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WATER HEATING SYSTEM

Abstract

According to an aspect of the invention there is provided a water heating system comprising an electrical heating device for heating water, a battery, a battery management system, a heat sink arrangement, and a thermally insulating shell. The battery is electrically coupled to the electrical heating device for powering the electrical heating device. The battery management system is electrically coupled to the battery for charging the battery. The heat sink arrangement is thermally coupled to the battery and is configured to store and release thermal energy. The thermally insulating shell encloses the battery and the heat sink arrangement.

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Background/Summary

TECHNICAL FIELD

[0001] The present invention relates to a water heating system comprising an electrical heating device for heating water, a battery, and a battery management system electrically coupled to the battery for charging the battery. The present invention further relates to methods for controlling such water heating systems, and to computer program products allowing a computer to carry out such methods.

BACKGROUND

[0002] Central heating boilers often use natural gas for heating water on demand when hot water is needed for domestic activities such as washing, bathing, cooking, or heating. The heat output of a domestic gas boiler is typically around 20-40 KW, which will usually be sufficient to meet the instantaneous hot water demand in a common household. To increase the available supply of hot water, it is possible to use a well-insulated hot water tank that is heated in times of low demand and used when hot water is consumed faster than it can be heated by the boiler.

[0003] A clear disadvantage of gas boilers is that they require a continuous supply of natural gas for which the necessary infrastructure needs to be present. Alternatively, space-occupying storage tanks can be used that will have to be replaced and/or refilled regularly. Furthermore, the burning of natural gas, which is a fossil fuel, leads to CO₂ emissions. In many countries, therefore, the use of gas boilers is being phased out and replaced by, e.g., heat pumps, solar thermal panels, and electric boilers which can be powered by renewable energy.

[0004] Electric boilers have the advantage of simple installation and connection. For example, an electric boiler can be connected to a supply of mains electricity very easily, such as via connection into a mains electricity socket, and can also be connected to the water supply in a simple manner. As such, electric boilers are a more practical gas boiler replacement than, for example, heat pumps or solar thermal panels. An important disadvantage of electric boilers, certainly when compared to gas boilers, is that their heating capacity is generally limited by the power available from the domestic mains electricity supply. A typical domestic electric boiler is not capable of delivering more than about 15 KW of heating power, compared to the 20-40 KW delivered by standard gas boilers. The energy required to heat water is a fundamental quantity, and temperature rise, flow rate and power are therefore fundamentally interrelated. As such, a typical domestic electric boiler cannot provide sufficient heating power to match the performance of standard gas boilers, i.e. cannot heat water flowing at a comparable flow rate to a comparable temperature. Instead, electric boilers typically supply hot water at a lower temperature because there is insufficient heating power available to heat all of the water, or at lower flow rate through the boiler such that the slower-flowing water can be heated to the desired temperature.

[0005] Other systems employ a hot water tank to achieve the desired water flow rate at the desired temperature. However, hot water tanks take up space that may not always be available and typically lead to efficiency losses because no insulation will keep the heated water in the tank at a constant temperature indefinitely. Furthermore, hot water coming from such water tanks can often not be delivered at the same high pressure as the water coming directly from the mains water supply.

Furthermore, the time taken for a tank to heat leads to a lack of flexibility for the user.

[0006] In the German patent application published as DE 10 2009 030 999 A1, an electric water heater is disclosed wherein a battery powered heat pump warms water that is stored in a water tank. The water in the tank can be heated and the battery can be charged at times when electricity costs are lower, such as at night if special night tariffs apply, or during the day when electricity from solar panels may be available. The battery is cooled by a cooling jacket filled with a cooling fluid. This cooling jacket is used to control the temperature of the battery and to ensure that it can be charged and discharged with optimal efficiency. A heat exchanger is provided for exchanging heat between the water in the tank and the cooling fluid in the battery cooling jacket. This makes it possible to use heat produced in the battery during charging for warming up the water in the tank, which contributes to the overall energy efficiency of the water heater. While the electric water heater of D10 2009 030 999 A1 may alleviate some of the known problems with electrically heating water, it leaves many of the above-mentioned problems unsolved. Most importantly, the heat pump and the large water tank of this heating system result in a complex setup that requires a lot of space.

[0007] It is an aim of the present invention to address one or more disadvantages associated with the prior art.

SUMMARY OF THE INVENTION

[0008] According to an aspect of the invention there is provided a water heating system comprising an electrical heating device for heating water, a battery, a battery management system, a heat sink arrangement, and a thermally insulating shell. The battery is electrically coupled to the electrical heating device for powering the electrical heating device. The battery management system is electrically coupled to the battery for charging the battery. The heat sink arrangement is thermally coupled to the battery and is configured to store and release thermal energy. The thermally insulating shell encloses the battery and the heat sink arrangement.

[0009] In contrast to the electric water heating systems known so far, the heat sink arrangement according to the invention is not limited to simply preventing overheating of the battery by withdrawing heat during the charging process. While known battery cooling arrangements try to withdraw all excess heat as efficiently as possible, the heat sink arrangement according to the invention absorbs and retains the generated heat, storing it for later use within the same thermally insulating shell that also encloses the battery. Advantageously, the heat sink arrangement according to the invention makes it possible to use the heat generated by the battery for supplying hot water on demand without requiring a separate water tank. Further, the heat sink arrangement reduces fluctuations in battery temperature, thereby reducing the risk of damaging the battery through excessive thermal cycling. The space-saving and energy-efficient characteristics of the electric water heating system described herein make it very suitable to be used for replacing existing heat-on-demand gas boilers or for installation in new buildings, as well as for use in other space-constrained applications.

[0010] The battery comprises means for storing electricity. In preferred examples the battery may comprise one or more cells. For example, the battery may comprise one or more chemical battery cells.

[0011] The battery management system is electrically coupled to the battery and is configured for charging the battery. As such, the battery management system may be referred to as a battery charger, or battery charging apparatus in some examples. In some examples the battery management system may be a separate modular unit provided within the insulating shell and electrically coupled to the battery. In other examples the battery management system may be integrated with the battery.

[0012] Preferably, the heat sink arrangement is additionally thermally coupled to the battery management system and the thermally insulating shell further encloses the battery management system. Like the battery, the battery management system may produce heat during the charging

process. This heat can also be stored in the heat sink arrangement within the insulating shell for warming water later.

[0013] In preferred examples, the water heating system includes an alternating current (AC) to direct current (DC) power supply for the battery management system. The AC to DC power supply is configured to be electrically coupled to a source of AC power, such as mains AC power. The AC to DC power supply may be part of the battery management system in some examples, or alternatively the AC to DC power supply may be a separate component configured to supply power to the battery management system. In either example, the AC to DC power supply is configured to receive AC electricity, e.g. mains electricity, and convert the AC electricity to DC electricity for charging the battery. For example, mains electricity may be supplied to the battery for charging via the battery management system and/or the AC to DC power supply. As such, the AC to DC power supply is directly or indirectly electrically coupled to the battery. The AC to DC power supply may be configured to convert the AC mains electricity to DC electricity having a higher voltage than the RMS of the AC mains electricity, for example using a power factor correction (PFC) based power supply. More preferably still, the AC to DC power supply may be configured to convert the AC mains electricity to DC electricity having a higher voltage than the fully charged voltage of cells within the battery.

[0014] The AC to DC power supply for the battery management system is preferably thermally coupled to the heat sink arrangement. Most preferably, the AC to DC power supply for the battery management system is situated within the thermally insulating shell, e.g. the thermally insulating shell encloses the AC to DC power supply for the battery management system. As such, heat energy produced by the AC to DC power supply when charging the battery can be stored by the heat sink arrangement within the thermally insulating shell. Power electronics for other electrical devices within the insulating shell, such as pumps and/or fans for example, may also be situated within the thermally insulating shell and in use may also produce heat which can be stored in the heat sink arrangement within the insulating shell.

[0015] In preferred embodiments, the heat sink arrangement has a heat capacity that is sufficient to store all heat produced by charging the battery, without causing the battery damage through excessive thermal cycling. For example, heat may be produced by the battery management system, the AC to DC power supply for the battery management system, the battery itself and other electrical components within the insulating shell during battery charging, and this heat may be stored by the heat sink arrangement. Preferably, the heat capacity of the heat sink arrangement is greater than the total heat produced by charging the battery. For example, the heat capacity of the heat sink arrangement is preferably greater than the total heat produced by electrical components, such as the battery management system, the AC to DC power supply for the battery management system and the battery, when charging the battery.

[0016] The optimal maximum temperature of the battery and the amount of heat produced during charging are known or measurable quantities. The heat capacity requirements of the heat sink arrangement can therefore be calculated. The heat capacity of materials in the heat sink arrangement is also a known or measurable quantity. As such, the thermal requirements of the heat sink arrangement can be calculated, and the heat sink arrangement can be configured to ensure that the heat sink provides a large enough maximum heat storage capacity to avoid causing the battery damage through excessive thermal cycling.

[0017] It is noted that heat will be produced while discharging the battery too. However, discharging of the battery will occur during periods of demand for hot water. When there is a demand for hot water, the electrical heating device uses the electrical energy stored in the battery to heat the water. Any heat already stored in the heat sink arrangement, as well as any heat generated in the battery itself while discharging, can be used to preheat the water that goes to the electrical heating device.

[0018] The heat sink arrangement may comprise a heat exchanger configured to facilitate heat

exchange between an interior of the insulating shell and water flowing to an inlet of the electrical heating device. As such, the temperature inside the insulating shell may be controlled by removing heat from the interior of the insulating shell via the heat exchanger.

[0019] The heat sink arrangement preferably comprises a heat sink volume for holding a heat exchange fluid. The heat sink volume may be configured for holding a heat exchange fluid that is either a liquid or a gas. In other words, the system may comprise a heat exchange fluid within the heat sink volume which may be a liquid or a gas. A heat exchange fluid may facilitate particularly effective removal of heat from the interior of the insulating shell. Further, a heat exchange fluid may facilitate flexibility in the way in which heat is removed from inside the insulated shell.

[0020] How the preheating of the water is achieved depends on whether the heat sink volume is an 'open system' or a 'closed system'.

[0021] In an open system, the heat sink volume may be fluidly coupled to an inlet of the electrical heating device. This allows the heat sink volume to be filled with the water to be heated which increases the heat capacity of the heat sink arrangement. This also allows the water to be routed through the heat sink arrangement before being led to the electrical heating device. As such, the water may be pre-heated before being delivered to the electrical heating device for further heating. In a closed system, water supplied to the electrical heating device and the heat sink volume are not fluidly coupled. Instead, the heat sink arrangement may comprise a heat exchanger for exchanging heat between the heat exchange fluid in the heat sink volume and water flowing to an inlet of the electrical heating device. In this way the water to be heated by the electrical heating device is still pre-heated by the heat exchanger. In a closed system, the heat exchange fluid may be water, air, or any other suitable fluid (i.e. liquid or gas).

[0022] A pump may be included in either an open system or a closed system to promote circulation of a fluid in the heat sink volume to ensure an even distribution of heat energy during charging and discharging of the battery. For example, in an open system a pump may be used to promote circulation of water through the heat sink volume. In a closed system, a pump may be provided for promoting circulation of the heat exchange fluid through the heat sink volume and to facilitate rejection of heat from the heat sink volume by further passing through the heat exchanger. It will be appreciated that in examples wherein the heat exchange fluid is a gas, the circulation pump may be a fan, for example.

[0023] Preferably, the water heating system further comprises a controller that is operationally coupled to the battery management system and/or the electrical heating device. The controller may control the charging process of the battery, for example to ensure that charging costs are minimised, or for example to ensure that the battery is fully charged at times of expected high demand of hot water.

[0024] A temperature sensor may be provided for measuring a temperature inside the thermally insulating shell.

[0025] In some examples, the controller may be operationally coupled to a device configured to initiate flow within the heat sink volume. Such a device may be a pump (or a fan in examples where the heat exchange fluid is a gas) or a release valve fluidly coupled to the heat sink volume, for example. The controller is preferably operationally coupled to the temperature sensor and the device and may be configured to selectively initiate flow within the heat sink volume to reject heat from the heat sink volume in dependence on the temperature inside the thermally insulating shell. The initiated flow may, for example, be a flow of heat exchange fluid out of the heat sink volume, or may be a circulation of the heat exchange fluid within the heat sink volume to promote heat exchange between the heat exchange fluid and water flowing to an inlet of the electrical heating device. In either example the flow within the heat sink volume ultimately results in the rejection of heat from the heat sink volume.

[0026] The system may further include a release valve fluidly coupled to the heat sink volume and configured to facilitate the release of heat exchange fluid from the heat sink volume. The controller

which is operationally coupled to the temperature sensor and the release valve is configured to open the release valve in dependence on the temperature inside the thermally insulating shell. [0027] In some examples, the release valve fluidly coupled to the heat sink volume may also be fluidly coupled to an inlet of the electrical heating device and configured to allow drainage of water from the heat sink volume into the inlet of the electrical heating device. When the temperature inside the thermally insulating shell rises above the optimal maximum temperature of the battery at a moment when there is no direct demand for warm water at an outlet, heat may be released by rejecting the pre-heated water into, e.g., a drain or a fluid-based room heating system such as a water-based room heating system.

[0028] In some examples, a fluid-based room heating system, such as a central heating system, may function as an additional heat sink. For example, even without actively flowing water through the central heating system, if the water within the central heating system is in fluid communication, and therefore also thermally coupled to, the heat sink volume within the insulating shell, then heat from the battery can also be conducted to the water in the central heating system. As such, opening the release valve to facilitate fluid communication between the central heating system and the heat sink volume may increase the heat capacity available for storing heat emitted by the battery and other electrical components within the shell.

[0029] In some examples, the controller may be operationally coupled to the temperature sensor and the pump configured to circulate the heat exchange fluid within the heat sink volume. The controller may therefore be configured to operate the pump in dependence on the temperature inside the thermally insulating shell. For example, if the temperature within the insulating shell rises above a set threshold, the controller may operate the pump to circulate the heat exchange fluid within the heat sink volume to promote heat exchange from the fluid to the water to be heated, via the heat exchanger in a closed system.

[0030] In some examples the controller may be operationally coupled to the temperature sensor, a pump and a release valve. The controller may operate both the pump and the release valve to motivate heat exchange fluid, in either liquid or gaseous form, out of the heat sink volume to reject heat from the heat sink volume.

[0031] In some examples, a refrigerant loop of a heat pump may be arranged within the insulating shell, or may be thermally coupled to the inside of the insulated shell. As such, heat emitted from the battery and other components within the shell may be rejected to the heat pump refrigerant loop.

[0032] In some embodiments, the water heating system may further comprise a secondary heating device. The secondary heating device is preferably configured to be powered by mains electricity. The secondary heating device may therefore be referred to as a secondary electrical heating device. Optionally, the secondary heating device may comprise a heat pump arrangement.

[0033] In some examples, the water heating system may be configured such that water to be heated by the secondary heating device is pre-heated by heat from inside the thermally insulating shell. In an open system the heat sink volume may therefore be fluidly coupled to an inlet of the secondary heating device. In a closed system, a heat exchanger may be configured to exchange heat between the heat exchange fluid in the heat sink volume and water flowing to an inlet of the secondary heating device.

[0034] In examples including an electrical heating device and a secondary heating device, there is a possibility to use either the (primary) electrical heating device, the secondary heating device, or both, depending on the circumstances. When the two heating devices are connected in series, the selection of which heating device to use may, for example, depend on the temperature increase that is desired, or the relative costs of operating one or the other. In some examples, the primary electrical heating device and the secondary heating device may be provided on parallel fluid flow paths. When the (primary) electrical heating device and the secondary heating device are provided on parallel fluid flow paths, using both simultaneously will allow for a higher throughput, i.e. a

higher hot water flow rate, and therefore higher water pressure at the outlet for the given flow rate. Selecting which of the two to use may thus also depend on the demand for hot water.

[0035] A controllable valve arrangement may be provided for controlling the fluid flow rate in each of the parallel fluid flow paths. For example, the controllable valve arrangement may comprise a first valve to control fluid flow rate in the fluid flow path comprising the (primary) electrical heating device, and a second valve to control the fluid flow rate in the second fluid flow path comprising the secondary heating device. Preferably, the first valve may be arranged downstream of the heat sink volume. This ensures that the heat sink volume may remain filled with water even with the first valve closed to halt fluid flow in the first fluid flow path. As previously described, the water in the heat sink volume adds to the heat capacity within the insulating shell. In some examples, the first valve may act as the previously-described release valve configured to be operated to control the temperature within the insulating shell. Preferably, the second valve may be arranged downstream of the secondary heating device.

[0036] Providing the (primary) electrical heating device and secondary heating device on separate, parallel fluid flow paths advantageously minimises the resistance effect experienced by the water to be heated. For example, the primary and secondary heating devices each provide a resistance to water flow. By arranging the heating devices on parallel fluid flow paths, the resistance provided by a given heating device is only encountered when that heating device is in use, i.e. when water is flowed through that fluid flow path. Such an arrangement provides an advantage over a system comprising heating devices arranged in series wherein water flows through, and is resisted by, multiple heating devices even if such heating devices are not actively heating the water.

[0037] Optionally, the heat sink arrangement includes a phase change material. Phase change materials are very suitable for storing large amounts of thermal energy in a relatively small volume and can do so while limiting the temperature fluctuations inside the thermally insulating shell. For example, the heat sink arrangement may comprise a sodium sulphate or paraffin-based phase change material.

[0038] In an exemplary embodiment, the battery comprises multiple modules, i.e. battery modules, each containing one or more individual cells. The modules are preferably formed of a material having a high thermal conductivity, such as aluminium, to efficiently transfer heat energy from the cells to the rest of the heat sink arrangement. The heat sink arrangement may comprise a frame with multiple compartments or fixings, each compartment or fixing arranged for holding one or more of the battery modules, all of which adds to the heat capacity of the heat sink as a whole within the insulating shell.

[0039] The heat sink volume may comprise heat exchange fluid channels that pass between respective battery modules. In some examples, the heat exchange fluid channels may pass through respective battery modules. With such a modular setup, the size and heating capacity of the system can easily be adapted to the needs and circumstances. It further allows for easy replacement of individual modules in the event of technical failure and makes it more practical to route the fluid channels of the heat sink volume through the battery structure and to make a large surface area available for heat transfer.

[0040] In some examples, one or more heat exchange fluid channels may be defined by conduits in the frame. For example, such conduits may be formed as an integral part of the frame. As such, the frame may perform multiple functions, including holding the battery modules, routing the heat exchange fluid around the battery modules, and conducting heat between the battery modules and the heat exchange fluid, all whilst itself also adding to the total heat capacity of the heat sink arrangement within the insulating shell. The frame may also comprise one or more compartments configured to retain a phase change material. In some examples, individual modules may comprise one or more compartments configured to retain a phase change material.

[0041] Housing the battery within the thermally insulating shell adds to the heat capacity within the insulating shell, such that the structure of the battery itself adds to the heat capacity to help store

the heat rejected by the cells during charging, even when the heat exchange fluid is not flowing within the heat sink volume. In such an instance, in contrast to examples in the prior art, the cells are not necessarily actively cooled. Instead, the heat sink arrangement within the insulating shell is configured to provide a sufficient heat capacity to ensure that the cells do not overheat or become damaged by excessive thermal cycling as a result of the predictable amount of thermal energy emitted during charging. Including the frame within the insulating shell adds further heat capacity within the insulating shell.

[0042] Providing the heat sink arrangement thermally coupled to the battery within the insulating shell helps to reduce fluctuations in the battery temperature. Reducing temperature fluctuations increases the longevity of the cells. In preferred examples, the temperature within the insulating shell may be maintained at between 0° C. and 85° C., more preferably between 20° C. and 40° C. To provide active control of the temperature within the insulating shell, the controller may operate the release valve and/or circulation pump and/or control charging of the battery as previously described.

[0043] The battery modules, i.e. cells, may be actively cooled by circulating or flowing heat exchange fluid through the heat sink volume. Such motivation of the heat exchange fluid may be achieved using a pump in an open system or a closed system as previously described. In some examples, the battery modules may be actively cooled by flowing water to be heated by the electrical heating device through the heat sink volume, e.g. in an open system. For example, heat may be discharged from inside the insulating shell, and the battery modules may therefore be actively cooled, when hot water is demanded, for example by turning on a tap or other outlet downstream of the heat sink volume.

[0044] The water heating system may further comprise a battery heating device that is enclosed in the thermally insulating shell. This battery heating device can be used to ensure that the battery temperature remains within an optimal range for high energy efficiency and low battery wear. In some examples, the system may comprise a return conduit configured to pipe heated water from downstream of the primary and/or secondary heating devices back into the heat sink volume within the insulating shell to warm the battery. The return conduit may comprise a controllable valve such that the temperature within the insulating shell, and therefore the temperature of the battery, can be actively managed by opening and closing the valve.

[0045] In some examples, the water heating system may comprise an outer casing. In preferred examples, the thermally insulating shell which encloses the battery and the heat sink arrangement, may be housed within the outer casing. Further, the battery management system may be housed within the same outer casing. In even more preferred examples, the outer casing may further house the previously-described heat exchanger. Most preferably, the outer casing may additionally house at least one of an electrical heating device and a secondary heating device. Optionally a controllable valve arrangement may also be situated within the outer casing.

[0046] According to other aspects of the invention, control methods are provided for controlling the above-described water heating system. For example, a control method may be used for controlling the fluid flow rate in each available parallel fluid flow path in dependence on at least one of a current demand for heated water, a charging status of the battery, a temperature inside the thermally insulating shell, and a current price of mains electricity. Other control methods may control charging of the battery in dependence on at least one of, a charging status of the battery, a temperature inside the thermally insulating shell, a predicted cost of charging the battery, a current price of mains electricity, and a predicted demand for heated water.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0047] Embodiments of the invention will now be described by way of example with reference to the accompanying drawings, in which:

[0048] FIG. **1** schematically shows a water heating system according to an embodiment of the invention;

[0049] FIG. **2** schematically shows a battery of the water heating system enclosed in a thermally insulating shell;

[0050] FIG. **3** shows a schematic representation of an inlet and an outlet of a heat sink volume of a water heating system with an open heat transfer configuration;

[0051] FIG. **4** shows a schematic representation of a heat exchanger arranged to transfer heat energy between the heat sink volume and the water supply in a system having a closed loop heat sink volume;

[0052] FIG. **5** shows a perspective view of a battery frame with battery modules and a heat sink arrangement suitable for use in the water heating system of claim **1**;

[0053] FIG. **6** shows a close-up view of a portion of the battery frame of FIG. **5**; and

[0054] FIG. **7** shows a cross section of a battery frame suitable for use in the water heating system of claim **1**.

DETAILED DESCRIPTION

[0055] FIG. **1** shows a schematic diagram of a water heating system **10** in accordance with an example of the invention. The water heating system **10** comprises a water inlet **12** configured to receive water from a water supply, such as a mains water supply or a water tank (not shown). The system **10** also includes an electrical heating device **14** for heating the water that enters the system **10** via the water inlet **12**. The electrical heating device **14** may be an electrical resistive heating element for example. The electrical heating device **14** is electrically coupled to a battery **16** such that the battery **16** can power the electrical heating device **14**.

[0056] In preferred examples the electrical heating device **14** may be powered by direct current (DC) power supplied by the battery **16**. In other examples, the electrical heating device **14** may be an alternating current (AC) heating device **14**, and the system **10** may further include a DC to AC converter (not shown) through which direct current power from the battery **16** may be converted to alternating current power for powering the heating device **14**.

[0057] As shown in FIG. **1**, the water heating system **10** further includes a battery management system **18** electrically coupled to the battery **16** to enable charging of the battery **16**, i.e. the battery management system **18** is configured to charge the battery **16**. The battery management system **18** is preferably connected to the mains electricity **20** to receive electrical power for charging the battery **16**. Whilst not shown in the figures, in some examples, the water heating system **10** may also include an AC to DC power supply for the battery management system **18**, which is configured to receive AC electricity from the mains supply **20**, and convert this to DC electricity for charging the battery **16**.

[0058] As shown schematically in FIG. **1**, the system **10** also includes a controller **22** that is operationally coupled to the battery management system **18** to control charging of the battery **16**. For example, the controller **22** may control charging of the battery **16** in dependence on at least one of, a charging status of the battery **16**, a predicted cost of charging the battery **16**, a current price of mains electricity, and a predicted demand for heated water. As such, the controller **22** may control the timing of charging the battery **16**. In some examples, the controller **22** may be configured to receive a user input to directly command charging the battery **16**. In some examples the controller **22** is also coupled to the electrical heating device **14** to control operation of the heating device **14** in use.

[0059] In some examples, the heating device **14** may be electrically coupled to the mains electricity **20** such that the heating device **14** may be powered by the mains electricity **20** in addition to power

provided by the battery **16**. In such examples, the system **10** may further comprise an AC to DC converter (not shown) such as a rectifier to rectify the AC mains electricity **20** to provide DC power to the heating device **14**. Whilst not shown in the accompanying figures, in some examples the system **10** may therefore include a heating device **14** powered by both the battery **16** and the mains electricity **20**. In such an example the heating device **14** may be powered primarily by the battery **16**, with supplementary power provided by the mains electricity **20**. Alternatively, the heating device **14** may be powered primarily by the mains electricity **20**, and the battery **16** may provide supplementary power to achieve a heating performance comparable to that of a conventional gas boiler.

[0060] Notably, the water heating system **10** includes a heat sink arrangement **24** that is specifically configured to store heat emitted from the battery **16** and other electrical components, and which therefore helps to regulate the temperature of the battery **16**. As such, the heat sink arrangement **24** is thermally coupled to the battery **16** to facilitate the transfer of heat energy from the battery **16** to the heat sink arrangement **24**. In preferred examples, the heat sink arrangement **24** is also thermally coupled to the battery management system **18** to receive heat from the battery management system **18**. Similarly, in examples wherein the water heating system **10** includes an AC to DC power supply for the battery management system **18**, such an AC to DC power supply is preferably also thermally coupled to the heat sink arrangement **24** such that the heat sink arrangement **24** may receive and store heat energy emitted by the AC to DC power supply during charging of the battery **16**.

[0061] The heat sink arrangement **24** will be described in more detail later with reference to FIGS. **5**, **6** and particularly the cross-sectional view of FIG. **7**. However, by way of an initial overview, the heat sink arrangement **24** is configured with a heat capacity that is sufficient to store all of the heat produced by charging the battery **16** without causing the battery **16** damage through excessive thermal cycling.

[0062] Referring still to FIG. **1**, but with reference additionally to FIG. **2**, the battery **16** and the heat sink arrangement **24** of the water heating system **10** are enclosed in a thermally insulating shell **26**. In preferred examples the thermally insulating shell **26** also encloses the battery management system **18** as shown in FIG. **2**. In examples including an AC to DC power supply for the battery management system **18**, such a power supply is preferably also enclosed within the thermally insulating shell **26**. The thermally insulating shell **26** ensures that heat produced by the battery **16** and other electrical components within the shell, and which is transferred to the heat sink arrangement **24**, is retained in the heat sink arrangement **24**, i.e. not wasted or immediately rejected.

[0063] The water heating system **10** therefore advantageously facilitates effective use of the heat produced by the battery **16** to improve the overall efficiency and longevity of the water heating system **10** as will be described later in more detail. In particular, retaining the heat produced by the battery **16** enables pre-heating water before such water is delivered to the electrical heating device **14** as shown schematically in FIG. **1**. Retaining the heat may also help to maintain the temperature of the battery **16** within an optimum operating range. Maximising the performance of the insulating shell **26**, i.e. increasing the thermal resistance of the shell **26**, increases the efficiency of the water heating system **10** by minimising the heat lost as a result of charging and discharging the battery **16**. In some examples the insulating shell **26** is therefore configured to retain 70%, preferably at least 80%, or more preferably at least 90%, of the heat energy generated by charging and discharging the battery **16**, in the heat sink arrangement **24** within the shell **26**. For example the thermal performance of the shell **26** may be comparable to that of an insulated hot water tank.

[0064] In preferred examples, the water heating system **10** additionally includes a secondary heating device **28** as shown in the schematic diagram of FIG. **1**. The secondary heating device **28** is preferably configured to be powered by mains electricity **20**, and may for example comprise an electrical resistive heating element. The inclusion of a secondary heating device **28** facilitates an

increased total heating power output, such that the heating power of the electrical water heating system **10** may be comparable to the heating power of a typical gas-powered boiler when both of the heating devices **14**, **28**, powered respectively by the battery **16** and mains **20**, are used to heat water.

[0065] As shown in FIG. **1**, in particularly preferred examples, the electrical heating device **14** and the secondary heating device **28** are provided on parallel fluid flow paths **30a**, **30b**. For example, the electrical heating device **14** may be arranged on a first fluid flow path **30a**, and the secondary heating device **28** may be arranged on a second fluid flow path **30b**. The water heating system **10** may include a controllable valve arrangement **32** for controlling a fluid flow rate in each of the parallel fluid flow paths **30a**, **30b**. For example, the system **10** may comprise a first controllable valve **34a** arranged on the first fluid flow path **30a**, and a second controllable valve **34b** arranged on the second fluid flow path **30b**.

[0066] The controller **22** is preferably operationally coupled to the controllable valve arrangement **32**. By opening and closing the first and second controllable valves **34a**, **34b** it is therefore possible to control the proportion of the water from the water inlet **12** that flows through each heating device **14**, **28**. The fluid flow rate in each of the parallel fluid flow paths **30a**, **30b** may be controlled in dependence on at least one of a current demand for heated water, a charging status of the battery **16**, a temperature inside the thermally insulating shell **26**, and a current price of mains electricity **20**.

[0067] Referring still to FIGS. **1** and **2**, but as most clearly shown in FIG. **7**, the heat sink arrangement **24** preferably comprises a heat sink volume **36** for holding a heat exchange fluid **38**. Heat produced by the battery **16** and the battery management system **18** is transferred to the heat exchange fluid **38** in the heat sink volume **36**. Providing a heat exchange fluid **38** in the heat sink volume **36** increases the heat capacity within the insulating shell **26**. Accordingly, heat energy emitted from the battery **16**, battery management system **18**, and other electrical components within the shell, may be stored in the heat exchange fluid **38** within the insulating shell **26**. The heat exchange fluid **38** helps to enable control of the temperature within the insulating shell **26**, and facilitates a plurality of options for removing heat from inside the insulating shell **26** as will be described in more detail later.

[0068] Referring additionally to FIG. **3**, but with continued reference to FIG. **1**, in some examples the water heating system **10** may be configured as an open system. In an open system configuration, the heat sink volume **36** is fluidly coupled to an inlet **40** of the electrical heating device **14**. In other words, the heat sink volume **36** is in fluid communication with the inlet **40** of the electrical heating device **14** such that fluid **38** from the heat sink volume **36** is delivered to the electrical heating device **14** for subsequent additional heating. Preferably, in an open system the heat exchange fluid **38** in the heat sink volume **36** may therefore be water that is introduced to the water heating system **10** via the main water inlet **12**.

[0069] In an open system the water flows from the water inlet **12**, through the heat sink volume **36** and is then delivered to the electrical heating device **14**, for example via the first fluid flow path **30a**. In such a configuration, water is pre-heated by the heat emitted from the battery **16**, battery management system **18** and other electrical components housed in the insulating shell **26** before being heated further by the electrical heating device **14**. Such a configuration provides an energy efficient water heating system **10** because surplus heat is transferred directly from the battery **16**, battery management system **18**, and other electrical components such as an AC to DC power supply, to the water to be heated. As such, energy input into the water heating system **10** is used either directly or indirectly for heating water, and is therefore not wasted.

[0070] An inlet **42** and an outlet **44** of the heat sink volume **36** in an open system are shown schematically in FIG. **3**. In this example, all of the water conveyed via the first fluid flow path **30a** flows through the heat sink volume **36** first, before arriving at the electrical heating device **14**. However, in some other examples the system **10** may be configured such that a portion of the water

flowing in the first fluid flow path **30a** is diverted to flow through the heat sink volume **36**, whilst the remaining water in the first fluid flow path **30a** bypasses the heat sink volume **36** and is delivered directly to the electrical heating device **14**.

[0071] In some examples the water heating system **10** may comprise a release valve (not shown) fluidly coupled to the heat sink volume **36**. In some examples the release valve may be configured to allow drainage of heat exchange fluid **38**, such as water, from the heat sink volume **36**. For example water may be released into the first fluid flow path **30a**. Whilst not shown in FIG. **3**, the system **10** may also include a temperature sensor configured to measure the temperature inside the thermally insulating shell **26**. The controller **22** is preferably operationally coupled to the temperature sensor and the release valve so that the release valve may be operated in dependence on the temperature inside the thermally insulating shell **26**. In some examples, the previously-described first controllable valve **34a** may perform the same function as the release valve, i.e. the first controllable valve **34a** may be opened or closed dependent on the temperature within the thermally insulating shell **26**. The valve **34a** may be operated independently from the electrical heating device **14**, i.e. the valve **34a** may be operated regardless of whether the electrical heating device **14** is operating to heat the water. As such, in some examples, the temperature inside the insulating shell **26** may be controlled by allowing or blocking the flow of water through the heat sink volume **36** by opening or closing the controllable valve **34a** to allow or block the rejection of heat from the heat sink volume **36**.

[0072] A closed system is configured such that heat is removed from the interior of the insulating shell **26** via a heat exchanger **48**. FIG. **4** shows an example of a portion of a closed system at an interface between the heat sink volume **36** and a fluid flow path **30a**. This configuration may be described as a closed system because the heat sink volume **36** is not in fluid communication with the first or second fluid flow path **30a**, **30b**. The heat exchanger **48** facilitates a transfer of heat energy from inside the insulating shell **26** to water flowing to an inlet **40** of the electrical heating device **14**. The heat exchanger **48** is therefore preferably arranged upstream of the electrical heating device **14**. As such, water delivered to the electrical heating device **14** may be pre-heated by the heat exchanger **48** using heat from within the insulating shell **26**.

[0073] In a closed system, a separate heat exchange fluid **38** is circulated within the heat sink volume **36** to receive heat energy emitted by the battery **16**. The heat exchanger **48** is preferably configured to transfer heat from the heat exchange fluid **38** to water flowing to an inlet **40** of the electrical heating device **14**. In some examples the heat exchange fluid **38** in the heat sink volume **36** of a closed system may be water. However, a closed system also facilitates the use of other heat exchange fluids **38**, because in such a system, the heat exchange fluid **38** is not fluidly coupled to an outlet at which heated water is delivered to a consumer. Therefore, the heat exchange fluid **38** does not need to be safe for human consumption, and may include advantageous additives, such as an anti-corrosion agent for example.

[0074] The heat sink volume **36** may be a complex configuration comprising a plurality of heat exchange fluid channels **50** (as shown in FIGS. **6** and **7** for example). It may therefore be advantageous to configure the heat sink volume **36** as a closed system to allow close control of the fluid **38** within the heat sink volume **36**. For example, mains water may comprise different natural minerals that could leave deposits, such as limescale, on surfaces over which such water flows over time. A closed system heat sink volume **36** means that specific chemical agents can be introduced into the heat sink volume **36** to ensure that heat exchange fluid channels **50** do not become damaged, restricted or blocked by such deposits. Finally, in some examples, water flowed over and around the battery **16** and other materials within the insulating shell **26** may not be suitable or safe for human consumption, and providing the heat sink volume **36** as a closed system therefore avoids any potential contamination of the water supplied to a consumer at an outlet.

[0075] A closed system may include a pump (not shown) for circulating the heat exchange fluid **38** through the heat sink volume **36**. A closed system may also include a temperature sensor (not

shown) inside the thermally insulating shell **26**. The controller **22** may be operationally coupled to the temperature sensor and the pump, and the controller **22** may operate the circulation pump in dependence on the temperature inside the insulating shell **26** to promote rejection of heat from the heat exchange fluid **38** to the incoming cold water flow in a fluid flow path **30a**, **30b** via the heat exchanger **48**.

[0076] In other examples, a closed system may additionally include a release valve (not shown). The release valve may be fluidly coupled to the heat sink volume **36**. The controller **22** may be operationally coupled to such a release valve such that the release valve may be operated in dependence on the temperature inside the insulating shell **26**. For example, a gaseous heat exchange fluid **38**, such as air, in the heat sink volume **36** may be released directly into the environment outside the insulating shell **26** to manage the temperature inside the insulating shell **26**. Alternatively, a liquid heat exchange fluid **38** may be released from the heat sink volume **36** via the release valve into a drain, for example, to control the temperature within the insulating shell **26**.

[0077] In some examples of a closed system, the release valve may be fluidly coupled to a fluid-based heating system, such as a water-based central heating system, such that, through operation of the release valve, heat may be rejected from the heat sink volume **36** to the fluid in the heating system. Such rejection of heat may be facilitated simply by fluidly and thermally coupling the heat sink volume **36** with the heating system by opening the release valve, without necessarily requiring the heating system to be actively flowing heat exchange fluid **38** through the heat sink volume **36**. Providing fluid communication between the heat sink volume **36** and a water-based heating system may increase the heat capacity available for storing heat emitted by the battery **16**.

[0078] Whilst not shown in the accompanying figures, in some examples the system **10** may also include a battery heating device that is enclosed in the thermally insulating shell **26**. The battery heating device may be operationally coupled to the controller **22** such that the controller **22** can, when required, increase the temperature within the insulating shell **26** by operating the battery heating device to ensure that the temperature of the battery **16** remains within an optimum operating range.

[0079] The battery **16** and other components of the water heating system **10** arranged within the thermally insulating shell **26** will now be described in more detail with reference to the remaining figures. The following description is equally applicable to the open system and the closed system that have been described previously. For ease of reference, the fluid **38** in the heat sink volume **36** is referred to herein as a heat exchange fluid **38** because heat is transferred, i.e. exchanged, from the battery **16** to the heat exchange fluid **38**. It will be appreciated that in an open system the heat exchange fluid **38** is the water to be heated using the heating device **14**, and in a closed system the heat exchange fluid **38** is a separate fluid to the water that is to be heated using the heating device **14**.

[0080] With reference to FIGS. **5**, **6** and **7**, the battery **16** preferably comprises multiple battery modules **52**. For example the battery modules **52** may each include one or more battery cells **54**, such as chemical battery cells **54** for example. The battery modules **52** may be electrically connected to one another in series to provide a high current to the electrical heating device **14**. Alternatively, the battery modules **52** may be electrically connected to one another in parallel such that high voltage power is provided to the electrical heating device **14**. In some other examples the electrical connections between the battery modules **52** may be selectively reconfigurable to facilitate active control of the current and voltage provided to the electrical heating device **14**.

[0081] The heat sink arrangement **24** includes a frame **56** that has multiple compartments or fixings which are arranged for holding one or more of the battery modules **52**. It will be appreciated that, being part of the battery structure, the frame **56** is also housed inside the insulating shell **26** (as shown in FIG. **2** for example). Therefore, the frame **56** provides additional heat capacity for storing heat energy emitted by the battery **16** and other electrical components within the shell **26**. In some examples, and as shown most clearly in FIG. **7**, the heat sink arrangement **24** within the insulating

shell **26** may include a phase change material **60**, and the phase change material **60** may be contained by the frame **56**.

[0082] With reference again more particularly to the cross-sectional view of an example in FIG. 7, the heat sink volume **36** comprises heat exchange fluid channels **50** that pass between or through respective battery modules **52**. This configuration provides the heat sink volume **36** with a high surface area via which heat can be transferred to the heat exchange fluid **38**. For reference, heat exchange fluid channels **50** of the heat sink volume **36** are also shown in the examples in FIGS. 5 and 6.

[0083] The advantages of the electric water heating system **10** of the present invention will now be described by way of a numerical example. However, it should be noted that the numerical values used by way of example are provided as an example only and are not intended to limit the scope of the invention defined in the appended claims.

[0084] For the purpose of demonstration, the following example assumes a charge efficiency of 90% and a battery capacity of 10 kWh. To charge the battery **16**, the battery **16**, i.e. the battery cells **54**, and battery management system **18** combined will reject $(10/0.9)-10=1.11$ kWh of heat energy. This is heat energy which, unless stored, would go to waste.

[0085] In this example each cell **54** has a mass of 0.65 kg, a nominal voltage of 3.2 V, a capacity of 30 Ah, and provides an energy storage of 96 Wh. The specific heat capacity of such a cell **54** depends on the cell's precise construction however, it would typically be in the region of 0.8-1.7 kJ/kgK. For the purpose of this example, each cell **54** has a specific heat capacity of 1 kJ/kgK.

[0086] A battery **16** having a capacity 10 kWh may be formed of one hundred and four of the previously defined cells **54** ($10 \text{ kWh}/96 \text{ Wh} \approx 104$ cells). Therefore the heat capacity of the cells **54** in this battery **16** in this example is $104 \times 1 \text{ kJ/kgK} \times 0.65 \text{ kg} = 67.6 \text{ kJ/K}$. 67.6 kJ of heat energy are therefore required to heat all the cells **54** by 1K ($=1^\circ \text{C}$). 1.11 kWh of heat energy is emitted by the battery **16** and battery management system **18** which is approximately 4 MJ, and $4 \text{ MJ}/67.6 \text{ kJ}$ provides a temperature increase of 59°C .

[0087] Whilst the battery temperature increase may technically be within the specified range for the cells **54**, thermal cycling in this range over a period of many years is likely to degrade battery health and/or performance. As previously described, the water heating system **10** of the present invention therefore additionally includes a heat sink arrangement **24** within the insulating shell **26** to increase the heat capacity within the shell **26**. The heat sink arrangement **24** within the insulating shell **26** includes the frame **56** for storing or mounting the battery modules **52** to hold them in position. For the purpose of this example, the frame **56** may be made from cast aluminium.

[0088] A numerical example will now be described to demonstrate the thermal performance of the heat sink arrangement **24** within the insulating shell **26**. For the purpose of the example, the frame **56** is configured to hold twelve of the previously-described cells **54** (for example, see FIG. 6). It will be appreciated that any calculation can be conducted with an arbitrary number of cells as long as respective numbers are observed. In doing so, temperature change can be directly compared.

[0089] Proceeding with the example shown in FIG. 6, twelve cells **54** have a combined heat capacity of $12 \times 1 \text{ kJ/kgK} \times 0.65 \text{ kg} = 7.8 \text{ kJ/K}$. The twelve cells **54** used in this example have a storage capacity of $12 \times 96 \text{ Wh} = 1.152 \text{ kWh}$. The heat energy emitted during charging at 90% efficiency is $=(1.152/0.9)-1.152=0.128 \text{ kWh}$ which is $=460.8 \text{ kJ}$. The temperature increase experienced by the cells as a result of the heat emitted during charging, without use of a heat sink **24** within the shell **26**, would therefore be $460.8 \text{ kJ}/7.8 \text{ kJ/K} = 59^\circ \text{C}$ in this example.

[0090] However, as previously described, providing a heat sink arrangement **24** within the thermally insulating shell advantageously reduces the temperature fluctuations experienced by the cells **54** of the battery **16**. The frame **56** inside the insulating shell **26** is part of the heat sink **24** in this example. For the purpose of this example, the frame **56** may be assumed to have a mass of 2.5 kg, and the specific heat capacity of aluminium is 0.96 kJ/kgK. The heat capacity of the frame **56** may therefore be calculated as $2.5 \text{ kg} \times 0.96 \text{ kJ/kgK} = 2.4 \text{ kJ/K}$. It follows that the total heat capacity

of the frame **56** and the cells **54** within the insulating shell **26** in this example is $7.8 \text{ kJ/K} + 2.4 \text{ kJ/K} = 10.2 \text{ kJ/K}$.

[0091] As previously described, the twelve cells **54** in this example have a storage capacity of 1.152 kWh, and the heat energy emitted during charging at 90% efficiency is 460.8 kJ. The total temperature increase within the insulating shell **26** as a result of charging can therefore be calculated as $460.8 \text{ kJ} / 10.2 \text{ kJ/K} = 45^\circ \text{ C}$. Providing a heat sink arrangement **24** that includes the frame **56** therefore reduces the temperature increase experienced by the cells **54** within the insulating shell **26** during charging.

[0092] The heat capacity within the shell **26** is further increased by including heat exchange fluid **38** in the heat sink volume **36** within the insulating shell **26**. For the purpose of this example the heat exchange fluid **38** is water. The heat sink volume **36**, i.e. including the heat exchange fluid channels **50**, may have a volume of 0.466 litres in this example. The heat exchange fluid **38** (water) in the heat sink volume **36** therefore has a mass of 0.466 kg, and the specific heat capacity of water is 4.2 kJ/kgK. Accordingly, the heat exchange fluid **38** in the heat sink volume **36** provides an additional heat capacity of 1.957 kJ/K (from $4.2 \text{ kJ/kgK} \times 0.466 \text{ kg} = 1.957 \text{ kJ/K}$).

[0093] The total heat capacity within the insulating shell **26**, including the cells **54**, the frame **56** and the heat exchange fluid **38**, is therefore $7.8 \text{ kJ/K} + 2.4 \text{ kJ/K} + 1.96 \text{ kJ/K} = 12.16 \text{ kJ/K}$. The total heat emitted during charging at 90% efficiency is 460.8 kJ. The total temperature increase experienced by the cells **54** within the insulating shell **26** is therefore $460.8 \text{ kJ} / 12.16 \text{ kJ/K} = 37.9^\circ \text{ C}$. increase in temperature. Evidently, the heat exchange fluid **38** within the heat sink volume **36** therefore further reduces the temperature increase.

[0094] As previously described, in some examples the water heating system **10** may additionally include a phase change material **60**, such as sodium sulphate, within the insulating shell **26**. For the purpose of this example the phase change material **60** is sodium sulphate which has a melting point of 32.4° C . and a heat of fusion of 252 kJ/kg. Accordingly, 252 kJ of energy are required to melt 1 kg of sodium sulphate, and this will occur at 32.4° C .

[0095] In preferred examples, the water heating system **10** is configured such that the melting point of the phase change material **60** is within the range of temperatures experienced inside the insulating shell **26** when charging and discharging the battery **16**. As such, the change in temperature will pause for the duration of time taken to melt (or freeze) a given volume of the phase change material **60**.

[0096] Referring again to the present example, three of the nine heat exchange fluid channels **50** in the frame **56** shown by way of example in FIG. **6** may be filled with sodium sulphate **60**. That is to say the sodium sulphate, i.e. phase change material **60**, may be housed in the heat sink arrangement **24** in a compartment provided by the frame **56**.

[0097] The energy required to melt this volume of phase change material **60** can be subtracted from the energy available to increase the temperature (or added to the energy rejected when cooling). In this example the heat exchange fluid channels **50** filled with heat exchange fluid **38** now have a volume of 0.311 litres, and the system **10** therefore comprises water with a mass of 0.311 kg in the heat sink volume **36**. The specific heat capacity of water is 4.2 kJ/kgK so the heat capacity added by including the heat exchange fluid **38** within the insulating shell **26** is $4.2 \times 0.311 = 1.306 \text{ kJ/K}$. In this example, having reduced the amount of heat exchange fluid **38**, the total heat capacity within the insulating shell **26** is therefore $7.8 \text{ kJ/K} + 2.4 \text{ kJ/K} + 1.31 \text{ kJ/K} = 11.51 \text{ kJ/K}$.

[0098] However, the mass of sodium sulphate **60** contained within the three channels is 0.414 kg, and the energy required to melt this mass of sodium sulphate is $0.414 \text{ kg} \times 252 \text{ kJ/kg} = 93 \text{ kJ}$. The heat emitted during charging at 90% efficiency 460.8 kJ. Removing the heat absorbed by melting the phase change material **60** leaves $460.8 \text{ kJ} - 93 \text{ kJ} = 367.8 \text{ kJ}$. The total increase in temperature experienced by the cells **54** in a system **10** including phase change material **60** within the insulating shell **26** in this example is $367.8 \text{ kJ} / 11.51 \text{ kJ/K} = 32.0^\circ \text{ C}$. The above calculation does not take the specific heat capacity of solid and liquid sodium sulphate into account, and in reality the

temperature increase is in fact even less severe. In summary, the inclusion of phase change material **60** within the shell **26** therefore further reduces the increase in temperature experienced by the cells **54** which increases their longevity as previously described.

[0099] The invention described herein and defined in the appended claims advantageously stores heat emitted by the battery **16** during charging and utilises it to enable more efficient water heating and increase battery longevity. Increasing the efficiency of a system typically results in an increase in materials and manufacturing costs. However, the water heating system **10** of the present invention facilitates an increased system efficiency without increasing cost. For example, less efficient cells **54** with higher internal resistance resulting in a greater heat output can be used because the emitted heat is recaptured in the heat sink arrangement **24** for later use. Use of such cells **54** is likely to carry a cost advantage. Similarly the electronics in the battery management system **18** can be deliberately designed to be less optimal, and therefore cheaper, because the heat energy emitted is captured and stored for later use.

[0100] It will be appreciated that any features described in relation to the various examples above may be readily combined with any other features described with reference to different examples without departing from the scope of the invention as defined in the appended claims. Further, it will be appreciated that the above description and accompanying figures are provided merely as an example. Many alternatives to the specific examples provided above are therefore possible without departing from the scope of the invention as defined in the appended claims.

Claims

1.-27. (canceled)

28. A water heating system comprising: an electrical heating device for heating water, a battery electrically coupled to the electrical heating device for powering the electrical heating device, a battery management system electrically coupled to the battery for charging the battery, a heat sink arrangement thermally coupled to the battery and configured to store and release thermal energy, and a thermally insulating shell enclosing the battery and the heat sink arrangement.

29. A water heating system according to claim 28, wherein the heat sink arrangement has a heat capacity that is sufficient to store all heat produced by charging the battery, without causing the battery damage through excessive thermal cycling.

30. A water heating system according to claim 28, wherein the heat sink arrangement is thermally coupled to the battery management system, and wherein the thermally insulating shell further encloses the battery management system.

31. A water heating system according to claim 28, wherein the heat sink arrangement comprises a heat exchanger configured to facilitate heat exchange between an interior of the insulating shell and water flowing to an inlet of the electrical heating device.

32. A water heating system according to claim 28, wherein the heat sink arrangement comprises a heat sink volume for holding a heat exchange fluid.

33. A water heating system according to claim 28, wherein the heat sink arrangement comprises a heat sink volume for holding a heat exchange fluid, and wherein the heat sink volume is fluidly coupled to an inlet of the electrical heating device.

34. A water heating system according to claim 28, wherein the heat sink arrangement comprises a heat sink volume for holding a heat exchange fluid, and wherein the heat sink arrangement comprises a heat exchanger for exchanging heat between a heat exchange fluid in the heat sink volume and water flowing to an inlet of the electrical heating device.

35. A water heating system according to claim 28, wherein the heat sink arrangement comprises a heat sink volume for holding a heat exchange fluid, wherein the heat sink arrangement comprises a heat exchanger for exchanging heat between a heat exchange fluid in the heat sink volume and water flowing to an inlet of the electrical heating device, and wherein the water heating system

further comprises a pump for circulating the heat exchange fluid through the heat sink volume.

36. A water heating system according to claim 28. further comprising a controller operationally coupled to the battery management system and/or the electrical heating device, and a temperature sensor for measuring a temperature inside the thermally insulating shell, wherein the heat sink arrangement comprises a heat sink volume for holding a heat exchange fluid, and wherein the controller is operationally coupled to a device configured to initiate flow within the heat sink volume, such as a pump or a release valve fluidly coupled to the heat sink volume, the controller being operationally coupled to the temperature sensor and the device and configured to selectively initiate flow within the heat sink volume to reject heat from the heat sink volume in dependence on the temperature inside the thermally insulating shell.

37. A water heating system according to claim 28. further comprising a controller operationally coupled to the battery management system and/or the electrical heating device, and a temperature sensor for measuring a temperature inside the thermally insulating shell, wherein the heat sink arrangement comprises a heat sink volume for holding a heat exchange fluid, and wherein the water heating system further comprises a release valve fluidly coupled to the heat sink volume and configured to facilitate the release of heat exchange fluid from the heat sink volume, the controller being operationally coupled to the temperature sensor and the release valve and configured to open the release valve in dependence on the temperature inside the thermally insulating shell.

38. A water heating system according to claim 28. further comprising a controller operationally coupled to the battery management system and/or the electrical heating device, and a temperature sensor for measuring a temperature inside the thermally insulating shell, wherein the heat sink arrangement comprises a heat sink volume for holding a heat exchange fluid, and wherein the water heating system further comprises a release valve fluidly coupled to the heat sink volume and configured to facilitate the release of heat exchange fluid from the heat sink volume, the controller being operationally coupled to the temperature sensor and the release valve and configured to open the release valve in dependence on the temperature inside the thermally insulating shell, and wherein the release valve is additionally fluidly coupled to an inlet of the electrical heating device and configured to allow drainage of water from the heat sink volume into the inlet of the electrical heating device.

39. A water heating system according to claim 28, further comprising a controller operationally coupled to the battery management system and/or the electrical heating device, and a temperature sensor for measuring a temperature inside the thermally insulating shell, wherein the heat sink arrangement comprises a heat sink volume for holding a heat exchange fluid, and wherein the water heating system further comprises a pump for circulating the heat exchange fluid through the heat sink volume, the controller being operationally coupled to the temperature sensor and the pump and configured to operate the pump in dependence on the temperature inside the thermally insulating shell.

40. A water heating system according to claim 28, further comprising a secondary heating device configured to be powered by mains electricity.

41. A water heating system according to claim 28, further comprising a secondary heating device, wherein the electrical heating device and the secondary heating device are provided on parallel fluid flow paths.

42. A water heating system according to claim 28, further comprising a secondary heating device, wherein the electrical heating device and the secondary heating device are provided on parallel fluid flow paths, wherein the water heating system further comprises a controllable valve arrangement for controlling a fluid flow rate in each of the parallel fluid flow paths.

43. A water heating system according to claim 28, wherein the heat sink arrangement includes a phase change material.

44. A water heating system according to claim 28, wherein the battery comprises multiple modules each containing one or more individual cells, and wherein the heat sink arrangement comprises a

frame with multiple compartments or fixings, each compartment or fixing arranged for holding one or more of the battery modules.

45. A water heating system according to claim 28, wherein the battery comprises multiple modules each containing one or more individual cells, and wherein the heat sink arrangement comprises a frame with multiple compartments or fixings, each compartment or fixing arranged for holding one or more of the battery modules, wherein the heat sink arrangement comprises a heat sink volume for holding a heat exchange fluid, and wherein the heat sink volume comprises heat exchange fluid channels that pass between and/or through respective battery modules.

46. A water heating system according to claim 28, further comprising a battery heating device that is enclosed in the thermally insulating shell.

47. A water heating system according to claim 28, further comprising an AC to DC power supply inside the insulating shell, the power supply being electrically coupled to at least one of the battery and/or battery management system to supply power to the battery, and the power supply being thermally coupled to the heat sink arrangement.
