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(71) Applicant: **ARISTON S.P.A.** [IT/IT]; 45, Viale Aristide Merloni, 60044 Fabriano (AN) (IT).

(72) Inventors: **BOARO, Matteo**; 38, Via Francesco Petrarca, 60128 Ancona (AN) (IT). **CANESTRARI, Paolo**; 135, Via Serraloggia, 60044 Fabriano (AN) (IT). **CECCACCI, Lorenzo**; 45, Via Sirio Sebastianelli, 60015 Falconara Marittima (AN) (IT). **CONTI, Alessandro**; 17/B, Viale Zonghi, 60044 Fabriano (AN) (IT). **SAMPAOLESI, Marco**; 107, Via Cristoforo Colombo, 62017 Porto Recanati (MC) (IT).

(74) Agent: **PREMRU, Rok**; 2, via San Filippo, 60044 Fabriano (IT).

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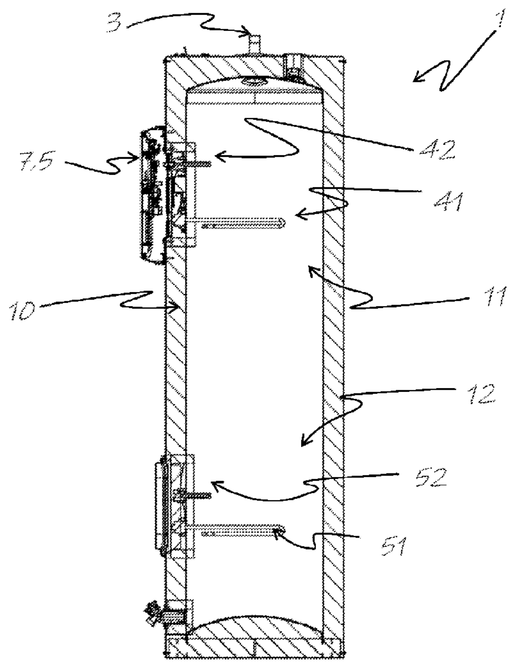

Fig.1,a

(57) Abstract: Object of the present invention is an electric water heater with a vertical development storage and upper and bottom resistive heating elements and possibly a lower heating element consisting of the condenser of a heat pump. The water to be heated enters the bottom portion and is drawn from the upper section. The water heater is configured to operate in different heating modes selectable by a user, wherein all the modes guarantee to meet a set temperature but different by control logic and consumption level and is further able to have flexible consumption depending on a condition of the power grid.

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WATER HEATER ENABLED TO RESPOND TO GRID CONDITIONS

DESCRIPTION

An electrical storage water heater for domestic or technical water for room heating is described below.

A method for managing an electrical storage water heater is also described.

Storage water heaters have the advantage of requiring less power compared to instant water heaters. However, storage water heaters have some drawbacks. For example, they are subject to heat standing losses, that increase as the average temperature of the water contained in the storage is increased.

Traditionally, such water heaters comprise electrical resistive heating elements, hereinafter for shortness “resistances”. Storage water heaters that use a heat pump as heating means are also known, in addition or as an alternative to the resistances.

The need to reduce the electricity consumption has led to the development of “intelligent” water heaters equipped with algorithms which, when regulating the storage temperature, take past events into account. Therefore, when the probability of a user needing to draw hot water is low, the storage is kept at a low average temperature, while when the probability of drawing hot water is high, the temperature of the storage is kept at a higher average temperature.

With the progressive transition of energy sources from fossil to renewable, the supply of electrical energy on the grid is subject to the availability of wind or photovoltaic energy, resources that are intermittent and uncontrollable by their nature. Furthermore, the power grid, for shortness “grid” is faced with a high variability in power demand during a day, for example different usage peaks in a day.

Therefore, the grid finds itself in conditions in which energy supply and demand must be balanced and, contrary to the past, it is now the demand that must at least in part adapt to the supply. At present there is a need for the household appliances to be able to adapt their consumption request i.e., supply, to the conditions of the grid. Storage water heaters are known in which the algorithms for managing the heating elements take into account an imbalanced situation of the power grid.

EP3662210B1 describes an electrical storage water heater, the heating is controlled by an electronic regulator which takes into account the user's habits. The water heater keeps the thermostating temperature low during the periods in which expectations for hot water drawing is low. The learning of the water drawing pattern, referred to as “withdrawal” patterns is based on an estimate of the withdrawals made by analysing temperature variations in the tank. The method links operation of the heating elements essentially to the expected withdrawals patterns, it provides significant reductions in consumption in normal operation, but does not teach how to respond to signals from the grid in an optimised way, for instance how to respond to grid imbalances, eventually adapting to conditions of scarcity or overabundance.

Document US11300325B2 describes a storage water heater with an electrical resistance in an upper zone and one in a bottom zone of the storage. The management of the resistances is assigned to an electronic regulator which takes into account the energy scarcity or overabundance of energy on the grid. A temperature hysteresis is applied both to the top and bottom heating element. In a balancing condition of the grid, the water heater does not adopt any strategy to rationalise consumption. In conditions of electricity scarcity (the energy supply exceeds the availability and there is an imbalance towards the supply) the power consumption of the bottom resistance is reduced according to a heuristic algorithm that takes into account past water withdrawals. The reduction is obtained by lowering both the activation and the deactivation thresholds a figure shows a corresponding reduction of the resulting hysteresis. In conditions of energy overabundance (imbalance towards the production), the water heater increases the energy consumption by raising the temperature threshold for activating for the resistances while keeping unchanged the deactivation threshold, thus reducing the hysteresis.. The activation temperature threshold increase does not take into any account the real needs of the user and therefore does not maximize the amount of energy that is stored and made available for future use, the increase in consumption results in part in a waste of energy.

There is a need that the energy consumption increase can be translated into an energy storage allowing a subsequent energy reduction.

Document US20130200168A1 describes a water heater with an upper and a bottom resistance, capable of operating in a normal mode and in an energy saving mode in which the thermostating temperature is reduced according to user habits. The water heater, possibly through an external controller associated with it, is able to respond to a condition of the power grid of scarcity or overabundance of energy by activating or deactivating the heating elements.

Document WO2019060 describes a water heater, with an upper and a bottom resistance, capable of receiving signals from the electricity grid indicative of a condition of scarcity or overabundance of energy and respond to a signal of overabundance of energy by passing in a high-consumption operating mode and to a signal of energy scarcity by switching to a low-consumption operating mode. The document does not teach modes selectable by a user.

There is a need to regulate the water heater in order to reduce the energy consumption under normal conditions and to have an additional level of flexibility in order to respond to grid imbalance conditions without excessively penalising the comfort. Comfort means a performance level that guarantees having water at the set temperature whenever the user wishes it. There are no known water heaters that handle both the needs of optimising the consumption under normal conditions and being further configured to have flexible consumption in response to grid conditions.

These and other objects, which shall become clear hereinafter, are achieved with a method and apparatus according to the method main claims and with an apparatus (or system) according to the apparatus main claims.

Other objects may also be achieved by means of the additional features of the dependent claims.

An electrical storage water heater is described below which comprises a vertically developing tank or storage, the tank comprising an upper zone wherefrom heated water is drawn and a bottom one in which water to be heated is introduced. The bottom and upper zones are heated by respective heating elements and respective temperature sensors. In short, such configuration shall be hereinafter referred to as “two-zone”.

A method for managing the operation of an electrical storage water heater of the “two-zone” type is also described.

Description of the figures:

- Figures 1.a, 1.b, 1.c, 1.d show various views of a possible embodiment of a water heater with electrical resistances;
- Figures 2.a, 2.b and 2.c show a second possible embodiment of a water heater comprising electrical resistances and a heat pump;
- Figures 3.a and 3.b show tables of correspondence between hourly rates and particular grid conditions;
- Figure 4 shows a table with values taken by a variable in different possible operating modes.

Further features of the present invention shall be better highlighted by the following descriptions of possible embodiments, in accordance with the claims and illustrated, purely by way of a non-limiting example, with the aid of the figures. It should be noted that the invention is not limited to the constructive details and examples and to what is illustrated in the figures; other embodiments are possible without thereby departing from the scope of the claims. The terms used in the description should not be construed as limiting. The terms “receive”, “read”, “detect”, “sense” are used in a broad sense to indicate receiving information comprising the cases of information contained in signals coming from outside, retrieved from a memory or received as input from a user interface. Similarly, “communication” or “connection” are not limited to communication via physical links or wiring.

In the figures, reference number 1 indicates a water heater comprising a vertically developing storage 10 having an upper 11 and a bottom 12 portion.

The upper portion 11 of the storage 10 comprises at least one first heating element 41, while the bottom portion 12 of the storage 11 comprises at least one second heating element 51, 61, hereinafter also referred to heating elements or elements in short. The at least one upper element 41 may comprise an electrical resistance, the at least one bottom element 51, 61 can be an electrical resistance 51 and/or a condenser 61 of a heat pump 6.

In the proximity of the respective elements 41, 51, 61, are a first temperature sensor or upper temperature sensor 42, which detects a higher temperature referred to as “Tdome”, or also “dome temperature” and a second temperature sensor or bottom temperature sensor 52 which detects a bottom temperature “Tbottom”. The temperature sensors 42, 52 may be conventional temperature sensors (for example thermistors).

A water heater 1 comprising as heating elements only resistances 41, 51 shall hereinafter be referred to as an electrical water heater or electrical model, to distinguish it from the “hybrid” model which also comprises a condenser 61 of a heat pump 6.

The storage 10 is configured to let cold water in in the proximity of the bottom 12 through a first opening 2, and to let heated water, directed to the user, out through a second opening 3 close to the top of the storage 10. This way, in stationary conditions, the stratification of the temperatures contributes to the fact that the water let out from the storage 10 is that at highest the temperature.

The water heater 1 also comprises a regulator 5 for regulating the operation of the heating elements 41, 51, 61.

The regulator 5 comprises memory means and is adapted to receive the temperature readings made by the temperature sensors 42, 52 and a temperature "Tset" which can be set by the user, via a user interface 7.

The regulator 5 is configured to calculate a control temperature for each heating element 41, 51, 61. The control temperatures may be equal to the temperatures detected by the temperature sensors 42, 52 or may be equal to their weighted average. A plurality of heating elements 41, 51, 61 may share the same control temperature.

The regulator 5 may be an electronic control unit comprising:

- a memory with program instructions and parameters,
- means for executing instructions and calculations,
- means for controlling the heating elements and receiving signals from the outside.

The regulator 5 is configured to implement a set temperature, Tset that may be set via a user interface 7.

The user interface 7 may be integrated in the water heater and comprise manual input means such as buttons or knobs and/or be external and comprise means for sending input data to the regulator 5 that is configured to receive it. When integrated in the water heater 1, the user interface 7 may be assembled in a single assembly with the regulator 5, as shown in figures 1.a, 1.b, 2.a and 2.b.

The upper section 11 of the storage is heated directly by the at least one upper heating element 41 and indirectly, by convection effect, by the at least one bottom heating element 51, 61. The at least one upper heating element 41 has the upper temperature Tdome as control temperature or has the upper temperature Tdome as the prevailing component in a weighted average of the temperatures sensed by the temperature sensors 42, 52. For the at least one bottom heating element 51, 61 the control temperature is the bottom temperature Tbottom or alternatively an average temperature "Tavg" that is obtained as the average between the dome temperature Tdome and the bottom temperature Tbottom. Preferably, such average is a weighted average, even more preferably the weight "Wdome" of the dome temperature is less than the weight "Wbottom" of the bottom temperature

Tbottom.

According to a preferred embodiment, the weight Wdome of the dome temperature is comprised in an interval between 0.25 and 0.40, for example 0.3. At least one of the weights Wdome, Wbottom is a parameter stored in the memory of the regulator 5, the other being calculable accordingly or being stored as well.

A thermostating temperature “Ttarget” is set for each heating element 41, 51, 61. In a possible embodiment, the regulator 5 sets a common thermostating temperature Ttarget at least for the electrical resistances 41, 51. The thermostating temperature Ttarget of each heating element 41, 51, 61 is comprised in an interval between a minimum “Tmin” and maximum “Tmax” temperature (Tmin ≤ Ttarget ≤ Tmax).

The maximum temperature Tmax is a factory parameter, possibly modifiable on site, and may vary, for example, between 55°C and 85°C. Preferably, it reaches the highest values if a thermostatic mixing valve is present.

The minimum temperature Tmin is one considered as acceptable to guarantee the comfort for domestic uses; it may be comprised between 37°C and 42°C, for example around 40°C. Thermostating at temperatures higher than the minimum Tmin enables mixing the drawn water with cold water bringing the advantage of increasing the volume of delivered water beyond the volume of the storage.

The heating elements 41, 51, 61 are configured to be activated when the respective control temperature drops below the thermostating temperature Ttarget minus a hysteresis value and to be deactivated at the thermostating temperature Ttarget. The at least one upper element 41 has an upper hysteresis ThystDome (so the switch on temperature is Ttarget – ThystDome) while the at least one bottom heating element 51, 61 has a bottom hysteresis Thyst (so the switch on is temperature Ttarget – Thyst). In general, there may be different hysteresis for each heating element. The median value between activation and deactivation temperatures is therefore:

for the upper heating element 41 Ttarget – ThystDome /2;

for the bottom heating element 51, 61 Ttarget – Thyst/2.

By shifting all the temperature values of the amplitude of the hysteresis, the present description can be applied also to a possible embodiment in which the heating elements are activated at the thermostating temperature, Ttarget, and are switched off at the temperature Target + Thyst, Ttarget + ThystDome, which is when the temperature increase is equal to the hysteresis Thyst, ThystDome. In this case, the median value between activation and deactivation temperatures is therefore:

for the upper heating element 41 Ttarget + ThystDome /2;

for the bottom heating element 51, 61 Ttarget + Thyst/2.

In an embodiment schematically illustrated in Figure 2.a, 2.b, the at least one bottom heating element 51, 61 comprises, a bottom resistance 51 and a condenser 61 of a heat pump 6.

In the illustrated example the condenser 61 comprises two sets of windings 611, 612 respectively positioned above and below the bottom resistance 51.

The heat pump 6 has a higher energy efficiency compared to the resistance 51, but may heat only up to a maximum heat pump temperature threshold Thp, hereon heat pump threshold Thp for brevity; a typical value for the heat pump threshold Thp of the pump is about 55°C. Beyond this heat pump threshold Thp, the heating function can be performed by the resistances 41, 51.

In the embodiment of figure 2 the bottom resistance 51 may work in relay with the condenser 61 of the heat pump 6. In the relay operation below the heat pump threshold Thp the bottom element used is the condenser 61, above the threshold Thp, the bottom element used is the resistance 51.

The relay operation between the exchanger 61 of the heat pump 6 and the bottom resistance 51 allows reducing both the instantaneous power consumption and the electrical energy consumption, because of the higher energy efficiency of the heat pump 6 compared to the resistance 51.

When the heat pump 6 and the bottom resistance 51 operate in relay, it is preferable that the control temperature for both is the average temperature Tavg for a more efficient operation of the water heater 1. According to some embodiments in the water heater models 1 which comprise a condenser 61 as a unique or additional bottom heating element, for all of the bottom heating elements 51, 61 the control temperature is the average temperature Tavg.

In the exclusively electrical models, for the bottom resistance 51 the control temperature is preferably the bottom temperature Tbottom as measured by the bottom sensor 52.

In the preferred embodiments the upper 41 and bottom 51 resistances never activate together and even more preferably, the upper resistance 41 has priority over the bottom one 51. In other words, in these embodiments, priority is always given to heating the water contained in the upper part 11 of the storage 10, (which is the first water to be supplied).

In order to meet the contrasting needs to reduce the energy consumption and to guarantee enough hot water, the water heater 1 has at least two heating modes which may be selected according to users' need.

The heating modes, hereinafter also called "modes" for brevity, allow having water at a set temperature Tset, but they are different for the control logic of the heating elements 41, 51, 61 and for consumption. The heating modes are preferably selectable with the user interface 7.

In a first heating mode called "Manual" or "Comfort", the water heater 1 sets the thermostating temperature Ttarget equal to the set temperature Tset for all the resistive heating elements 41, 51 and for any heat pump 6, provided the user temperature Tset is not higher than the heat pump threshold Thp. The user temperature Tset varies between the minimum temperature Tmin and the maximum temperature Tmax. In the first heating mode, Comfort:

- the upper 41 and bottom 51 resistances are never activated together,
- the upper resistance 41 has priority over the bottom one 51,
- if a condenser 61 is present as a bottom element, the bottom resistance 51 operates in relay with the heat pump 6.

According to a possible embodiment, the heating modes further comprise a second heating mode which is an optimised mode, called "I-memory". The second mode

I-memory differs from the first mode, Comfort, for the thermostating temperature Ttarget which is equal to an optimised temperature Tmem that varies over time and is a function of a saved withdrawals pattern (the withdrawals pattern comprising the data of volume and temperature of withdrawals over a period). The optimised temperature Tmem may vary from the minimum Tmin to the maximum Tmax temperature. Methods for calculating such optimised temperature are known; by way of an example a method is described in EP2366081B1 (the content whereof forms an integral part of the present description).

In Figure 2, the water heater 1 comprises at least one heating element of the resistive type 41, 51 and one consisting of the condenser 61 of a heat pump 6, adapted to heat up to a maximum temperature heat pump threshold Thp.

In particular, in the embodiments herein described that include a heat pump 6, the water heater 1 may also comprise a third heating mode that is a sustainable mode called “Green” and/or a fourth heating mode that is a quick mode called “Fast”.

The third heating mode, Green, prioritizes reducing the electrical consumption, and is uses exclusively the heat pump 6, while the resistive elements 41, 51 are always deactivated. In the third mode Green, the thermostating temperature Ttarget is equal to the minimum between the user temperature Tset, and the heat pump 6 threshold Thp.

The fourth mode, Fast, prioritizes heating rapidly and differs from the first mode, Comfort, in that the bottom resistance 51 is not activated in relay, but simultaneously with the heat pump 6, with the only additional constraint that the upper resistance 41 is and remains off, while the bottom resistance 51 is on. In the fourth mode, Fast, the heat pump 6 is preferably controlled with the average temperature Tavg, while the bottom resistance 51 is preferably controlled with the bottom temperature Tbottom.

In the third Green and fourth Fast mode, the thermostating temperature Ttarget is equal to the user set temperature Tset. It is possible to implement a fifth mode called “I-memory green” which is equal to the third mode, Green, with the thermostating temperature, Ttarget, equal to the minimum between the optimised temperature, Tmem, and the heat pump temperature threshold Thp . Similarly, it is possible to implement a sixth mode called “I-memory fast” that is equal to the fourth mode, Fast, with the thermostating temperature Ttarget equal to the optimised temperature Tmem. This allows combining the advantages of the second mode I-memory with the third mode Green, or the fourth mode Fast. Figure 4 shows in a table the values of the thermostating temperature Ttarget for each heating mode.

From the above description it is clear that each heating mode is configured to reach one of a user set temperature Tset, a temperature threshold Thp of a heating element which is a condenser 61 of a heat pump 6 or an optimised temperature Tmem.

According to some possible variants, at least two hysteresis values are defined: an upper hysteresis “ThystDome” for the upper element 41 and a bottom hysteresis “Thyst” for the at least one bottom element 51, 61. It has been observed that adopting different hysteresis values for the upper 41 and bottom heating elements 51, 61 allows further reducing the consumption or, for the same consumption, improving comfort. Hereinafter, dome hysteresis ThystDome indicates the hysteresis of one or more upper elements, bottom hysteresis Thyst indicates that of one or more bottom elements 51.

In particular, in the embodiments of the water heater 1 with only electrical resistances 41, 51 it is advantageous having a bottom hysteresis Thyst of higher value, (for example comprised between 2°C and 21°C, preferably between 12°C and 18°C, in particular 15°C) and a hysteresis at the dome ThystDome of smaller value (for example between 1°C and 20°C, preferably between 3°C and 9°C, in particular 5°C).

Instead, in the embodiments in which the water heater 1 comprises a condenser 61 of a heat pump 6 as a bottom heating element, the situation is reversed and it is more convenient having a bottom hysteresis Thyst of smaller value (for example in an interval between 1°C at 20°C, preferably between 3°C and 9°C, in particular 5°C) and a hysteresis at the dome ThystDome of higher value (for example an interval comprised between 2°C and 21°C, preferably between 9°C and 18°C, in particular 12°C).

This is because in the embodiments in which the water heating is obtained only by means of electrical resistances, it is preferred to avoid the activation of the bottom resistance 51 for small and momentary temperature oscillations which are due to the entry of cold water caused by small withdrawals and subsequent turbulences of water. A higher value hysteresis Thys at the bottom resistance 51, renders it more stable and less sensitive to small turbulences. To compensate for less sensitivity, it is very useful to set an upper hysteresis ThystDome at a smaller value,so as to render the upper resistance 41 very sensitive even to small turbulences so that it is promptly activated to guarantee the correct temperature at the outlet 3 of the water heater 1..

In the embodiments that also include a condenser 61 as a bottom heating element, the priority is in maximizing use of the heat pump 6 thus limiting the use of the resistances 41, 51. Herein here it is therefore advisable to activate the heat pump 6 even for small water temperature fluctuations by adopting a bottom hysteresis Thyst smaller in value than the upper hysteresis ThystDome.

Optionally, in the heat pump models the electrical model hysteresis are used when the average temperature Tavg, or the thermostating temperature Ttarget, is greater than the heat pump threshold Thp. In these conditions the heat pump 6 is unable to make a contribution and the water heater 1 may be controlled as if it were an electrical model.

According to a possible embodiment, the water heater 1 is powered by energy from a power grid and is configured to operate with at least two heating modes selected between the first mode “Comfort”, the second mode “I-memory”, the third mode “Green”, the fourth mode “Fast”, the fifth mode “I-memory green”, or the sixth mode “I-memory fast” and to receive the heating mode selection from a user interface. The regulator 5 is further configured to deactivate the heating elements 41, 51, 61 and/or modify the control parameters thereof according to a scarcity or overabundance condition (detected or estimated or foreseen) of electrical energy and of the selected heating mode.

In ideal conditions, the demand for electrical energy and the energy fed into the power grid balance each other. In practice these values vary with respect to each other giving rise to imbalance conditions which cause a frequency and voltage drift. Beyond an allowed interval, the grid does not tolerate this imbalance, and to avoid damage or generalised blackouts, or in any case to comply with voltage and frequency standards, either users or generators may have to be disconnected. In what follows conditions of significant imbalance towards the energy supply will be referred to as conditions of scarcity and vice versa those of significant imbalance towards the energy fed into the grid will be referred to as conditions of overabundance.

Both in the scarcity condition of the grid (imbalance towards the demand) and/or in the overabundance (imbalance towards the supply) of energy, several severity levels may be defined and preferably the water heater 1 is configured to respond to at least two different severity levels (hereinafter "level") for to a condition of energy scarcity and/or overabundance from the grid.

In a possible embodiment, the regulator 5 is adapted to manage the following severity levels, listed in order of increasing severity:

- a first scarcity level that indicates a moderate imbalance towards the demand referred to as "Load shed",
- a second scarcity level that indicates a strong imbalance towards the demand referred to as "Critical peak event",
- a third scarcity level that indicates a very strong imbalance towards the demand with the risk of detachment referred to as "Grid emergency",
- a first overabundance level that indicates a moderate imbalance towards the supply called "Load up",
- a second overabundance level that indicates a strong imbalance towards the supply referred to as "Advanced load up".

It should be noted that the response of the water heater 1 does not guarantee an immediate and certain change in the consumption level, but there is a probability associated to the change in consumption and the probability increases with the severity level and with the persistence of the grid condition over time. This is because of the physical constraints of the thermodynamic system and because the regulator 5 of the water heater 1 preferably implements rules which ensure that a minimum comfort level is maintained. If several water heaters 1 exist in the same power grid, over large numbers, the overall effect to have a variation of energy demand is certain, therefore the objective of balancing the grid is achieved.

According to a first embodiment, the water heater 1 is able to receive and the regulator 5 is configured to respond to signals S, that indicate a condition of scarcity or overabundance of energy in the grid, according to at least some of the five severity levels defined, first, second and third scarcity levels: “Load shed”, “Critical peak event”, “Grid emergency”, first and second overabundance levels: “Load up”, “Aadvanced load up”.

Several known protocols allow a device connected to the grid to receive signals S that correspond to at least some of the listed severity levels. Some protocols include in a signal S a severity level and a duration required for the response.

By way of a non-limiting example, the water heater 1 may be configured to receive signals compatible with the protocol CTA2045. In general, similar protocols are increasingly widespread because they are functional for implementing so-called “demand response” services, that allow the energy supply in a period to be flexible in order to follow the demand.

The water heater 1 may receive the signals S directly from the grid or may receive them indirectly by means of other devices that receive them from the grid.

According to possible embodiments, the signals S are sent to the water heater 1 by a local device that manages the energy consumption of one or more devices.

In a second embodiment, the water heater 1 responds to an hourly schedule of the energy price and assigns one of the severity levels to price values higher or lower with respect to an average value. Without loss of generality, the hourly schedule may be preset in the water heater 1, manually updated by a user, periodically updated or received in real time by the water heater 1 that is set up to receive and manage an hourly price signal. By way of a non-limiting example, the water heater 1 may be configured to receive hourly rate signals with the protocol JA-13.

The same water heater 1 may be configured to receive signals S and to have hourly schedules set. The first, second and third scarcity level “Load shed”, “Critical peak event”, “Grid emergency” have priority over any other setting comprising hourly price schedules. Preferably, the response to a grid condition has priority over the hourly schedules. In general, the water heater 1 gives priority to the signals S from the grid.

The water heater 1 described above may operate as follows:

1. receiving from a user interface the input of a heating mode “Comfort”, “I-memory”, “Green”, “Fast”, “I-memory green”, “I-memory fast” that defines a control logic for each heating element,
2. receiving a first signal S to which one of the severity levels of a scarcity or overabundance condition in the grid is associated and a time duration, the severity level being one among the list containing the first, second, third scarcity level, “Load shed”, “Critical peak event, “Grid emergency”, and first and second overabundance level “Load up”, “Advanced load up”,
3. according to the selected heating mode and to the severity level, a new thermostating temperature Ttarget is set for all the heating elements and/or a new hysteresis Thyst is set for the bottom heating elements,
   - in the event of a third scarcity level “Grid emergency”, the heating elements are deactivated,
   - in the event of a second scarcity level “Critical peak event”, in the heat pump model, deactivating the resistances 41, 51, in the case of an electrical water heater, deactivating the bottom resistance 51,
   - if a second signal S arrives, going back to step 2,
   - if a new heating mode “Comfort”, “Green”, “I-memory”, “fast”, “I-memory green”, “I-memory fast” is selected or a new temperature Tset is set, continuing the step 3 with the new heating mode or the new set temperature value Tset for the remaining time duration,

- at the end of the time duration associated with the signal S, restoring the control logic associated to the selected heating mode.

The water heater 1 may be configured to respond to an energy price hourly schedule, by associating to the lower price values the severity levels corresponding to the overabundance condition, by decreasing price and increasing overabundance severity level and by associating to the higher prices the severity levels corresponding to the scarcity condition, by increasing price and increasing scarcity severity level. Preferably prices that are in an intermediate level are not associated with any severity level.

A method is described for optimising the consumption according to an hourly rate schedule, using figures 3.a and 3.b. The method comprises the following steps:

step 1: receiving from a user interface 7 a heating mode that defines a control logic for each heating element;

step 2: reading in memory or receiving from input or from the grid an hourly scheduling of the energy prices, each associated with a period of the day referred to as time band;

wherein the order of execution between step 1 or 2 is indifferent:

step 3: identifying the minimum and maximum price among all those associated with the various time bands;

step 4: selecting the severity levels to which there is a need to respond;

step 5: dividing the interval between minimum and maximum price into as many sub-intervals as the selected severity levels plus a possible intermediate interval;

step 6: sorting the intervals by increasing price and:

- associating the lowest price intervals with the conditions of energy overabundance in order of decreasing severity and increasing price;
- associating the higher price intervals with the energy scarcity conditions in order of decreasing severity and decreasing price;
- leaving the intermediate price interval not associated with any severity level;

step 7: for each new time band in which the price does not belong to the intermediate level, controlling the heating elements according to the active heating mode and severity level.

Figure 3.a shows a depiction according to a possible embodiment in which the selected severity levels are a first and second scarcity level “Load shed”, “Critical peak event”, and first overabundance level “Load up”. Figure 3.b shows a second possible embodiment wherein all the defined severity levels are selected.

Some preferred embodiments for changing the control parameters according to the severity levels are described below.

It has been said that the water heater 1 is configured to respond to the different severity levels by modifying the control parameters; according to a preferred embodiment the control parameters comprise at least the thermostating temperature Ttarget. Preferably the control parameters comprise also upper hysteresis Thystdome and/or bottom hysteresis Thyst.

For the first scarcity level “load shed” the water heater 1 sets the thermostating temperature Ttarget to the minimum value between a comfort threshold Tcomfort, and the previous thermostating temperature Ttarget, in formulas there is:

Ttarget = min (Tcomfort, Ttarget)

The comfort threshold Tcomfort is a value comprised in the comfort interval that corresponds to about 40°C-50°C, preferably it is equal to about 42°C.

In any heating mode the thermostating temperature Ttarget may already be lower than a comfort threshold Tcomfort = 42°C either because the user has already set it to the minimum value or because it is set by the algorithm in case of second mode I-memory. In all the other cases an actual reduction of the consumptions is achieved.

In some possible embodiments the water heater 1 combines both the reduction of the described thermostating temperature Ttarget, and the deactivation of the bottom resistance 51 in order to respond to the second scarcity level “critical peak event”, and in case of heat pump model it deactivates also the upper resistance 41, by heating only with the heat pump. This response is applicable to all heating modes.

The water heater 1, for responding to the third scarcity level “Grid emergency”, may deactivate all the heating elements and/or may set the thermostating temperature Ttarget to a value just above the average temperature of the mains water, by way of a non limiting example equal to 16°C. In this case, the functionality is no longer guaranteed; the third scarcity level “Grid emergency” indicates the risk of blackouts or an hourly cost of energy that the user is not willing to bear.

According to a possible embodiment, the bottom hysteresis Thyst under normal mains conditions is greater than or equal to 4°C and the water heater 1, in order to respond to the first overabundance level “Load up”, increases the average temperature in the bottom section with respect to the thermostating temperature Ttarget; this is achieved by reducing the bottom hysteresis Thyst, which corresponds to increasing the temperature at which the elements are reactivated. By way of an example, the hysteresis may be reduced to a value lower than or equal to 3°C. It should be noted that in an alternative embodiment where the hysteresis defined the switch-off threshold, the hysteresis would be increased in order to obtain the same effect of average temperature increase.

In response to the second overabundance level “Advanced load up”, in addition to increasing the average temperature in the bottom section, by reducing the bottom hysteresis Thyst, the water heater 1 may increase the thermostating temperature Ttarget up to the maximum temperature Tmax. In case of third mode “Green”, the thermostating temperature Ttarget maximum value has the heat pump threshold Thp as upper limit.

It should be noted that the response to the severity level maintains the essential characteristics of the heating mode, for example if in the second mode I-memory the thermostating temperature Ttarget is 40°C, a severity level “Load up” causes a reduction in the bottom hysteresis Thyst (i.e. a small increase in the average temperature in the bottom section with respect to the thermostating control temperature Ttarget) but not a thermostating increase at unnecessary temperatures.

In other words, the regulator 5 is configured so that the response to the severity level does not constitute a shift from one mode to another, but a modification within the selected heating mode. Therefore, the response to severity levels is combined with the control logic determined by the selected heating mode resulting in a modified logic that depends both on the selected heating mode and the severity level.

Any reference to a user interface is to be understood in the broad sense and includes any device able to receive an input from a user and send it to the regulator 5; in particular it includes, by way of a non-limiting example, a dedicated physical user interface 7 comprised in the water heater, or the interface of a smart phone or other devices that are not part of the water heater 1, but from which the water heater 1 is configured to receive input with any known communication technology including wireless communication or a vocal command sensor.

It is clear for the expert of the field that a system with the characteristics of water heater 1 can be used to heat other types of liquid and is not limited to water.

CLAIMS

1. Water heater (1) powered by energy from a power grid, the water heater comprising:
   - a vertical development storage (10) having an upper portion (11) and a bottom portion (12) to which are associated respective upper temperature sensor (42) and bottom temperature sensors (52) and at least one respective upper heating element (41) and bottom heating element (51; 61), adapted to heat the liquid in the storage (10),
   - an interface (7) for selecting one of at least two heating modes (Comfort, I-memory, Green, Fast, I-memory green, I-memory fast) differing from each other by control logic of the heating elements (41; 51; 61) and which are configured to reach one of a user set temperature Tset, or a temperature threshold Thp of a heating element which is a condenser (61) of a heat pump (6) or an optimised temperature Tmem,
   - a regulator (5) of the heating elements (41; 51; 61), adapted to receive readings from the temperature sensors (42; 52) the selected heating mode (Comfort, I-memory, Green, Fast, I-memory green, I-memory fast) and to implement the control logic of the heating elements (41; 51; 61) according to the selected heating mode,

   the water heater (1) characterised in that the regulator (5) is configured to modify the control parameters of the heating elements (41; 51; 61) in response to a detected and/or estimated and/or expected condition of energy scarcity or overabundance of the grid and that the behaviour resulting from a response to a grid condition is a function of both the power grid condition and the heating mode selected by the user.
2. Water heater (1) as in claim 1, wherein the control parameters modified in response to a condition of the grid comprise at least a thermostating temperature Ttarget common to all the active heating elements.
3. Water heater (1) as in claim 1 or 2, wherein to the condition of energy scarcity and/or overabundance of the power grid can be associated severity levels and the

regulator (5) is configured to respond in a different way to at least two of the following severity levels listed in increasing order for each condition:

- a first scarcity level (Load shed),
- a second scarcity level (Critical peak event),
- a third scarcity level (Grid emergency)
- a first overabundance level (Load up),
- a second overabundance level (Advanced load up).

4. Water heater (1) as in claim 3 wherein the regulator (5) is configured to set a possible new thermostating temperature Ttarget for all the heating elements and/or a possible new hysteresis Thyst for the bottom heating elements according to the severity level detected.

5. Water heater (1) according to claim 3 or 4, configured to respond to the first scarcity level (Load shed) by setting the thermostating temperature Ttarget to the minimum value between a comfort threshold Tconfort and the previous thermostating temperature Ttarget, in formulas:

$$Ttarget = \min(Tconfort, Ttarget)$$

where the comfort threshold Tconfort is a value comprised in the interval 40°C to 50°C, preferably it is equal to about 42°C.

6. Water heater (1) as in claim5, configured to respond to the second scarcity level (Critical peak event) by implementing the response to the first scarcity level (Load shed) and in addition:
if the heating elements comprise a heat pump (6) by deactivating any resistive elements (41; 51),
otherwise by deactivating the at least one of the bottom resistive elements (51).

7. Water heater (1) as in any one among claims 34 to 6, configured to have a hysteresis Thyst of the bottom heating elements (51; 61):
   - in models with only bottom resistive type elements, comprised in an interval from 4°C to 21°C and preferably equal to 15°C,
   - in models comprising at least one condenser of a heat pump as a bottom heating element comprised in an interval from 4°C to 20°C and preferably

equal to 5°C,

and to respond to the first overabundance level (Load up), by bringing the hysteresis Thyst of the bottom elements to a value lower than or equal to 3°C.

8. Water heater (1) as in claim 7, configured to respond to the second overabundance level (Advanced load up) by implementing the response to the first overabundance level (Load up) and in addition:
   - if provided with resistive heating elements only, by setting the thermostating temperature Ttarget equal to a predefined maximum temperature Tmax,
   - if provided with at least one heat pump (6) and having a sustainable heating mode selected (Green; I-memory green) characterised by limiting the use of the heating elements to the heat pump (6) only, by setting the thermostating temperature Ttarget equal to the minimum between a maximum temperature Tmax provided for the thermostating and a maximum temperature threshold Th) that may be reached by the heat pump (6).
9. Water heater (1) as in to any one among claims 2, 3, 4, 5, 6, 7, or 8 configured to receive signals (S) that the regulator (5) is able to process and that convey a condition of the grid and optionally the severity level.
10. Water heater (1) as in any one among claims 3, 4, 5, 6, 7, 8 or 9, configured to respond to an energy price hourly schedule, by associating to the lower price values the severity levels corresponding to the overabundance condition, by increasing price and decreasing severity level and to the higher prices the severity levels corresponding to the scarcity condition, by increasing cost and increasing severity level.
11. Method for heating a liquid in a water heater (1) according to any of claims 3 to 10, the method comprising:

step 1: receiving from a user interface (7) the selection of a heating mode (Comfort), (I-memory), (Green), (Fast), (I-memory green), (I-memory fast) that defines a control logic for each heating element,

step 2: receiving a first signal (S) associated with a severity level of an energy scarcity or overabundance condition of energy in the grid and a time duration, the severity level belonging to the list: a first scarcity level (Load shed), a second scarcity level (Critical peak event), a third scarcity level (Grid emergency), a first overabundance level (Load up), a second overabundance level (Advanced load up),

step 3: according to the selected heating mode and to the severity level, setting a possible new thermostating temperature Ttarget for all the heating elements and/or a possible new hysteresis Thyst for the bottom heating elements,

- in the event of a third scarcity level (Grid emergency), deactivating the heating elements,
- in the event of a second scarcity level (Critical peak event) if the heating elements comprise a heat pump, deactivating any resistive elements (41, 51),
- otherwise deactivating the at least one of the bottom resistive elements (51),
- if a second signal arrives (S), repeating step 2,
- otherwise, if a new heating mode (Comfort), (green), (I-memory), (fast), (I-memory green) or (I-memory fast) is selected or a new temperature Tset is set, continuing with step 3 with the new heating mode or the new value of set temperature Tset for the remaining time duration.

12. Method for heating a liquid in a water heater (1) according to an hourly rate schedule, water heater (1) according to claim 3 or to any claim depending from 3, the method comprises the following steps:

step 1: receiving from a user interface (7) a heating mode that defines a control logic for each heating element,

step 2: reading into memory or receiving from an input or from the grid an hourly schedule of the prices, wherein the order between step 1 or 2 makes no difference,

step 3: dividing the interval between minimum and maximum price into as many sub-intervals as the overall severity levels are plus a possible intermediate interval,

step 4: sorting the intervals by increasing price and associating them to the severity levels by associating the lower price intervals with the energy overabundance conditions by decreasing severity and increasing price order and the higher cost intervals with the decreasing severity order of scarcity conditions and decreasing price by leaving an intermediate interval not associated with any severity level,

step 5: for each new time band in which the price does not belong to the intermediate interval, deactivating the heating elements and/or modifying the control parameters thereof according to the active heating mode (Comfort), (Green), (I-memory), (Fast), (I-memory green) or (I-memory fast) and to the severity level (Load shed), (Critical peak event), (Grid emergency), (Load up), (Advanced Load up).

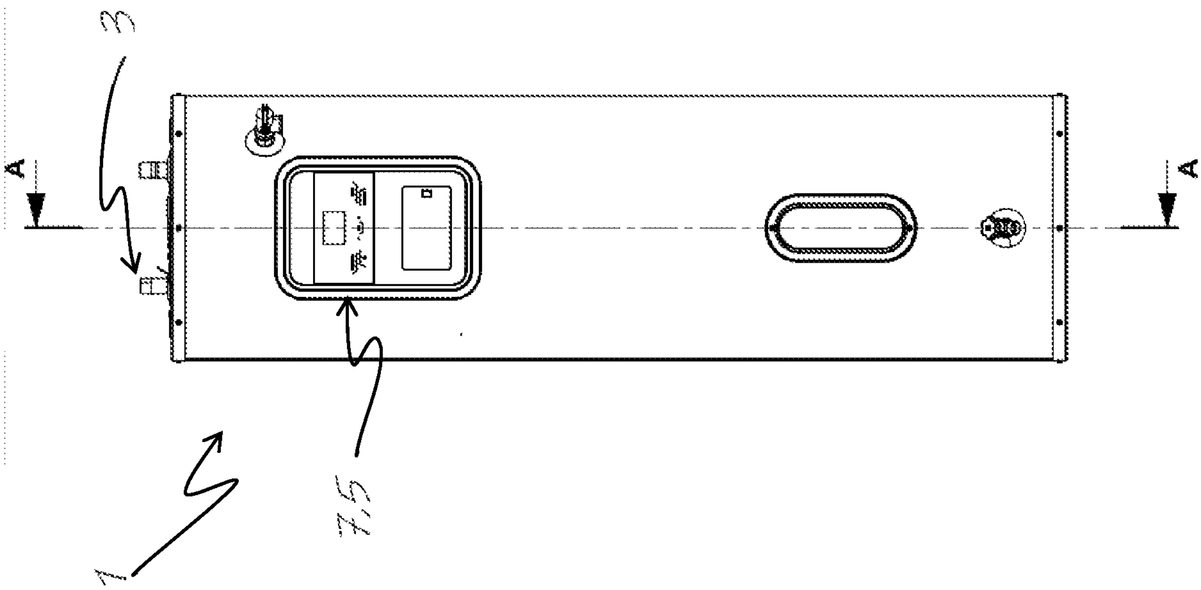


Fig. 1.b

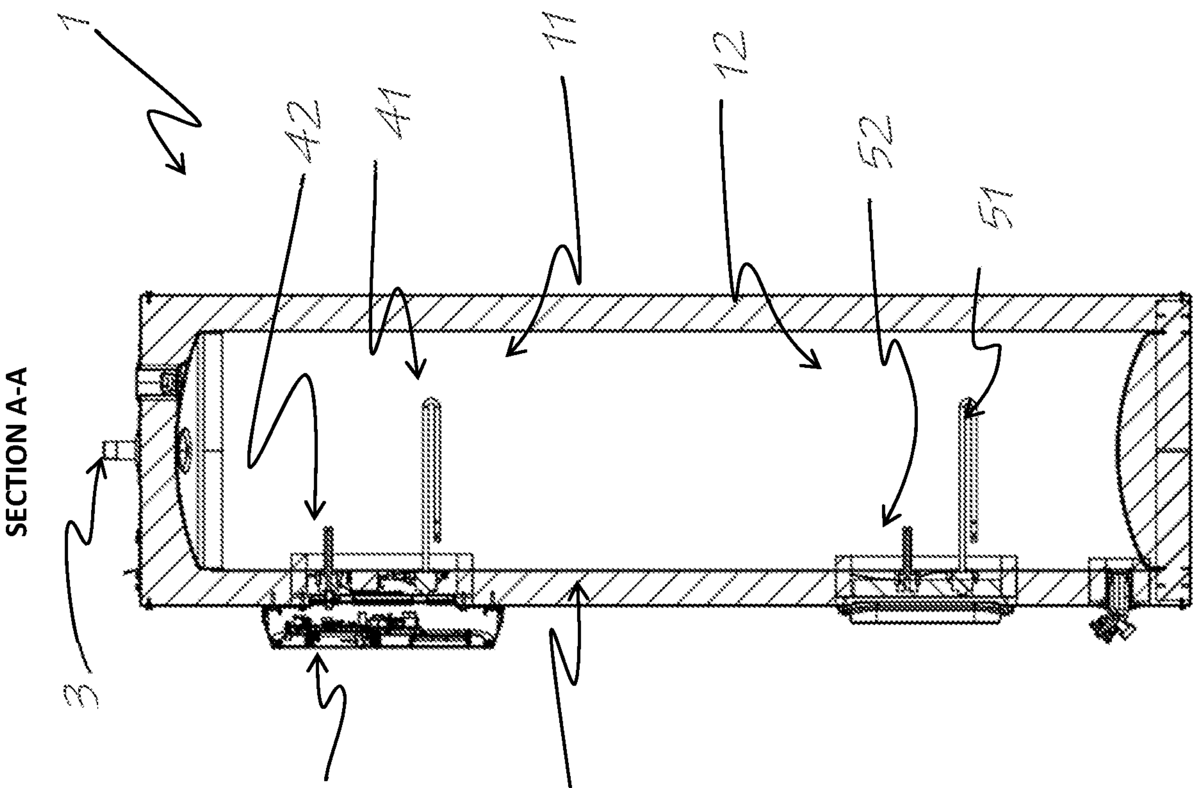


Fig.1.a

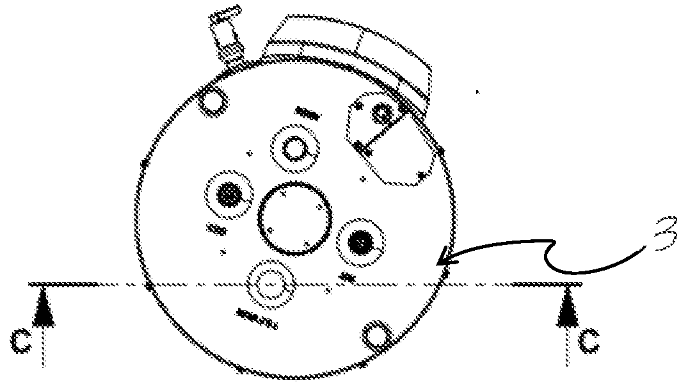
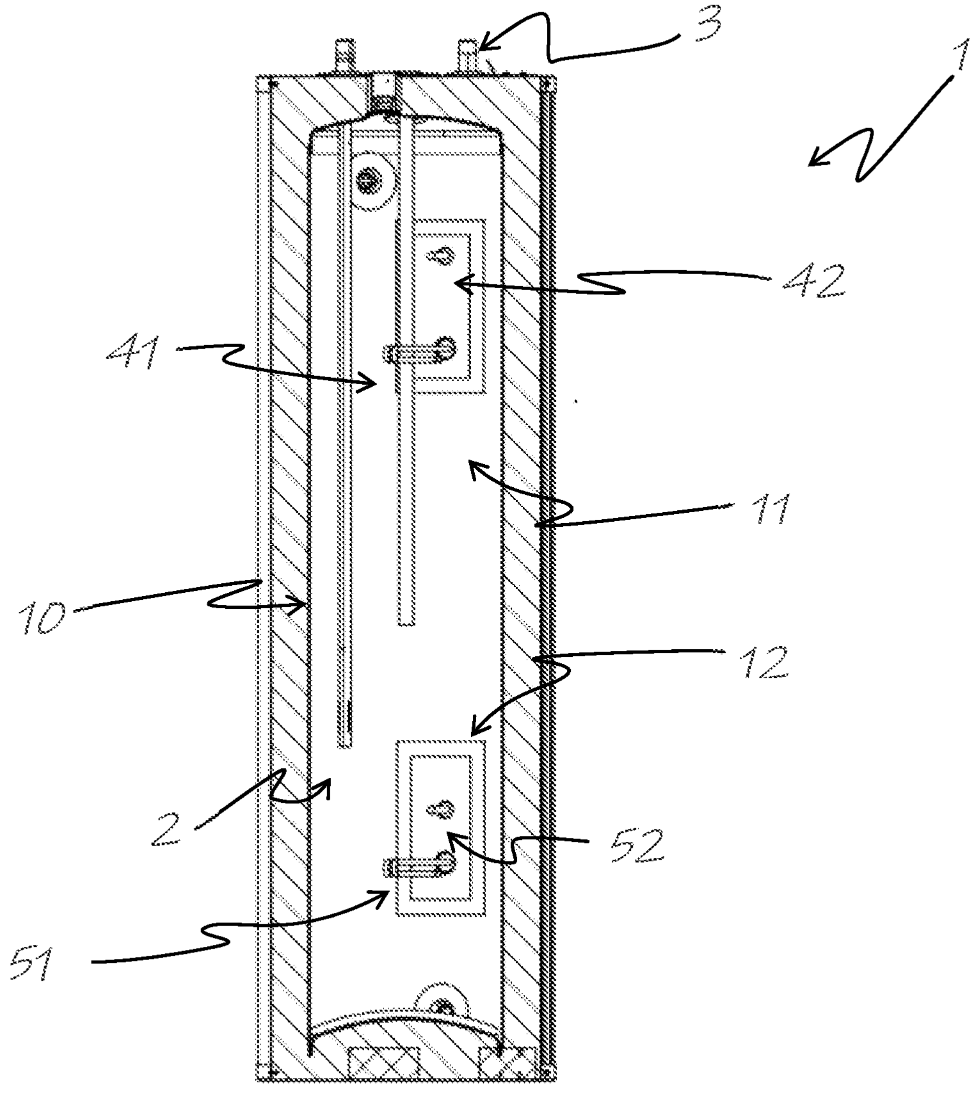


Fig. 1.c



SECTION C-C

Fig. 1.d

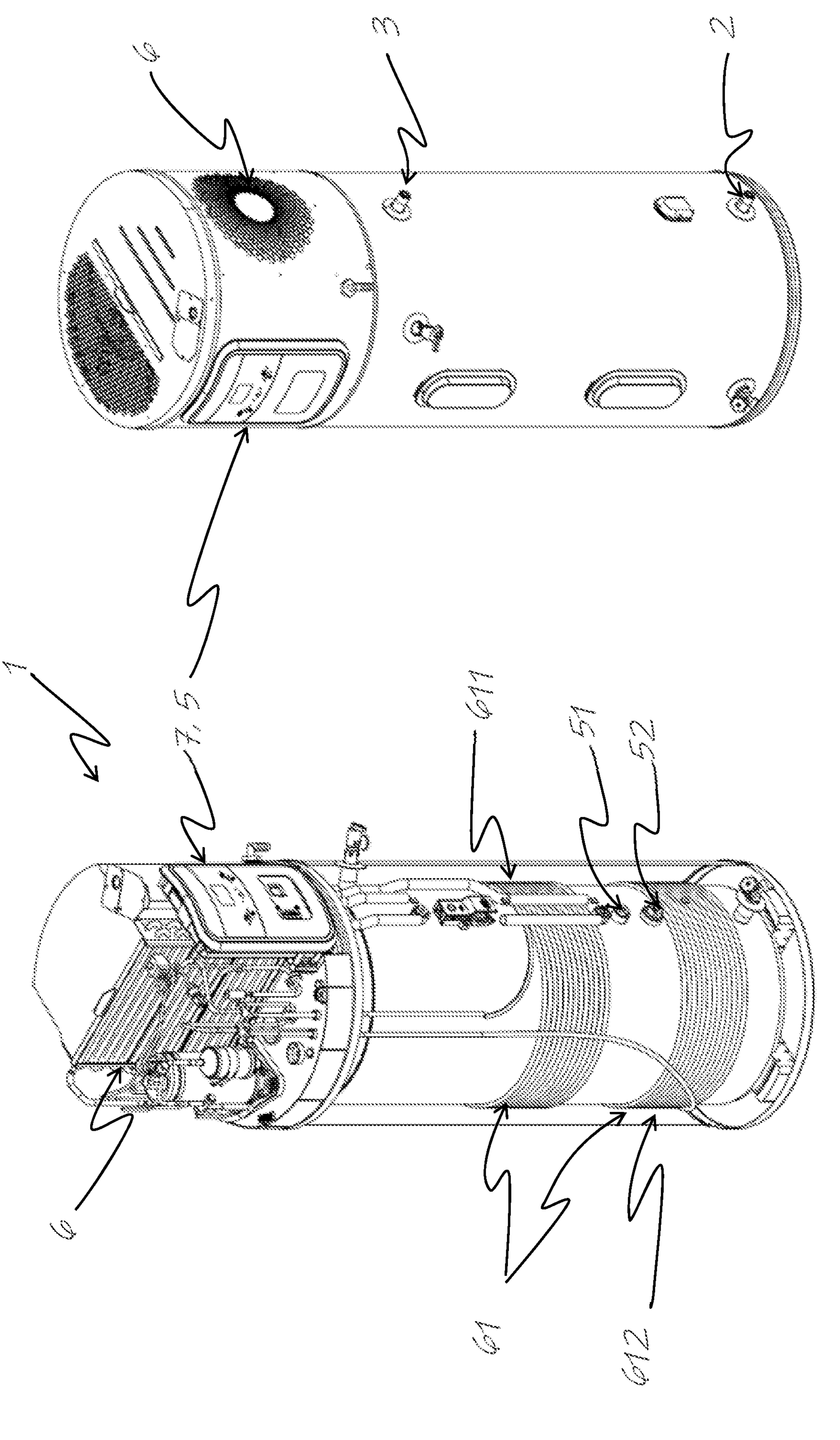


Fig 2.a

Fig. 2.b

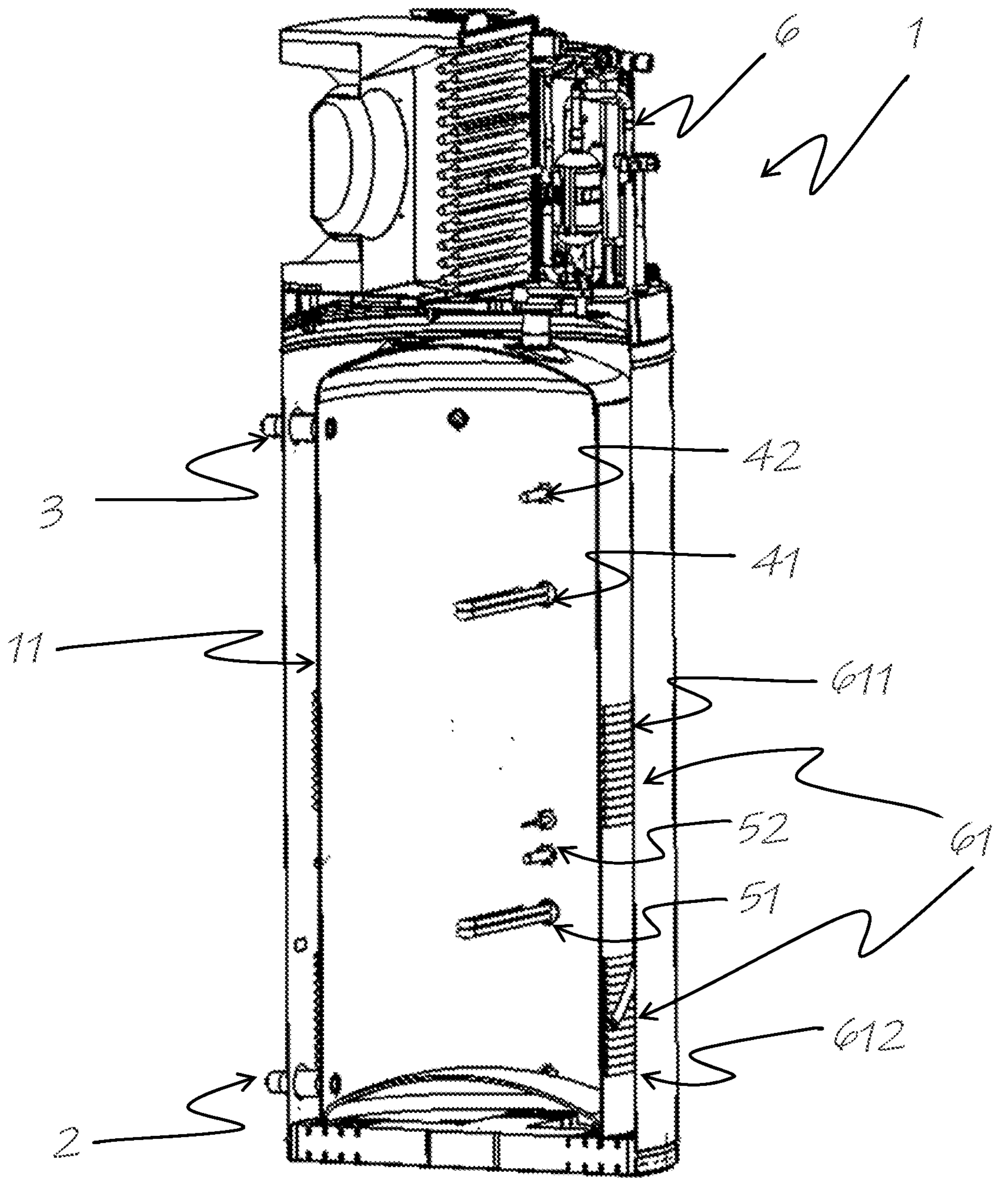


Fig.2.c

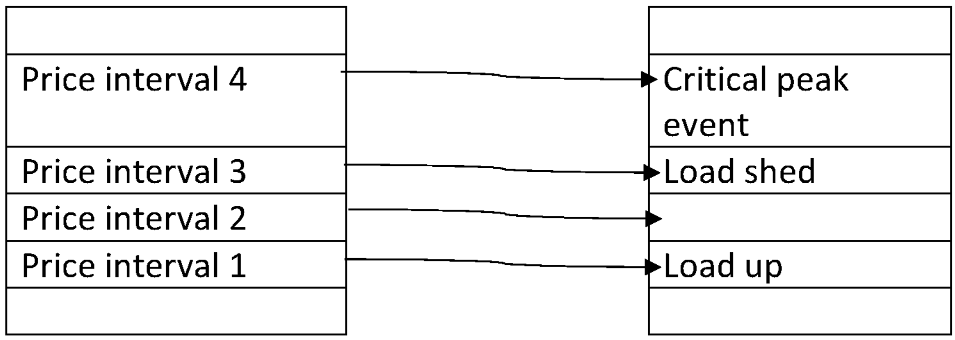

Price interval 4
Price interval 3
Price interval 2
Price interval 1
Critical peak event
Load shed
Load up

Fig. 3.a

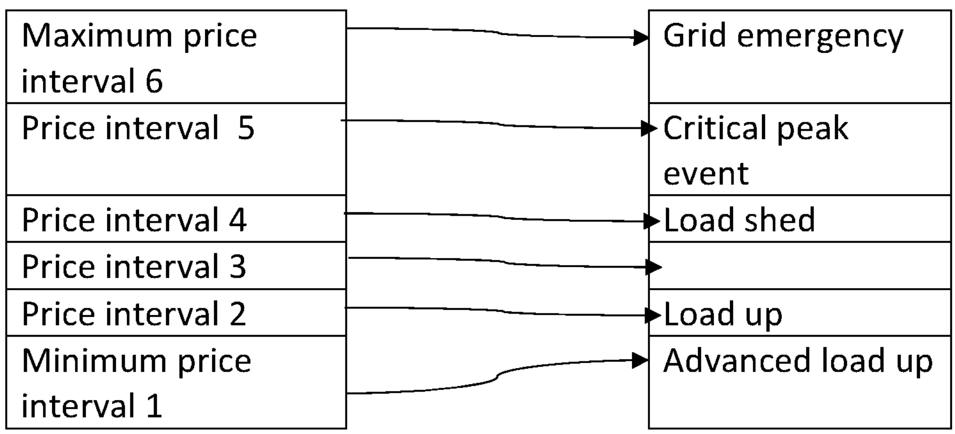

Maximum price interval 6
Price interval 5
Price interval 4
Price interval 3
Price interval 2
Minimum price interval 1
Grid emergency
Critical peak event
Load shed
Load up
Advanced load up

Fig. 3.b

	Ttarget
Confort	Tset
I-memory	Tmem
Green	Tset
Fast	Tset
I-memory Green	Tmem
I-memory Fast	Tmem

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2023/059949

A. CLASSIFICATION OF SUBJECT MATTER
INV. F24H1/20 F24H4/04 F24H9/20 F24H15/225 F24H15/37
F24H15/375 H02J3/14
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F24H H02J F24D

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2013/200168 A1 (BUESCHER THOMAS P [US] ET AL) 8 August 2013 (2013-08-08) paragraphs [0020] - [0112]; figures 1,9 -----	1-5,8-10 6,7,11,12
A	WO 2019/060371 A1 (SMITH CORP A O [US]; BRANECKY BRIAN THOMAS [US]; LEE YONGGON [US]) 28 March 2019 (2019-03-28) paragraphs [0008] - [0072]; figures 1-5 -----	1-12
A	WO 2010/093509 A2 (GEN ELECTRIC [US]; NELSON JONATHAN D [US] ET AL.) 19 August 2010 (2010-08-19) paragraphs [0007] - [0052]; figures 1, 4a,4b -----	1-12

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 January 2024	23/01/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Hoffmann, Stéphanie

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2023/059949

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		WO 2010093509 A2	19-08-2010