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(54) **SYSTEM FOR CONTROLLING HOT WATER CYLINDERS**

(57) The present invention discloses a system allowing the temperature of water inlet and outlet tubes in a water cylinder to be measured. Thereby, the amount of energy stored in the device and the times when hot water is used can be estimated, in addition to allowing the users' behaviour to be predicted, any abnormal functioning of the device to be detected and the energy consumption of the device to be optimised. The device comprises a water cylinder controller (100) arranged on a housing; two thermocouple cables (300) to measure the temperature of the water inlet and outlet in the cylinder and an antenna (200) coupled to the antenna connector (12) for the connection of the controller (100) with another server or with the cloud, where the information is processed.

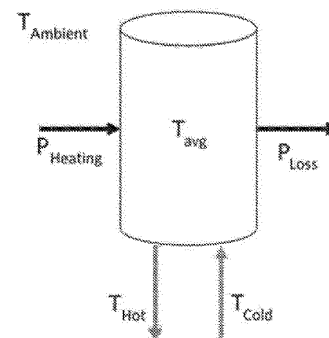


FIG 4

Description

OBJECT OF THE INVENTION

5 **[0001]** The present invention discloses a system allowing the temperature of water inlet and outlet tubes of a water heater with a tank to be measured, in particular in water cylinders, as well as consumption measurements. Thereby, the amount of energy stored in the cylinder and the times when hot water is used can be estimated, in addition to allowing the users' behaviour and any abnormal functioning of hot water to be predicted and the energy consumption of the device to be optimised.

BACKGROUND OF THE INVENTION

10 **[0002]** Conventional electrical household hot water heaters typically comprise a tank for water storage and at least an electrical element for heating water stored in the tank. Typically, an electrical hot water heater is fitted with two ohmic electrical elements for heating, with one being near the top of the tank and the other one at a small distance to the bottom of the tank.

[0003] The top and bottom thermostats are usually located closer to each element. These thermostats keep water temperature in the top and bottom region at a single preselected adjustment point. Thermostats having bimetallic switches are frequently utilised to maintain the tank's temperature.

20 **[0004]** From the point of view of an energy provider, conventional water heaters require energy throughout the day. Consequently, although a user does not need hot water and electric energy may be advantageous for the energy provider due to the maximum energy demand in the entire electricity grid, the elements of a hot water heater may be consuming electric energy.

25 **[0005]** From the consumer's perspective, a system for controlling the heating of an electric hot water tank reducing net energy provided to the tank in comparison with the energy provided by a conventional hot water heater is desirable.

[0006] From the perspective of an energy provider, a control system that allows heating of most of the heating of a hot water tank during times when energy is not in high demand is desirable. It is known that time change in hot water heating in sanitary hot water tanks can be used to 'change' the energy demand requirements for an electric energy provider.

30 **[0007]** The present invention discloses a system allowing the temperature of water inlet and outlet tubes in a water cylinder to be measured. Thereby, the amount of energy stored in the device and the times when hot water is used can be estimated, in addition to allowing the users' behaviour to be predicted and the energy consumption of the device to be optimised. The device comprises a water cylinder controller arranged on a housing; two thermocouple cables to measure the temperature of the water inlet and outlet in the cylinder and a Wi-Fi antenna coupled to the Wi-Fi antenna connector.

35 **[0008]** In the state of the art, document US20150019027 discloses an energy management system for a water heater system comprising a water heater unit to heat water and a motorised unit making said hot water circulate in a recirculating circuit to define one or more user points, wherein said energy management system comprises a control centre for collecting operating parameters of said water heater system and for collecting information on hot water use in real time in each of said user points; and a management centre operatively linked to said control centre for managing said operating parameter of said water heater system and said information of said hot water use in real time. The system disclosed herein is conceived to work with facilities that make hot water recirculate, which is not generally the case in residential facilities as in the main objective of this invention. Therefore, the device does not control motors or is not equipped with remote sensors, etc. Furthermore, the present invention provides a lot of information about water consumption and its patterns of use and enables the estimation of thermal consumption and energy stored and dissipated to the environment.

40 **[0009]** Document EP2636960 discloses a system for controlling hot water supply, comprising a hot water storage tank; means for water heating to carry out water heating when an amount of hot water of the hot water storage tank drops below a water heating threshold; means of acquisition of energy consumption to acquire the energy consumed by a plurality of electrical appliances, including the means for water heating; and means to adjust the water heating threshold to be established, when the energy consumption acquired by the means of acquisition of energy consumption indicates an initial energy consumption that is bigger than an energy consumption threshold. The above mentioned document does not indicate the possibility to predict users' behaviour and optimise energy consumption of the device as in the preceding document there is no automatic mode in which the cloud platform will take control of the hot water cylinder in order to automatically operate it.

55 **[0010]** European patent EP 3270350 shows an estimation method of future consumption of sanitary hot water supplied by at least a sanitary hot water tank comprising a determination of a previous extraction history of sanitary hot water, and an estimation of a length of time between two previous extractions of sanitary hot water of a chosen duration model, the model comprising at least a variable parameter, determining the parameter according to the history, and a generation

of a scenario of future extractions of sanitary hot water in a future period, based on the determination of the variable parameter of the chosen model. It is about optimisation of energy consumption of sanitary tap water in residential facilities by taking measurements of hot water consumption and of consumption of electricity. This reduction in energy consumption is achieved by switching the heater on and off based on the predictions of the use of demand by means of past behaviours.

[0011] Patent EP 3270350 utilises stochastic methods for the determination of future consumption scenarios, by means of a demand prediction model and based on the volume of flow without considering water temperatures as an input. This invention relies on the temperature measurement of the sleeves and the measurement of the power provided to the device in such a manner that the total amount of energy stored in the **thermostat** can be estimated. According to this patent, a flow meter needs to be installed at the outlet of the hot water cylinder and measuring electrical power supplied to the cylinder and estimating the internal temperature profile of the **thermostat** are required. However, the object of the present invention is to determine the temperature inside the tank without the installation of an internal sensor or flow meters being necessary. Furthermore, the estimation of the size of the hot water cylinder in litres and the determination of their insulation can be used to develop a virtual model of the equipment and does not include that in automatic mode the cloud platform will take control of the hot water cylinder in order to automatically operate it.

DESCRIPTION OF THE DRAWINGS

[0012] To complement this description and for a greater understanding of the features of the invention in accordance with an exemplary preferred embodiment of the same, a set of drawings is attached as an integral part of said description, these drawings merely provided for illustrative and non-limiting purposes:

Figure 1/4.- shows a front view of the front panel of the controller (100), where the different elements allowing the system according to the invention to be controlled can be seen.

Figure 2/4.- shows a horizontal view of the Wi-Fi antenna (200) of the system.

Figure 3/4.- shows a view of the connection of the thermocouple cables (300) in the rear of the controller (100).

Figure 4/4.- shows a schematic representation of a hot water cylinder, where the variables allowing the algorithm estimating the energy stored in the cylinder to be modelled are shown.

BRIEF DESCRIPTION OF THE INVENTION

[0013] The invention discloses a system for the controlling of electrical hot water cylinders, taking temperature measurements of the tank's water inlet and outlet tubes as well as their consumption measurements. Thereby, the amount of energy stored in the device and the times when hot water is used can be estimated. The temperature measurement is taken by means of thermocouple cables. The system is provided with an Internet connection, the communication with servers or the cloud being thereby possible, both to enable remote management with an application or web page and to be controlled by artificial intelligence. The device of the invention allows hot water to be controlled according to the number of heating elements contained in the cylinder, base load element and reinforcing load element.

PREFERRED EMBODIMENT OF THE INVENTION

[0014] The present invention discloses a system allowing both the temperature of water inlet and outlet tubes in a water cylinder as well as consumption to be measured. Thereby, the amount of energy stored in the device and the times when hot water is used can be estimated, in addition to allowing the prediction of the users' behaviour, the detection of abnormal behaviours of hot water and the optimisation of energy consumption of the device. The system is provided with an Internet connection, the communication with servers or the cloud being thereby possible, both to enable remote management with an application or web page and to be controlled by artificial intelligence.

[0015] The system can be utilised in those cases where the hot water cylinder has two heating elements or just one heating element.

[0016] The system comprises a water cylinder controller (100), a communication antenna (200) allowing it to be connected to the Internet, preferably by Wi-Fi, and two thermocouple cables (300).

[0017] The water cylinder controller (100) is arranged on a housing with a front panel on which elements allowing the system to be managed are arranged, wherein the front panel incorporates a mode button (1) allowing the operating mode to be changed; an operating indicator (2) showing the current operating mode and the status of the load switch; a boost button (3) enabling the reinforcing load; a reset button (4) restoring the controller if required; a communication indicator (5) showing connectivity status; a configuration button (6) allowing communications to be configured using the

connection passwords; a light sensor (7) measuring the intensity of ambient light; a temperature sensor (8) measuring ambient temperature; a fuse for base load (9) protecting the base circuit against overloads; a fuse for reinforcing load (10) protecting the reinforcing circuit against overloads; a main switch (11) insulating loads in off position and allowing the controller (100) to control loads in on position; and a communication antenna connector (12).

[0018] Furthermore, the system comprises two thermocouple cables (300), wherein the end of a first thermocouple cable (300) is arranged at the cold water inlet of the hot water cylinder and the end of the second thermocouple cable (300) is arranged at the hot water outlet (300) and wherein the free ends of both thermocouple cables (300) are routed and connected to the controller (100); and an antenna (200) coupled to the communication antenna connector (12) for the connection of the controller (100) with another server or with the cloud, where the information is processed.

[0019] The communications allow the connection of the system with another server or with the cloud, where the information is processed by means of the collected data on the user's use and electricity tariffs and by means of an algorithm modelling the user's behaviour and the temperature of the water cylinder.

[0020] The mode button (1) works according to the following modalities of hot water controller:

Off mode: the system does not heat the content of the hot water cylinder. Data such as ambient temperature or the temperature of the tube can still be captured. This may be useful if there are other heating elements such as boilers feeding the tank.

[0021] Manual mode: the system heats the content of the cylinder during the time periods selected by the user. This is useful when the user has different electricity tariffs according to the time of day. The system still collects data on use and temperatures, which are sent to the server or the cloud for the modelling of the user's and the hot water cylinder's behaviour.

[0022] Automatic mode: the system collects data and models the user's and the hot water cylinder's behaviour and communicates with a server or the cloud planning the heating periods to optimise several target behaviours while considering the user's convenience. This target behaviour may include the stability of the electric grid, efficiency, reduction in consumption and cost reduction, among others.

[0023] Temperature is measured by means of the thermocouple cables (300). As is known, a thermocouple cable is a temperature sensor composed of two different metals, joined at an end, that is sensitive to temperature changes. Although there are many thermocouples of different types, those most commonly utilised for industrial use are the type K and J thermocouple. As indicated, they are models composed of a positive and negative conductor generating a MV signal, which will be converted by controlling equipment like the controller (100) of the invention.

[0024] The thermocouple cables (300) are installed by arranging a cable both at the cold water inlet into the hot water cylinder and the hot water outlet. This is preferably effected with Kapton heat-resistant tape. The opposite end of the cables (300) is marked before routing them to the controller (100) to ensure their subsequent correct installation in their positions, and the thermocouple cables (300) are run to the controller box (100), i.e., the end of a first thermocouple cable (300) is arranged at the cold water inlet of the hot water cylinder and the end of the second thermocouple cable (300) is arranged at the hot water outlet (300) and the free ends of both thermocouple cables (300) are routed and connected to the controller (100).

[0025] Finally, the thermocouple cables (300) are connected to the terminal blocks in the rear part of the front cover of the controller (100), taking into account the labels for the cold inlet and the hot outlet and the positive and negative signs. Following the colour coding standard of thermocouples, negative poles (-) will be labelled in white and positive poles (+) can be of any other colour.

[0026] The system can measure the inlet and outlet temperature of cylinder's water in addition to the electrical power. This makes opening the water circuit for installation unnecessary, which can be effected by simply coupling devices to the surface of the cylinder tubes. By measuring the temperatures and the power supplied to the system, a suitable algorithm can estimate the total energy stored in the cylinder. The obtained measured data are sent either to a central server or to the cloud where they are stored together with data on electricity tariffs, data from the user's history, connection time, etc., and are processed by means of an algorithm allowing the stored energy, times when hot water is used, etc., to be estimated, the user behaviour to be predicted and the energy consumption of the device to be optimised.

Algorithms for the controlling system for hot water

[0027] The system measures the temperature of hot water tubes (THot) and cold-water tubes (TCold) as well as ambient temperature (TAmbient) (see figure 4). The system also records the heating power fed into the hot water cylinder, and whether the power is applied to the heating element of the cylinder or not.

[0028] It benefits from the fact that, when the cylinder is requested to heat water, the heating element stops consuming energy after a period of time in order not to exceed the maximum temperature of the cylinder (TMax). This is the maximum energy status (EMax).

[0029] Similarly, when THot equals TCold, while water is being used, there is a known energy status of the cylinder because it means that the cylinder is full of water at a known temperature. This is usually a minimum energy status (EMin).

[0030] Water consumption is important when the temperature of the tube is measured. When there is no consumption, both THot and TCold will tend towards Tambient, while, when there is consumption, these measurements will deviate from it.

[0031] The model can be applied by means of the following algorithms:

Modelling of maximum temperature reachable by water TMax

[0032] TMax is the maximum heating temperature of the cylinder and corresponds to the water temperature in the cylinder when this reaches maximum energy status (EMax). The user can provide this temperature manually or it can be easily measured as the maximum Thot temperature recorded. This maximum Thot temperature recorded will occur at any time of water consumption during a maximum energy status of the hot water cylinder.

Energy loss modelling (Ploss)

[0033] Environmental losses of the hot water cylinder can be modelled by having two known energy statuses of the system at two separate points of time. This can be achieved by measuring the power fed into the system between two maximum energy statuses without any hot water demand between them. This is a common scenario which can also be met by controlling the heating element of the cylinder.

$$Et0 - EP_{Loss} + EP_{Heating} = Et1$$

[0034] Given that $Et0 = Et1$, because they are maximum energy statuses:

$$EP_{Heating} = EP_{Loss}$$

Where:

Et0: energy stored in the cylinder at point in time t0.

Et1: energy stored in the cylinder at point in time t1.

EP_{Loss}: energy loss between t0 and t1.

EP_{Heating}: energy employed to heat the cylinder between t0 and t1.

[0035] Knowing the energy loss in the system in a determined period of time allows losses to be modelled. Depending on the model, several models can be considered here:

A simple model would consist in assuming that lost energy is constant in time. This means that P_{Loss} is constant and known.

$$P_{Loss} = EP_{Loss} / (t1 - t0)$$

[0036] A more realistic model would consist in assuming that P_{Loss} varies over time (P_{Loss}(t)) and follows an exponential behaviour. This would be the same as assuming that ambient temperature is constant in a real system:

$$P_{Loss}(t) = EXPONENTIAL(t, EP_{Loss}, t1, t0)$$

[0037] A more precise model would also take ambient temperature as an input to the P_{Loss} model, which varies over time (P_{Loss}(t)). The actual thermal losses must be proportional to temperature difference between inside the hot water cylinder and ambient temperature (Tavg-TAmbient). If the tank starts the period in a maximum energy status, Tavg is known because it equals T_{max}, the maximum heating temperature. This information can be utilised to train the adjusting of loss coefficients of the model.

$$P_{Loss}(t) = FUNCTION(t, Tavg, T_{Ambient}, t1, t0, EP_{Loss})$$

Modelling of energy consumption of hot water (Euse)

[0038] The temperature of the tube will reach a stable state near ambient temperature when no hot water is being consumed.

[0039] When hot water is being consumed, the temperature of the outlet tube (where T_{hot} is measured) will change following an exponential curve towards the water temperature from inside the cylinder (t_1). The demand of hot water starts precisely at this moment (t_0). The rate of the temperature change of the tube allows the amount of water mass being demanded (Q) to be estimated.

t_0 : point in time at which T_{hot} starts to be higher than $T_{Ambient}$. Start of transient.

t_1 : point in time at which the transient of T_{hot} finishes, equalling water temperature from inside the cylinder. End of transient.

Q : demanded water flow.

$Q = \text{FUNCTION}(t_1, t_0);$

[0040] Another transient takes place when water consumption stops but, in this scenario, the transient goes to $T_{Ambient}$. The demand of hot water will finish precisely at this moment (t_2).

- Linear regression between the use energy and the temperatures together with the water demand:

$$E_{use} = A * \text{FUNCTION}(t_1, t_2, T_{hot}) + B$$

In this case, the volume of flow is implicitly contained in A and B .

- Linear regression between the use energy and the temperatures together with the duration of water demand and its volume of flow.

$$E_{use} = A * \text{FUNCTION}(Q, t_1, t_2, T_{hot}) + B$$

- Models based on reinforcement learning, such as neural networks or others $E_{use} = \text{NEURALNETWORK}(Q, t_1, t_2, T_{hot})$

[0041] For the adjustment of parameters A , B and of the neural network, an essay derived from a maximum energy status is utilised. If hot water is demanded at this time, the energy required to, if a user extracts hot water, heat the cylinder water up to the maximum energy status, coincides with the amount of energy used and losses occurred.

$$E_{use} = E_{Pheating} - E_{Ploss}$$

Estimation of the total capacity of the tank (m)

[0042] After a user has consumed all the hot water in the cylinder and a minimum energy status is reached, if the content of the tank is heated until a maximum energy status is reached, given that the energy fed into the system can be measured by monitoring the consumption of electricity, the total amount of water in the cylinder can be estimated along with the energy storage capacity.

$$E(\text{Min}) + E_{Pheating} = E_{tMax}$$

$$E_{Pheating} = E_{Max} - E_{Min} = m \cdot C \cdot (T_{Max} - T_{Min})$$

where T_{Min} is the average temperature of T_{cold} during the process.

[0043] In the equation preceding the heating energy, the specific heating capacity of water (C) and the temperature increase ($T_{Max} - T_{Min}$) are known. This allows the total water mass (m) present in the tank to be deduced. This total mass (m) may also be provided by the user, since water cylinders are commonly characterised by their capacity in litres.

Estimation of energy stored in real time (E)

[0044] The energy stored in real time is calculated as the energy present at the previous point in time, by subtracting the used energy of hot water and the losses.

$$E(t) = E(t-1) - EP_{loss} + EP_{heating} - E_{use}$$

Prediction of water consumption

[0045] The water consumption and the user's behaviour models can be utilised to estimate future energy extractions through hot water consumption.

[0046] Models as simple as probabilistic prediction can be applied between extractions. Other options include ARMA or GARCH models or adaptive neural networks. Reinforcement learning models can also perform this task but, in general, prediction of water consumption is closely linked to the duration of extractions. For example, there are routines requiring consumption of hot water which can be characterised. For this reason, the duration of the extraction and the time between extractions are closely linked to each other. In this case, the prediction of both parameters together may lead to better results when predicting the user's behaviour.

[0047] The prediction of both parameters allows water heating to be optimised according to several objectives such as efficiency maximisation, cost reduction or even the stability of the electrical system, among others.

Claims

1. A system for the controlling of hot water cylinders, **characterised in that** it comprises:
 - a water cylinder controller (100) arranged on a housing with a front panel on which elements allowing the system to be controlled are arranged, wherein the front panel incorporates a mode button (1) allowing the operating mode to be changed; an operating indicator (2) showing the current operating mode and the status of the load switch; a boost button (3) enabling the reinforcing load; a reset button (4) restoring the controller; a communication indicator (5) showing connectivity status; a configuration button (6) allowing communications to be configured using the connection passwords; a light sensor (7) measuring the intensity of ambient light; a temperature sensor (8) measuring ambient temperature; a fuse for base load (9) protecting the circuit against overloads; a fuse for reinforcing load (10) protecting the reinforcing circuit against overloads; a main switch (11) insulating loads in off position and allowing the controller (100) to control loads in on position; and a communication antenna connector (12); two thermocouple cables (300), wherein the end of a first thermocouple cable (300) is arranged at the cold water inlet of the hot water cylinder and the end of the second thermocouple cable (300) is arranged at the hot water outlet (300) and wherein the free ends of both thermocouple cables (300) are routed and connected to the controller (100); and an antenna (200) coupled to the communication antenna connector (12) for the connection of the controller (100) with another server or with the cloud, where the information is processed.
2. The system for the controlling of hot water cylinders according to claim 1, **characterised in that** the mode button (1) works according to the following modalities of hot water controller: off mode, manual mode and automatic mode.
3. The system for the controlling of hot water cylinders according to claim 2, **characterised in that** the system does not heat the content of the hot water cylinder in off mode.
4. The system for the controlling of hot water cylinders according to claim 2, **characterised in that** the system heats the content of the cylinder in manual mode during the time periods selected by the user and collects data on use and temperatures, which are sent to the server or the cloud for the modelling of the user's and the hot water cylinder's behaviour.
5. The system for the controlling of hot water cylinders according to claim 2, **characterised in that**, in automatic mode, the system collects data and models the user's and the hot water cylinder's behaviour and communicates with a server or the cloud for the planning of the heating periods and optimising several target behaviours while considering the user's convenience.

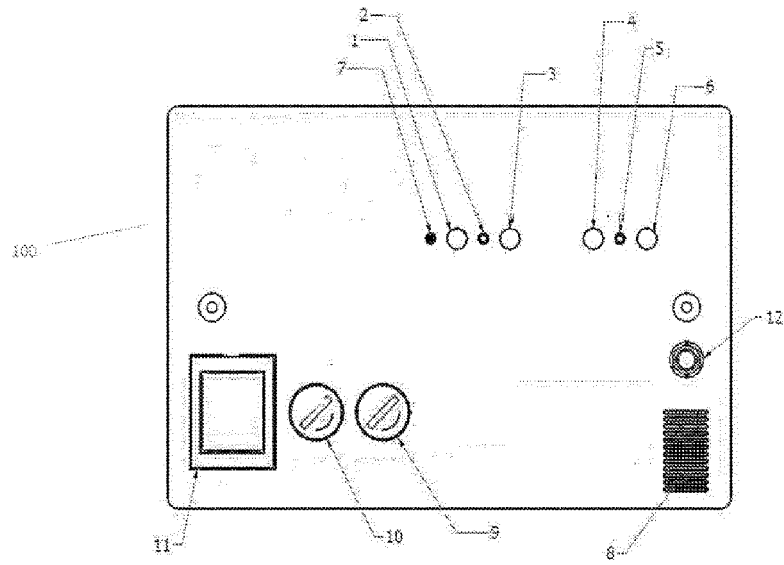


FIG 1

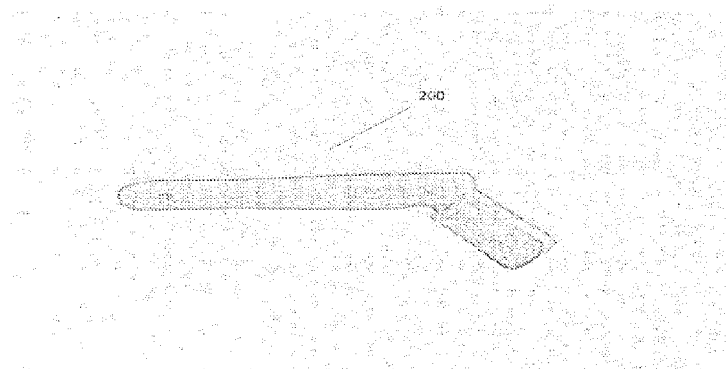


FIG 2

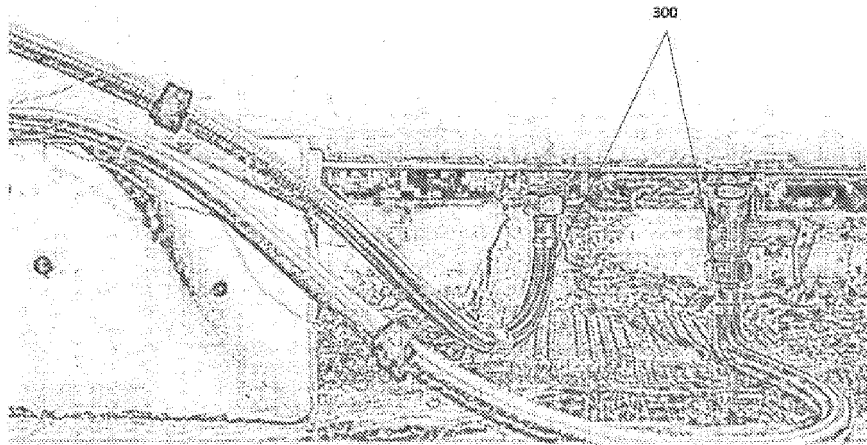


FIG 3

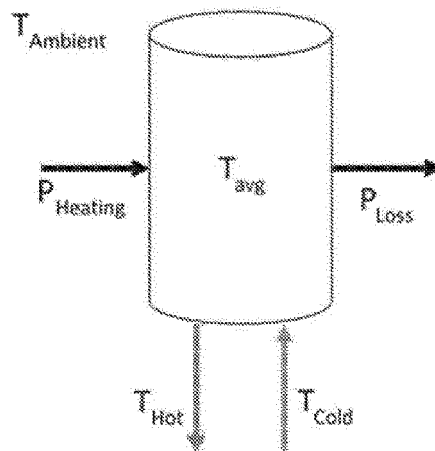


FIG 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/ES2020/070283

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

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)
G05B, F24D, F24H

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)

EPODOC, INVENES, WPI, NPL

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2019003741 A1 (VAN HOUTEN ARNOUD BRUINS JAN) 03/01/2019, abstract; paragraphs [0001, 0002, 0006-0010, 0023-0024, 0029-0032, 0037-0041, 0048-0054, 0057-0066]; figures 1, 2, 8, 9; the whole document.	1-5
X	US 2011139259 A1 (NAGATA EIKO ET AL.) 16/06/2011, abstract, paragraphs [0025, 0047, 0064, 0068, 0091-0093, 0201]; figures 1, 3, 4, 10; the whole document.	1-5
X	FR 3056706 A1 (ELECTRICITE DE FRANCE) 30/03/2018, abstract, pages 7, 10-17; figures 1-4, 6; the whole document.	1-5

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

☒ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance.	
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"P" document published prior to the international filing date but later than the priority date claimed	"&" document member of the same patent family

Date of the actual completion of the international search
01/02/2021

Date of mailing of the international search report
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Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.

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Information on patent family members

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Form PCT/ISA/210 (patent family annex) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.

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CLASSIFICATION OF SUBJECT MATTER

G05B13/02 (2006.01)
F24D19/10 (2006.01)
F24D17/00 (2006.01)
F24H9/02 (2006.01)
F24H1/50 (2006.01)

REFERENCES CITED IN THE DESCRIPTION

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