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(54) METHOD AND CONTROLLER TO OPERATE A HOT WATER STORAGE DEVICE HEATER AND HOT WATER STORAGE DEVICE

(57) Method to operate a hot water storage device (10), the hot water storage device (10) comprising a tank (11) configured to store water, a heating unit (15) positioned at a first distance from a bottom wall (12) of the tank (11), the heating unit (15) being configured to heat the water stored with-in the tank (11) such that heated water rises up within the tank (11) and is stratified above unheated water within the tank (11), at least one temperature sensor (19, 20) positioned at a distance from the bottom wall (12) of the tank (11) being greater than said first distance, a controller (21) configured to control the heating unit (15). The method comprises the following steps: Determine from a water temperature measurement signal provided by the at least one temperature sensor (19, 20) a water usage profile, said water usage profile providing for defined time intervals of a day and/or for defined days of a week a nominal temperature and a nominal volume of the heated water to be stored within the tank. Operate the heating unit (15) in such a manner that for each defined time interval of a day and/or for each defined day of a week the actual temperature and the actual volume of the heated water stored withing the tank corresponds automatically to the respective nominal value of the water usage profile

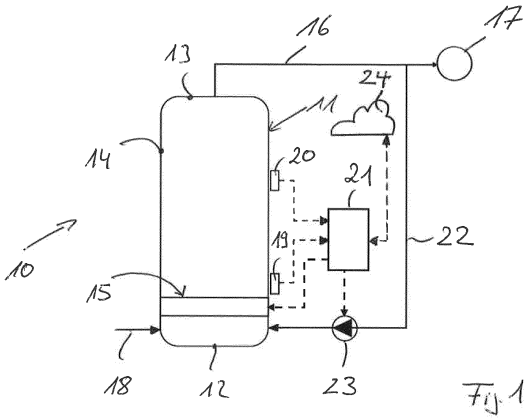

Fig 1

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Description

[0001] The present disclosure relates to a method to operate a hot water storage device. Further, the present disclosure relates to a controller to operate a hot water storage device and to a hot water storage device.

[0002] Hot water storage devices known from prior art comprise a tank configured to store water, wherein the tank has a bottom wall, a top wall and a side wall extending between the bottom wall and the top wall. Hot water storage devices known from prior art further comprise a heating unit positioned at a first distance from the bottom wall, wherein the heating unit is configured to heat the water stored within the tank, namely in such a manner that water heated by the heating unit rises up within the tank such that the heated water is stratified above unheated water within the tank. Hot water storage devices known from prior art further comprise a temperature sensor positioned at a distance from the bottom wall, the temperature sensor being configured to measure a water temperature of the heated water. Hot water storage devices known from prior art further comprise a controller being configured to control the heating unit and thereby the water temperature of the heated water stored within the tank. Heating of the water within the tank may be initiated when the temperature of the water within the tank falls under a respective threshold.

[0003] GB 2 518 365 A, US 2009 / 0 188 486 A1, US 11 060 763 B2, US 10 295 199 B2 and US 7 971 796 B2 disclose hot water storage devices.

[0004] Controllers of a hot water storage devices known form prior art keep permanently a defined water volume within the tank of the hot water storage device at a defined hot water temperature, either 24 hours per day and 7 days per week or according to a daily ON/OFF schedule of the hot water storage device when the hot water storage device is in the ON status. Keeping the defined water volume within the tank of the hot water storage device permanently at a defined hot water temperature is energy inefficient and creates carbon emissions when no actual hot water demand is present.

[0005] Against this background a novel method to operate a hot water storage device as de-fined in claim 1 and a novel controller of a hot water storage device as defined in claim 13 as well as a novel hot water storage device as defined in claim 15 are provided that allow an energy efficient operation of a hot water storage device with lower carbon emissions.

[0006] The method according to claim 1 determines from a water temperature measurement signal provided by the at least one temperature sensor a water usage profile, said water usage profile providing for defined time intervals of a day and/or for defined days of a week a nominal temperature and a nominal volume of the heated water to be stored within the tank.

[0007] The method according to claim 1 operates the heating unit in such a manner that for each defined time interval of a day and/or for each defined day of a week the actual temperature and the actual volume of the heated water stored withing the tank corresponds automatically to the respective nominal value of the water usage profile.

[0008] According to a first alternative, the at least one water temperature measurement signal provided by the at least one temperature sensor is provided to a database like a cloud-database, wherein the database determines the water usage profile providing for each respective time interval of a respective day of a week the nominal temperature and the nominal volume of the heated water to be stored within the tank, and wherein the controller operates the heating unit of basis of said water usage profile provided by the database to the controller. In the first alternative, the functionality of the method is split up between the database and the controller.

[0009] According to a second alternative, the at least one water temperature measurement signal provided by the at least one temperature sensor is provided to the controller, wherein the controller determines the water usage profile providing for each respective time interval of a respective day of a week the nominal temperature and the nominal volume of the heated water to be stored within the tank, and wherein the controller operates the heating unit of basis of said water usage profile. In the second alternative, the functionality of the method is provided by the controller only.

[0010] The controller of the hot water storage device according to claim 13 is configured to determine from a water temperature measurement signal provided by the at least one temperature sensor of the hot water storage device a water usage profile, said water usage profile providing for defined time intervals of a day and/or for defined days of a week a nominal temperature and a nominal volume of the heated water to be stored within the tank.

[0011] The controller of the hot water storage device according to claim 13 is configured to operate the heating unit of the hot water storage device in such a manner that for each defined time interval of a day and/or for each de-fined day of a week the actual temperature and the actual volume of the heated water stored withing the tank of the hot water storage device corresponds automatically to the respective nominal value of the water usage profile.

[0012] The method as well as the controller of the hot water storage device according to the present disclosure allow an energy efficient operation of a hot water storage device with lower carbon emissions. The water usage profile is determined from the water temperature measurement signal provided by the at least one temperature sensor. Said water usage profile provides for each respective time interval of a day and for each respective day of a week the nominal temperature and the nominal volume of the heated water to be stored within the tank. So, the water usage profile does not only provide a nominal value for the water temperature but also a nominal value for the volume of the heated water to be stored

within the tank.

[0013] Preferably, the water usage profile is determined from a first water temperature measurement signal provided by a first temperature sensor positioned at a second distance from the bottom wall of the tank and from a second water temperature measurement signal provided by the second temperature sensor positioned at a third distance from the bottom wall of the tank and/or from an average water temperature signal of the first water temperature measurement signal and the second water temperature measurement signal, wherein said second distance is greater than said first distance and said third distance is greater than said second distance. This allows an even more precise control of the temperature and of the volume of the heated water within the tank to provide an energy efficient operation of a hot water storage device with lower carbon emissions.

[0014] Preferably, the water usage profile is determined as a function of a change rate of the at least one water temperature measurement signal in the respective time interval of the respective day and/or as a function of a frequency and as a function of an amount of a hot water demand in the respective time interval of the respective day. This allows to determine the water usage profile in a reliable and simple manner.

[0015] Preferably, the water usage profile is determined in such a manner that for each respective time interval of each respective day of a week a nominal value pair comprising the nominal temperature and the nominal volume of the heated water to be stored within the tank is determined, namely a nominal value pair N of a set of nominal value pairs comprising at least the following nominal value pairs: pair 1: first nominal volume and first nominal temperature, pair 2: first nominal volume and second nominal temperature, pair 3: second nominal volume and first nominal temperature, pair 4: second nominal volume and second nominal temperature, wherein the second nominal volume is greater than the first nominal volume, and wherein the second nominal temperature is greater than the first nominal temperature. The set of nominal value pairs on basis of which the water usage profile for each respective time interval of each respective day of a week is determined may comprise the following additional nominal value pair: pair 5: third volume and second nominal temperature, wherein the third nominal volume is greater than the second nominal volume. The set of nominal value pairs on basis of which the water usage profile for each respective time interval of each respective day of a week is determined may comprise the following additional nominal value pair: pair 0: fourth volume and fourth nominal temperature, wherein the fourth nominal volume is smaller than the first nominal volume and the fourth nominal temperature is smaller than the first nominal temperature. Pair 0 may correspond to on OFF status or STANDBY status of the hot water storage device 10. Pairs 1 to 5 all belong to an ON status of the hot water storage device 10. With pairs 1 to 4 a respective volume of heated water is stratified above unheated water within the tank. With pair 5 the tank may become de-stratified such that the full volume of the tank is filled with heated water. This allows an simple and reliable, energy efficient operation of a hot water storage device with lower carbon emissions using a limited number of nominal value pairs defining the nominal temperature and the nominal volume of the heated water to be stored within the tank.

[0016] Preferably, for each respective time interval of each respective day a confidence factor associated with the nominal temperature and the nominal volume of the heated water to be stored within the tank is determined, wherein the confidence factor depends on the frequency and from the amount of a hot water demand in the respective time interval of the respective day. Based on the confidence factor the nominal value pair used for the operation of the hot water storage device may be changed.

[0017] Preferably, the confidence factor of a respective time interval is increased if the frequency of hot water demands and/or the amount of a hot water demand in the respective time interval is above a respective upper threshold within the respective time interval of the respective day. The confidence factor of a respective time interval is decreased if the frequency of hot water demands and/or the amount of a hot water demand in the respective time interval is below a respective lower threshold within the respective time interval of the respective day. The confidence factor of a respective time interval remains unchanged if the frequency of hot water demands and/or the amount of a hot water demand in the respective time interval is above a respective lower threshold and below the respective upper threshold. A change of the confidence factor of a respective time interval of a respective day may affect the confidence factor of time intervals adjoining the respective time interval in which the confidence factor has changed. Such a confidence factor allows an simple and reliable change of the nominal value pair used in a respective time interval to control temperature and volume of heated water stored within the tank of the hot water storage device and to provide an energy efficient operation of a hot water storage device with lower carbon emissions.

[0018] Preferably at an initial state or at an initialization state of the hot water storage device, the water usage profile of each time interval of each day is initialized with the pair N (N=2 or 3 or 4) of the nominal value pairs, preferably with pair 4. If the confidence factor of the respective time interval of the respective day is below a lower limit, then the water usage profile of the respective time is changed to pair N-1 of the nominal value pairs. If the confidence factor of the respective time interval of the respective day is above an upper limit, then the water usage profile of the respective time interval is changed to pair N+1 of the nominal value pairs. If the confidence factor of the respective time interval of the respective day is above the lower limit and below the upper limit, then the water usage profile of the respective time interval

remains at pair N of the nominal value pairs. This allows an simple and reliable change of the nominal value pair used in a respective time interval to control temperature and volume of the heated water within the tank to provide an energy efficient operation of a hot water storage device with lower carbon emissions.

[0019] Further on, a hot water storage device as defined in the claim 15 having such a controller is provided.

[0020] Preferred developments of the invention are provided by the dependent claims and the description which follows. Exemplary embodiments are explained in more detail on the basis of the drawing, in which:

Figure 1 shows a schematic block diagram of a hot water storage device having a tank, a heating unit, temperature sensors and a controller,

Figure 2 the tank of the hot water storage device in different conditions,

Figure 3 a detail of a water usage profile for time intervals of the same,

Figure 4 a time diagram to illustrate some details how the determine the water usage profile.

[0021] Figure 1 shows a hot water storage device 10. The water hot storage device 10 comprises a tank 11 configured to store water. The tank 11 of the hot water storage device 10 has a bottom wall 12, a top wall 13 and a side wall 14 extending between the bottom wall 12 and the top wall 13.

[0022] The hot water storage device 10 further comprises a heating unit 15 positioned at a first distance from the bottom wall 12 of the tank 11. The heating unit 15 is configured to heat the water stored within the tank 11 in such a manner that water heated by the heating unit 15 rises up within the tank 11 such that the heated water is stratified above unheated water within the tank 11.

[0023] Figure 1 shows a pipe 16 through which heated water can be taken out of the tank 11 in order to provide the heated water to a hot water consumer 17. The pipe 16 is connected to the top wall 13 or to the side wall 14 adjacent to the top wall 13. Figure 1 further shows a pipe 18 through which unheated water can be provided to the tank 11 in order to replace the volume of water which has been taken out of the tank 11 through the pipe 16. The pipe 18 is connected to the bottom wall 12 or to the side wall 14 adjacent to the bottom wall 12.

[0024] The hot water storage device 10 further comprises at least one temperature sensor 19, 20 positioned at a distance from the bottom wall 12, wherein the at least one temperature sensor 19, 20 is configured to measure a water temperature of the heated water stored within the tank 11.

[0025] In the preferred embodiment shown in Figure 1, the hot water storage device 10 comprises a first temperature sensor 19 positioned at a second distance from the bottom wall 12 of the tank 11, said second distance being greater that said first distance, and a second temperature sensor 20 positioned at a third distance from the bottom wall 12 of the tank 11, said third distance being greater that said second distance. Both temperature sensors 19, 20 are assigned to the side wall 14 of the tank. Both temperature sensors 19, 20 are configured to measure a water temperature of the heated water stored within the tank 11.

[0026] The hot water storage device 10 further comprises a controller 21. The controller 21 is configured to control the heating unit 15 and thereby the water temperature of the water stored within the tank 11.

[0027] The controller 21 provides a control signal to the heating unit 15 in order to control the operation of the heating unit 15 of the hot water storage device 10.

[0028] The controller 21 is configured to receive a respective water temperature measurement signal from the respective temperature sensor 19, 20.

[0029] Figure 1 further shows an optional recirculation pipe 22 extending between the pipe 16 and the tank 11. A pump 23 is assigned to the recirculation pipe 22. The pump 23 and recirculation pipe 22 may be used to recirculate the heated water taken out of the tank 11 through the tank 11. The recirculation pipe 22 is connected to the bottom wall 12 or to the side wall 14 adjacent to the bottom wall 12. With the pump 23 the water within the tank 11 may be de-stratified.

[0030] Controllers of a hot water storage device known form prior art keep permanently a defined water volume within the tank of the hot water storage device at a defined hot water temperature, either 24 hours per day and 7 days per week or according to a daily ON/OFF schedule of the hot water storage device when the same is in the ON status. Keeping the defined water volume within the tank of the hot water storage device permanently at a defined hot water temperature is energy inefficient and creates carbon emissions when no actual hot water demand is present.

[0031] According to the present disclosure, the controller 21 of the hot water storage device 10 is configured to determine from a water temperature measurement signal provided by at least one temperature sensor 19, 22 a water usage profile, said water usage profile providing for defined time intervals of a day and/or for defined days of a week a nominal temperature and a nominal volume of the heated water to be stored within the tank 11 of the hot water storage device 10.

[0032] Preferably, the controller 21 is configured to determine from a first water temperature measurement signal provided by the first temperature sensor 19 and from a second water temperature measurement signal provided by the second temperature sensor 20 and/or from an average water temperature signal of the first water temperature measurement signal and the second water temperature measurement signal the water usage profile providing for defined time intervals of a day and/or for defined days of a week the nominal temperature and the nominal volume of the heated water to be stored within the tank 11 of the hot water storage device 10.

[0033] The controller 21 according to the present dis-

closure is configured to operate the heating unit 15 of the hot water storage device 10 in such a manner that for each defined time interval of a day and/or for each defined day of a week the actual temperature and the actual volume of the heated water stored withing the tank 11 of the hot water storage device 10 corresponds automatically to the respective nominal value of the water usage profile.

[0034] The controller 21 of the hot water storage device 10 according to the present disclosure allows an energy efficient operation of a water storage device with lower carbon emissions.

[0035] If the controller 21 is configured to determine the water usage profile, the functionality of the present disclosure is provided by the controller 21 only. In this case the at least one water temperature measurement signal provided by the at least one temperature sensor 19, 20 is provided to the controller 21, wherein the controller 21 determines the water usage profile providing for each respective defined time interval of a respective day of a week the nominal temperature and the nominal volume of the heated water to be stored within the tank, and wherein the controller 21 operates the heating unit 15 of basis of said water usage profile.

[0036] Alternatively, the functionality of the present disclosure may be split up between the controller 21 and a database 24 like a cloud database. In this alternative, the at least one water temperature measurement signal provided by the at least one temperature sensor 19, 20 is provided to the database 24 preferably through the controller 21, wherein the database 24 determines the water usage profile providing for each respective defined time interval of a respective day of a week the nominal temperature and the nominal volume of the heated water to be stored within the tank, and wherein the controller 21 operates the heating unit 15 of basis of said water usage profile provided by the database 24 to the controller 21.

[0037] Figure 2 shows the tank 11 in different conditions, The conditions can be provided with the method and controller 21 of the present disclosure.

[0038] In condition I of Figure 2, the tank 11 stores a first volume V1 of heated water being stratified above unheated water within the tank 11. In condition I of Figure 2, the volume V1 has a size that the first, lower temperature sensor 19 measures the temperature of the unheated water and the second, upper temperature sensor 20 measures the temperature of the heated water. The second, upper temperature sensor 20 measures the temperature of the heated water of volume V1 in a lower section of volume V1, preferably adjacent to or abutting a lower boundary surface of volume V1. In condition I of Figure 2, the heated water being present at the first volume V1 may have a first, relative low temperature T1 of example given 45°C or a second, relative high temperature T2 of example given 60°C.

[0039] In condition II of Figure 2, the tank 11 stores a second volume V2 of heated water being stratified above unheated water within the tank 11. The second volume is greater than the first volume. In condition II of Figure 2, the volume V2 has a size that the first, lower temperature sensor 19 and the second, upper temperature sensor 20 both measure the temperature of the heated water. The first, lower temperature sensor 19 measures the temperature of the heated water of volume V2 in a lower section of volume V2, preferably adjacent to or abutting a lower boundary surface of volume V2. In condition II of Figure 2, the heated water being present at the first volume V2 may have the first, relative low temperature T1 of example given 45°C or the second, relative high temperature T2 of example given 60°C.

[0040] In both conditions I and II of Figure 2, the heated water of the respective volume V1, V2 is stratified above unheated water within the tank 11.

[0041] In condition III of Figure 2, the tank 11 stores a third volume V3 of heated water occupying the entire volume of the tank 11. In condition III of Figure 2, no unheated water is present within the tank 11 and the tank 11 is de-stratified. In condition III of Figure 2, the first, lower temperature sensor 19 and the second, upper temperature sensor 20 both measure the temperature of the heated water. In condition III of Figure 2, the heated water being present at the first volume V3 has the second, relative high temperature T2 of example given 60°C.

[0042] Depending on the above combination of the volumes V1, V2, V3 of the heated water within the tank 11 and the temperatures T1, T2 the tank 11 may have different conditions in case the hot water storage device 10 is in an ON status. A sixth condition may be the OFF status of hot water storage device10.

[0043] The controller 21 of the hot water storage device10 may be configured to determine the water usage profile as a function of the change rate of the at least one water temperature measurement signal in the respective time interval of the respective day. The controller 21 may further be configured to determine the water usage profile as a function of a frequency and as a function of an amount of a hot water demand in the respective time intervals of the respective day.

[0044] The controller 21 of the hot water storage device 10 may be configured to determine the water usage profile in such a manner that for each respective time interval of each respective day of a week a nominal value pair comprising the nominal temperature and the nominal volume of the heated water to be stored within the tank 11 is determined, namely a nominal value pair of a set of nominal value pairs comprising at least:

Pair 1: first nominal volume and first nominal temperature.
Pair 2: first nominal volume and second nominal temperature.
Pair 3: second nominal volume and first nominal temperature.
Pair 4: second nominal volume and second nominal temperature.

[0045] The second nominal volume of the heated water

to be stored in the tank 11 is greater than the first nominal volume of the heated water to be stored in the tank 11. The second nominal temperature of the heated water to be stored in the tank 11 is greater than the first nominal temperature of the heated water to be stored in the tank 11.

[0046] Pairs 1 and 2 may be used to provide condition I of Figure 2, namely pair 1 a first volume V1 of heated water having the first temperature T1 and pair 2 a first volume V1 of heated water having the second temperature T2.

[0047] Pairs 3 and 4 may be used to provide condition II of Figure 2, namely pair 3 a second volume V2 of heated water having the first temperature T1 and pair 4 a second volume V2 of heated water having the second temperature T2.

[0048] The nominal value pairs on basis of which the water usage profile for each respective time interval of each respective day of a week is determined may comprise the following additional nominal value pair:
Pair 5: third nominal volume and second nominal temperature.

[0049] The third nominal volume is greater than the second nominal volume.

[0050] Pair 5 may be used to provide condition III of Figure 2, namely a third volume V3 of heated water having the second temperature T2.

[0051] The second nominal volume and thereby the second volume V2 is greater than the first nominal volume and thereby the first volume V1. A ratio R2/1 between the second nominal volume and thereby the second volume V2 and the first nominal volume and thereby the first volume V1 may be from 2:1 to 4:1, preferably from 2.5:1 to 3.5:1. The third nominal volume and thereby the third volume V3 is greater than the first and second nominal volume and thereby the first volume V1 and second volume V2. A ratio R3/1 between the third nominal volume and thereby the third volume V3 and the first nominal volume and thereby the first volume V1 may be from 3:1 to 5:1, preferably from 3.5:1 to 4.5:1. In any case the ratio R3/1 is greater than the ratio R2/1. In an embodiment the ratio R2/1 may be 3:1 and the ratio R3/1 may be 4:1. These ratios are of exemplary nature.

[0052] The nominal value pairs on basis of which the water usage profile for each respective time interval of each respective day of a week is determined may comprise the following additional nominal value pair:
Pair 0: fourth nominal volume and fourth nominal temperature.

[0053] The fourth nominal volume is smaller than the first nominal volume and fourth nominal temperature is smaller than the first nominal temperature.

[0054] Pair 0 may be used to provide as sixth condition of the hot water storage device10 corresponding preferably to the OFF status or STANDBY status of hot water storage device 10 in which no heated water in stored with the tank 11 of the hot water storage device 10.

[0055] The water usage profile based on nominal value pairs may also be determined by the database 24.

[0056] The controller 21 of the hot water storage device 10 may be configured to determine for each respective time interval of each respective day a confidence factor associated with the nominal temperature and the nominal volume of the heated water to be stored within the tank 11.

[0057] The confidence factor depends on the frequency and from the amount of a hot water demand in the respective time interval of the respective day. The amount of a hot water demand corresponds to the duration of the same or to the volume of heated water taken out of the tank 11 in connection with the respective hot water demand. The amount of the hot water demand may be determined on basis of the time needed to replace the heated water taken out of the tank, namely to recover the hot volume and temperature of the water within the tank according to the nominal volume and nominal temperature.

[0058] The controller 21 of the hot water storage device 10 is configured to increase the confidence factor of a respective time interval if the frequency of hot water demands and/or the amount of a hot water demand in the respective time interval is above a respective upper threshold.

[0059] The controller 21 of the hot water storage device 10 is configured to decrease the confidence factor of a respective time interval if the frequency of hot water demands and/or the amount of a hot water demand in the respective time interval is below a respective lower threshold.

[0060] The controller 21 of the hot water storage device 10 is configured to remain the confidence factor of a respective time interval unchanged if the frequency of hot water demands and/or the amount of a hot water demand in the respective time interval is above a respective lower threshold and below the respective upper threshold.

[0061] The confidence factor of the respective time intervals may also be determined by the database 24.

[0062] A change of the confidence factor of a respective time interval of a respective day may affect the confidence factor of time intervals adjoining the respective time interval in which the confidence factor has changed on basis of a weight factor. Example give, if the confidence factor of a time interval may change by 10%, the confidence factor of time intervals adjoining said respective time interval may change by 5% if a weight factor of 50% is used or by 2.5% if a weight factor of 25% is used.

[0063] At an initial state or at an initialization state of the hot water storage device 10, the water usage profile of each time interval of each day is initialized with the pair N (N=2 or 3 or 4) of the nominal value pairs. Preferably, the water usage profile of each time interval of each day is initialized with the pair 4, meaning that for each time interval of each day the controller 21 would use the second nominal volume and the second nominal temperature to control the volume and temperature of the heated water within the tank 11.

[0064] During operation of the hot water storage device

10 the confidence factor is determined as described above as a function of the frequency and as a function of the amount of a hot water demand in the respective time intervals of the respective day. The amount depends on the change rate of the respective water temperature measurement signal and preferably the time to recover the heated water within the tank 11 according to the nominal volume and nominal temperature.

[0065] If the confidence factor of the respective time interval of the respective day is below a lower limit, the water usage profile of said time interval is changed from pair N to pair N-1. In other words, if the initialized nominal value pair or actual nominal value pair of a respective time internal is pair 3 but the confidence factor of said respective time interval is below the lower limit, pair 2 is used as new nominal value pair for said respective time internal. If there is no pair N-1 available, the actual pair is preferably remained unchanged. There may be a factor in the above learning algorithm that provides a time-based decay or forgetfulness. This would allow the confidence factor to reduce over time if there is no water usage over a certain time frame. A rate of memory loss produced by this decay or forgetfulness may depend on the implementation of the hot water storage device 10 in the field.

[0066] If the confidence factor of the respective time interval of the respective day is above an upper limit, the water usage profile of said time interval is changed from pair N to pair N+1. In other words, if the initialized nominal value pair or actual nominal value pair of a respective time internal is pair 4 but the confidence factor of said respective time interval is above the upper limit, pair 5 is used as new nominal value pair for said respective time internal. If there is no pair N+1 available, the actual pair is remained unchanged.

[0067] If the confidence factor of the respective time interval of the respective day is above the lower limit and below the upper limit, the water usage profile of said time interval is remained at pair N. In other words, if the initialized nominal value pair or actual nominal value pair of a respective time internal is pair 5 and the confidence factor of the respective time interval of the respective day is above the lower limit and below the upper limit, pair 5 is kept unchanged as nominal value pair for said respective time internal.

[0068] Figure 3 shows a detail of a water usage profile 30 for six individual time intervals 31 of the water usage profile 30. In Figure 3, each time interval has a duration of 15 minutes. The time intervals 31 may have a longer or shorter duration than 15 minutes. Figure 3 further shows actual nominal value pairs 32 for each of the time intervals 31 defining the nominal temperature and the nominal volume of the heated water to be stored within the tank 11. Pair 3 is valid for time intervals 31a, 31b. Pair 5 is valid for time intervals 31c, 31d, 31e. Pair 4 is valid for time intervals 31c. Figure 3 further shows actual confidence factors 33 determined for each time intervals 31. For time interval 31a the confidence factor of 30% as been determined which may cause a subsequent change to pair 2 for time interval 31a. For time interval 31f the confidence factor of 90% as been determined which may cause a subsequent change to pair 5 for time interval 31f.

[0069] Figure 4 shows an average water temperature signal 40 determined from said first and second water temperature measurement signals provided by said first and second temperature sensors 19, 20. At times t1, t2 the respective change rate of the average water temperature signal 40 is relatively small but higher that a change rate caused by thermal losses of the tank 11. This is determined as a relatively small amount of a hot water demand in the respective time interval of the respective day. At time t3 the respective change rate of the average water temperature signal 40 is relatively high. This is determined as a relatively large amount of a hot water demand in the respective time interval of the respective day. Depending on the amount and frequency of such water demands the confidence factor 33 is determined for each time interval 31. The amount of a water demand may be determined on basis of the time needed to recover the water within the tank according to the nominal volume and nominal temperature.

[0070] The controller 21 defines both the temperature and volume of the heated water within the tank 11 of the water storage device on basis of the determined water usage profile. At a peak demand (corresponding to nominal value pair 5) the water of the whole volume V3 of the tank 11 is heated up to temperature T2 using the pump 23. This state elevates the thermal energy stored within the tank 11 above the normal maximum capacity of the tank 11. This state may be initiated by external factors like communicated energy tariffs from the cloud.

[0071] At time intervals with a small hot water demand a smaller volume V1 at the first temperature T1 is sufficient (corresponding to nominal value pair 1). The hot water storage device 10 minimizes the energy required to heat the water and minimizes heat loss over time as well as an energy inefficient operation of the hot water storage device 10. The hot water storage device 10 can be operated very energy efficiently with lower carbon emissions. Based on the detected water usage (see Figure 4) which influences the confidence factor 33 a learned pattern of nominal value pairs 32 is built up which is used to operate the hot water storage device 10 over time.

[0072] At an initial state or at an initialization state of the controller 21, the nominal value pair 32 of each time interval is preferably chosen so that the hot water storage device 10 is operated by the controller 21 at full capacity. The controller 21 may adapt on basis of the confidence factors the nominal value pair 32 of each time interval 31 individually.

List of reference signs

[0073]

10 hot water storage device

11 tank
12 bottom wall
13 top wall
14 side wall
15 heating unit
16 pipe
17 hot water consumer
18 pipe
19 temperature sensor
20 temperature sensor
21 controller
22 recirculation pipe
23 pump
24 database

30 water usage profile
31 time interval
32 nominal value pair
33 confidence factors

40 average water temperature signal

Claims

1. Method to operate a hot water storage device (10), the hot water storage device (10) comprising

a tank (11) configured to store water,
a heating unit (15) positioned at a first distance from a bottom wall (12) of the tank (11), the heating unit (15) being configured to heat the water stored within the tank (11) such that heated water rises up within the tank (11) and is stratified above unheated water within the tank (11),
at least one temperature sensor (19, 20) positioned at a distance from the bottom wall (12) of the tank (11) being greater than said first distance,
a controller (21) configured to control the heating unit (15), **characterized by** the following steps:

determine from a water temperature measurement signal provided by the at least one temperature sensor (19, 20) a water usage profile, said water usage profile providing for defined time intervals of a day and/or for defined days of a week a nominal temperature and a nominal volume of the heated water to be stored within the tank,
operate the heating unit (15) in such a manner that for each defined time interval of a day and/or for each defined day of a week the actual temperature and the actual volume of the heated water stored withing the tank corresponds automatically to the respective nominal value of the water usage profile.

2. Method of claim 1, wherein

the hot water storage device (10) has a first temperature sensor (19) positioned at a second distance from the bottom wall (12) of the tank (11) and a second temperature sensor (20) positioned at a third distance from the bottom wall (12) of the tank (11), said second distance being greater than said first distance and said third distance being greater than said second distance, said water usage profile is determined from a first water temperature measurement signal provided by the first temperature sensor (19) and from a second water temperature measurement signal provided by the second temperature sensor (20) and/or from an average water temperature signal of said first and second water temperature measurement signals.

3. Method of claim 1 or 2, wherein the water usage profile is determined on basis the change rate of the respective water temperature measurement signal in the respective time interval of the respective day.

4. Method of one of claims 1 to 3, wherein the water usage profile is determined on basis of a frequency and of an amount of a hot water demand in the respective time intervals of the respective day.

5. Method of one of claims 1 to 4, wherein the water usage profile is determined in such a manner that for each respective time interval of each respective day of a week a nominal value pair comprising the nominal temperature and the nominal volume of the heated water to be stored within the tank is determined, namely a nominal value pair of a set of nominal value pairs comprising at least:

pair 1: first nominal volume and first nominal temperature,
pair 2: first nominal volume and second nominal temperature,
pair 3: second nominal volume and first nominal temperature,
pair 4: second nominal volume and second nominal temperature,
wherein the second nominal volume is greater than the first nominal volume,
wherein the second nominal temperature is greater than the first nominal temperature.

6. Method of claim 5, wherein the set of nominal value pairs on basis of which the water usage profile for each respective time interval of each respective day of a week is determined comprises the following additional nominal value pair:

pair 5: third nominal volume and second nominal

temperature, and/or
pair 0: fourth nominal volume and fourth nominal temperature,
wherein the third nominal volume is greater than the second nominal volume
wherein the fourth nominal volume is smaller than the first nominal volume and the fourth nominal temperature is smaller than the first nominal temperature.

7. Method of one of claims 4 to 7, having the following step: determine for each respective time interval of each respective day a confidence factor associated with the nominal temperature and the nominal volume of the heated water to be stored within the tank, wherein the confidence factor depends on the frequency and the amount of a hot water demand in the respective time intervals of the respective day.

8. Method of claim 8, wherein

the confidence factor is increased if the frequency of hot water demands and/or the amount of a hot water demand is above a respective upper threshold within the respective time interval of the respective day,
the confidence factor is decreased if the frequency of hot water demands and/or the amount of a hot water demand is below a respective lower threshold within the respective time interval of the respective day,
the confidence factor remains unchanged if the frequency of hot water demands and/or the amount of a hot water demand is above a respective lower threshold and below the respective upper threshold.

9. Method of one of claims 7 to 8, wherein

at an initial state or at an initialization state of the hot water storage device (10) the water usage profile of each time interval of each day of a week is initialized with the pair N (N=2 or 3 or 4) of the nominal value pairs,
if the confidence factor of the respective time interval of the respective day is below a lower limit, the water usage profile is changed to pair N-1 of the nominal value pairs,
if the confidence factor of the respective time interval of the respective day is above an upper limit, the water usage profile is changed to pair N+1 of the nominal value pairs,
if the confidence factor of the respective time interval of the respective day is above the lower limit and below the upper limit, the water usage profile remains at pair N of the nominal value pairs.

10. Method of one of claims 8 to 9, wherein a change of the confidence factor of a respective time interval of a respective day affects the confidence factor of time intervals adjoining the respective time interval in which the confidence factor has changed.

11. Method of one of claims 1 to 10, wherein the at least one water temperature measurement signal provided by the at least one temperature sensor (19, 20) is provided to a database (24) like a cloud-database, wherein the database (24) determines the water usage profile providing for each respective defined time interval of a respective day of a week the nominal temperature and the nominal volume of the heated water to be stored within the tank, and wherein the controller (21) operates the heating unit (15) of basis of said water usage profile provided by the database (24) to the controller (21).

12. Method of one of claims 1 to 10, wherein the at least one water temperature measurement signal provided by the at least one temperature sensor (19, 20) is provided to the controller (21), wherein the controller (21) determines the water usage profile providing for each respective defined time interval of a respective day of a week the nominal temperature and the nominal volume of the heated water to be stored within the tank, and wherein the controller (21) operates the heating unit (15) of basis of said water usage profile.

13. Controller (21) of a hot water storage device (10),

the hot water storage device (10) comprising

a tank (11) configured to store water,
a heating unit (15) positioned at a first distance from a bottom

wall (12) of the tank (11),
at least one temperature sensor (19, 20) positioned at a distance from the bottom wall (12) of the tank (11), said distance being greater than said first distance,
wherein the controller (21) is configured to control the heating unit (15) and thereby the water temperature of the water stored within the tank (11),
wherein the controller (21) is configured to determine from a water temperature measurement signal provided by the at least one temperature sensor (19, 20) a water usage profile, said water usage profile providing for defined time intervals of a day and/or for defined days of a week a nominal temperature and a nominal volume of the heated water to be stored within the tank,
wherein the controller (21) is configured to operate the heating unit (15) in such a manner that

for each defined time interval of a day and/or for each de-fined day of a week the actual temperature and the actual volume of the heated water stored withing the tank corresponds automatically to the respective nominal value of the water usage profile.

14. Controller (21) of claim 13, wherein the controller is configured to automatically carry out the method of one of claims 1-12.

15. Hot water storage device (10), comprising

a tank (11) configured to store water, the tank (11) having a bottom wall (12), a top wall (13) and a side wall (14) extending between the bottom wall (12) and the top wall (13),
a heating unit (15) positioned at a first distance from the bottom wall (12), the heating unit (15) being configured to heat the water stored within the tank (11) in such a manner that water heated by the heating unit (15) rises up within the tank (11) such that the heated water is stratified above unheated water within the tank (11),
at least one temperature sensor (19, 20) positioned at a distance from the bottom wall (12), the at least one temperature sensor (19, 20) being configured to measure a water temperature of the heated water,
a controller (21) according to one of claims 13 to 14.

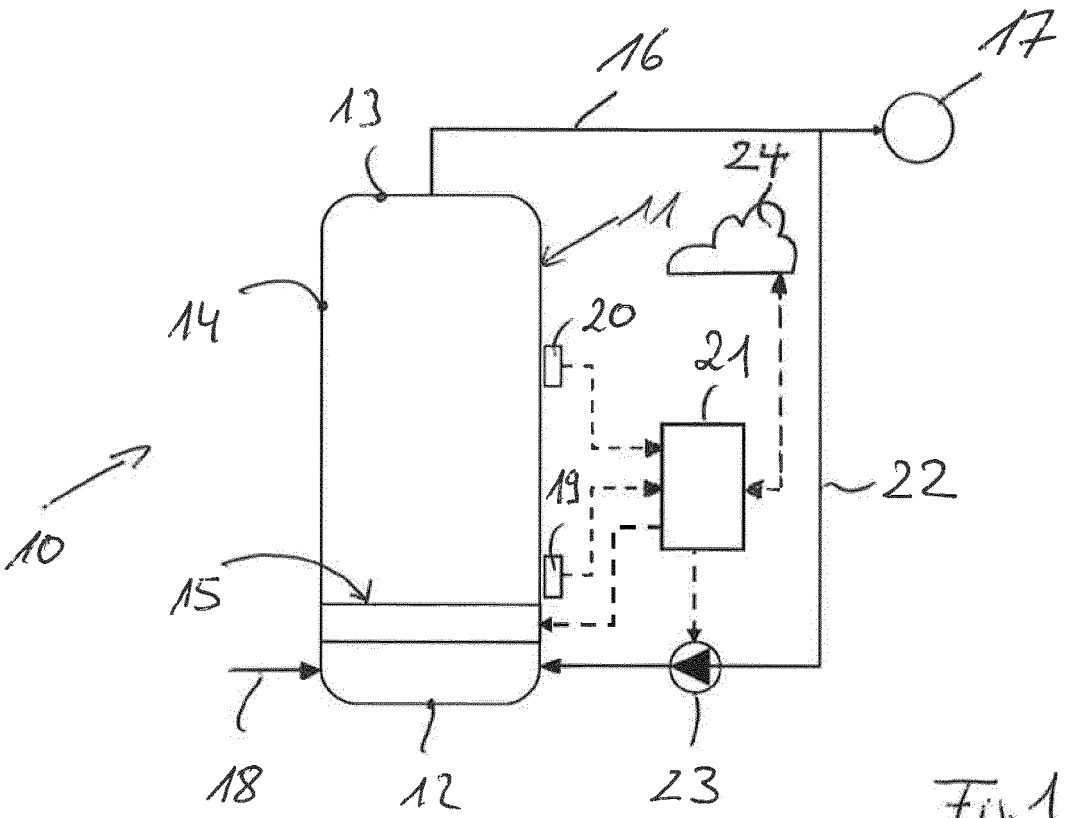
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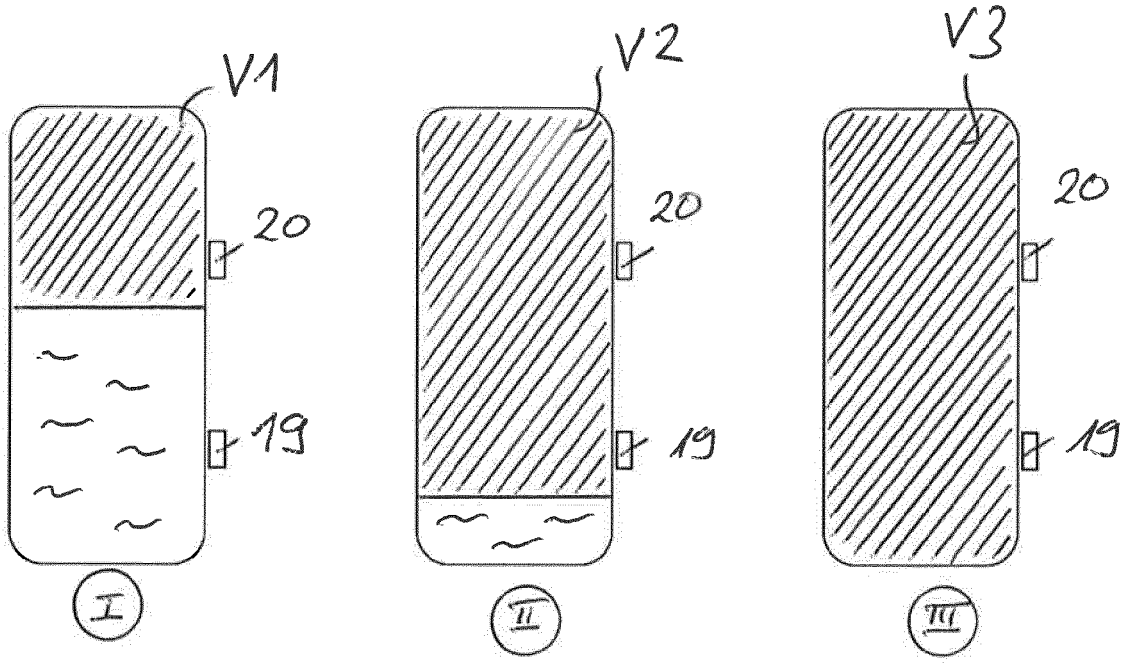
Fig. 1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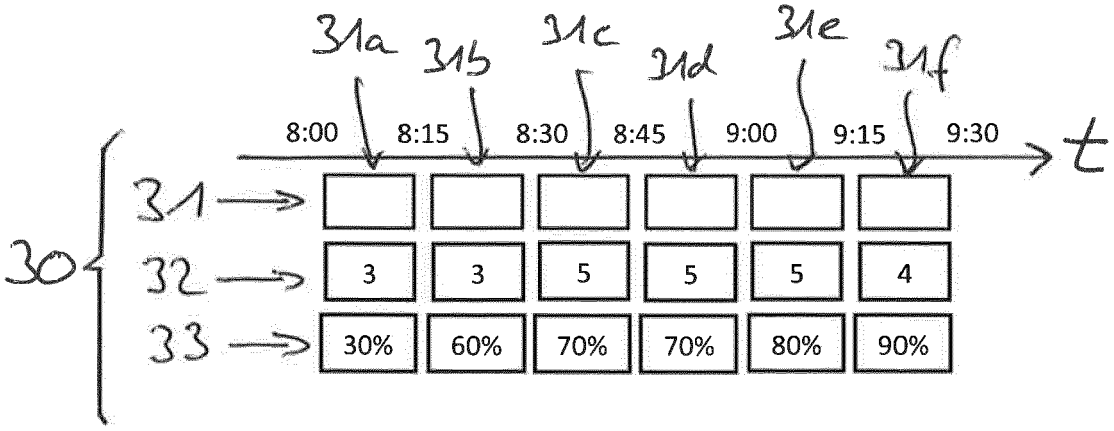
V2
V3
20
20
20
19
19
19
I
II
III

Fig. 2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80%
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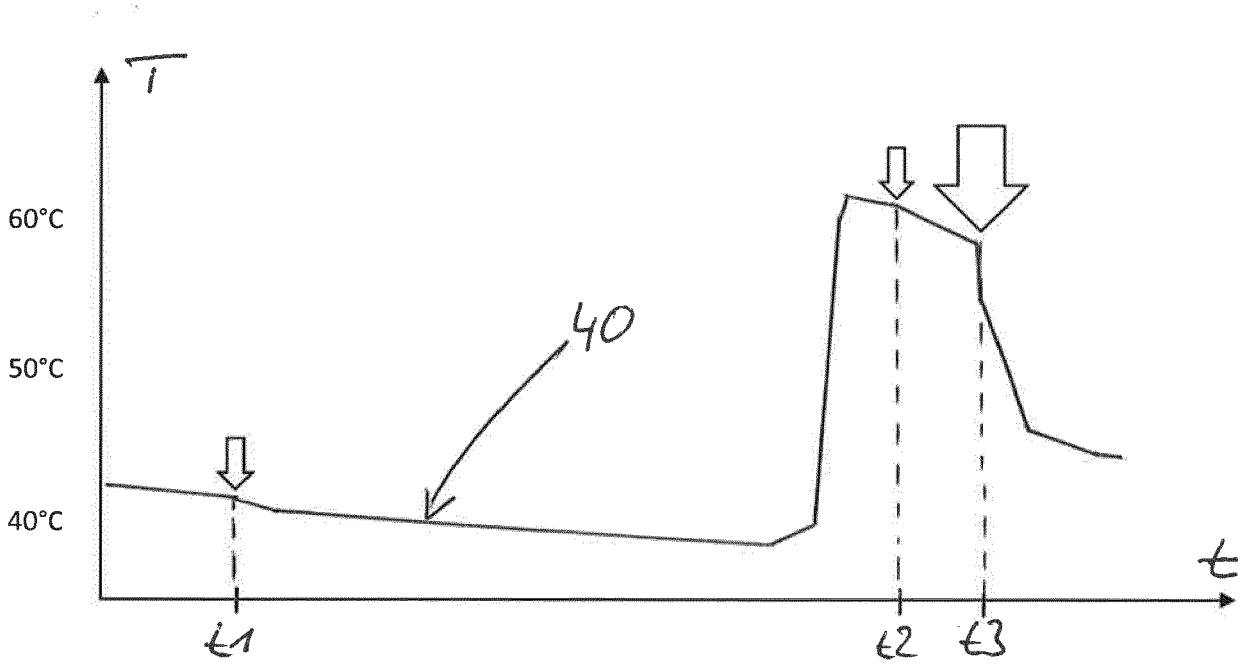
Fig. 3


T
60°C
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40°C
40
t
t1
t2
t3

Fig. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 22 17 7831

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	DE 10 2021 124584 A1 (MISHCO GMBH [DE]) 24 March 2022 (2022-03-24)	1-6, 11-15	INV. F24D19/10
A	* paragraphs [0018] - [0041]; figures 1, 3, 4a, 4b *	7-10	F24D17/00 F24H1/20 F24H15/148 F24H15/152 F24H15/172 F24H15/223 F24H15/225 F24H15/269 F24H15/355 F24H15/421 F24H15/457 G05B17/00
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A	* pages 9-14; claims 26-28,31-35; figures 1-5 *	7-10	
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F24D
F24H
G05B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	22 November 2022	Schwaiger, Bernd

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22-11-2022

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