various aspects of the disclosure will now be described by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram showing an energy bank including a phase change material and a heat exchanger coupled to a heat pump energy source;

Figure 2 is a schematic diagram showing a potential arrangement of components of an interface unit, incorporating energy bank according to an aspect of the disclosure;

Figure 3 is a schematic diagram showing an in-building water supply installation according to an aspect of the disclosure;

Figure 4 illustrates schematically a method of configuring a hot-water supply installation having a plurality of controllable hot-water outlets;

Figure 5 is a high-level flow chart for a method performed by an installation including an energy bank such as that of Figure 1;

Figure 6 is a high-level flow chart for a method performed by an energy bank such as that of Figure 1;

Figure 7 is a flow chart for a method performed by an energy bank such as that of Figure 1; and

Figure 8 is a flow chart for a method performed by an energy bank such as that of Figure 1.

Detailed description of Embodiment(s) of the Invention

One of the many constraints on the applicability of heat pumps is their relatively limited ability to satisfy demand for hot water – at least when compared to instantaneous gas and electric water heaters, such as combi boilers, compared to their strengths as sources of heat for space heating. As noted earlier, for the typically modestly sized dwellings of the UK, space heating demands are commonly as low as 6kW, whereas gas combi boilers even in modest one or two bed flats can typically provide 20kW to 30kW for instant water heating. The 6kW space heating demand is readily achievable in Europe with even an air source heat pump, but a unit that could provide 20 to 30kW would be unacceptably large and expensive. Heat pumps suffer from a further limitation in respect of their application to domestic hot water supplies, and that is the long lag between a heat pump receiving a start signal and hot water actually being supplied by the heat pump. Generally, this lag is well over a minute, and sometimes as much as two minutes or more. While that doesn't at first sight sound significant, when one realises that for things like handwashing – one of the most common uses of hot water in a domestic setting, the average time for which a hot tap runs is between 30 seconds and 1 minute – so it becomes clear that heat pumps have a significant hurdle to overcome. Typically, this problem is addressed by storing hot water – in a hot water storage tank, so that it is available on demand. But that solution is unattractive for smaller dwellings, such as the kinds of one, two and three bed properties in the UK that currently make use of gas combination boilers – and which are almost universally installed without an external hot water storage tank.

One technology which has potential to improve the applicability of heat pumps to the demands of, in particular, domestic hot demands, is thermal energy storage – but not in the guise of hot water storage.

Such an alternative form of thermal energy storage is the use of phase change materials (PCMs). As the name suggests, phase change materials are materials which exhibit a thermally induced phase change: heating the PCM to its phase transition temperature results in energy being stored as latent (rather than sensible) heat. Many different PCMs are known, the choice for any particular application being dictated by, among other things, the required operating temperature, cost constraints, health and safety restrictions (taking account of toxicity, reactivity, flammability, stability, etc. of the PCM, and the constraints that these impose on such as things as materials needed for containment of the PCM). With an appropriate

choice of PCM, a thermal energy storage arrangement can be designed so that energy from a heat pump is available for instantaneous heating of water for a (domestic) hot water system, thereby helping address the slow start problem inherent with the use of a heat pump without the need for a bulky hot water tank.

We will now introduce and describe an energy storage arrangement based on the use of PCMs, and particularly suited for use in installations in which a heat pump is to be used to heat water in a hot water supply. Such an energy storage arrangement may include a heat exchanger comprising an enclosure, and within the enclosure: an input-side circuit for connection to an energy source such as a heat pump, an output-side circuit for connection to an energy sink such as a hot water supply installation, and a phase-change material for the storage of energy.

The input-side circuit receives liquid heated by the heat source, in our case a heat pump, and provided the liquid is hotter than the material inside the heat exchanger, energy is transferred from the liquid into the material within the heat exchanger. Likewise, energy from the material within the heat exchanger is transferred to liquid in the output-side circuit provided the liquid is cooler than the material within the heat exchanger. Of course, if there is no flow through the output-side circuit, the amount of energy transferred out of the heat exchanger is limited, so that most of the input energy remains within the heat exchanger. In our case, the heat exchanger contains a phase change material, for example, a paraffin wax or a salt-hydrate (examples of suitable materials are discussed later) so that the input energy is largely transferred to the PCM. With an appropriate choice of phase change material and heat pump operating temperature, it becomes possible to use energy from the heat pump to “charge” the energy “bank” represented by the PCM. Optionally, the energy supply from the heat pump may be supplemented by including one or more electrical heating elements in the heat exchanger, the heating elements being controlled by a processor of the system, and being used, for example, when a low-cost tariff applies to the electricity supply, or for example local or domestic electricity production such as from wind, hydraulic or photovoltaic generation, is able to provide “cheap” energy when there an anticipated or expected future need for hot water.

One characteristic of phase change materials which must be accommodated when designing systems that use them is the volume change which occurs on transition between phases, for example expansion on the phase change between liquid and solid, and contraction on the phase change between solid and liquid. Typically, the volume change is of the order of 10%. This volume change can be considered a disadvantage which must be accommodated with careful design of enclosures used to contain the phase change materials, but the volume change can also be used positively. By including one or more sensors to provide a measurement of pressure within the PCM enclosure it is possible to provide a processor with data from which the processor may determine a status of the phase change material. For example, the processor may be able to determine an energy storage value for the phase change material.

In addition to, or as an alternative to, the measurement of pressure within the enclosure as a means of determining an energy storage amount of the phase change material, it is possible to use changes in the optical or sonic properties that occur in the PCM on changes of phase. Examples of these alternative approaches will be described later, but first we will consider the use of pressure sensing as a means to gather information on the energy storage state of the PCM.

Figure 1 shows schematically an energy bank 110 including a heat exchanger, the energy bank comprising an enclosure 112. Within the enclosure 112 are an input-side circuit 114 of the heat exchanger for connection to an energy source - shown here as a heat pump 116, an output-side circuit 118 of the heat exchanger for connection to an energy sink - shown here as a hot water supply system connected to a cold-water feed 120 and including one or more outlets 122. Within the enclosure 112 is a phase-change material for the storage of energy. The energy bank 110 also includes one or more status sensors 124, to provide a measurement of indicative of a status of the PCM. For example, one or more of the status sensors 124 may be a pressure sensor to measure pressure within the enclosure. Preferably the enclosure also includes one or more temperature sensors 126 to measure temperatures within the phase change material (PCM). If, as is preferred, multiple temperature sensors are provided within the PCM, these are preferably spaced apart from the structure of the input and output circuits of the heat exchanger, and suitably spaced apart within the PCM to obtain a good "picture" of the state of the PCM.

The energy bank 110 has an associated system controller 128 which includes a processor 130. The controller may be integrated into the energy bank 110, but is more typically mounted separately. The controller 128 may also be provided with a user interface module 131, as an integrated or separate unit, or as a unit that may be detachably mounted to a body containing the controller 128. The user interface module 131 typically includes a display panel and keypad, for example in the form of a touch-sensitive display. The user interface module 131, if separate or separable from the controller 128 preferably includes a wireless communication capability to enable the processor 130 of controller 128 and the user interface module to communicate with each other. The user interface module 131 is used to display system status information, messages, advice and warnings to the user, and to receive user input and user commands - such as start and stop instructions, temperature settings, system overrides, etc.

The status sensor(s) is/are coupled to the processor 130, as is/are the temperature sensor(s) 126 if present. The processor 130 is also coupled to a processor/controller 132 in the heat pump 116, either through a wired connection, or wirelessly using associated transceivers 134 and 136, or through both a wired and a wireless connection. In this way, the system controller 128 is able to send instructions, such as a start instruction and a stop instruction, to the controller 132 of the heat pump 116. In the same way, the processor 130 is also able to receive information from the controller 132 of the heat pump 116, such as status updates, temperature information, etc.

The hot water supply installation also includes one or more flow sensors 138 which measure flow in the hot water supply system. As shown, such a flow sensor may be provided on the cold-water feed 120 to the system, and or between the output of the output-side circuit 18 of the heat exchanger. Optionally, one or more pressure sensors may also be included in the hot water supply system, and again the pressure sensor(s) may be provided upstream of the heat exchanger/energy bank, and/or downstream of the heat exchanger/energy bank - for example alongside one or more of the one or more flow sensors 138. The or each flow sensor, the or each temperature sensor, and the or each pressure sensor is coupled to the processor 130 of the system controller 128 with either or both of a wired or wireless connection, for example using one or more wireless transmitters or transceivers 140. Depending upon the nature(s) of the

various sensors 1124, 26, and 138, they may also be interrogatable by the processor 130 of the system controller 128.

Optionally, an electrically controlled thermostatic mixing valve, not shown, may be coupled between the outlet of the energy bank and the one or more outlets 122 of the hot water supply system, and includes a temperature sensor at its outlet. An additional instantaneous water heater, for example an electrical heater (inductive or resistive) controlled by the controller 128, is preferably positioned in the water flow path between the outlet of the energy bank and the mixing valve. A further temperature sensor may be provided to measure the temperature of water output by the instantaneous water heater, and the measurements provided to the controller 128. The thermostatic mixing valve is also coupled to a cold water supply, and is controllable by the controller 128 to mix hot and cold water to achieve a desired supply temperature.

Optionally, as shown, the energy bank 110 may include, within the enclosure 112, an electrical heating element 142 which is controlled by the processor 130 of the system controller 128, and which may on occasion be used as an alternative to the heat pump 116 to recharge the energy bank.

The heat pump shown in Figure 1 is an air source heat pump with an external heat pump coil which is used to extract energy from ambient air. In order to be able to extract heat from ambient air even when the air temperature is low, the refrigerant in the heat pump coil has to be cooler than the ambient air – and for the sake of efficiency the refrigerant should be much colder than the ambient air temperature. The air conditioner includes a fan to blow ambient air over the coil, and as the air passes over the coil it gives up heat to the refrigerant in the coil. Any moisture in the ambient air is also cooled, and if the refrigerant is cool enough, the moisture turns to ice on the surface of the coil. As more and more air passes over the coil, more and more ice forms, reducing the efficiency of the heat transfer process.

In order to restore the efficiency of the heat transfer process, the ice needs to be removed. The removal process is known as the defrost cycle, or defrost mode, during which the heat pump in effect works in reverse, with hot refrigerant being sent to the external heat pump coil to melt the ice that has formed on the outside of the coil. During the defrost cycle, the fan that normally blows ambient air over the coil 117 is stopped, to eliminate the cooling that would result from the fan blowing cold air over the warming coil 117. Typically, the coil 117 is heated until it reaches a temperature of about 14 or 15 Celsius. Air source heat pumps typically include a heating element to heat the refrigerant that is used in the defrost cycle. Once the external heat pump coil 117 is free from frost, the heat pump stops pumping warm refrigerant to the coil and reverts to normal operation – to once again extract heat from the ambient air.

The time between defrost cycles depends upon the ambient conditions (temperature and humidity levels), and on the amount of heat being delivered by the heat pump, but may be as frequent as every 40 minutes or less, with each defrost cycle typically taking about 5 to 10 minutes to complete - although defrosting may be completed in much shorter times, it will be appreciated that during the defrost cycle the heat pump is working in reverse and hence is effectively putting energy into the ambient rather than extracting it from the ambient.

Heat pumps that extract energy from bodies of water (e.g., lakes, rivers, ponds, the sea) may also need to provide a defrost mode, particularly if the body of water is shallow or otherwise particularly constrained. It will be appreciated that the inventions and ideas set out in the current application are

equally applicable to such heat pumps as to air source heat pumps, and the present disclosure should be read with that understanding.

Of course, in defrost mode, the heat pump 116 is unable to provide energy to heat the energy bank or provide space heating (as discussed below with reference to Figure 2)

Figure 1 is merely a schematic, and only shows connection of the heat pump to a hot water supply installation. It will be appreciated that in many parts of the world there is a need for space heating as well as hot water. Typically, therefore the heat pump 116 will also be used to provide space heating. An exemplary arrangement in which a heat pump both provides space heating and works with an energy bank for hot water heating will be described later in the application. For ease of description the following description of a method of operation of an energy bank according to an aspect of the invention, for example as illustrated in Figure 1, applies equally to the energy bank installation whether or not the associated heat pump provides space heating.

Figure 2 shows schematically a potential arrangement of components of an interface unit 10 according to an aspect of the disclosure. The interface unit interfaces between a heat pump (not shown in this Figure), such as the air source heat pump 116 of Figure 1, and an in-building hot water system, such as the system shown in Figure 1. The interface unit 10 includes a heat exchanger 12 comprising an enclosure (not separately numbered) within which is an input-side circuit, shown in very simplified form as 14, for connection to the heat pump, and an output-side circuit, again shown in very simplified form as 16, for connection to the in-building hot water system (not shown in this Figure). The heat exchanger 12 also contains a thermal storage medium for the storage of energy, but this is not shown in the Figure. In the example that will now be described with reference to Figure 2 the thermal storage medium is a phase-change material which stores energy as latent heat (as well as being able to store energy as sensible heat). It will be recognised that the interface unit corresponds to the previously described energy bank. Throughout this specification, including the claims, references to energy bank, thermal storage medium, energy storage medium and phase change material should be considered to be interchangeable unless the context clearly requires otherwise.

Typically, the phase-change material in the heat exchanger has an energy storage capacity (in terms of the amount of energy stored by virtue of the latent heat of fusion) of between 2 and 5 MJoules, although more energy storage is possible and can be useful. And of course, less energy storage is also possible, but in general one wants to maximise (subject to practical constraints based on physical dimensions, weight, cost and safety) the potential for energy storage in the phase-change material of the interface unit 10. More will be said about suitable phase-change materials and their properties, and also about dimensions etc. later in this specification.

The input side circuit 14 is connected to a pipe or conduit 18 which is in turn fed from node 20, from pipe 22 which has a coupling 24 for connection to a feed from a heat pump. Node 20 also feeds fluid from the heat pump to pipe 26 which terminates in a coupling 28 which is intended for connection to a heating network of a house or flat – for example for plumbing into underfloor heating or a network of radiators or both. Thus, once the interface unit 10 is fully installed and operational, fluid heated by a heat pump (which is located outside the house or flat) passes through coupling 24 and along pipe 22 to node 20, from where, depending upon the setting of the 3-port valve 32, the fluid flow passes along pipe 18 to the

input-side circuit 14 of the heat exchanger, or along pipe 26 and out through coupling 28 to the heating infrastructure of the house or flat.

Heated fluid from the heat pump flows through the input-side circuit 14 of the heat exchanger and out of the heat exchanger 12 along pipe 30. In use, under some circumstance, heat carried by the heated fluid from the heat pump gives up some of its energy to the phase change material inside the heat exchanger and some to water in the output-side circuit 16. Under other circumstances, as will be explained later, fluid flowing through the input-side circuit 14 of the heat exchanger actually acquires heat from the phase change material.

Pipe 30 feeds fluid that leaves the input-side circuit 14 to a motorized 3-port valve 32 and then, depending upon the status of the valve out along pipe 34 to pump 36. Pump 36 serves to push the flow on to the external heat pump via coupling 38. The motorized 3-port valve 32 also receives fluid from pipe 40 which receives, via coupling 42, fluid returning from the heating infrastructure (e.g., radiators) of the house or flat.

Between the motorized 3-port valve 32 and the pump 36 a trio of transducers are provided: a temperature transducer 44, a flow transducer 46, and a pressure transducer 48. In addition, a temperature transducer 49 is provided in the pipe 22 which brings in fluid from the output of the heat pump. These transducers, like all the others in the interface unit 10, are operatively connected to or addressable by a processor, not shown, which is typically provided as part of the interface unit – but which can be provided in a separate module.

Although not illustrated in Figure 2, an additional electrical heating element may also be provided in the flow path between the coupler 24, which receives fluid from the output of the heat pump. This additional electrical heating element may again be an inductive or resistive heating element and is provided as a means to compensate for potential failure of the heat pump, but also for possible use in adding energy to the thermal storage unit (for example based on the current energy cost and predicted for heating and/or hot water. The additional electrical heating element is also of course controllable by the processor of the system.

Also coupled to pipe 34 is an expansion vessel 50, to which is connected a valve 52 by means of which a filling loop may be connected to top up fluid in the heating circuit. Also shown as part of the heating circuit of the interface unit are a pressure relief valve 54, intermediate the node 20 and the input-side circuit 14, and a strainer 56 (to capture particulate contaminants) intermediate coupling 42 and the 3-port valve 32.

The heat exchanger 12 is also provided with several transducers, including at least one temperature transducer 58, although more (e.g., up to 4 or more) are preferable provided, as shown, and a pressure transducer 60. In the example shown, the heat exchanger includes 4 temperature transducers uniformly distributed within the phase change material so that temperature variations can be determined (and hence knowledge obtained about the state of the phase change material throughout its bulk). Such an arrangement may be of particular benefit during the design/implementation phase as a means to optimise design of the heat exchanger – including in optimising addition heat transfer arrangements. But such an arrangement may also continue to be of benefit in deployed systems as having multiple sensors can provide

useful information to the processor and machine learning algorithms employed by the processor (either of just the interface unit, and/or of a processor of a system including the interface unit.

The arrangement of the cold-water feed and the hot water circuit of the interface unit 10 will now be described. A coupling 62 is provided for connection to a cold feed from a water main. Typically, before water from the water main reaches the interface unit 10, the water will have passed through an anti-syphon non-return valve and may have had its pressure reduced. From coupling 62 cold water passes along pipe to the output-side circuit 16 of the heat exchanger 12. Given that we provide a processor that is monitoring numerous sensors in the interface unit, the same processor can optionally be given one more task to do.

That is to monitor the pressure at which cold water is delivered from the mains water supply. To this end, a further pressure sensor can be introduced into the cold-water supply line upstream of coupling 62, and in particular upstream of any pressure reducing arrangement within the premises. The processor can then continually or periodically monitor the supplied water pressure, and even prompt the owner/user to seek compensation from the water supply company if the water main supplies water at a pressure below the statutory minimum.

From the output-side circuit 16 water, which may have been heated by its passage through the heat exchanger, passes along a pipe 66 to an electrical heating unit 68. The electrical heating unit 68, which is under the control of the processor mentioned previously, may comprise a resistive or inductive heating arrangement whose heat output can be modulated in accordance with instructions from the processor. The processor is configured to control the electrical heater, based on information about the status of the phase-change material and of the heat pump.

Typically, the electrical heating unit 68 has a power rating of no more than 10kW, although under some circumstances a more powerful heater, e.g., 12kW, may be provided.

From the electric heater 68, what will by now hot water passes along a pipe 70 to a coupling 74 to which the hot water circuit, including controllable outlets such as taps and showers, of the house or flat will be connected.

A temperature transducer 76 is provided after the electric heater 68, for example at the outlet of the electric heater 68 to provide information on the water temperature at the outlet of the hot water system. A pressure relief valve 77 is also provided in the hot water supply, and while this is shown as being located between the electric heater 68 and the outlet temperature transducer 76, its precise location is unimportant – as indeed is the case for many of the components illustrated in Figure 2.

Also somewhere in the hot water supply line is a pressure transducer 79 and or a flow transducer 81 either of which can be used by the processor to detect a call for hot water – i.e., detect the opening of a controllable outlet such as a tap or shower. The flow transducer is preferably one which is free from moving parts, for example based on sonic flow detection or magnetic flow detection. The processor can then use information from one or both of these transducers, along with its stored logic, to decide whether to signal to the heat pump to start.

It will be appreciated that the processor can call on the heat pump to start either based on demand for space heating (e.g., based on a stored program either in the processor or in an external controller, and/or based on signals from one or more thermostats – e.g., room stats, external stats, underfloor heating

stats) or demand for hot water. Control of the heat pump may be in the form of simple on/off commands but may also or alternatively be in the form of modulation (using, for example, a ModBus).

As is the case with the heating circuit of the interface unit, a trio of transducers are provided along the cold-water feed pipe 64: a temperature transducer 78, a flow transducer 80, and a pressure transducer 82. Another temperature transducer 84 is also provided in pipe 66 intermediate the outlet of the output-side circuit 16 of the heat exchanger 12 and the electric heater 68. These transducers are again all operatively connected to or addressable by the processor mentioned previously.

Also shown on the cold water supply line 64 are a magnetic or electrical water conditioner 86, a motorised and modulatable valve 88 (which like all the motorised valves may be controlled by the processor mentioned previously), a non-return valve 86, and an expansion vessel 92. The modulatable valve 88 can be controlled to regulate the flow of cold water to maintain a desired temperature of hot water (measured for example by temperature transducer 76).

Valves 94 and 96 are also provided for connection to external storage tanks for the storage of cold and heated water respectively. Finally, a double check valve 98 connects cold feed pipe 64 to another valve 100 which can be used with a filling loop to connect to previously mentioned valve 52 for charging the heating circuit with more water or a mix of water and corrosion inhibitor.

It should be noted that Figure 2 shows various of the pipes crossing, but unless these crossing are shown as nodes, like node 20, the two pipes that are shown as cross do not communicate with each other, as should by now be clear from the foregoing description of the Figure.

We will now describe a method of controlling a heating installation including an energy store 110 including a latent heat energy storage medium, and a heat pump 116 and 117 having a defrost cycle, the heating installation arranged to supply instantaneous heated water and space heating to a building. The method comprises: controlling the supply of heat from the heat pump 116/117 to the energy store 110 to store heat for heating of water and to a heating circuit (such as that represented by connections 28 and 42 for providing space heating in the building. The method further includes: estimating, using a processor 130 of the installation, a likelihood of a defrost cycle by the heat pump 116/117; in anticipation of an impending defrost cycle, under the control of the processor 130, storing additional energy by at least one of:

heating the latent heat energy storage medium in the energy store 110 to a higher level than a level set for anticipated water heating demand alone and/or heating the building and/or circulating heating fluid to a higher level than a level set for desired building heating; to compensate for an absence of heat from the heat pump during the impending defrost cycle. Thus, building occupants can still enjoy hot water, during defrosting of the heat pump, without the need for a hot water storage tank and without reliance of another source of instantaneous water heating. Similarly, despite the inability of the heat pump to provide space heating during the defrost cycle, building occupants may be unlikely to notice any loss of space heating

Energy from the latent heat energy storage medium in the energy bank 110 may be used by the heat pump 116 in defrosting the external heat pump coil or evaporator 117 cycle. Heat can be carried from the energy bank 110 in liquid returning to the heat pump, the energy being transferred via a heat exchanger in the heat pump to refrigerant that flows through the evaporator 117. For example, energy from the latent heat energy store may supplement a heater, such as an electrical heater, built into the heat pump. Because

the heat pump 116/117 will generally be a stand-alone unit, it will generally include a conventional electrical heating element under the control of the processor 132 of the heat pump. The processor 132 may be configured to utilise energy received in the return feed from the energy bank 110 to supplement the electrical heating element or even, under some circumstances to provide all the heat used in defrosting the evaporator matrix.

The heating of the latent heat energy storage medium to a higher level than a level set for anticipated water heating demand alone may include heating the latent heat energy storage medium to a temperature that exceeds the temperature of a phase transition temperature of the medium by at least 5 Celsius: for example in the range 5 to 15 Celsius above the phase transition temperature, optionally in the range 8 to 12 Celsius above, e.g. by at least 10 Celsius above the phase transition temperature. That is, rather than simply heating the phase change material to just above its phase transition temperature, the temperature may be raised by adding energy that is stored as sensible heat.

Conventionally, the heating installation will include one or more room thermostats used to regulate temperatures of rooms in the building. Occupants or user of the building, or of rooms in the building may be able to set to a temperature maximum in respect of one or more rooms of the building, or the thermostat setting(s) may be set by the system or set remotely. In any event, heating the building and/or circulating heating fluid to a higher level than a level set for desired building heating may include raising the temperature in the one or more rooms to a level greater than the temperature maximum set by the thermostat. Thus, even though the space heating system may set for a maximum normal upper room temperature, the installation is able to increase the room temperature to store energy in the fabric of the building and possibly in a circulating heating fluid (e.g., the liquid inside the radiators and pipework of the space heating system).

The system may be configured to estimate the likelihood of a defrost cycle by processing, with the system processor 130, data from one or more sensors, the data representing exterior temperature, and optionally exterior humidity. Thus, the system processor 130 may be coupled, directly or indirectly, with one or more sensors located outside the building, to measure at least external temperature – preferably in the vicinity of the heat pump evaporator 117.

Additionally, or alternatively, estimating the likelihood of a defrost cycle may include processing data provided by a processor of the heat pump. The heat pump will include a temperature sensor associated with the evaporator /coil 117, so that as a stand-alone unit the heat pump can control its own defrosting cycle. Preferably, the data connection between the processor 132 of the heat pump and the processor 130 of the system is used to feed data from the heat pump's evaporator thermometer to the system processor 130 – or else related heat pump management data are fed to the system processor 130, and control signals and instructions sent from the system processor 130 to the heat pump processor 132.

In winter or in cold climates it is common for householders to leave household heating on, even when the home is unoccupied – both as a safety precaution to prevent water pipes and wet heating pipes freezing, with consequent risk of damage, and also so that the occupants return home to a warm house. The temporary interruptions in heat supply that accompany the defrost cycle are short so that there is no real risk, in a house where the heating has been left on, of pipes in the house freezing during these interruptions. There is therefore no need to go through the process of storing additional energy in anticipation of an

impending defrost cycle if the building is uninhabited. Hence, preferably the processor of the installation is provided with information about the occupancy status of the building. The information can come from motion detectors, such as PIR detectors – either stand-alone or ones that also serve a security monitoring system covering the building, or from other activity detection devices. The method may therefore further comprise monitoring with the one or more processors of the installation one or more motion sensors within the building.

The building may include a security monitoring/alarm system coupled to the one or more processors of the installation, and this may enable the system processor 130 to determine occupancy directly from the monitoring system: for example, the alarm/security system may have an “armed away” setting for when the alarm system is active and the house unoccupied, and an “armed at home” setting for when the alarm is set but the house is occupied (the alarm typically then only being triggered by the opening or breaching of a secured perimeter of the building. If the monitoring system is “armed away” the system processor 130 knows that the storage of additional energy is unnecessary, so that the heat pump can be left to perform its usual defrost cycle under its own control. Whereas an “armed at home” status signifies that the building is occupied, so that storing additional energy may be justified. Thus, the method may comprise only storing additional energy in anticipation of an impending defrost cycle if the status of the security monitoring system does not indicate that the building is unoccupied.

As noted previously, the heating installation may include a heater, such as heater 142 within the energy bank 110, and the heating of the thermal storage medium to a higher level may be performed using this heater. In this way, the energy storage medium can be heated, for example under the control of the processor 130, for example when electricity is cheap or free. The processor is preferably provided with tariff information for the electrical supply, optionally via an Internet link, and knowledge of any domestic or local electricity generation or supply facilities, so that the system processor 130 can make appropriate choices in terms of electricity and more generally energy usage.

The heating installation of the second aspect, the latent heat energy storage medium may comprise a mass of phase change material in the energy store 110, the energy store including a heat exchanger 114/118 that is coupled between the hot water system and the heat pump 116/117. The one or more processors 130 may be configured to provide a signal to the heat pump 116/117 based on the opening of an outlet, e.g. 122, of the hot water supply system. Preferably, the mass of phase change material has enough latent heat capacity to heat to a predetermined temperature a predetermined quantity of water in the interval from the opening of an outlet of the hot water supply system until at least the heat pump begins to heat water in the hot water supply system.

The heating installation may include a heater 142 within the thermal storage medium, and the one or more processors 130 of the installation may be configured to activate the heater 142 to heat the latent heat energy storage medium to the higher level.

The one or more processors 130 of the installation may be provided with logic to enable identification of time windows when demand for hot water and or space heating is likely to be such that there is no need for additional energy storage during defrost cycles, and the one or more processors 130 may be configured not to cause additional energy to be stored in anticipation of an impending defrost cycle during such time windows. The one or more processors 130 of the installation may have access to one or more of: a database

of past patterns of behaviour of the household, comparables from different or averaged households (for example based on season, current and predicted weather/ climate microclimate), the Internet – for example to receive weather forecasts and energy tariff information.

Although not shown in Figure 2, as previously mentioned the heat exchanger 12 may include one or more additional electrical heating elements (e.g., 142 of Figure 1) configured to put heat into the thermal storage medium. While this may seem counter intuitive, it permits the use of electrical energy to pre-charge the thermal storage medium at times when it makes economic sense to do so, as will now be explained.

It has long been the practice of energy supply companies to have tariffs where the cost of a unit of electricity varies according to the time of day, to take account of times of increased or reduced demand and to help shape customer behaviour to better balance demand to supply capacity. Historically, tariff plans were rather coarse reflecting the technology both of power generation and of consumption. But increasing incorporation of renewable energy sources of electrical power – such as solar power (e.g., from photovoltaic cells, panels, and farms) and wind power, into the power generation fabric of countries has spurred the development of a more dynamic pricing of energy. This approach reflects the variability inherent in such weather-dependent power generation. Initially such dynamic pricing was largely restricted to large scale users, increasingly dynamic pricing is being offered to domestic consumers.

The degree of dynamism of the pricing varies from country to country, and also between different producers within a given country. At one extreme, “dynamic” pricing is little more than the offering of different tariffs in different time windows over the day, and such tariffs may apply for weeks, months, or seasons without variation. But some dynamic pricing regimes enable the supplier to change prices with a day’s notice or less – so for example, customers may be offered today prices for half-hour slots tomorrow. Time slots of as short as 6 minutes are offered in some countries, and conceivably the lead time for notifying consumers of forthcoming tariffs can be reduced further by including “intelligence” in energy-consuming equipment.

Because it is possible to use short- and medium-term weather predictions to predict both the amount of energy likely to be produced by solar and wind installations, and the likely scale of power demand for heating and cooling, it becomes possible to predict periods of extremes of demand. Some power generation companies with significant renewable generation capacity have even been known to offer negative charging for electricity – literally paying customers to use the excess power. More often, power may be offered at a small fraction of the usual rate.

By incorporating an electric heater into an energy storage unit, such as a heat exchanger of systems according to the disclosure, it becomes possible for consumers to take advantage of periods of low-cost supply and to reduce their reliance on electrical power at times of high energy prices. This not only benefits the individual consumer, but it is also beneficial more generally as it can reduce demand at times when excess demand must be met by burning fossil fuels.

The processor of the interface unit has a wired or wireless connection (or both) to a data network, such as the Internet, to enable the processor to receive dynamic pricing information from energy suppliers. The processor also preferably has a data link connection (e.g., a ModBus) to the heat pump, both to send instructions to the heat pump and to receive information (e.g., status information and temperature information) from the heat pump. The processor has logic which enables it* to learn the behaviour of the

household, and with this and the dynamic pricing information, the processor is able to determine whether and when to use cheaper electricity to pre-charge the heating system. This may be by heating the energy storage medium using an electrical element inside the heat exchanger, but alternatively this can be by driving the heat pump to a higher-than-normal temperature – for example 60 Celsius rather than between 40 and 48 Celsius. The efficiency of the heat pump reduces when it operates at higher temperature, but this can be taken into account by the processor in deciding when and how best to use cheaper electricity.

*Because the system processor is connectable to a data network, such as the Internet and/or a provider's intranet, the local system processor can benefit from external computing power. So, for example the manufacturer of the interface unit is likely to have a cloud presence (or intranet) where computing power is provided for calculations of, for example, predicted: occupancy; activity; tariff (short/long); weather forecasts (which may be preferable to generally available weather forecasts because they can be pre-processed for easy use by the local processor, and they may also be tailored very specifically to the situation, location, exposure of the property within which the interface unit is installed); identification of false positives and/or false negatives.

To protect users from the risk of scalding by overheated water from the hot water supply system it is sensible to provide a scalding protection feature. This may take the form of providing an electrically controllable (modulatable) valve to mix cold water from the cold-water supply into hot water as it leaves the output circuit of the heat exchanger (the extra valve can be mounted between the nodes to which existing valves 94 and 96 previously mentioned).

Figure 2 shows schematically what might be considered the "guts" of the interface unit but does not show any container for these "guts". An important application of interface units according to the disclosure is as a means to enable a heat pump to be used as a practical contributor to the space heating and hot water requirements of a dwelling that was previously provide with a gas-fired combination boiler (or which might otherwise have such a boiler installed), it will be appreciated that it will often be convenient both to provide a container both for aesthetics and safety, just as is the case conventionally with combi boilers. Moreover, preferably any such container will be dimensioned to fit within a form factor enabling direct replacement of a combi boiler – which are typically wall mounted, often in a kitchen where they co-exist with kitchen cabinets. Based on the form of a generally rectangular cuboid (although of course, for aesthetics, ergonomics, or safety, curved surfaces may be used for any or all of the surfaces of the container) with a height, width and depth, suitable sizes may be found in the approximate ranges: height 650mm to 800mm; width 350mm to 550mm; depth 260mm to 420mm; for example 800 mm high, by 500mm wide, and 400mm deep, although larger, and in particular taller, units may be provided for installation where these can be accommodated.

One notable distinction of interface units according to the disclosure with respect to gas combi boilers is that while the containers of the latter generally have to be made of non-combustible materials – such as steel, due to the presence of a hot combustion chamber, the internal temperatures of an interface unit will generally be considerably less than 100 Celsius, typically less than 70 Celsius, and often less than 60 Celsius. So, it becomes practical to use flammable materials such a wood, bamboo, or even paper, in fabricating a container for the interface unit.

The lack of combustion also opens up the possibility to install interface units in locations that would generally never be considered as suitable for the installation of gas combi boilers – and of course, unlike a gas combi boiler, interface units according to the disclosure, do not require a flue for exhaust gases. So, for example, it becomes possible to configure an interface unit for installation beneath a kitchen worktop, and even to make use of the notorious dead spot represented by an under counter corner. For installation in such a location the interface unit could actually be integrated into an under-counter cupboard – preferably through a collaboration with a manufacturer of kitchen cabinets. But greatest flexibility for deployment would be retained by having an interface unit that effectively sits behind some form of cabinet, the cabinet being configured to allow access to the interface unit. The interface unit would then preferably be configured to permit the circulation pump 36 to be slid out and away from the heat exchanger 12 before the circulation pump 36 is decoupled from the flow path of the input-side circuit.

Consideration can also be given to taking advantage of other space frequently wasted in fitted kitchens, namely the space beneath under-counter cupboards. There is often more a space with a height of more than 150mm, and a depth of around 600mm, with widths of 300, 400, 500, 600mm or more (although allowance needs to be made for any legs supporting the cabinets). For new installations in particular, or where a combi boiler is being replaced along with a kitchen refit, it makes sense to use these spaces at least to accommodate the heat exchanger of the interface unit – or to use more than one heat exchanger unit for a given interface unit.

Particularly for interface units designed for wall mounting, although potentially beneficial whatever the application of the interface unit, it will often be desirable to design the interface unit as a plurality of modules. With such designs it can be convenient to have the heat exchanger as one of the modules, because the presence of the phase-change material can result in the heat exchanger alone weighing more than 25kg. For reasons of health and safety, and in order to facilitate one-person installation, it would be desirable to ensure that an interface unit can be delivered as a set of modules none of which weighs more than about 25kg.

Such a weight constraint can be supported by making one of the modules a chassis for mounting the interface unit to a structure. For example, where an interface unit is to be wall mounted in place of an existing gas combi boiler, it can be convenient if a chassis, by which the other modules are supported, can first be fixed to the wall. Preferably the chassis is designed to work with the positions of existing fixing points used to support the combi boiler that is being replaced. This could potentially be done by providing a “universal” chassis that has fixing holes preformed according to the spacings and positions of popular gas combi boilers. Alternatively, it could be cost effective to produce a range of chassis each having hole positions/sizes/spacings to match those of particular manufacturer’s boilers. Then one just needs to specify the right chassis to replace the relevant manufacturer’s boiler. There are multiple benefits to this approach: it avoids the need to drill more holes for plugs to take fixing bolts – and not only does this eliminate the time needed to mark out, drill the holes and clean up, but it avoids the need to further weaken the structure of the dwelling where installation is taking place – which can be an important consideration given the low cost construction techniques and materials frequently used in “starter homes” and other low cost housing.

Preferably the heat exchanger module and the chassis module are configured to couple together. In this way it may be possible to avoid the need for separable fastenings, again saving installation time.

Preferably an additional module includes first interconnects, e.g., 62 and 74, to couple the output side circuit 16 of the heat exchanger 12 to the in-building hot water system. Preferably the additional module also includes second interconnects, e.g., 38 and 24, to couple the input side circuit 14 of the heat exchanger 12 to the heat pump. Preferably the additional module also includes third interconnects, e.g., 42 and 28, to couple the interface unit to the heat circuit of the premises where the interface unit is to be used. It will be appreciated that by mounting heat exchanger to the chassis, which is itself directly connected to the wall, rather than first mounting the connections to the chassis, the weight of the heat exchanger is kept closer to the wall, reducing the cantilever loading effect on the wall fixings that secure the interface unit to the wall.

Phase change materials

One suitable class of phase change materials are paraffin waxes which have a solid-liquid phase change at temperatures of interest for domestic hot water supplies and for use in combination with heat pumps. Of particular interest are paraffin waxes that melt at temperatures in the range 40 to 60 Celsius, and within this range waxes can be found that melt at different temperatures to suit specific applications. Typical latent heat capacity is between about 180kJ/kg and 230kJ/kg and a specific heat capacity of perhaps $2.27\text{Jg}^{-1}\text{K}^{-1}$ in the liquid phase, and $2.1\text{Jg}^{-1}\text{K}^{-1}$ in the solid phase. It can be seen that very considerable amounts of energy can be stored taking using the latent heat of fusion. More energy can also be stored by heating the phase change liquid above its melting point. For example, when electricity costs are relatively low and it can be predicted that there will shortly be a need for hot water (at a time when electricity is likely to, or known to be going to, cost more perhaps), then it can make sense to run the heat pump at a higher-than-normal temperature to “overheat” the thermal energy store.

A suitable choice of wax may be one with a melting point at around 48 Celsius, such as n-tricosane C_{23} , or paraffin $\text{C}_{20}\text{-C}_{33}$. Applying the standard 3K temperature difference across the heat exchanger (between the liquid supplied by the heat pump and the phase change material in the heat exchanger) gives a heat pump liquid temperature of around 51 Celsius. And similarly on the output side, allowing a 3K temperature drop, we arrive at a water temperature of 45 Celsius which is satisfactory for general domestic hot water – hot enough for kitchen taps, but potentially a little high for shower/bathroom taps – but obviously cold water can always be added to a flow to reduce water temperature. Of course, if the household are trained to accept lower hot water temperatures, or if they are acceptable for some other reason, then potentially a phase change material with a lower melting point may be considered, but generally a phase transition temperature in the range 45 to 50 is likely to be a good choice. Obviously, we will want to take into account the risk of Legionella from storing water at such a temperature.

Heat pumps (for example ground source or air source heat pumps) have operating temperatures of up to 60 Celsius (although by using propane as a refrigerant, operating temperatures of up to 72 Celsius are possible), but their efficiencies tend to be much higher when run at temperatures in the range of 45 to 50 Celsius. So, our 51 Celsius, from a phase transition temperature of 48 Celsius is likely to be satisfactory.

Consideration also needs to be given to the temperature performance of the heat pump. Generally, the maximum ΔT (the difference between the input and output temperature of the fluid heated by the heat pump) is preferably kept in the range of 5 to 7 Celsius, although it can be as high as 10 Celsius.

Although paraffin waxes are a preferred material for use as the energy storage medium, they are not the only suitable materials. Salt hydrates are also suitable for latent heat energy storage systems such as the present ones. Salt hydrates in this context are mixtures of inorganic salts and water, with the phase change involving the loss of all or much of their water. At the phase transition, the hydrate crystals are divided into anhydrous (or less aqueous) salt and water. Advantages of salt hydrates are that they have much higher thermal conductivities than paraffin waxes (between 2 to 5 times higher), and a much smaller volume change with phase transition. A suitable salt hydrate for the current application is $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$, which has a melting point around 48 to 49 Celsius, and latent heat of 200/220 kJ/kg.

In terms simply of energy storage, consideration can also be given to using PCMs with phase transition temperatures that are significantly above the 40-50 Celsius range. For example, a paraffin wax, waxes being available with a wide range of melting points:

- n-henicosane C_{24} which has a melting point around 40 Celsius;
 - n-docosane C_{21} which has a melting point around 44.5 Celsius;
 - n-tetracosane C_{23} which has a melting point around 52 Celsius;
 - n-pentacosane C_{25} which has a melting point around 54 Celsius;
 - n-hexacosane C_{26} which has a melting point around 56.5 Celsius;
 - n-heptacosane C_{27} which has a melting point around 59 Celsius;
 - n-octacosane C_{28} which has a melting point around 64.5 Celsius;
 - n-nonacosane C_{29} which has a melting point around 65 Celsius;
 - n-triacosane C_{30} which has a melting point around 66 Celsius;
 - n-hentriacosane C_{31} which has a melting point around 67 Celsius;
 - n-dotriacosane C_{32} which has a melting point around 69 Celsius;
 - n-triatriacosane C_{33} which has a melting point around 71 Celsius;
 - paraffin $\text{C}_{22}\text{-C}_{45}$ which has a melting point around 58 to 60 Celsius;
 - paraffin $\text{C}_{21}\text{-C}_{50}$ which has a melting point around 66 to 68 Celsius;
 - RT 70 HC which has a melting point around 69 to 71 Celsius.
- Alternatively, a salt hydrate such as $\text{CH}_3\text{COONa} \cdot 3\text{H}_2\text{O}$ – which has a melting point around 58 Celsius, and latent heat of 226/265 kJ/kg.

Figure 3 shows schematically an in-building hot water supply installation 300 having a plurality of controllable water outlets (various taps and showers that will be described more fully later), a supply of hot water 305 with at least one outlet 307 having a controllable outflow temperature, and in a water flow path between the supply of water 305 and the plurality of controllable water outlets, at least one first temperature sensor 309 to detect the outflow temperature, at least one flow measurement device 310 and at least one flow regulator 315. The supply of water 305 may be provided by an installation such as those shown in Figures 1 and 2.

A processor 320 is operatively connected to the at least one flow measurement device 310 and the at least one flow regulator 315. The illustrated water supply installation represents a dwelling with a master bathroom 321, a first en-suite shower room 322, a second en-suite shower room 323, a cloakroom 324, and a kitchen 325. The master bathroom and the first en-suite shower room may be on one floor of the dwelling, whereas the cloakroom, second en-suite and kitchen may be on another floor of the dwelling. In such a situation, it may be convenient to have, as shown, two separate circuits, 330 and 331, to supply water to the various outlets. Although the two circuits 330 and 331 are shown as being supplied from a single outlet 307 from the hot water supply, with a single temperature sensor 309, it will be understood that the two circuits 330 and 331 may each be fed from a different outlet 307, the temperature of the two outlets 307 being separately adjustable, and each outlet 307 having its own associated temperature sensor 309. The temperature of the water at the outlet (s) 307 may be adjusted by mixing cold water with hot water from a source of fixed or variable temperature, or it may be adjusted by controlling the energy put into a heat source, such as an electric heating element or even a gas fired heater. Later we will describe hot water systems which include PCM energy storage arrangements, generally in combination with a heat pump, and in such systems generally the hot water supply temperature may be adjusted by mixing in different proportions of cold water from a cold-water supply. Sometimes such systems may include an instantaneous heat source (such as an electrical heating element) downstream of the PCM energy storage arrangement, controlled by a processor of the system, and in such installations control of hot water supply temperature may involve controlling the amount of energy supplied to the instantaneous water heater, as well possibly by mixing in different proportions of cold water from a cold-water supply.

The master bathroom 321 is shown as including a shower outlet 335, a bath tap or faucet 336, and a tap 337 for a sink. The en-suite shower rooms 322 and 323 also include a shower outlet 335, and a tap 337 for a sink. Conversely, the cloakroom contains just a W.C. (not shown) and a hand basin with a tap 338. Finally, the kitchen has a sink with a tap 339.

A processor, or system controller, 340, with an associated memory 341, is coupled to the at least one flow measurement device 310 and the at least one flow regulator 315. It will be appreciated that each of the two circuits 330 and 331 is provided with a respective flow measurement device 310 and flow regulator 315. The processor is also optionally connected to one or more temperature sensors 343, one for each of the circuits 330 and 331. This processor may be associated with an energy bank as previously described.

The processor may also be coupled to an RF transceiver 342, which includes at least one RF transmitter and at least one RF receiver, for bidirectional communication via Wi-Fi, Bluetooth, or the like, and preferably also to the Internet 344 for connection to a server or central station 345, and optionally to a cellular radio network (such as LTE, UMTS, 4G, 5G, etc.). By means of the RF transceiver 342 and/or the connection to the Internet, the processor 340 is able to communicate with a mobile device 350, which may for example be a smart phone or tablet, for use by an installation engineer in configuring (and also optionally in mapping) the in-building water supply installation. The mobile device 350 includes software, such as a specific app, that co-operates with corresponding software in the system controller 340 and also potentially within server 345, to facilitate the configuring (and optionally mapping) methods according to embodiments of the invention, and in particular to synchronize actions taken by the engineer to a clock of

the system controller 340 / server 345. The memory 341 contains code to enable the processor to perform a method of configuring (and optionally mapping) an in-building water supply installation processor, for example during a process of commissioning a new installation.

During the commissioning process, in order to configure the hot-water supply installation 300, the engineer may be asked to setup a temperature sensor direct under a particular hot-water outlet, e.g. a specific tap or shower outlet, and to open the outlet fully at a specific moment. The system processor is configured to measure flow, the difference between both outflow and provided temperature, time delay and, preferably, outdoor temperature (data provided from an external temperature sensor). This will allow algorithms (e.g., MLAs) to calculate heat loss through the distribution system, distance between the outlet (tap or shower outlet) and the source of hot water, and finally, accurately adjust the outflow temperature at 107 to achieve the correct water temperature at the relevant controllable outlet (e.g., tap). For example, if the household includes children, then the maximum hot water temperature to every outlet other than, for example, the kitchen sink may be limited to 40C or 41C, whereas if there are infants in the house, the maximum temperature may be limited to 37C. Even in the absence of children, the maximum temperature for all outlets other than the kitchen sink may be set at 43C, and possibly 41C for shower outlets.

The system may also be set up to restrict the flow of hot water to some classes of water outlets, such as handbasins and sinks, and possibly showers, with different maximum flow rates being set for each class of outlet, and/or maximum specific flow rates may be set for specific outlets – so lower flow rates set for bathrooms and cloakrooms used by children, for example. The determination of maximum temperatures and flow rates may be based on rules provided by the system supplier. Later we will discuss hot water supply systems which use heat pumps and PCM-based energy storage arrangements, and such systems benefit significantly from the imposition of temperature and flow rate control – since heat pumps sized according to the space heating need of a modestly sized 1 to 3 bedroom dwelling generally do not have the heating capacity to satisfy the instantaneous hot water demands of the household, without the provision of voluminous hot water storage tanks. By managing hot water flow and temperature, it may be possible to eliminate the need to provide hot water storage, while minimizing the size of the energy shortfall to be accommodated by other means. If the installation does include a PCM energy storage arrangement and a heat pump, the system supplier will typically pre-program the processor with suitable values for temperature and flow based on outlet type and household composition.

A database of temperatures and optionally flow rates, based on outlet type and household composition may also be made available to the system controller over the internet, and updated from time to time. A user interface for the system controller may provide a means for occupiers and or service engineers to adjust the various settings according to changes in the household composition – for addition the arrival of guests with infants, children or elderly or infirm persons, of for example to allow users to set lower maximum temperatures and/or flow rates.

Figure 4 illustrates schematically such a method of configuring a hot-water supply installation having a plurality of controllable hot-water outlets – for example a plurality of taps, and one or more shower outlets. In order to improve the efficiency of energy usage in an installation, a processor of the system is used in conjunction with a portable temperature sensor 800 that is placed beneath each of the

outlets in turn (although clearly more than one sensor may be used, rather than the same one being used for every outlet).

An installer may have an app on a smart phone, for example, or some other wireless transmission/reception unit (WTRU) that is able to receive an instruction from the processor that tells the installer to open the relevant tap, and preferably to open it to its maximum opening as quickly as possible.

Thus, as shown in the plot of flow against time in Figure 4, there is an initial lag (time T0 to T1), due to the reaction time of the installer, before flow through the outlet and through the hot water system (as only one outlet at a time is opened) goes from zero to a maximum at T1 (the maximum possibly being different and unique to each outlet of the hot water system). Or the installer may use the WTRU, or more typically an app on the WTRU, to inform the processor that an agreed/identified tap is being opened now.

In either event, the processor also receives information from a temperature sensor 309 at the outlet 307 of the source of hot-water 305 with an outlet having a controllable outflow temperature. The portable temperature sensor 800 also preferably includes an internal clock (preferably synchronised to the system time of the processor) and an RF (e.g, Wi-Fi, Bluetooth, or IMS) capability for communicating time and temperature information to the remote processor 140. The temperature against time plot of Figure 4 shows how the temperature sensed by portable sensor 800 initially remains low, and then climbs to reach a stable maximum at time T2, some time after time T1. It can also be seen that the maximum detected temperature sensed by portable sensor 800 (from time T1 to T3) is lower, by ΔT , than the temperature at the outlet 107 of the source of hot water having a controllable outflow temperature.

It will be appreciated that the temperature sensor 800 may be configured in such a way that the data that it gathers (time vs temperature) is only provided to the system processor 340 after the event – i.e., by a wired download process or using NFC, but this will generally be less satisfactory than providing direct RF communication as already described.

The foregoing description of the method of configuring a hot water supply system, and of controlling the temperature of water delivered from a hot water supply installation was deliberately kept simple for ease of application, but it should be appreciated that these methods apply equally to installations that include a PCM energy storage arrangement and a heat pump as previously described with reference to Figures 1 to 3.

A method of controlling an installation according to an aspect of the invention will now be described with reference to Figure 5. Figure 5 is a simplified flow chart illustrating various actions performed by a processor associated with an installation according to any variant of the third or fourth aspect of the invention.

The method begins at 520 with generating a determination of the amount of energy stored as latent heat in the phase change material, based on information from one or more of the status sensors 24.

Then, at step 530, based at least in part on that determination, the processor decides whether to provide a start signal to the heat pump. Various factors which the processor may take into account in addition to the status of the PCM are introduced and discussed later in the specification.

Figure 6 is another simplified flow chart illustrating various actions performed by a processor associated with an installation according to any variant of the third or fourth aspect of the invention.

The method begins at 600 with the processor receiving a signal indicating the opening of an outlet of the hot water supply system. The signal may for example come from a flow sensor 138 in the hot water supply system, or in the cold-water feed to the hot water system. At 602 the processor estimates a demand for hot water from the hot water supply system, based for example on an identity or type of the outlet that has been opened, or based on an instantaneous flow rate. The processor compares the estimated demand with a first threshold demand level. If the estimated demand is above the first threshold demand level, the processor generates at 604 a heat pump start message. If the estimated demand is below the first threshold demand level, the processor compares the estimated demand with a second threshold demand level, lower than the first. If the estimated demand is below the second threshold demand level, the processor determines at 606 to not to generate a heat pump start message.

If the estimated demand is between the first and the second threshold demand levels, the processor at 608 takes account to the energy storage level of the energy bank. This may involve the processor establishing afresh the energy storage level of the energy bank, or the processor may use recently generated information on the energy storage level of the energy bank.

If the determination of the energy storage level for the energy bank is greater than a first energy storage level threshold, the processor determines at 604 not to generate a heat pump start message. Conversely, if the determination of the energy storage level for the energy bank is less than the first energy storage level threshold, the processor determines to generate a heat pump start message at 606.

A method of controlling an installation according to an aspect of the invention will now be described with reference to Figure 7. Figure 7 is a simplified flow chart illustrating various actions performed by a processor associated with an energy bank such as that illustrated in Figure 1. The process begins at step 700 when the processor 130 detects a flow of water in the hot water supply system. Detection is preferably based on data from a flow sensor such as flow sensor 138 of Figure 1 but could alternatively be based on data from a pressure sensor in the hot water supply system. The relevant sensor may be configured continuously to supply measurement data to the processor 130 or may be configured only to report changes in the measurement data, or the processor may continuously or periodically (for example at least once per second) read the relevant sensor(s).

At step 702 the processor 130 determines whether the flow rate indicated by the data from the sensor(s) indicate a high or a low flow, for example above or below a particular threshold. The processor may use more than one threshold to categorize the flow rate as high, medium, or low, or the categories could include very high, high, medium, and low. There may also be a category of very low or de minimus flow. The processor 130 may also be provided with information (e.g. in the form of a database, model, or MLA) about flow rates and flow signatures for each of the outlets 122, or each of the outlet types, of the hot water supply system (for example using a technique such as that described later in this patent application), the processor then characterising the detected flow rate as associated with a particular one of the outlets 122 or a particular type (shower outlet, bath outlet, kitchen sink outlet, washbasin outlet, handbasin outlet, for example).

If the determination indicates that the demand for hot water is low 703, the processor then, in step 704, takes account of the status of the power bank 110, based on information from at least the status sensor

124. The processor 130 may interrogate the status sensor 124 (e.g., a pressure sensor) at this stage, or may check a recently updated energy bank status, in either case determining whether the energy bank is in a high energy state 705 (with a large proportion of the potential latent heat capacity of the energy bank available for use) or in a low energy state 706 (with a small proportion of the potential latent heat capacity of the energy bank available for use). The processor may also take account of information from the temperature sensor(s) 126, for example to take account of sensible energy stored in the energy bank 110. If the processor 130 determines a high energy state, the processor determines not to send a start instruction to the heat pump, and the process terminates at 707. If the processor 130 determines a low energy state, the processor may then determine at 706 to send 722 a start instruction to the heat pump.

If the determination indicates that the demand for hot water is high 708, the processor may then, in step 709, takes account of the status of the power bank 110, based on information from at least the status sensor 124. The processor 130 may interrogate the status sensor 124 at this stage, or may check a recently updated energy bank status, in either case determining whether the energy bank is in a high energy state 710 (with a large proportion of the potential latent heat capacity of the energy bank available for use) or in a low energy state 712 (with a small proportion of the potential latent heat capacity of the energy bank available for use). The processor may also take account of information from the temperature sensor(s) 126, for example to take account of sensible energy stored in the energy bank 110. If the processor 130 determines a high energy state 710, the processor optionally determines a predicted hot water demand in step 714. But the processor may alternatively be configured to issue an instruction to start the heat pump at 722 based simply on the magnitude of the flow rate, and without predicting hot water demand (as indicated by the cross-hatched arrow 711).

In step 714, the processor 130 may take account of the determined identity (i.e., a particular outlet) or type of water outlet to predict hot water demand. For example, if the outlet is identified as a kitchen sink outlet, it is unlikely that the tap will be run for more than 130 seconds to a minute. Whereas, if the outlet is a bath tap, the tap is likely to remain open for several minutes with a demand for perhaps 120 to 150 litres of hot water.

In the first situation, the processor 130 will determine at 716 not to send a start signal to the heat pump, but will instead either end the process, or more preferably continue to monitor the flow rate at 718 to see how long the flow continues. If the flow stops within the predicted time, the process ends at 720, but if the flow of water continues for longer than predicted, the processor moves at 719 back to step 709. In the second situation, the processor 130 will determine at 721 to send 722 a start signal to the heat pump (and the arrow 711 indicates a decision to start the heat pump based simply on the instantaneous flow rate or the identification of the outlet (or outlet type) as being associated with the withdrawal of significant volumes of hot water from the hot water supply system.

After starting the heat pump at 722 (either from the determination at 706 or at 721), the processor 130 continues at 724 to monitor (periodically or continuously) the power bank status, until the status reaches some threshold level of charge 725, at which the processor sends a signal 726 to turn off the heat pump.

Figure 8 is another simplified flow chart illustrating various actions performed by a processor associated with the energy bank, such as processor 130 of Figure 1. Unlike the method described with

reference to Figure 7, the method of Figure 8 is not dependent on detection of a call for hot water, i.e., not dependent on the opening of an outlet of the hot water system. Generally, Figure 8 illustrates a method of controlling an installation, the method comprising generating a determination of the amount of energy stored as latent heat in the phase change material; and based on that determination deciding whether to provide a start signal to the heat pump. Although, as will be seen, an optional but preferred step may take place between the step of generating a determination of the amount of energy stored as latent heat in the phase change material, and the step of, based on that determination, deciding whether to provide a start signal to the heat pump.

The method begins at step 800 with the processor 130 estimating the amount of energy stored in the phase change material of the energy bank 110 as latent heat. The amount of heat may be an absolute amount in KJoules but may equally well be simply a measure of the proportion of the potential latent heat capacity that is currently available. In other words, the processor may effectively determine the proportion of the phase change material that is still in the phase with the higher energy state. So, for example, if the phase change material is a paraffin wax, with a phase change from liquid to solid, the liquid phase is the higher energy phase, incorporating the latent heat of fusion, and the solid phase is the lower energy phase, the latent heat of fusion having been given up on solidification.

If the processor determines that the amount of energy stored as latent heat is sufficient 802, i.e., exceeds some predetermined threshold, the method moves to step 804 at which the process halts, and the processor awaits the next check 800.

If the processor determines that the amount of energy stored as latent heat is not sufficient 806, i.e., is at or below some predetermined threshold the method moves to step 808. At step 808, the processor determines the likelihood of significant hot water demand within a coming period of time (e.g., within the next half hour, hour, 2, 3, or 4 hours). The period of time considered is a factor of the heat capacity of the energy bank, the size of the energy shortfall determined, and the capacity of the heat pump to recharge the energy bank under those circumstances. It will be appreciated that the demand period considered should be great enough to enable the heat pump to recharge the energy bank sufficiently within the period so that the energy bank will be optimally charged (possibly fully charged) to be able to cope with the predicted or anticipated demand. Conversely, the heat pump should not be being used to recharge the energy bank so long in advance of the expected/predicted energy demand that the energy bank will lose a significant quantity of energy through radiation, conduction, or convection.

The processor may rely on a database, model, calendar or schedule, and any and all of these may include learned behaviours and patterns of behaviour, and scheduled events (such as scheduled absences or events scheduled for some other location). The processor may also have access to local weather reports, for example provided (pushed or received) over the Internet, or in a radio transmission, and/or an external thermometer.

If the processor determines 810 that there is a low likelihood of significant hot water demand within the period, the method moves to step 804 at which the process halts, and the processor awaits the next check 800.

If the processor determines 812 that there is a high likelihood of significant hot water demand within the period, the method moves to step 814 at which the heat pump is turned on: for example, the

processor 130 sends an instruction to the heat pump 116, so that the processor 132 of the heat pump initiates the heat pump starting procedure, after which the heat pump starts to supply heat to the input side of the heat exchanger, thereby putting energy into the phase change material. The processor then, in step 816, repeatedly determines whether sufficient energy is now stored in the energy bank as latent heat of the phase change material. Once the processor has determined 818 that sufficient energy is now stored in the energy bank as latent heat of the phase change material, the method moves to step 820, and the heat pump is turned off, for example by the processor 130 sending an appropriate instruction. As long as the processor determines 822 that insufficient energy is stored, the method continues.

Referring back to Figure 1, instead of or in addition to providing one or more status sensors 124 to measure pressure within the enclosure, other sensor types can be provided to measure optical properties, such as transparency, absorption, refraction, refractive index, of the PCM, because various of these change with phase transitions in the PCM. In addition, various of these properties may exhibit a wavelength dependence that changes with a change of phase.

The energy bank may therefore further comprise one or more optical sources to launch light into the phase change material, and the one or more status sensors 124 may include an optical sensing arrangement to detect light launched from the optical source (s) after the light has passed through the phase change material. The change between phases in the phase change material gives rise to reversible changes in optical properties of the phase change material, and hence observing optical properties of the PCM can be used to glean information about the state of the PCM. Preferably, optical properties of the PCM are observed in several areas of the PCM, and preferably in different directions within the material. For example, optical sources and sensors may be arranged so that light from the source(s) passes lengthwise through the PCM at one or more positions, and other source(s) and sensor(s) may be arranged so that light from the source(s) passes width wise through the PCM at one or more positions and in one or more orientations (through the width and or through the thickness).

The optical source(s) may be controllable to produce light of different colours and the optical sensing arrangement(s) may be configured to detect at least some of different colours. By selecting appropriate colours of light, based on the particular PCM chosen for any application, it may be possible to determine more accurately the extent to which the phase of the PCM has changed.

Preferably the optical source comprises a plurality of separately activatable devices.

Coupling the optical sensing arrangement to a processor which is configured to estimate an amount of energy stored in the phase change material based on information received from the optical sensing arrangement provides a means of determining the amount of energy stored as latent heat within the PCM, and this information can be used in controlling the heat pump. In particular, such information may make possible more efficient and appropriate use of the heat pump in charging the PCM energy bank.

As a further option, the one or more status sensors 124 to provide measurement data indicative of the amount of energy stored as latent heat in the phase change material may include an acoustic source configured to launch sound into the phase change material, and an acoustic sensing arrangement to detect sound launched from the acoustic source after the sound has passed through the phase change material. The change between phases in the phase change material gives rise to reversible changes in sound absorbing properties of the phase change material, and hence observing sonic properties of the PCM can

be used to glean information about the state of the PCM. The acoustic source may be configured to produce ultrasound.

During the commissioning process that was described with reference to Figure 3, an engineer may also be asked by the processor/system controller 340 to define all hot water outlets (for e.g., tap, shower, bath, kitchen), or in other words to map the system. In this process, the system controller will ask the engineer to fully open each of the outlets (taps, shower outlets, etc.) in turn, closing each before opening the next, and will monitor the resulting water flows, by means of the relevant flow measurement device 310. During this process, the relevant flow measurement device 310 will measure water flow and the processor will receive these data and will add the results to a database. Based on this information, the system will subsequently be able to provide the most efficient flow into each single tap, by controlling the relevant flow control device 315, when any outlet is opened.

A method of mapping an in-building water supply installation according to a first aspect of the disclosure will now be described with reference to Figure 3.

The method comprises opening a first of the plurality of controllable water outlets and processing signals from the at least one flow measurement device 310 with the processor 340 at least until a first flow characteristic is determined, and then closing the first of the plurality of controllable water outlets. The opening of the first of the plurality of controllable water outlets is preferably instructed by the processor or system controller 340 sending a message to the mobile device 350 carried by the relevant engineer. For example, the instruction may be sent by Wi-Fi and tell the engineer to open the hot bath tap 336 in the master bathroom 321. The engineer, carrying the mobile device 350, then goes to the master bathroom and opens the hot bath tap 336 fully. The mobile device may provide the engineer with a prompt, preferably audible and with a countdown, to tell the engineer when precisely to open the tap.

Alternatively, the app on the mobile device may be configured to accept an input from the engineer, such as the pressing or release of a button, at the moment that the tap 336 is opened. In either case, the app may capture a local time for the prompt or the moment, and then send this local time, along with the identity of the relevant controllable outlet, to the system controller 340 or server 345. In this way, delays in the prompt reaching the mobile device 350 or of the timing of the instruction reaching the controller 340 or server 345 can be accounted for (the mobile device 350 and the system controller 340 preferably go through some handshaking procedure, either before or after the mapping process, so that wither offsets between the clocks of the two devices can be eliminated or they can also be accounted for).

The engineer may then work her way around the premises selecting an outlet identity from a list or menu on the app, or entering an unambiguous identifier, opening each of the outlets in turn. Or the system controller may already have been provided with a list of all the taps, etc. (generally "controllable outlets") and may prompt the engineer, by sending another message to the mobile device 350, to go to the relevant outlet. The app preferably includes the option for the engineer to send a message to the system controller 340 / server 345, that the engineer is in place and ready to receive an instruction to open the next controllable outlet. The process is then repeated for each of the other hot water outlets, until all the outlets and their flow characteristics – namely the lag before flow is detected, the rate of rise of flow, the maximum flow rate, and any other identifiable characteristics have been captured and stored in a database. By using the characteristics stored in the database, the processor 340 is then subsequently able to identify

the opening of a particular one of the plurality of controllable water outlets based on the similarity of a detected flow characteristic to a respective flow characteristic.

The processor is also provided with some rules concerning preferred flow rates and, optionally, flow durations, based on the type of outlet (bath tap, kitchen tap, basin tap, cloakroom tap) and its location (main bathroom, en-suite, child's room, adult's room, cloakroom, kitchen, for example), and use these rules, along with the outlet identity recognised from the detected flow characteristics, to determine a target flow rate. The targeted flow rate is then imposed by the system controller 340 by controlling the relevant flow controller 315, and preferably monitored by the corresponding flow measurement device 310. In this way, by controlling at least one flow regulator, based on the identification of the relevant outlet, the processor 340 is able control a supply of water to the identified controllable water outlet.

Each of the respective flow characteristic may include a respective stable flow rate. The method may then further comprise configuring the processor 340 to control the at least one flow regulator 315 to impose at least a 10% cut in the flow rate to each of each of the plurality of controllable water outlets, based on the respective stable flow rate. Optionally, the method may further comprise configuring the processor 340 to control the at least one flow regulator 315 to impose at least a 10% cut in the flow rate, based on respective stable flow rate, to any of the plurality of controllable water outlets whose respective stable flow rate is greater than 7 litres per minute. This is of particular application for taps that serve basins in bathrooms, en suites, and most particularly cloakrooms, where taps are often largely used to provide water for handwashing – which can be achieved effectively with quite modest flow rates.

The above-described technique of mapping a hot water supply installation may be used to populate a database or train logic, such as a neural network or machine learning algorithm (MLA), which may be used by a processor associated with an energy bank as previously described, so that the processor is better able to identify a particular outlet or outlet type from detected flow behaviour and hence to more readily estimate a demand for hot water from a hot water supply. This in turn may improve the efficiency of controlling the heat pump and of using the energy bank.

Thus far, the thermal energy store has largely been described as having a single mass of phase change material within a heat exchanger that has input and output circuits each in the form of one or more coils or loops. But it may also be beneficial in terms of rate of heat transfer for example, to encapsulate the phase change material in a plurality of sealed bodies – for example in metal (e.g. copper or copper alloy) cylinders (or other elongate forms) – which are surrounded by a heat transfer liquid from which the output circuit (which is preferably used to provide hot water for a (domestic) hot water system) extracts heat.

With such a configuration the heat transfer liquid may either be sealed in the heat exchanger or, more preferably, the heat transfer liquid may flow through the energy store and may be the heat transfer liquid that transfers heat from the green energy source (e.g. a heat pump) without the use of an input heat transfer coil in the energy store. In this way, the input circuit may be provided simply by one (or more generally multiple) inlets and one or more outlets, so that heat transfer liquid passes freely through the heat exchanger, without being confined by a coil or other regular conduit, the heat transfer liquid transferring heat to or from the encapsulated PCM and then on to the output circuit (and thus to water in the output circuit). In this way, the input circuit is defined by the one or more inlets and the one or more

out for the heat transfer liquid, and the freeform path(s) past the encapsulated PCM and through the energy store.

Preferably the PCM is encapsulated in multiple elongate closed-ended pipes arranged in one or more spaced arrangements (such as staggered rows of pipes, each row comprising a plurality of spaced apart pipes) with the heat transfer fluid preferably arranged to flow laterally (or transverse to the length of the pipe or other encapsulating enclosure) over the pipes – either on route from the inlets to the outlets or, if an input coil is used, as directed by one or more impellers provided within the thermal energy store.

Optionally, the output circuit may be arranged to be at the top of the energy store and positioned over and above the encapsulated PCM – the containers of which may be disposed horizontally and either above an input loop or coil (so that convection supports energy transfer upwards through the energy store) or with inlets direction incoming heat transfer liquid against the encapsulated PCM and optionally towards the output circuit above. If one or more impellers is used, preferably the or each impeller is magnetically coupled to an externally mounted motor – so that the integrity of the enclosure of the energy store is not compromised.

Optionally the PCM may be encapsulated in elongate tubes, typically of circular cross section, with nominal external diameters in the range of 20 to 67 mm, for example 22 mm, 28 mm, 35mm, 42mm, 54mm, or 67mm, and typically these tubes will be formed of a copper suitable for plumbing use. Preferably, the pipes are between 22mm and 54mm, for example between 28mm and 42mm external diameter.

The heat transfer liquid is preferably water or a water-based liquid such as water mixed with one or more of a flow additive, a corrosion inhibitor, an anti-freeze, a biocide, – and may for example comprise an inhibitor of the type designed for use in central heating systems – such as Sentinel X100 or Fernox F1 (both RTM) – suitably diluted in water.

Thus, throughout the description and claims of the present application the expression input circuit should be construed, unless the context clearly requires otherwise, to include an arrangement as just described and in which the path of liquid flow from the input of the input circuit to its output is not defined by a regular conduit but rather involves the liquid flowing substantially freely within the enclosure of the energy store.

The PCM may be encapsulated in a plurality of elongate cylinders of circular or generally circular cross section, the cylinders preferably being arranged spaced apart in one or more rows. Preferably the cylinders in adjacent rows are offset with respect to each other to facilitate heat transfer from and to the heat transfer liquid. Optionally an input arrangement is provided in which heat transfer liquid is introduced to the space about the encapsulating bodies by one or more input ports which may be in the form of a plurality of input nozzles, that direct the input heat transfer liquid towards and onto the encapsulating bodies fed by an input manifold. The bores of the nozzles at their outputs may be generally circular in section or may be elongate to produce a jet or stream of liquid that more effectively transfers heat to the encapsulated PCM. The manifold may be fed from a single end or from opposed ends with a view to increasing the flow rate and reducing pressure loss.

The heat transfer liquid may be pumped into the energy store as the result of action of a pump of the green energy source (e.g. a heat pump or solar hot water system), or of another system pump, or the thermal energy store may include its own pump. After emerging from the energy store at one or more

outlets of the input circuit the heat transfer liquid may pass directly back to the energy source (e.g. the heat pump) or may be switchable, through the use of one or more valves, to pass first to a heating installation (e.g. underfloor heating, radiators, or some other form of space heating) before returning to the green energy source.

The encapsulating bodies may be disposed horizontally with the coil of the output circuit positioned above and over the encapsulating bodies. It will be appreciated that this is merely one of many possible arrangements and orientations. The same arrangement could equally well be positioned with the encapsulating bodies arranged vertically.

Alternatively an energy store using PCM encapsulation may again use cylindrical elongate encapsulation bodies such as those previously described, but in this case with an input circuit in the form of conduit for example in the form of a coil. The encapsulation bodies may be arranged with their long axes disposed vertically, and the input 14 and output 18 coils disposed to either side of the energy store 12. But again this arrangement could also be used in an alternative orientation, such as with the input circuit at the bottom and the output circuit at the top, and the encapsulation bodies with their long axes disposed horizontally. Preferably one or more impellers are arranged within the energy store 12 to propel energy transfer liquid from around the input coil 14 towards the encapsulation bodies. The or each impeller is preferably coupled via a magnetic drive system to an externally mounted drive unit (for example an electric motor) so that the enclosure of the energy store 12 does not need to be perforated to accept a drive shaft - thereby reducing the risk of leaks where such shafts enter the enclosure.

By virtue of the fact that the PCM is encapsulated it becomes readily possible to construct an energy store that uses more than one phase change material for energy storage, and in particular permits the creation of an energy storage unit in which PCMs with different transition (e.g. melting) temperatures can be combined thereby extending the operating temperature of the energy store.

It will be appreciated that in embodiments of the type just described the energy store 12 contains one or more phase change materials to store energy as latent heat in combination with a heat transfer liquid (such as water or a water/inhibitor solution).

A plurality of resilient bodies that are configured to reduce in volume in response to an increase in pressure caused by a phase change of the phase change material and to expand again in response to a reduction in pressure caused by a reverse phase change of the phase change material are preferably provided with the phase change material within the encapsulation bodies (they may also be used in energy banks using "bulk" PCMs as described elsewhere in this specification).

The present application contains a number of self-evidently inter-related aspects and embodiments, generally based around a common set of problems, even if many aspects do have broader applicability. In particular the logic and control methods, whilst not necessarily *limited* to operating with the hardware disclosed and may be more broadly applied, are all particularly suited to working with the hardware of the various hardware aspects and the preferred variants thereof. It will be appreciated by the skilled person that certain aspects relate to specific instances of other features and the preferred features described or claimed in particular aspects may be applied to others. The disclosure would become unmanageably long if explicit mention were made at every point of the inter-operability and the skilled person is expected to appreciate, and is hereby explicitly instructed to appreciate, that preferred features

of any aspect may be applied to any other unless otherwise explicitly stated otherwise or manifestly inappropriate from the context. Again, for the sake of avoiding repetition, many aspects and concepts may be described only in method form or in hardware form but the corresponding apparatus or computer program or logic is also to be taken as disclosed in the case of a method or the method of operating the hardware in the case of an apparatus discussion. For an example of what is meant by the above, there are a number of features of both hardware and software relating to the combination of a fluid based (typically air source) heat pump and a phase change material and an electric supplementary heating element and control by a processor (within the unit or remote or both). Although this is the preferred application, most methods and hardware are more generally applicable to other heat pumps (thermoelectric and ground source) and to other renewable energy sources (a pump for a solar array for example) and to alternative supplementary heating (including the less preferred arrangement of a combustion heater such as a gas boiler, or even a less efficient higher temperature lower COP heat pump) and alternative thermal storage, including multi-temperature thermal storage arrays. Moreover, aspects which give particular arrangements for any of the components, or their interaction can be used freely with aspects which focus on alternative elements of the system. Throughout this specification and the claims which follow, including the specification from which the current application claims priority, unless the context requires otherwise, the word "comprise", and variations such as "comprises" and "comprising", will be understood to mean the inclusion of a stated feature or step, or group of features or steps, but not the exclusion of any other feature or step, or group of features or steps.

Any reference to prior art in this specification is not, and should not be taken as an acknowledgement, or any suggestion that, the prior art forms part of the common general knowledge.

The Claims defining the invention are as follows:

1. A method of controlling a heating installation including an energy store including a heat energy storage medium for storing thermal energy, and a heat pump having a defrost cycle, the heating installation arranged to supply instantaneous heated water and space heating to a building, the method including:
 - controlling the supply of heat from the heat pump to the heat energy storage medium to store thermal energy for heating of water and to a heating circuit for providing space heating, the method further including:
 - estimating, using a processor of the heating installation, a likelihood of a defrost cycle being performed by the heat pump;
 - in anticipation of an impending defrost cycle, under the control of the processor, storing additional thermal energy by at least one of:
 - heating the heat energy storage medium to a higher level than a level set for anticipated water heating demand alone; and/or
 - heating the building and/or circulating heating fluid of the heating installation to a higher level than a level set for desired building heating;
 - to compensate for an absence of heat from the heat pump during the impending defrost cycle, further including using energy from the heat energy storage medium in performing the defrost cycle.
2. A method according to claim 1, wherein the heating installation includes a thermostat set to a temperature maximum in respect of one or more rooms of the building, and wherein heating the building and/or circulating heating fluid of the heating installation to a higher level than the level set for desired building heating includes raising the temperature in the one or more rooms to a temperature greater than the temperature maximum set by the thermostat.
3. A method according to any one of the preceding claims, wherein estimating the likelihood of a defrost cycle includes processing with the processor data from one or more sensors, the data representing exterior temperature.
4. A method according to claim 3, wherein the data also represents exterior humidity.
5. A method according to either claim 1 or claim 2, wherein estimating the likelihood of a defrost cycle includes processing data provided by a processor of the heat pump, the processor of the heat pump being distinct from the processor of the heating installation.
6. A method according to any one of the preceding claims, wherein the storing of additional energy in anticipation of an impending defrost cycle only occurs if the processor of the heating installation determines that the building is occupied.

7. A method according to claim 6, further including monitoring with the one or more processors of the heating installation one or more motion sensors within the building.
8. A method according to either claim 6 or claim 7, wherein the building includes a security monitoring system coupled to the one or more processors of the heating installation, the method further including only storing additional energy in anticipation of an impending defrost cycle if the status of the security monitoring system does not indicate that the building is unoccupied.
9. A method according to any one of the preceding claims, wherein the heating installation includes a heater within the heat energy storage medium, and the heating of the heat energy storage medium to a higher level is performed using the heater.
10. A heating installation including an energy store including a heat energy storage medium for storing thermal energy, and a heat pump having a defrost cycle, the heating installation including a hot water supply system arranged to supply instantaneous heated water and space heating to a building, and one or more processors to control the heating installation, the one or more processors configured to:
- control the supply of heat from the heat pump to the heat energy storage medium to store thermal energy for heating water and to a heating circuit for providing space heating;
 - estimate a likelihood of a defrost cycle being performed by the heat pump;
 - and in anticipation of an impending defrost cycle, control operation of the heating installation to store additional energy by at least one of:
 - heating the heat energy storage medium to a higher level than a level set for anticipated water heating demand alone; and/or
 - heating the building and/or circulating heating fluid to a higher level than a level set for desired building heating;
- to compensate for an absence of heat from the heat pump during the impending defrost cycle, wherein the one or more processors is configured to cause the heat pump to use energy from the heat energy storage medium in performing the defrost cycle.
11. A heating installation according to claim 10, wherein the heating installation includes a thermostat set to a temperature maximum in respect of one or more rooms of the building, and wherein the one or more processors is configured to cause the heating the building and/or circulating heating fluid of the heating installation to a higher level than a level set for desired building heating by increasing the temperature in the one or more rooms to a temperature greater than the temperature maximum set by the thermostat.

12. A heating installation according to either claim 10 or claim 11, wherein the one or more processors is configured to estimate the likelihood of a defrost cycle by processing data from one or more sensors, the data representing exterior temperature and optionally humidity.
13. A heating installation according to claim 12, wherein the data also represent exterior humidity.
14. A heating installation according to any one of claims 10 to 13, wherein the one or more processors is configured to estimate the likelihood of a defrost cycle by processing data provided by a processor of the heat pump, the processor of the heat pump being distinct from the one or more processors of the heating installation.
15. A heating installation according to any one of claims 10 to 14, wherein the one or more processors are configured to cause the storing of additional energy in anticipation of an impending defrost cycle only if the one or more processors of the heating installation determines that the building is occupied.
16. A heating installation according to claim 15, wherein the one or more processors of the heating installation is coupled to one or more motion sensors within the building.
17. A heating installation according to either claim 15 or claim 16, wherein the building includes a security monitoring system coupled to the one or more processors of the heating installation.
18. A heating installation according to claim 17, wherein the one or more processors of the heating installation is configured not to cause additional energy to be stored in anticipation of an impending defrost cycle if the status of the security monitoring system indicates that the building is unoccupied.
19. A heating installation according to any one of claims 10 to 18, wherein the one or more processors to control the heating installation include a first processor controlling the internal functioning of the heat pump and a second processor associated with the energy store and coupled to sensors in the hot water supply system.
20. A heating installation according to any one of claims 10 to 19, wherein the energy store includes a heat exchanger that is coupled between the hot water system and the heat pump.
21. A heating installation according to claim 20, wherein one of the one or more processors is configured to provide a signal to the heat pump based on the opening of an outlet of the hot water supply system.
22. A heating installation according to claim 21, wherein the heat energy storage medium has enough heat capacity to heat to a predetermined temperature a predetermined quantity of water in the

interval from the opening of an outlet of the hot water supply system until at least the heat pump begins to heat water in the hot water supply system.

23. A heating installation according to any one of claims 10 to 22, wherein the heating installation includes a heater within the heat energy storage medium, and the one or more processors of the heating installation is configured to activate the heater to heat the heat energy storage medium to the higher level.

24. A heating installation according to any one of claims 10 to 23, wherein the one or more processors of the heating installation is provided with logic to enable identification of time windows when demand for hot water and or space heating is likely to be such that there is no need for additional energy storage during defrost cycles, the one or more processors being configured not to cause additional thermal energy to be stored in anticipation of an impending defrost cycle during such time windows.

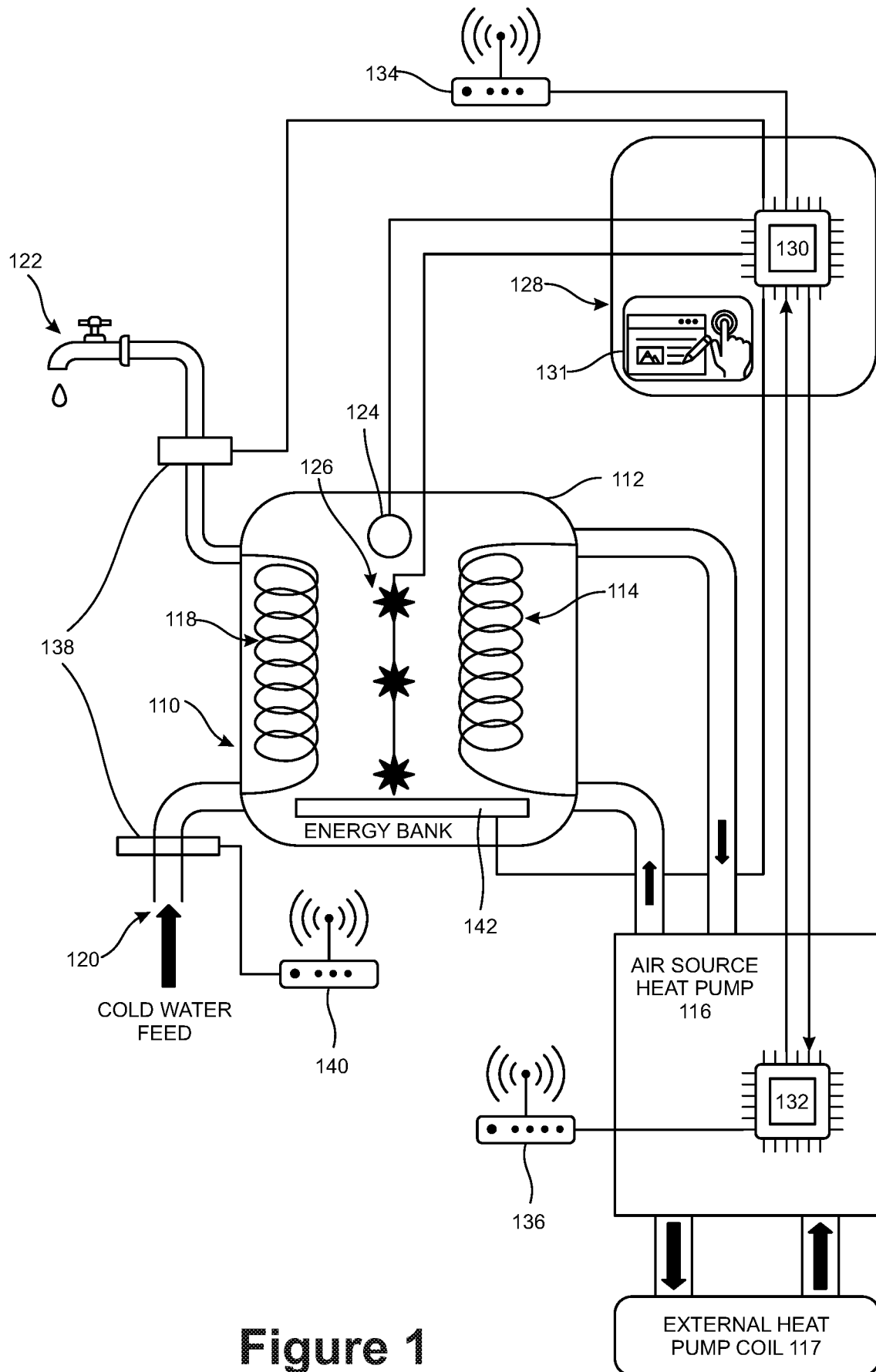


Figure 1

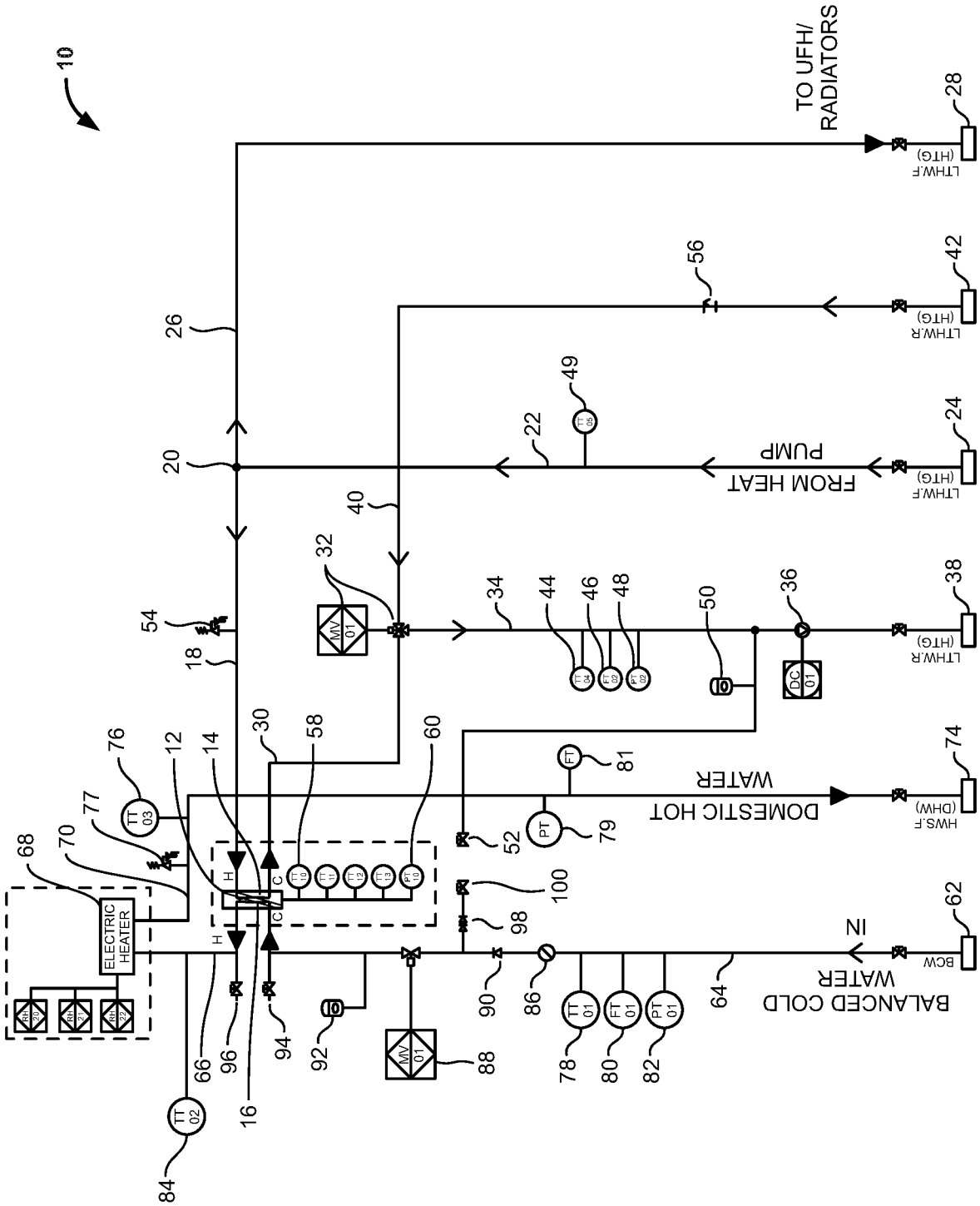


Figure 2

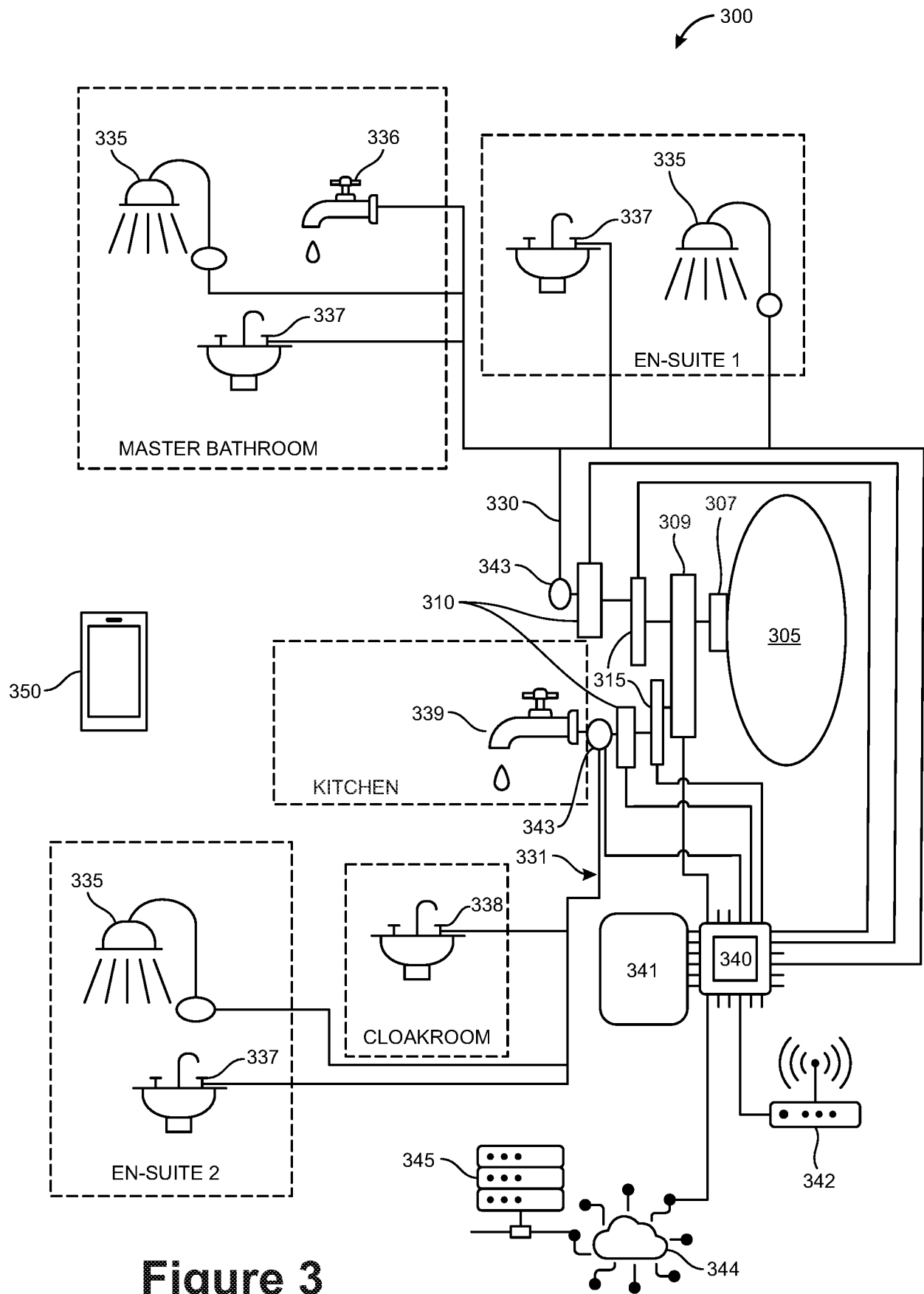


Figure 3

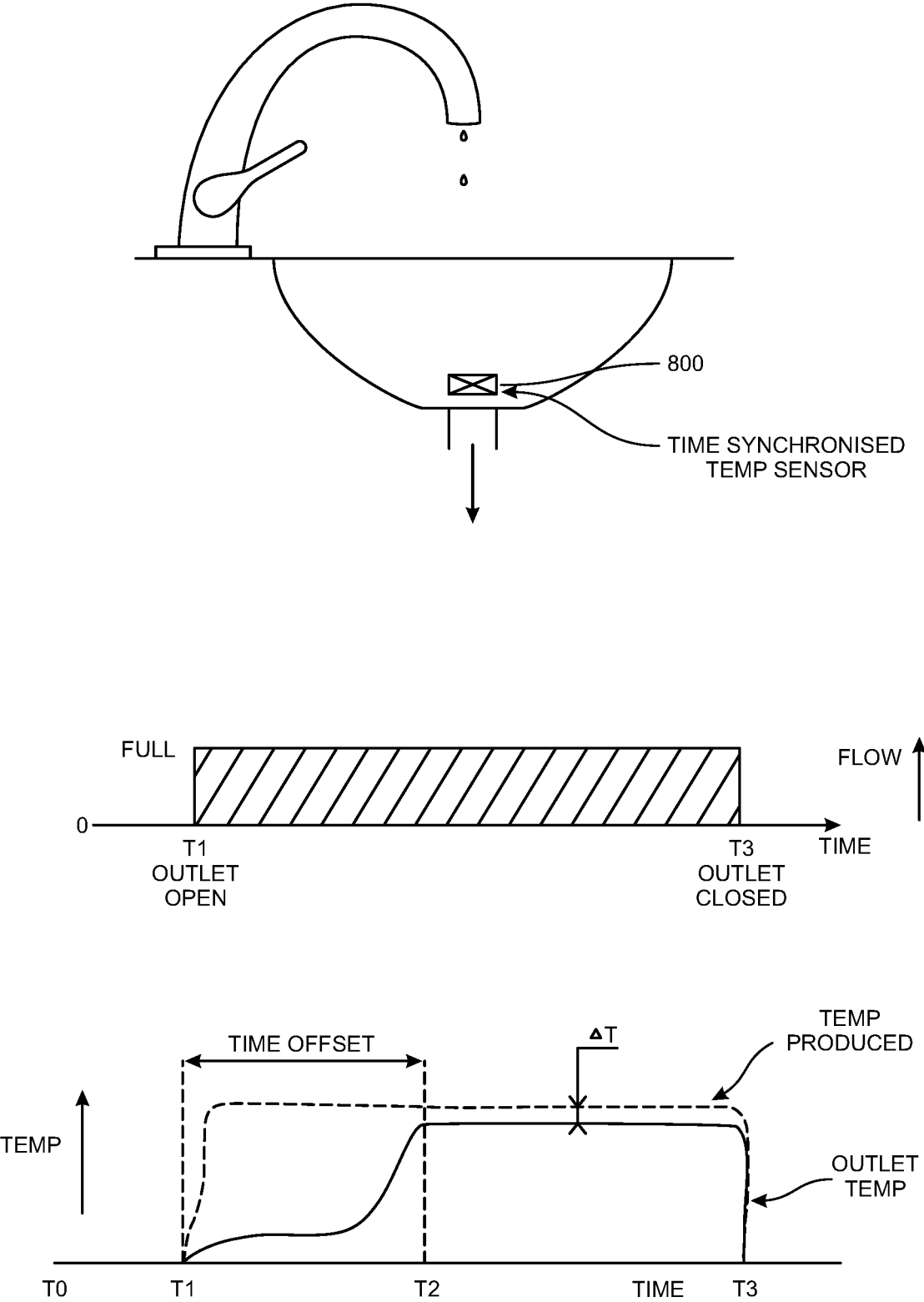
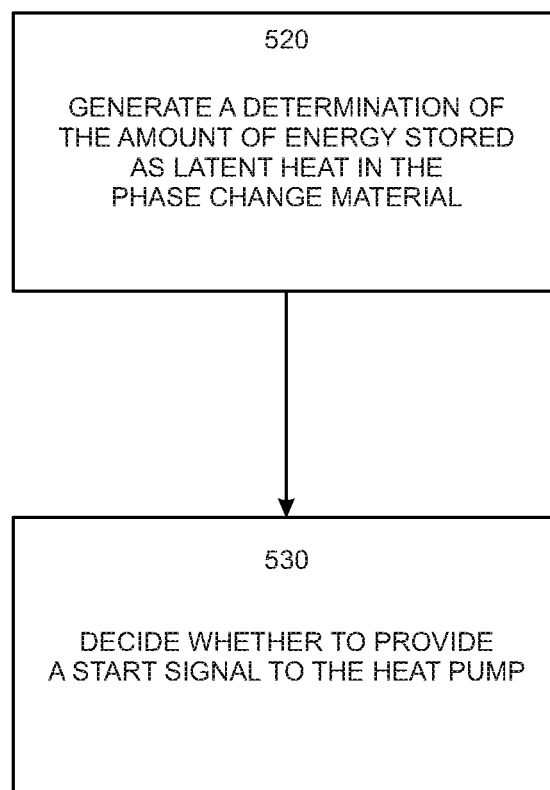
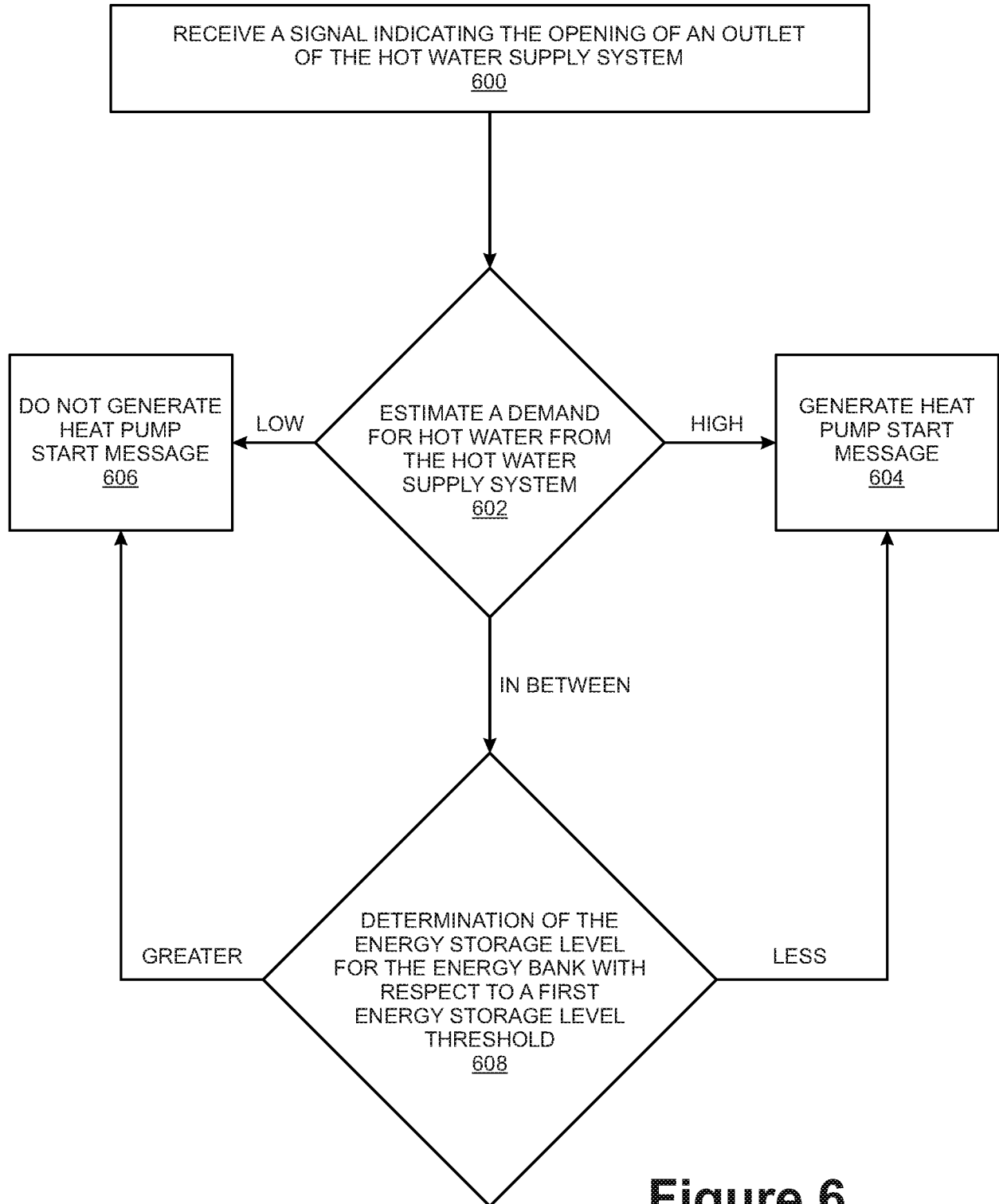
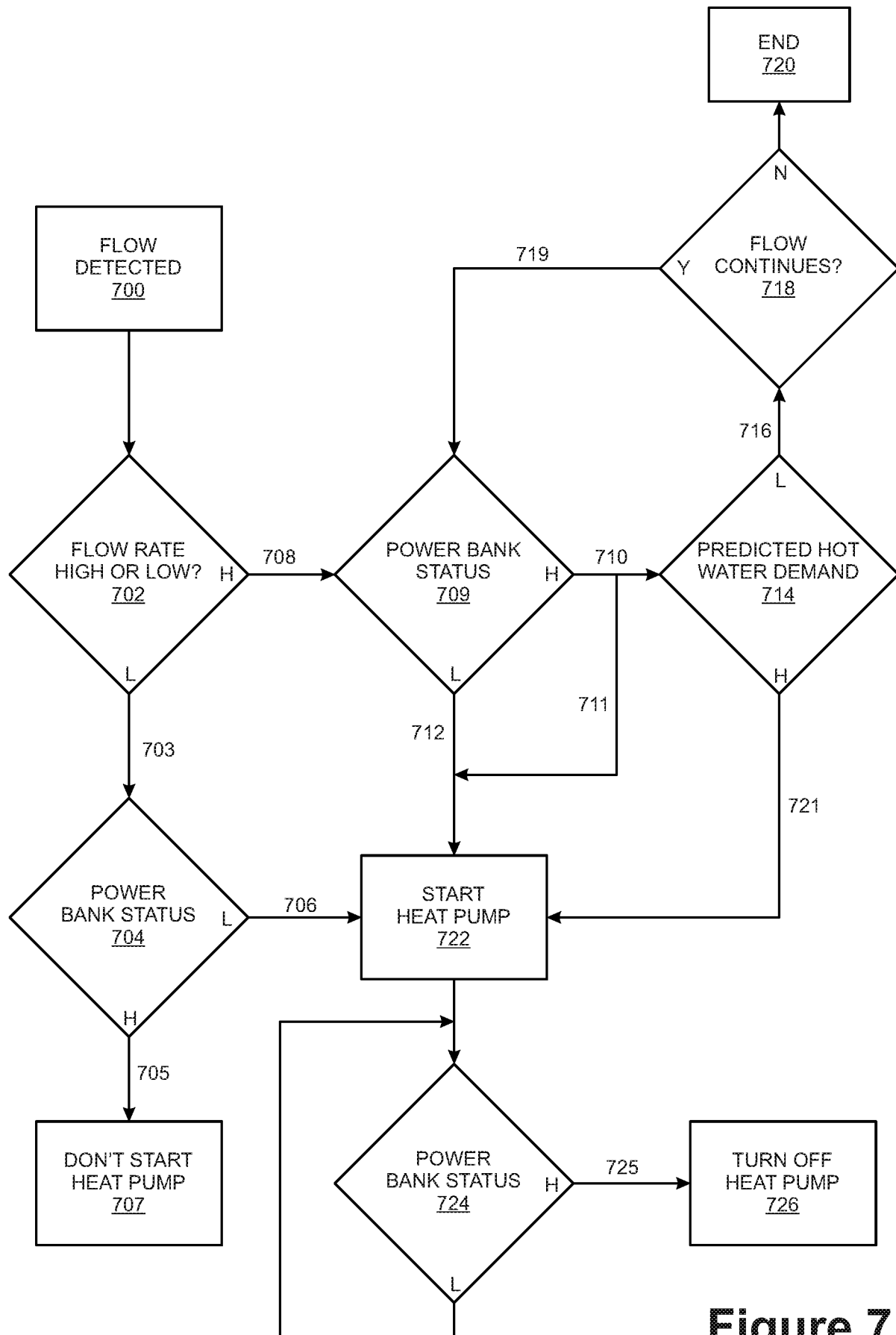
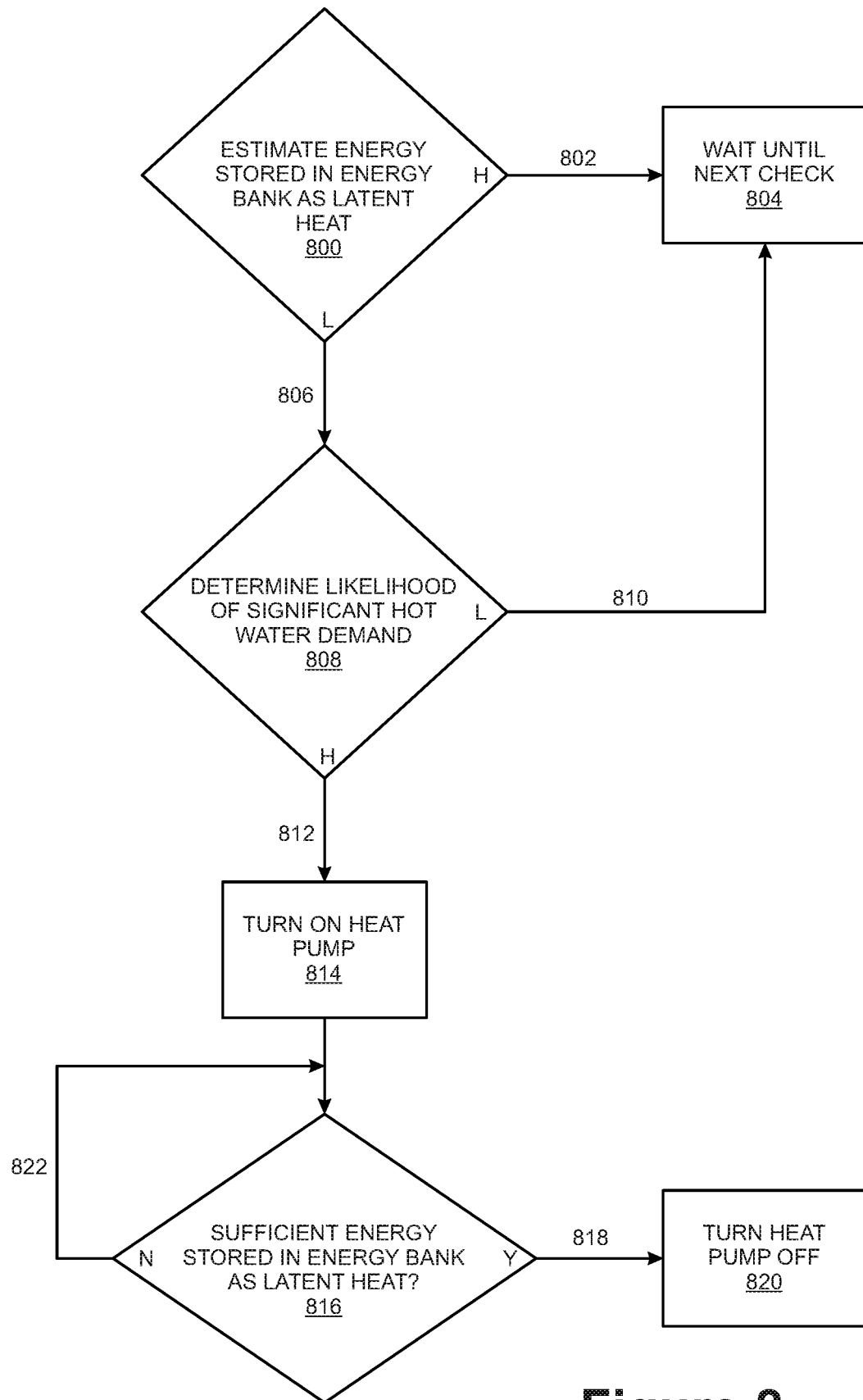


Figure 4

**Figure 5**

**Figure 6**

**Figure 7**

**Figure 8**