US 20210278093A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2021/0278093 A1**

GREEN (43) **Pub. Date: Sep. 9, 2021**

(54) **CONTROL SYSTEMS AND METHODS FOR MANAGING RATE OF HEAT DELIVERY IN HYDRONIC SYSTEMS**

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(21) Appl. No.: **17/191,645**

(22) Filed: **Mar. 3, 2021**

Related U.S. Application Data

(60) Provisional application No. 62/985,023, filed on Mar. 4, 2020.

Publication Classification

(51) **Int. Cl.**

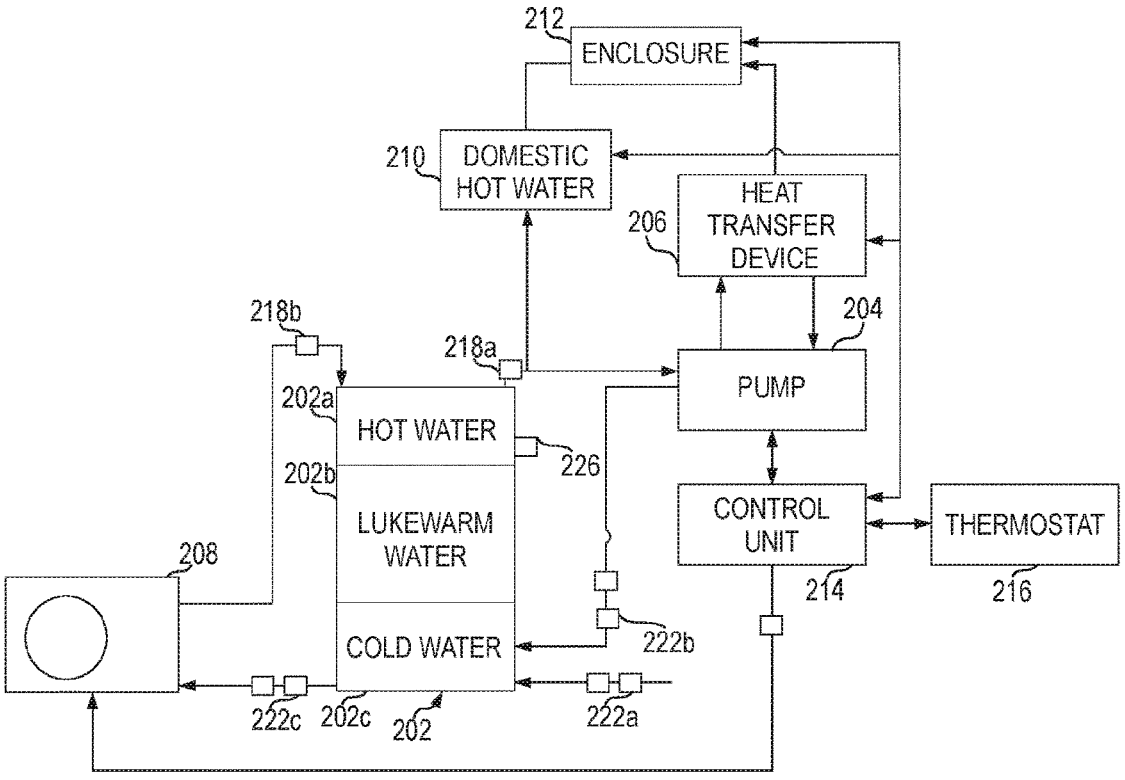
F24D 19/10	(2006.01)
F24H 1/14	(2006.01)
F24H 1/40	(2006.01)
F24H 9/00	(2006.01)
F24D 3/02	(2006.01)
F24D 3/08	(2006.01)
G05B 15/02	(2006.01)

(52) **U.S. Cl.**

CPC ***F24D 19/1066*** (2013.01); ***F24H 1/14*** (2013.01); ***F24H 1/40*** (2013.01); ***F24H 9/0015*** (2013.01); ***F24D 3/02*** (2013.01); *F24D 2240/00* (2013.01); ***G05B 15/02*** (2013.01); *F24D 2220/0207* (2013.01); *F24D 2220/042* (2013.01); *F24D 2220/044* (2013.01); ***F24D 3/08*** (2013.01)

(57) **ABSTRACT**

The present disclosure provides a method for controlling rate of heat delivery in a hydronic system, which includes receiving, by a control unit, at least a first temperature, a second temperature from two spatially separated points in the hydronic system and a flow rate. The two spatially separated points correspond to inlet of heat transfer device and outlet of heat transfer device. The method also includes calculating at predefined interval, by the control unit, an actual rate of heat delivery to the heat transfer device based on flow rate and temperature difference between the two spatially separated points. The control unit determines heat delivery rate difference between actual rate of heat delivery and target rate of heat delivery. The control unit adapts flow rate of fluid into inlet of heat transfer device based on heat delivery rate difference to maintain target rate of heat delivery in heat transfer device.



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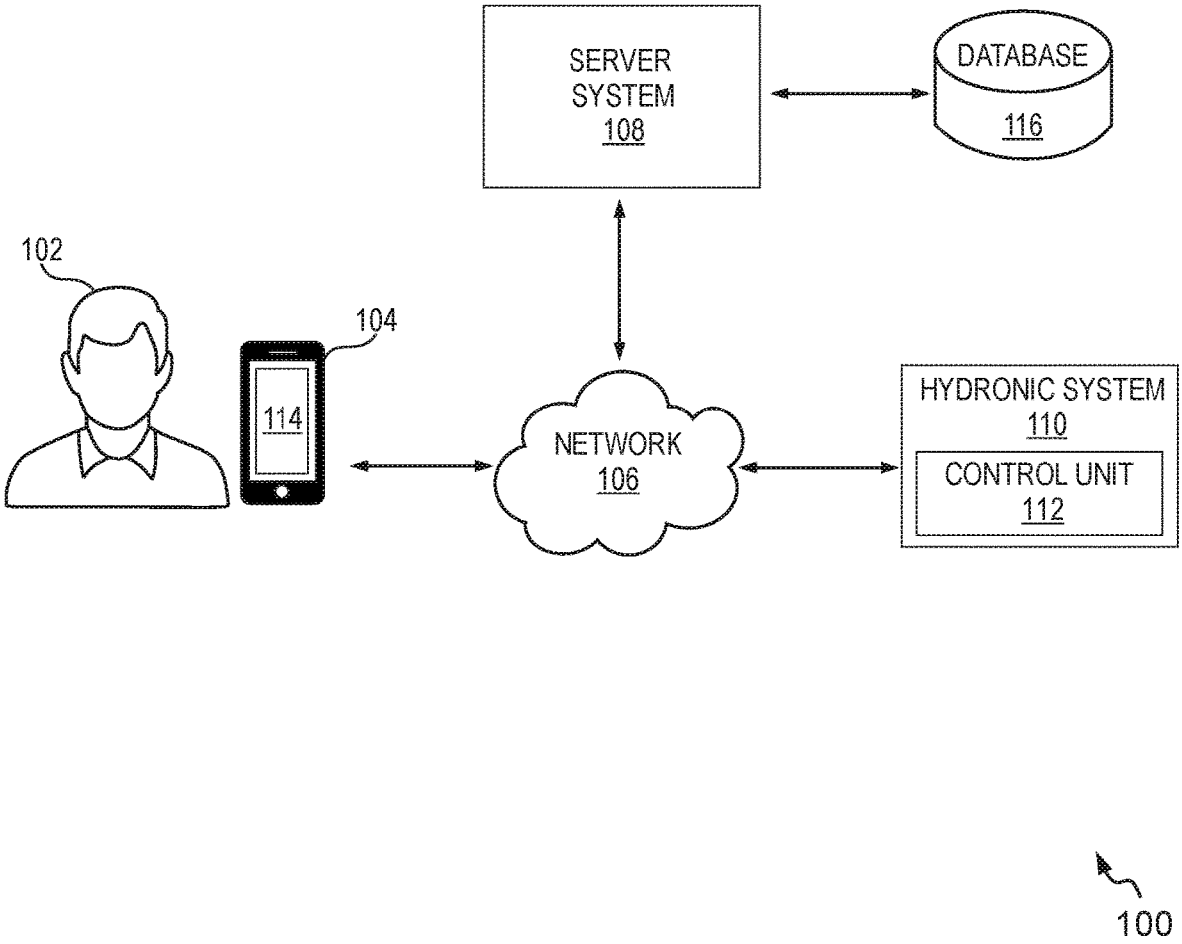
SERVER SYSTEM 108
DATABASE 116
102
104
114
NETWORK 106
HYDRONIC SYSTEM 110
CONTROL UNIT 112
100

FIG. 1

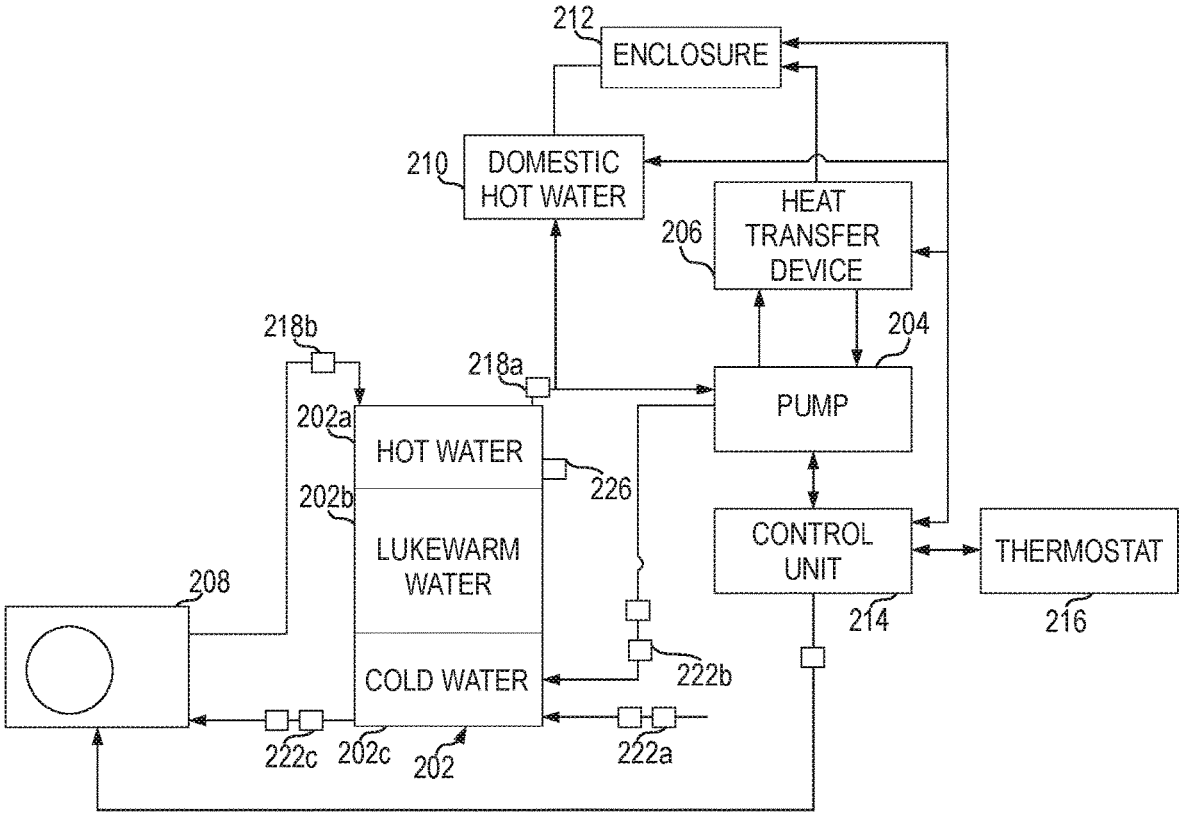
212
ENCLOSURE
210
DOMESTIC HOT WATER
206
HEAT TRANSFER DEVICE
218b
218a
204
PUMP
202a
HOT WATER
226
202b
LUKEWARM WATER
CONTROL UNIT
THERMOSTAT
208
214
216
COLD WATER
222b
222c
202c
202
222a
200

FIG. 2A

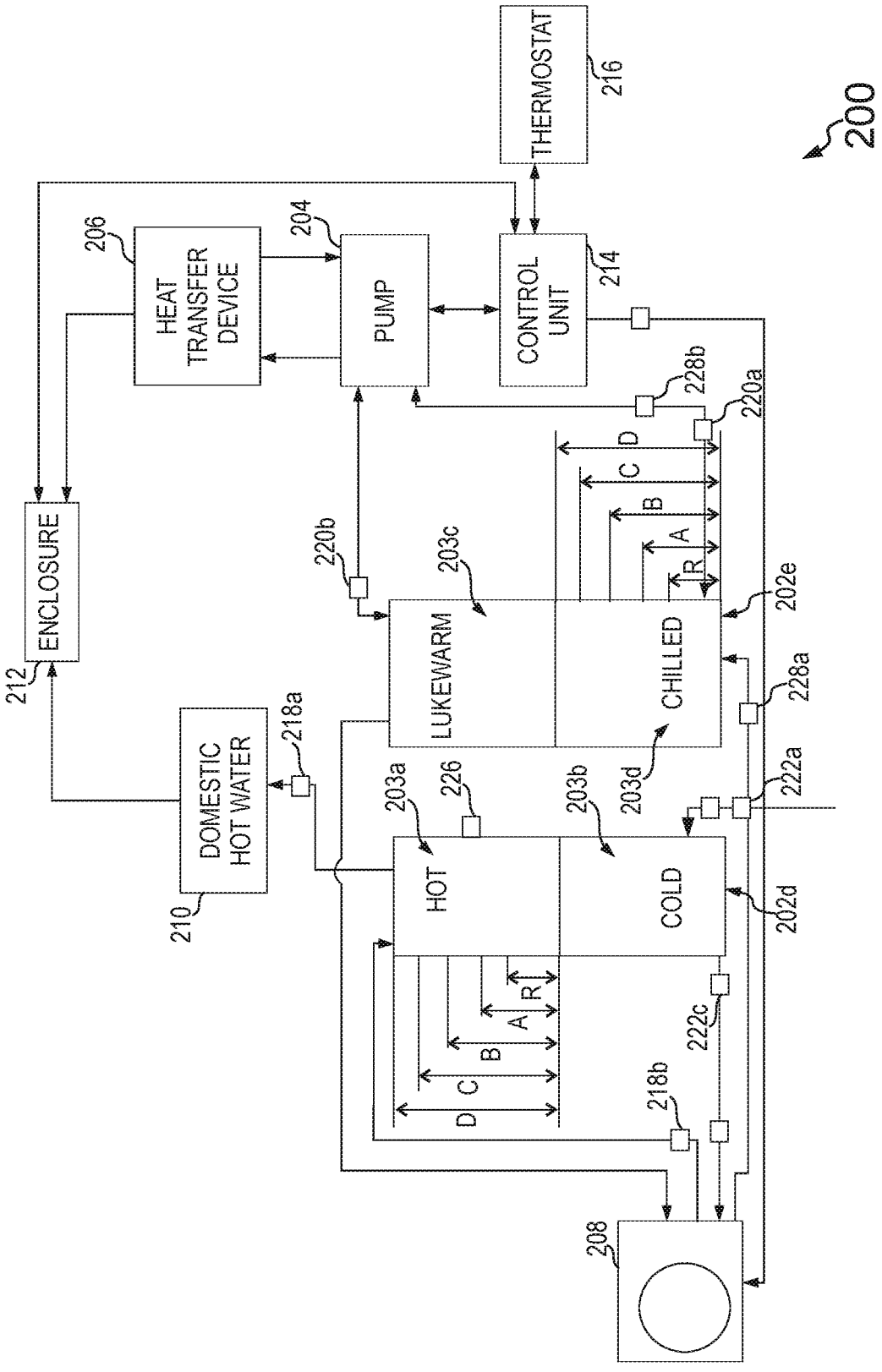
200
THERMOSTAT
216
HEAT TRANSFER DEVICE
206
PUMP
204
CONTROL UNIT
214
ENCLOSURE
212
DOMESTIC HOT WATER
210
LUKEWARM
CHILLED
HOT
COLD
203a
203b
203c
203d
202d
202e
208
218a
218b
220a
220b
222a
222c
226
228a
228b
A
B
C
D
R

FIG. 2B

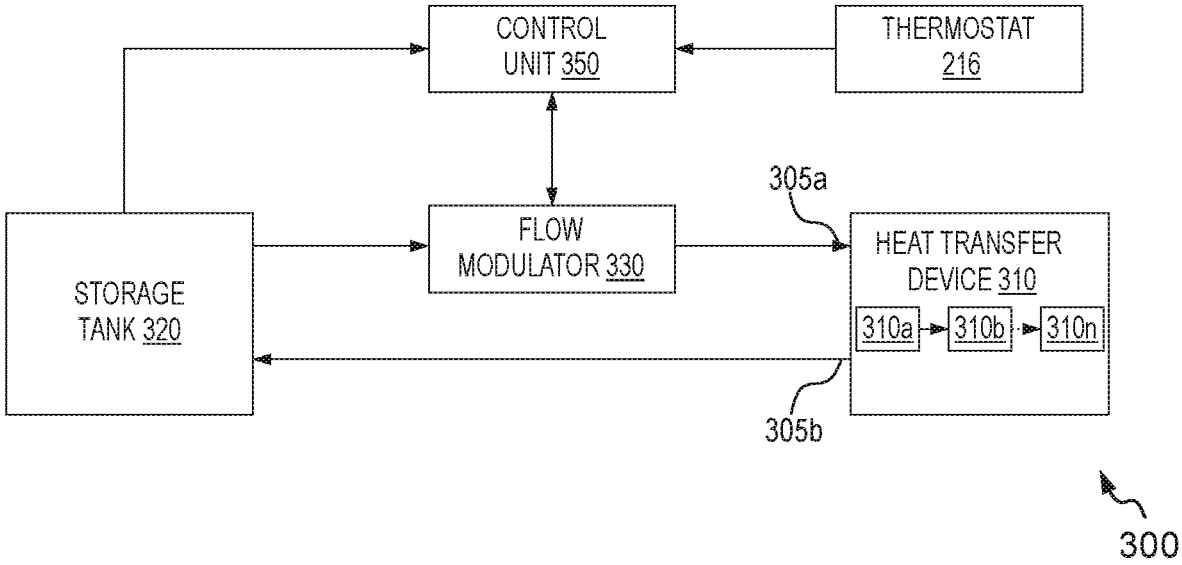
CONTROL UNIT 350
THERMOSTAT 216
305a
FLOW MODULATOR 330
HEAT TRANSFER DEVICE 310
310a
310b
310n
STORAGE TANK 320
305b
300

FIG. 3A

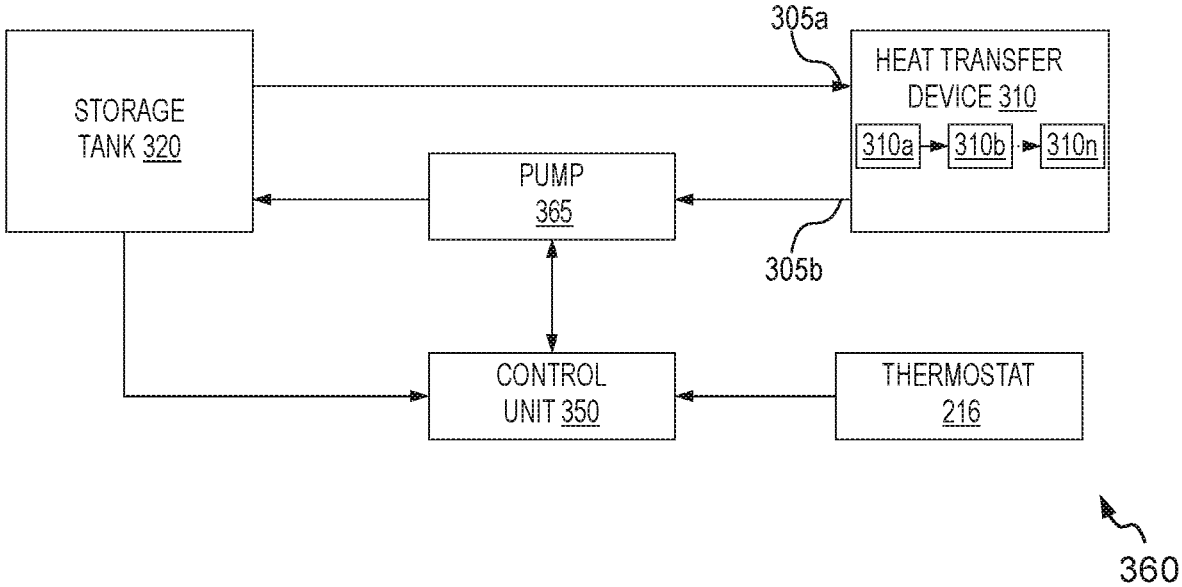
305a
HEAT TRANSFER DEVICE 310
310a
310b
310n
STORAGE TANK 320
PUMP 365
305b
CONTROL UNIT 350
THERMOSTAT 216
360

FIG. 3B

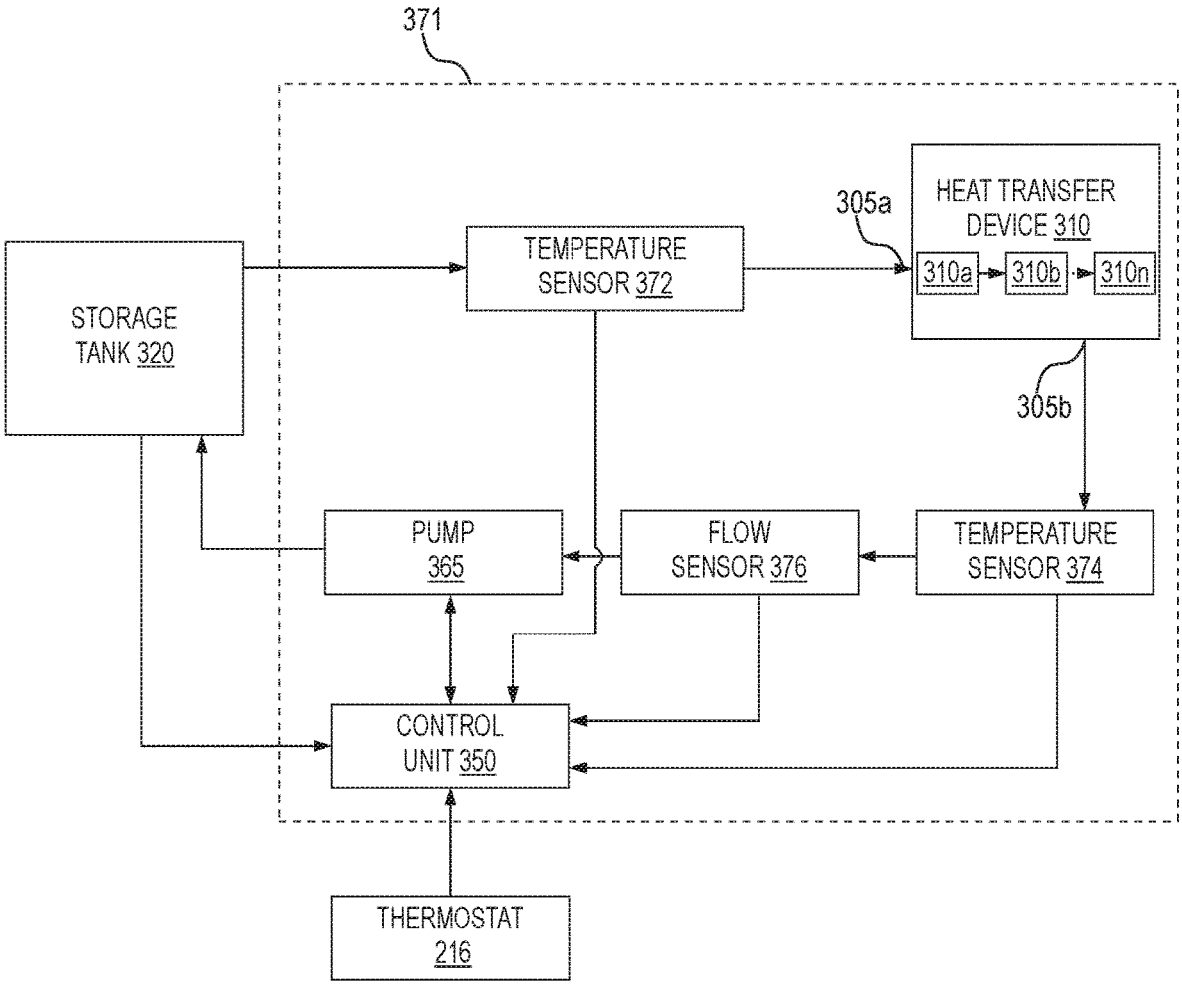
371
STORAGE TANK 320
TEMPERATURE SENSOR 372
305a
HEAT TRANSFER DEVICE 310
310a
310b
310n
305b
PUMP 365
FLOW SENSOR 376
TEMPERATURE SENSOR 374
CONTROL UNIT 350
THERMOSTAT 216
370

FIG. 3C

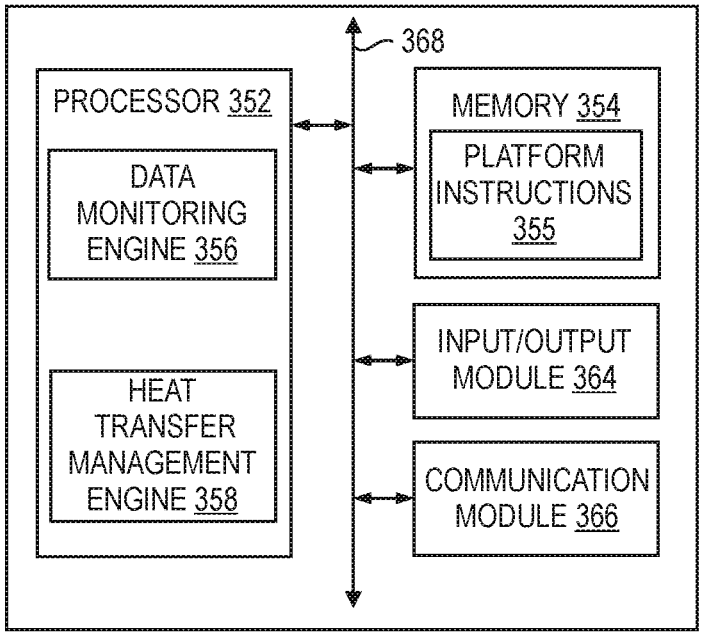
368
PROCESSOR 352
DATA MONITORING ENGINE 356
HEAT TRANSFER MANAGEMENT ENGINE 358
MEMORY 354
PLATFORM INSTRUCTIONS 355
INPUT/OUTPUT MODULE 364
COMMUNICATION MODULE 366
350

FIG. 4

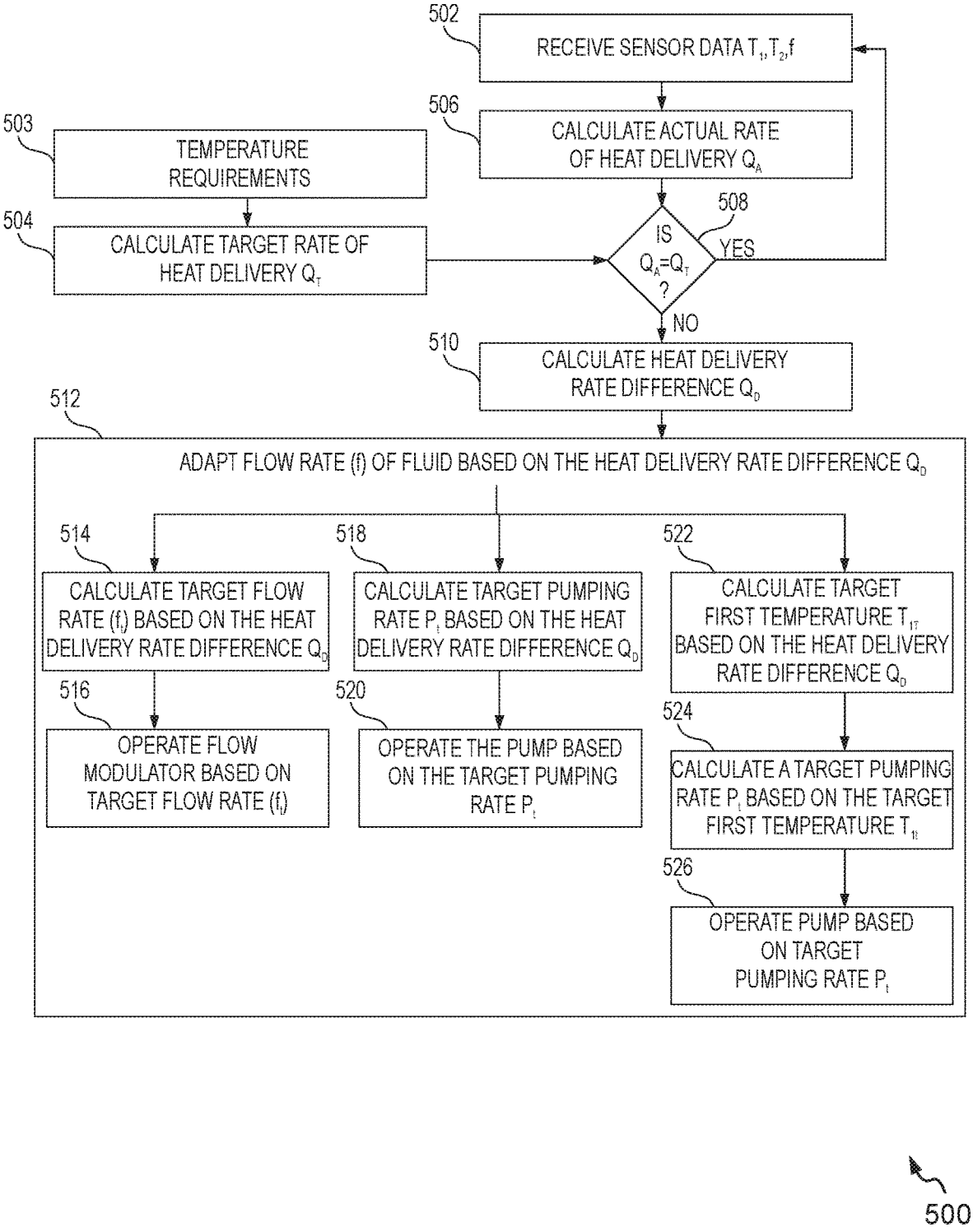
502
RECEIVE SENSOR DATA T_1,T_2,f
506
CALCULATE ACTUAL RATE OF HEAT DELIVERY Q_A
503
TEMPERATURE REQUIREMENTS
504
CALCULATE TARGET RATE OF HEAT DELIVERY Q_T
508
IS Q_A=Q_T ?
YES
NO
510
CALCULATE HEAT DELIVERY RATE DIFFERENCE Q_D
512
ADAPT FLOW RATE (f) OF FLUID BASED ON THE HEAT DELIVERY RATE DIFFERENCE Q_D
514
CALCULATE TARGET FLOW RATE (f_t) BASED ON THE HEAT DELIVERY RATE DIFFERENCE Q_D
516
OPERATE FLOW MODULATOR BASED ON TARGET FLOW RATE (f_t)
518
CALCULATE TARGET PUMPING RATE P_t BASED ON THE HEAT DELIVERY RATE DIFFERENCE Q_D
520
OPERATE THE PUMP BASED ON THE TARGET PUMPING RATE P_t
522
CALCULATE TARGET FIRST TEMPERATURE T_{1T} BASED ON THE HEAT DELIVERY RATE DIFFERENCE Q_D
524
CALCULATE A TARGET PUMPING RATE P_t BASED ON THE TARGET FIRST TEMPERATURE T_{1t}
526
OPERATE PUMP BASED ON TARGET PUMPING RATE P_t
500

FIG. 5

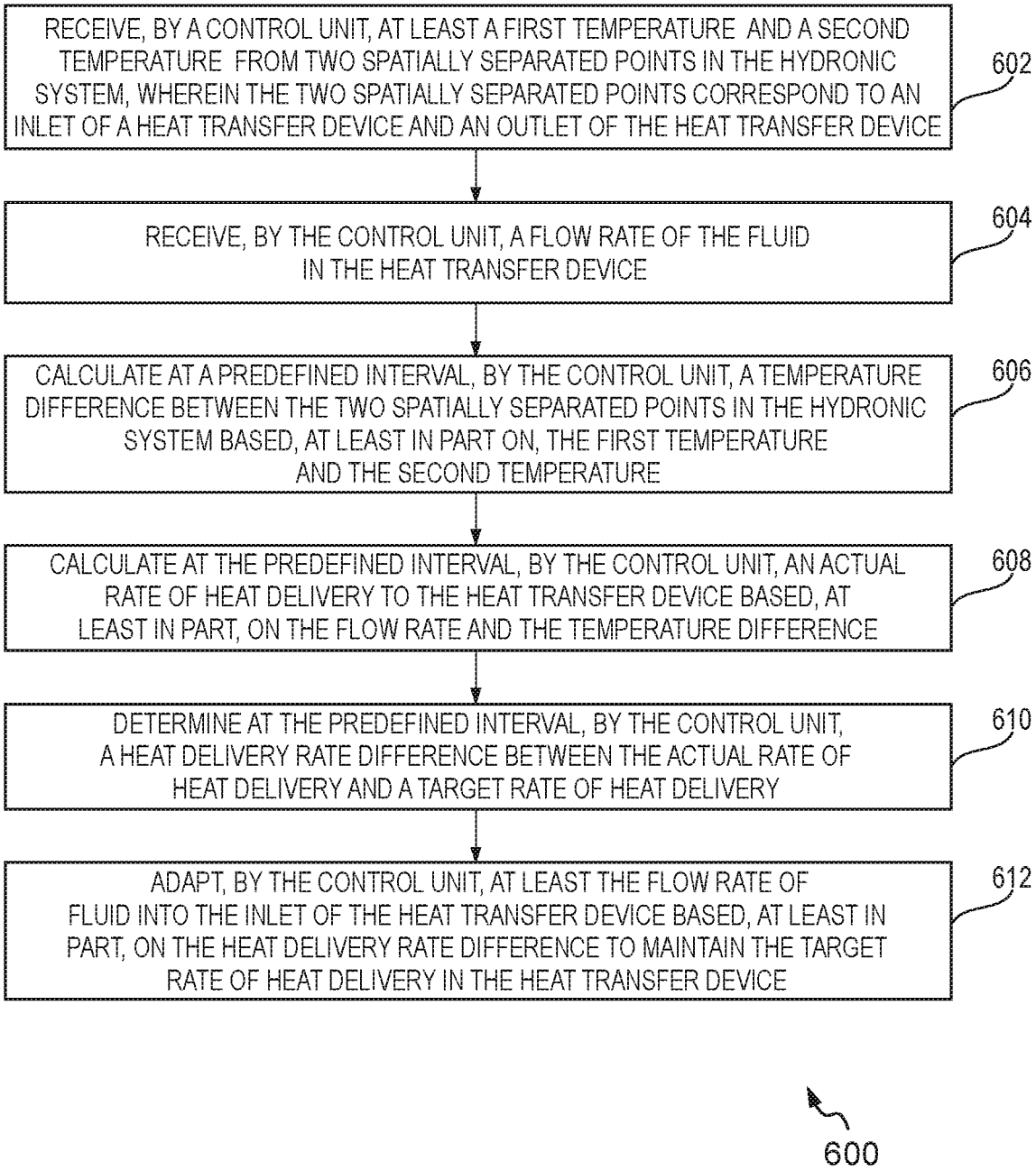
RECEIVE, BY A CONTROL UNIT, AT LEAST A FIRST TEMPERATURE AND A SECOND TEMPERATURE FROM TWO SPATIALLY SEPARATED POINTS IN THE HYDRONIC SYSTEM, WHEREIN THE TWO SPATIALLY SEPARATED POINTS CORRESPOND TO AN INLET OF A HEAT TRANSFER DEVICE AND AN OUTLET OF THE HEAT TRANSFER DEVICE
602
RECEIVE, BY THE CONTROL UNIT, A FLOW RATE OF THE FLUID IN THE HEAT TRANSFER DEVICE
604
CALCULATE AT A PREDEFINED INTERVAL, BY THE CONTROL UNIT, A TEMPERATURE DIFFERENCE BETWEEN THE TWO SPATIALLY SEPARATED POINTS IN THE HYDRONIC SYSTEM BASED, AT LEAST IN PART ON, THE FIRST TEMPERATURE AND THE SECOND TEMPERATURE
606
CALCULATE AT THE PREDEFINED INTERVAL, BY THE CONTROL UNIT, AN ACTUAL RATE OF HEAT DELIVERY TO THE HEAT TRANSFER DEVICE BASED, AT LEAST IN PART, ON THE FLOW RATE AND THE TEMPERATURE DIFFERENCE
608
DETERMINE AT THE PREDEFINED INTERVAL, BY THE CONTROL UNIT, A HEAT DELIVERY RATE DIFFERENCE BETWEEN THE ACTUAL RATE OF HEAT DELIVERY AND A TARGET RATE OF HEAT DELIVERY
610
ADAPT, BY THE CONTROL UNIT, AT LEAST THE FLOW RATE OF FLUID INTO THE INLET OF THE HEAT TRANSFER DEVICE BASED, AT LEAST IN PART, ON THE HEAT DELIVERY RATE DIFFERENCE TO MAINTAIN THE TARGET RATE OF HEAT DELIVERY IN THE HEAT TRANSFER DEVICE
612
600

FIG. 6

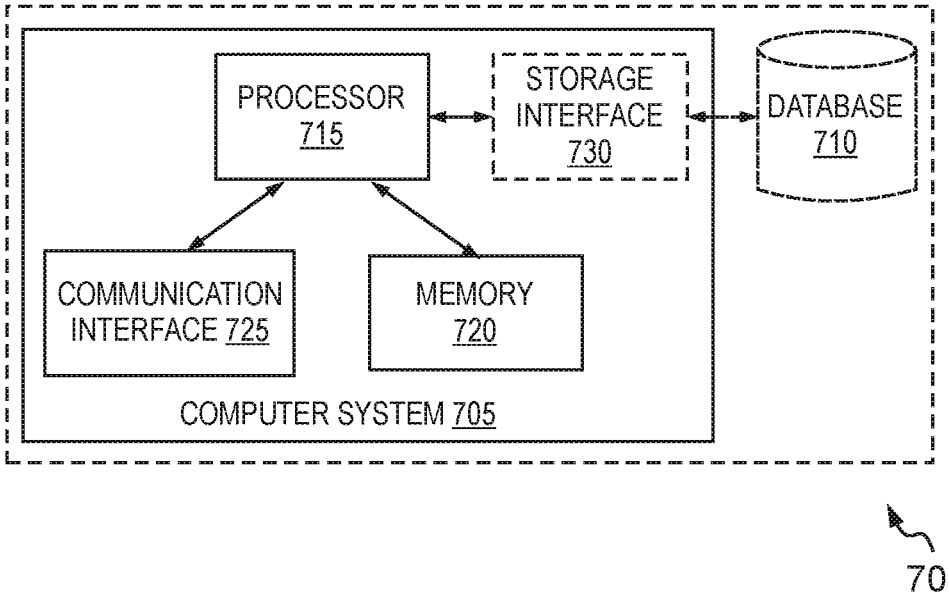
PROCESSOR
715
STORAGE
INTERFACE
730
DATABASE
710
COMMUNICATION
INTERFACE 725
MEMORY
720
COMPUTER SYSTEM 705
700

FIG. 7

CONTROL SYSTEMS AND METHODS FOR MANAGING RATE OF HEAT DELIVERY IN HYDRONIC SYSTEMS

TECHNICAL FIELD

[0001] The present disclosure relates to hydronic systems, and more particularly to control systems and methods for measuring and managing rate of heat delivery in hydronic heating and cooling systems.

BACKGROUND

[0002] Hydronic systems are typically thermo-fluid dynamic systems that use a fluid as heat-transfer medium for heating and cooling homes, commercial, and/or industrial spaces. In general, the hydronic systems employ fluid as a heat transfer medium for heating or cooling the interiors of a building (e.g., homes, industrial facilities). More often, the hydronic systems employ different control techniques to cool or heat the fluid with a boiler or chiller depending on the requirements.

[0003] Conventional hydronic systems can use energy sources obtained by the combustion of natural gas, propane, coal, fuel oil, wood, and other fuels for powering boilers to heat fluid. This combustion results in the emission of greenhouse gases (GHG) and potentially other pollutants including particulates, ozone, nitrogen dioxide, sulphur dioxide, etc. Alternatively, electricity can be used, for example to operate heat pumps for heating or cooling fluid, or electric resistance devices for heating fluid. Electric hydronic systems utilize the energy generated by power plants, many of them powered by the combustion of fossil fuels, which also generates GHG and the other air pollutants listed above. Emissions from grid-supplied electricity vary by time of day and day of the year and can range from zero when the marginal generator is renewable, hydro, or nuclear, to very high when the marginal generator is a peak power plant at times of peak grid demand.

[0004] Further, as hydronic systems move thermal energy from one location to another, the rate of heat delivery is important for the efficient management of the hydronic system. Moreover, as some hydronic systems employ thermal storage, the rate of heat delivery plays an important role in the optimal use of storage capacity. Some hydronic systems employ load shifting to generate heat at a time instant that may be different from a time instant when it will be delivered. In such hydronic systems, the rate of heat delivery is an important parameter that can be optimized to achieve energy efficiency and cost savings. As time-varying electricity rates become increasingly common, the cost incurred for operating electric hydronic systems also varies by time of operation. Therefore, the rate of heat delivery plays a crucial role for an efficient, low-emission, and cost-effective operation of an electric hydronic system.

[0005] In view of the above, there exists a technical need for control systems and techniques that can measure and manage the rate of heat delivery along with providing other technical advantages.

SUMMARY

[0006] Various embodiments of the present disclosure provide control methods and systems for measuring and managing the rate of heat delivery in the hydronic system.

[0007] In an embodiment, a hydronic system is disclosed. The hydronic system includes a control unit for managing a rate of heat delivery across two spatially separated points in the hydronic system. The control unit includes a communication module, a memory and a processing module. The communication module is configured to: (1) receive at least a first temperature and a second temperature of a fluid from a first point and a second point, respectively in the hydronic system, wherein the first point and the second point correspond to the two spatially separated points, and (2) receive a flow rate of the fluid across the two spatially separated points. The processing module is communicably coupled to the memory and the communication module. The processor is configured to execute the stored instructions to cause the hydronic system to perform at least: (1) calculating an actual rate of heat delivery in the two spatially separated points based, at least in part, on flow rate and temperature difference of the fluid in the two spatially separated points, (2) determining a heat delivery rate difference between the actual rate of heat delivery and a target rate of heat delivery, and (3) adapting at least the flow rate of the fluid flowing between the two spatially separated points based, at least in part, on the heat delivery rate difference to maintain the target rate of heat delivery.

[0008] In another embodiment, a hydronic system is disclosed. The hydronic system includes a heat transfer device, at least one pump and a control unit. The at least one pump is operatively coupled to a storage tank for pumping fluid from the storage tank to the heat transfer device. The control unit is operatively coupled to the heat transfer device and the at least one pump. The control unit is configured to perform the following steps at predefined intervals: (1) receiving at least a first temperature and a second temperature from two spatially separated points in the hydronic system, wherein the first temperature corresponds to temperature of the fluid entering an inlet of the heat transfer device and the second temperature corresponds to temperature of the fluid leaving an outlet of the heat transfer device, (2) receiving a flow rate of the fluid in the heat transfer device, (3) calculating a temperature difference between the two spatially separated points in the hydronic system based, at least in part, on the first temperature and the second temperature, (4) calculating an actual rate of heat delivery in the heat transfer device based, at least in part, on the flow rate and the temperature difference, (5) determining a heat delivery rate difference between the actual rate of heat delivery and a target rate of heat delivery, (6) calculating a target pumping rate based, at least in part, on the heat delivery rate difference, and (7) operating the at least one pump at the target pumping rate for adapting at least the flow rate of fluid into the inlet of the heat transfer device to maintain the target rate of heat delivery in the heat transfer device.

[0009] In yet another embodiment, a method for controlling rate of heat delivery in a hydronic system is disclosed. The method includes receiving, by a control unit, at least a first temperature and a second temperature from two spatially separated points in the hydronic system. The two spatially separated points correspond to an inlet of a heat transfer device and an outlet of the heat transfer device. The method includes receiving, by the control unit, a flow rate of the fluid in the heat transfer device. The method also includes calculating at a predefined interval, by the control unit, a temperature difference between the two spatially separated points in the hydronic system based, at least in

part, on the first temperature and the second temperature. The method further includes calculating at the predefined interval, by the control unit, an actual rate of heat delivery to the heat transfer device based, at least in part, on the flow rate and the temperature difference. The method includes determining at the predefined intervals, by the control unit, a heat delivery rate difference between the actual rate of heat delivery and a target rate of heat delivery. The method also includes adapting, by the control unit, at least the flow rate of fluid into the inlet of the heat transfer device based, at least in part, on the heat delivery rate difference to maintain the target rate of heat delivery in the heat transfer device.

BRIEF DESCRIPTION OF THE FIGURES

[0010] The following detailed description of illustrative embodiments is better understood when read in conjunction with the appended drawings. For the purpose of illustrating the present disclosure, exemplary constructions of the disclosure are shown in the drawings. However, the present disclosure is not limited to a specific device or a tool and instrumentalities disclosed herein. Moreover, those in the art will understand that the drawings are not to scale. Wherever possible, like elements have been indicated by identical numbers:

[0011] FIG. **1** is an example representation of an environment related to at least some example embodiments of the present disclosure;

[0012] FIG. **2**A is a schematic representation of a hydronic system, in accordance with an example embodiment of the present disclosure;

[0013] FIG. **2**B is a schematic representation of a hydronic system, in accordance with another example embodiment of the present disclosure;

[0014] FIG. **3**A is a simplified block diagram representation of a hydronic system for managing rate of heat delivery, in accordance with an embodiment of the present disclosure;

[0015] FIG. **3**B is a simplified block diagram representation of a hydronic system for managing rate of heat delivery, in accordance with another example embodiment of the present disclosure;

[0016] FIG. **3**C is a simplified block diagram representation of a hydronic system for managing rate of heat delivery, in accordance with yet another example embodiment of the present disclosure;

[0017] FIG. **4** is a block diagram of a control unit configured to manage rate of heat delivery in the hydronic systems of FIGS. **2**A-**2**B, **3**A-**3**C, in accordance with an embodiment of the present disclosure;

[0018] FIG. **5** is a flow diagram illustrating a method for managing rate of heat delivery to a hydronic system, in accordance with an embodiment of the present disclosure;

[0019] FIG. **6** is a flow diagram illustrating a method for managing rate of heat delivery to a hydronic system, in accordance with another embodiment of the present disclosure; and

[0020] FIG. **7** is a block diagram of a server system capable of implementing at least some embodiments of the present disclosure.

[0021] The drawings referred to in this description are not to be understood as being drawn to scale except if specifically noted, and such drawings are only exemplary in nature.

DETAILED DESCRIPTION

[0022] In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present disclosure. It will be apparent, however, to one skilled in the art that the present disclosure can be practiced without these specific details. Descriptions of well-known components and processing techniques are omitted so as to not unnecessarily obscure the embodiments herein. The examples used herein are intended merely to facilitate an understanding of ways in which the embodiments herein may be practiced and to further enable those of skill in the art to practice the embodiments herein. Accordingly, the examples should not be construed as limiting the scope of the embodiments herein.

[0023] Reference in this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present disclosure. The appearance of the phrase "in an embodiment" in various places in the specification is not necessarily all referring to the same embodiment, nor are separate or alternative embodiments mutually exclusive of other embodiments. Moreover, various features are described which may be exhibited by some embodiments and not by others. Similarly, various requirements are described which may be requirements for some embodiments but not for other embodiments.

[0024] Moreover, although the following description contains many specifics for the purposes of illustration, anyone skilled in the art will appreciate that many variations and/or alterations to said details are within the scope of the present disclosure. Similarly, although many of the features of the present disclosure are described in terms of each other, or in conjunction with each other, one skilled in the art will appreciate that many of these features can be provided independently of other features. Accordingly, this description of the present disclosure is set forth without any loss of generality to, and without imposing limitations upon, the present disclosure.

[0025] The term 'hydronic' as used herein refers to the use of a fluid such as, water, glycol or steam as the heat-transfer medium in heating and cooling systems for buildings such as, homes, commercial and industrial facilities.

Overview

[0026] Various embodiments of the present disclosure provide systems and methods for measuring and managing the rate of heat delivery in a hydronic system configured to condition an enclosure as per requirement. More specifically, embodiments of the present disclosure provide a control unit that adapts operation of one or more components of the hydronic system for managing the rate of heat delivered to the hydronic system. Such techniques for managing the rate of heat delivery in hydronic systems improve the operational and energy efficiency.

[0027] In an example, the present disclosure describes a method performed by a control unit of the hydronic system. The control unit receives at least a first temperature and a second temperature of a fluid from two spatially separated points in the hydronic system. The two spatially separated points correspond to an inlet of a heat transfer device and an outlet of the heat transfer device. The heat transfer device

may be a radiator or a hydronic panel that acts as a heat exchanger to transfer thermal energy from one medium to another for heating or cooling the enclosure. Further, the control unit is configured to receive a flow rate of the fluid in the heat transfer device. A storage tank may store the fluid that may be pumped to the heat transfer device for heating/cooling.

[0028] In an embodiment, the control unit is configured to calculate a temperature difference of the fluid between the two spatially separated points (i.e., across ends of the heat transfer device) in the hydronic system based on the first temperature and the second temperature of the fluid at a predefined interval. The temperature difference indicates a difference in fluid temperature between the inlet of the heat transfer device and the outlet of the heat transfer device. The control unit calculates an actual rate of heat delivery to the heat transfer device based on the flow rate and the temperature difference. The actual rate of heat delivery determines an amount of heat or thermal energy transferred per unit time via the fluid to the heat transfer device. Further, the delivery rate difference between the actual rate of heat delivery and a target rate of heat delivery is determined by the control unit. In some example embodiments, the control unit is configured to determine the target rate of heat delivery from temperature requirements of an enclosure.

[0029] The control unit is configured to adapt the flow rate of fluid into the inlet of the heat transfer device based on the heat delivery rate difference to maintain the target rate of heat delivery in the heat transfer device. In one embodiment, the control unit calculates a target flow rate based on the heat delivery rate difference. Further, the control unit is configured to operate a flow modulator based on the target flow rate. The flow modulator is configured at the inlet of the heat transfer device. In another embodiment, the control unit is configured to calculate a target pumping rate for operating a pump based on the heat delivery rate difference. The pump can be operatively coupled to the storage tank for pumping fluid from the storage tank to the heat transfer device. The pump is operated at the target pumping rate for adapting the flow rate of the fluid into the inlet of the heat transfer device.

[0030] In some example embodiments, the control circuit is configured to calculate a target first temperature at the outlet of the heat transfer device based on the heat delivery rate difference. As the fluid flow rate via the inlet of the heat transfer device affects the temperature of the fluid, the control circuit calculates a desired fluid temperature at the outlet of the heat transfer device. Further, a target pumping rate for operating the pump is calculated based on the target first temperature. In one embodiment, the control circuit operates the pump at the target pumping rate for adapting the flow rate of fluid via the inlet of the heat transfer device. In an alternate embodiment, the control circuit operates the flow modulator based on the target flow rate for adapting the flow rate of fluid via the inlet of the heat transfer device.

[0031] Although process steps, method steps or the like in the disclosure may be described in sequential order, such processes and methods may be configured to work in alternate orders. In other words, any sequence or order of steps that may be described in this patent application does not, in and of itself, indicate a requirement that the steps be performed in that order. The steps of described processes may be performed in any order practical. Further, some steps may be performed simultaneously despite being described or implied as occurring non-simultaneously (e.g., because one step is described after the other step). Moreover, the illustration of a process by its depiction in a drawing does not imply that the illustrated process is exclusive of other variations and modifications thereto, does not imply that the illustrated process or any of its steps are necessary to one or more of the invention(s), and does not imply that the illustrated process is preferred.

[0032] Various example embodiments of the present disclosure are described hereinafter with reference to FIG. **1** to FIG. **7**.

[0033] FIG. **1** is an example representation of an environment **100** related to at least some example embodiments of the present disclosure. The environment **100** includes a user **102** interacting with a hydronic system **110** (for e.g. as shown in FIG. **2**A). The user **102** may be an individual or an entity, which is in need of conditioning (i.e., heating/cooling) an indoor space. The user **102** is associated with a device **104**, for providing user input for operating the system **110** via a network **106**. The network **106** may include, without limitation, a light fidelity (Li-Fi) network, a local area network (LAN), a wide area network (WAN), a metropolitan area network (MAN), a satellite network, the Internet, a fiber-optic network, a coaxial cable network, an infrared (IR) network, a radio frequency (RF) network, a virtual network, and/or another suitable public and/or private network capable of supporting communication among the entities illustrated in FIG. **1**, or any combination thereof.

[0034] The user input from the user **102** may include temperature requirements, a rate of heat delivery, variation in the temperature of conditioning the indoor space (see, enclosure **212**), timing information for temperature control or any other information required for operation of the hydronic system **110**. The user **102** uses an interactive application (hereinafter referred to as "application **114**") on his/her device **104** to provide the user input to the hydronic system **110** for operating the hydronic system **110** (e.g., set temperature to 70° F.). The device **104** may be any electronic device such as, but not limited to, a personal computer (PC), a tablet device, a Personal Digital Assistant (PDA), a voice activated assistant, wearable devices, a Virtual Reality (VR) device, a smartphone and a laptop.

[0035] The server system **108** is configured to host and manage the application **114**, which is accessible to the device **104**. The application **114** may be accessible through a website associated with the server system **108**, so that the user **102** may access the website over the network **106** using Web browser applications installed in the device **104** and, thereafter perceive to operate the hydronic system **110**. In an embodiment, the server system **108** is configured to facilitate instances of the application **114** to the device **104**, upon receiving a request for accessing the application **114**. The server system **108** upon receiving the request allows instances of the application **114** to be downloaded into the device **104** for accessing the application **114**. In one configuration, the application **114** is also configured to generate and dynamically update a dashboard (not shown in Figures) by including the user input provided by the user **102**. In another configuration, the application **114** is also configured to generate and dynamically update the dashboard by including estimated costs associated with operation of the hydronic system **110** based on the user input.

[0036] The environment **100** further includes a database **116** configured to store information pertaining to the user input provided by the user **102**. The database **116** may also

be configured to store data pertaining to the determined temperatures, determined heat delivery rate, pumping rate, flow rate, capacities of the storage tanks, estimated costs, power savings and the like. The database **116** may be maintained by a third party or embodied within the server system **108**.

[0037] In one embodiment, the hydronic system **110** includes a control unit **112** that controls operation of the hydronic system **110** based on the user input provided via the application **114**. It shall be noted that the control unit **112** can be a standalone component operating apart from the hydronic system **110** for controlling operations of the hydronic system **110**. However, in other embodiments, the control unit **112** may actually be incorporated, in whole or in part, into one or more parts of the environment **100**, for example, the server system **108**. Further, the control unit **112** should be understood to be embodied in at least one computing device which may be specifically configured, via executable instructions, to perform as described herein, and/or embodied in at least one non-transitory computer readable media.

[0038] The hydronic system **110** is configured to perform one or more of the operations described herein. In particular, the control unit **112** is configured to adapt one or more parameters of the hydronic system **110** for managing the rate of heat delivery in the hydronic system **110**. In one example, the user **102** may preset a rate of heat delivery (e.g., 10,000 BTU/hr) for the hydronic system **110** for cost savings. During use, the user **102** may provide the user input to increase temperature of the indoor space on a cold day. In such scenarios, increasing ambient room temperature may require a higher rate of heat delivery. As such, the control unit **112** adapts a parameter (e.g., flow rate, temperature) associated with the rate of heat delivery to increase the rate of heat delivery until the temperature requirements provided by the user **102** are met.

[0039] The number and arrangement of systems, devices, and/or networks shown in FIG. **1** are provided as an example. There may be additional systems, devices, and/or networks; fewer systems, devices, and/or networks; different systems, devices, and/or networks; and/or differently arranged systems, devices, and/or networks than those shown in FIG. **1**. Furthermore, two or more systems or devices shown in FIG. **1** may be implemented within a single system or device, or a single system or device shown in FIG. **1** may be implemented as multiple, distributed systems or devices. Additionally, or alternatively, a set of systems (e.g., one or more systems) or a set of devices (e.g., one or more devices) of the environment **100** may perform one or more functions described as being performed by another set of systems or another set of devices of the environment **100**.

[0040] FIGS. **2**A and **2**B are schematic representations of the hydronic system **200**, in accordance with some example embodiments of the present disclosure. The system **200** includes a thermal storage tank **202** configured to store fluid therein. The thermal storage tank **202** may be divided into a compartment **202***a* (i.e. a top portion) for storing hot fluid, a compartment **202***b* for storing warm fluid and a compartment **202***c* (i.e. a bottom portion) for storing cold fluid. The thermal storage tank **202** may be configured with a thermal shielding surface for maintaining the temperature of the fluid therein. More specifically, the compartments **202***a*-**202***c* may be formed due to the temperature difference between the hot fluid, the warm fluid and the cold fluid. In general, a thermocline layer (referenced as a line within the tank **202**) forms the compartments **202***a*-**202***c* due to significant difference in temperatures.

[0041] In one implementation, the hot fluid may be fluid heated to a temperature between 130° F.-170° F., the lukewarm fluid may be fluid at room temperature (e.g., 68° F.-72° F.), and the cold fluid may be the fluid cooled to temperatures of 50° F. or any other temperature as per requirement.

[0042] The thermal storage tank **202** is fluidically coupled to a pump **204**. The pump **204** is further fluidically coupled via conduits, to a heat transfer device **206** (also referred to as 'a thermal distributor **206**'), a heat pump unit **208**, a domestic hot fluid tank **210** and the enclosure **212**. As such, the pump **204** is configured to circulate or route the hot fluid, the cold fluid and the lukewarm fluid suitably within the system **200**. Examples of the pump **204** include, but not limited to, a positive displacement pump, a peristaltic pump, a centrifugal pump, and the like as per design feasibility and requirement.

[0043] In one configuration, the thermal storage tank **202** may be divided into a first storage tank **202***d* and a second storage tank **202***e* (shown in FIG. **2**B). As shown in FIG. **2**B, the first storage tank **202***d* may be configured to store hot fluid at a top portion **203***a* and cold fluid at a bottom portion **203***b*. The thermocline layer will separate the hot fluid and the cold fluid. The second storage tank **202***e* may be configured to store lukewarm fluid in a top portion **203***c* and chilled fluid in a bottom portion **203***d*. The thermocline layer will separate the lukewarm fluid and the chilled fluid. The first storage tank **202***d* and the second storage tank **202***e* may be fluidic ally coupled to the pump **204** for enabling circulation of the hot fluid and the cold fluid suitably.

[0044] Further, the system **200** may be configured with a first set of flowmeters **222***a*, **222***b* and **222***c* mounted at an inlet and outlet of the first storage tank **202***d*. The first set of flowmeters **222***a*, **222***b* and **222***c* are configured to monitor the volume of the fluid entering and leaving the first storage tank **202***d* over time and thereby enable the control unit **214** to determine the volume of hot fluid in the first storage tank **202***d*. The first set of flowmeters **222***a*, **222***b* and **222***c* may be one of an optical sensor, a mechanical sensor or any other sensor configured for monitoring the fluid flow within the conduits entering and leaving the first storage tank **202***d*. The system **200** may also include a first set of temperature sensors **218***a* and **218***b* mounted to the conduit exiting and entering the portion of the first storage tank **202***d* containing the hot fluid. The first set of temperature sensors **218***a*, **218***b* are configured to monitor the temperature of the fluid exiting or entering the hot first storage tank **202***d*. In one configuration, the first set of flowmeters **222***a*, **222***b* and **222***c* and the temperature sensors **218***a*, **218***b* may also be suitably incorporated in the thermal storage tank **202** (not shown in Figures).

[0045] The second storage tank **202***e* may be configured with a second set of flowmeters **228***a* and **228***b* mounted at an inlet and an outlet of the portion containing the chilled fluid. The second set of flowmeters **228***a* and **228***b* are configured to monitor the volume of the chilled fluid entering and leaving the second storage tank **202***e* over time and thereby, enabling the control unit **214** to determine the volume of chilled fluid in the second storage tank **202***e*. The second set of flowmeters **228***a* and **228***b* may be one of an

optical sensor, a mechanical sensor or any other sensor configured for monitoring the chilled fluid flowing within the conduits entering and leaving the second storage tank **202***e*. The system **200** also includes a second set of temperature sensors **220***a* and **220***b* (for e.g. as shown in FIG. **2**B) mounted to conduit exiting/entering a portion of the second storage tank **202***e* containing the chilled fluid and exiting/entering the portion of the second storage tank **202***e* containing the lukewarm fluid. The second set of temperature sensors **220***a* and **220***b* are configured to monitor the temperature of the fluid exiting or entering the second storage tank **202***e*. In one configuration, the second set of flowmeters **228***a* and **228***b* (for e.g. as shown in FIG. **2**B) and the temperature sensors **220***a* and **220***b* may be suitably incorporated in the thermal storage tank **202**.

[0046] Further, the system **200** includes a first temperature sensor **226** mounted to the first storage tank **202***d*. The first temperature sensor **226** is configured to monitor the temperature of the hot fluid within the first storage tank **202***d*. In one configuration, the conduit extending from the first storage tank **202***d* for supplying the hot fluid, may be directly connected to the enclosure **212** (not shown in Figures). In one configuration, the conduit extending from the second storage tank **202***e* for supplying the chilled fluid to the heat transfer device **206** may be directly connected instead to a domestic hot fluid tank **210** (not shown in Figures). The heat transfer device **206** on receiving either of the hot fluid or the chilled fluid via the pump **204** distributes the heat content to the enclosure **212** for conditioning. Examples of the heat transfer device **206** may include but are not limited to, a blower, a radiator or hydronic panel configured for distributing the heat content into the enclosure **212**. The heat transfer device **206** includes a plurality of heat transfer components connected together, for example, plurality of radiators connected in series so as to provide adequate heating/cooling to the enclosure.

[0047] The system **200** also includes the heat pump unit **208** configured for generating either the hot fluid or the chilled fluid. The hot fluid and the chilled fluid generated in the heat pump unit **208** is routed back to the thermal storage tank **202**, the first storage tank **202***d* or the second storage tank **202***e*, respectively. In one configuration, the heat pump unit **208** receives cold fluid from (i.e. the bottom portion) the first storage tank **202***d* which would be heated for generating the hot fluid. The generated hot fluid is routed to the first storage tank **202***d* (i.e. the top portion), for recharging the hot fluid. In another configuration, the heat pump unit **208** receives lukewarm fluid from (i.e. the top portion) the second storage tank **202***e*, which would be cooled to generate the chilled fluid. The chilled fluid is circulated back to the second storage tank **202***e* (i.e. to the bottom portion).

[0048] The system **200** also includes a control unit **214** communicably coupled with the thermal storage tank **202** (shown in FIG. **2**A) or the first storage tank **202***d*, and the second storage tank **202***e*. The control unit **214** is also communicably coupled to the pump **204**, the heat transfer device **206**, the domestic hot fluid tank **210**, the heat pump unit **208** and the enclosure **212**. The control unit **214** is also configured to receive the user input from the user **102**, based on which the control unit **214** may operate the system **200**. Additionally, the hydronic system **200** includes a thermostat **216** that senses any change in temperature from the required thermal value (as preset by the user **102**) or temperature value in the system **200** suitably, and provides such data to the control unit **214**. In one implementation, the control unit **214** may automatically determine the requirements of the enclosure **212** and accordingly, operate the system **200** for conditioning the enclosure **212** suitably. To that effect, the control unit **214** determines a target rate of heat delivery across the heat transfer device **206** based on the thermal requirements either preset by the user **102** or automatically for conditioning the enclosure **212**. Further, the control unit **214** is configured to control operations of the components in the system **200** for ensuring optimal operational efficiency by managing the rate of heat delivery in the hydronic system **200**, while incurring minimal operation costs, emissions or any other parameter, which would be further explained with reference to FIGS. **3**-**6**.

[0049] As such, when the heat transfer device **206** is configured with thermal storage capacity, the rate of heat delivery is important for management and optimal use of storage capacity. Further, if the heat transfer device **206** employs load shifting techniques, the rate of heat delivery needs to be optimized for minimizing atmospheric carbon generation and usage cost. This optimization is performed by the control unit **214**. An example of managing the rate of heat delivery in hydronic system **200** is shown and explained with reference to FIGS. **3**A-**3**C.

[0050] FIG. **3**A is a simplified block diagram representation of a hydronic system **300** for managing the rate of heat delivery in a heat transfer device, in accordance with an embodiment of the present invention. The hydronic system **300** is a simplified example representation of the hydronic system **200**. The number and arrangement of devices, and/or components shown in FIG. **3**A are provided as an example. There may be additional devices, and/or components; fewer devices, and/or components; different devices, and/or components; and/or differently arranged devices, and/or components than those shown in FIG. **3**A. Further, operations of one or more components may be performed using software, hardware or a combination thereof.

[0051] The hydronic system **300** includes at least a heat transfer device **310**, a storage tank **320**, at least one flow modulator **330** and a control unit **350**.

[0052] The storage tank **320** is configured to supply fluid to the heat transfer device **310** via conduits. The storage tank **320** can be a thermal storage tank **202** as shown in FIG. **2**A or the thermal storage tanks **202***d*, **202***e* shown and explained with reference to FIG. **2**B. The heat transfer device **310** is an example of the heat transfer device **206** shown and explained with reference to FIGS. **2**A and **2**B. The heat transfer device **310** is a type of heat exchanger used to transfer thermal energy from one medium to another medium for heating or cooling an indoor space i.e., the enclosure **212**. More specifically, the heat transfer device **310** is a thermal distributor including a distribution system such as a radiant floor, wall, ceiling, wall-mounted radiators or any other such system for conditioning the enclosure **212**. Examples of the heat transfer device **310** include, but not limited to, radiators, hydronic panels, fan convectors, heat emitters, air handlers, radiant surfaces and the like. The fluid enters the heat transfer device **310** via an inlet **305***a* and leaves the heat transfer device **310** via an outlet **305***b*.

[0053] Generally, rate of heat of heat delivered to the heat transfer device **310** varies over time based on ambient temperature variations or user requirements (i.e., temperature requirements) thereby resulting in an increased rate of

heat delivery that affects optimum performance and increases operational costs of the hydronic systems **300/360/370**.

[0054] "Rate of heat delivery" as used herein is the amount of heat that is transferred per unit of time in some material i.e., fluid in the hydronic systems **300/360/370**. Factors that affect the rate of heat delivery in the hydronic systems **300/360/370** include the thermal conductivity of the fluid, temperature difference of the fluid across spatially separated points and flow rate of the fluid in the hydronic system **300/360/370**. Different materials have greater or lesser resistance to heat transfer, making them better insulators or better conductors.

[0055] The management of the rate of heat delivery is explained hereinafter with reference to the heat transfer device **310**, i.e. radiator or heat emitter that employs heat transfer mechanisms such as, convection, conduction, thermal radiation, and evaporative cooling for transferring heat to the fluid that conditions the enclosure based on user requirements (i.e., user input) as will be explained in further detail later. However, it shall be noted that the rate of heat delivery across other sub-systems of the hydronic system **300/360/370** or any heating and cooling systems can be measured and managed in the same or substantially similar way with same or substantially similar components and has not been explained herein for the sake of brevity.

[0056] The heat transfer device **310** may include a single heat exchanger, for example, a radiator, or a number of heat exchangers (i.e., a plurality of radiators) connected in series configuration to heat/cool the indoor space as per user requirement. In this example representation, a plurality of radiators **310***a*, **310***b*, . . . **310***n* (hereinafter referred to as 'the heat transfer device **310**') is connected together in series. It shall be noted that the number of heat exchangers may not be necessarily connected in series but may be connected in parallel or any combination thereof as per design feasibility and requirement. Accordingly, the rate of heat delivery across each radiator (e.g., radiator **310***a*) may be monitored and adapted as per requirements. It is understood that other devices/components of the hydronic systems **200/300** may be monitored similarly for managing the rate of heat delivery within the hydronic system **200/300**. Furthermore, rate of heat delivery across multiple devices/components of the hydronic system **200/300** can be similarly monitored to optimize the rate of heat delivery that may result in cost savings and energy efficiency.

[0057] In some example embodiments the hydronic systems **200/300** may include a forced air heat delivery component, for example, an air handler (not shown in Figures). Such forced air systems may enable an additional control component that measures and or controls the flow of air in the hydronic systems **200/300**. The rate of airflow may be measured or controlled to effect change in rate of heat delivery as performed with measuring and managing the flow rate of the fluid in the hydronic systems **200/300**. In such an implementation, it may be possible that flow rate of both fluid and air can be controlled to achieve the desired rate of heat delivery. Moreover, utilizing two control elements allows further optimizations, for example, to minimize airflow disturbance in the conditioned space.

[0058] The control unit **350** is configured to control operations of the components in the hydronic system **300** for managing the rate of heat delivery in the heat transfer device **310**. The control unit **350** is an example of the control unit **214** shown and explained with reference to FIGS. **2**A and **2**B. The operations of the control unit are explained next with reference to FIG. **4**.

[0059] FIG. **4** is a block diagram of the control unit **350** configured to manage the rate of heat delivery in the hydronic system **300/360/370**, in accordance with an embodiment of the invention. The control unit **350** is an example of the control unit **214** shown and explained with reference to FIGS. **2**A-**2**B.

[0060] The term 'manage' as used herein refers to regulation or modulation of the rate of heat delivery in the hydronic system **200/300/360/370**, for example, maintaining the rate of heat delivery across the heat transfer device **206** or the heat transfer device **310** even with change in user input (e.g., temperature change). In one embodiment, the control unit **350** may be embodied in the server system **108** accessible over a communication network, such as the communication network **106** shown in FIG. **1**.

[0061] The control unit **350** includes at least one processor, such as a processing module **352** and a memory **354**. It is noted that although the control unit **350** is depicted to include only one processor, the control unit **350** may include more number of processors therein. In an embodiment, the memory **354** is capable of storing machine executable instructions, referred to herein as platform instructions **355**. Further, the processing module **352** is capable of executing the platform instructions **355**. In an embodiment, the processing module **352** may be embodied as a multi-core processor, a single core processor, or a combination of one or more multi-core processors and one or more single core processors. For example, the processing module **352** may be embodied as one or more of various processing devices, such as a coprocessor, a microprocessor, a controller, a digital signal processor (DSP), a processing circuitry with or without an accompanying DSP, or various other processing devices including integrated circuits such as, for example, an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), a microcontroller unit (MCU), a hardware accelerator, a special-purpose computer chip, or the like. In an embodiment, the processing module **352** may be configured to execute hard-coded functionality. In an embodiment, the processing module **352** is embodied as an executor of software instructions, wherein the instructions may specifically configure the processing module **352** to perform the algorithms and/or operations described herein when the instructions are executed.

[0062] The memory **354** may be embodied as one or more volatile memory devices, one or more non-volatile memory devices, and/or a combination of one or more volatile memory devices and non-volatile memory devices. For example, the memory **354** may be embodied as semiconductor memories (such as mask ROM, PROM (programmable ROM), EPROM (erasable PROM), flash memory, RAM (random access memory), etc.), magnetic storage devices (such as hard disk drives, floppy disks, magnetic tapes, etc.), optical magnetic storage devices (e.g., magneto-optical disks), CD-ROM (compact disc read only memory), CD-R (compact disc recordable), CD-R/W (compact disc rewritable), DVD (Digital Versatile Disc) and BD (BLU-RAY® Disc).

[0063] In at least some embodiments, the memory **354** stores instructions for determining temperature difference across two spatial points, calculating actual rate of heat delivery across the spatial points, calculating heat delivery

rate difference between target value and actual rate of heat delivery, calculating target flow rate, calculating target pumping rate, calculating target temperature and adapting flow rate of the fluid for managing the rate of heat delivery in the hydronic system **300/360/370/200**. The instructions stored in the memory **354** are used by the processing module **352** to manage the rate of heat delivery to the hydronic system **300/360/370/200** as will be explained in further detail later.

[0064] The control unit **350** also includes an input/output module **364** (hereinafter referred to as an 'I/O module **364**') and at least one communication module such as a communication module **366**. In an embodiment, the I/O module **364** may include mechanisms configured to receive inputs from and provide outputs to the user of the control unit **350**. For example, the I/O module **364** is configured to receive user input from the user **102** related to temperature requirements, rate of heat delivery, time settings, etc. To that effect, the I/O module **364** may include at least one input interface and/or at least one output interface. Examples of the input interface may include, but are not limited to, a keyboard, a mouse, a joystick, a keypad, a touch screen, soft keys, a microphone, and the like. Examples of the output interface may include, but are not limited to, a display such as a light emitting diode display, a thin-film transistor (TFT) display, a liquid crystal display, an active-matrix organic light-emitting diode (AMOLED) display, a microphone, a speaker, a ringer, a vibrator, and the like.

[0065] In an example embodiment, the processing module **352** may include I/O circuitry configured to control at least some functions of one or more elements of the I/O module **364**, such as, for example, a speaker, a microphone, a display, and/or the like. The processing module **352** and/or the I/O circuitry may be configured to control one or more functions of the one or more elements of the I/O module **364** through computer program instructions, for example, software and/or firmware, stored on a memory, for example, the memory **354**, and/or the like, accessible to the processing module **352**.

[0066] The communication module **366** may include communication circuitry such as for example, a transceiver circuitry including antenna and other communication media interfaces to connect to a wired and/or wireless communication network. The communication circuitry may, in at least some example embodiments, enable transmission of data signals and/or reception of signals from other network entities, such as the database **116** (shown in FIG. **1**) or other systems configured to maintain real-time information related to temperature and flow.

[0067] In at least one example embodiment, the communication module **366** is configured to (1) receive temperature from two spatially separated points (i.e., a first temperature T_1 and a second temperature T_2) in the hydronic system **200/300/360**, (2) receive a flow rate f of a fluid at the inlet **305***a* of a heat transfer device **310** and (3) receive a temperature requirement for conditioning an enclosure, for example an indoor space either from the user (i.e., the user input) or the thermostat **216**. For example, the communication module **366** may receive sensor data (e.g., temperature measurements and flow rates) from other systems configured to measure temperature/flow rate in real-time or from a database that stores near real-time information as recorded by other devices/systems coupled to the hydronic system **200/300/360**. The communication module **366** may be configured to forward the temperature measurements T_1, T_2, the flow rate and the temperature requirements for the enclosure to the processing module **352**. The modules of the processing module **352** in conjunction with the instructions stored in the memory **354** may be configured to process the sensor data and the temperature requirements and adapt one or more parameters (e.g., target first temperature, temperature difference, flow rate, etc.,) of components in the hydronic system **200/300/360** for managing the rate of heat delivery in the hydronic system **300/360**.

[0068] In at least one embodiment, the processing module **352** includes a data monitoring engine **356** and a heat transfer management engine **358**. The modules of the processing module **352** may be implemented as software modules, hardware modules, firmware modules or as a combination thereof. Moreover, it shall be noted that the components are shown for exemplary purposes and the control unit **350** may include fewer or additional modules than those depicted in FIG. **3**.

[0069] In one embodiment, the data monitoring engine **356** in conjunction with the instructions in the memory **354** is configured to monitor sensor data and the temperature requirements for the enclosure. In one embodiment, the engine **356** is configured to monitor temperature requirements or changes in temperature in the enclosure to determine a target rate of heat delivery Q_t to the heat transfer device **310**. In an illustrative example, thermal readings from the thermostat **216** are monitored to determine any change in conditioning of the enclosure. Further, the heat transfer management engine **358** is configured to calculate a target rate of heat delivery Q_t based on the temperature requirements of the enclosure. In addition, the engine **356** is configured to monitor operating temperatures T_1, T_2 across two spatially separated points i.e., temperature of the fluid across two different points. The two spatially separated points (e.g., a first point P_1 and a second point P_2) correspond to different ends of a device/component across which the rate of heat delivery is to be monitored and regulated. For example, if the rate of heat delivery across the heat transfer device **310** is to be managed, temperature T_1 of the fluid at the inlet **305***a* of the heat transfer device **310** (i.e., first point P_1) and temperature T_2 at the outlet **305***b* of the heat transfer device **310** (i.e., second point P_2), are measured. Further, the data monitoring engine **356** is configured to monitor the flow rate f of the fluid at the inlet **305***a* of the heat transfer device **310**. The sensor data are continuously monitored for determining optimal parameters so as to regulate the rate of heat delivery in the hydronic system **300/360**. For example, any difference between an actual rate of heat delivery and the target rate of heat delivery in the hydronic system **300/360** initiates adaptation of system parameters (e.g., flow rate, temperature) to achieve the target rate of heat delivery in the hydronic system **300/360**.

[0070] In one embodiment, the heat transfer management engine **358** in conjunction with the instructions in the memory **354** is configured to manage the rate of heat delivery in the hydronic system **300/360/370** at an optimal rate i.e., the desired rate of heat delivery for fuel efficiency. To that effect, the heat transfer management engine **358** is configured to determine the actual rate of heat delivery by the fluid to the heat transfer device **310** at predefined intervals as shown below by Equation (1).

$$Q_A = \frac{dq}{dt} = kf\Delta T \quad \text{Equation (1)}$$

where,

k is the heat capacity per volume of the fluid, and

$$\frac{dq}{dt}$$

is the rate of heat delivery to the hydronic system

$$\Delta T = T_1 - T_2$$

[0071] The heat transfer management engine **358** is configured to compare an actual rate of heat delivery Q_A with the target rate of heat delivery Q_T to calculate a heat delivery rate difference Q_D ($Q_D = Q_T - Q_A$). This delivery rate difference Q_D is used to adapt one or more parameters of the hydronic system **300**/**360**/**370** that affect the heat transfer, for example, flow rate of the fluid f, temperatures T_1/T_2. In one embodiment, the heat transfer management engine **358** is configured to adapt the flow rate f of the fluid in the hydronic system **300**. Accordingly, the heat transfer management engine **358** is configured to calculate a target flow rate f_t for the fluid based on the heat delivery rate difference Q_D.

[0072] Referring back to FIG. **3**A, the target flow rate f_t is used to adapt operation of the flow modulator **330** to achieve the desired rate of heat delivery Q_T The flow modulator **330** is a control element including one or more control valves and coupled to the inlet **305***a* of the heat transfer device **310**. The heat transfer management engine **358** is configured to operate the one or more valves based on the target flow rate f_t to regulate the flow of the fluid via the flow modulator **330** so as to achieve the target rate of heat delivery Q_T.

[0073] In another embodiment, the heat transfer management engine **358** is configured to adapt temperature i.e., temperature T_1 or T_2 of the fluid to achieve or maintain the target rate of heat delivery Q_T To that effect, the flow rate f of the fluid flowing through the heat transfer device **310** has to be adapted. In one example, to adapt the temperature T_2 at the outlet **305***b* of heat transfer device **310** to a target first temperature T_{1t}, the heat transfer management engine **358** is configured to calculate a target flow rate f_t based on the target first temperature T_{1t}. Further, the heat transfer management engine **358** is configured to adapt the flow rate f of the fluid by operating the flow modulator **330** at the target flow rate f_t. As such, when the fluid flows at the target flow rate f_t through the heat transfer device **310**, the temperature of the fluid at the outlet **305***b* of the heat transfer device **310** reaches the target first temperature T_{1t}, thereby regulating the rate of heat delivered to the hydronic system **300** at the target rate of heat delivery Q_T.

[0074] Referring now to FIG. **3**B in conjunction with FIG. **4**, the heat transfer management engine **358** is configured to adapt the flow rate f of the fluid by operating a pump **365** at a target pumping rate P_t. The pump **365** is a control element that is configured to pump fluid from the storage tank **320** to the inlet **305***a* of the heat transfer device **310**. More specifically, the heat transfer management engine **358** calculates the target pumping rate P_t based on the heat delivery rate difference Q_D. During use, when the pump **365** is operated at the target pumping rate P_t, the flow rate f of the fluid is adapted to reach the target rate of heat delivery Q_T.

[0075] Alternatively, the heat transfer management engine **358** is configured to operate the pump **365** at the target pumping rate P_t to achieve the target first temperature T_{1t} at the outlet **305***b* of the heat transfer device **310**. More specifically, the target pumping rate P_t is calculated based on the target first temperature Tu. When the heat transfer management engine **358** detects the heat delivery rate difference Q_D, the target first temperature T_{1t} is calculated based on the difference Q_D. Thereafter, the pump **365** is operated at the target pumping rate P_t to adapt the temperature T_2 to the target first temperature T_{1t}. Simultaneously, adapting the temperature T_2 to the target first temperature T_{1t}, adapts the actual rate of heat delivery Q_A to the target rate of heat delivery Q_T.

[0076] It is noted that the management of the rate of heat delivery is explained herein by adapting parameters such as, pumping rate, flow rate, target first temperature to adjust a component as they affect the rate of heat delivered to the hydronic system **300**/**360**/**370**. However, it is noted that the rate of heat delivery can be adapted to the target rate of heat delivery by adapting other parameters associated with other components, for example, temperature difference, input temperature, and the like.

[0077] In an embodiment, various components of the control unit **350**, such as the processing module **352**, the memory **354**, the I/O module **364** and the communication module **366** are configured to communicate with each other via or through a centralized circuit system **368**. The centralized circuit system **368** may be various devices configured to, among other things, provide or enable communication between the components of the control unit **350**. In certain embodiments, the centralized circuit system **368** may be a central printed circuit board (PCB) such as a motherboard, a main board, a system board, or a logic board. The centralized circuit system **368** may also, or alternatively, include other printed circuit assemblies (PCAs) or communication channel media.

[0078] FIG. **3**C is a simplified block diagram representation of a hydronic system **370**, in accordance with yet another embodiment of the invention. The hydronic system **370** includes a smart hydronic emitter **371**. The components of the smart hydronic emitter **371** are configured to dynamically measure and manage rate of heat delivery across the heat transfer device **310**. The smart hydronic emitter **371** includes one or more sensors (e.g., a first temperature sensor **372**, and a second temperature sensor **374**) to monitor temperature (T_1, T_2) at two spatially separated points P_1, P_2, respectively (a first point P_1, and a second point P_2), a flow sensor **376** to measure flow rate f of the fluid across the spatially separated points P_1, P_2, the heat transfer device **310**, the pump **365** and the control unit **350**. The operation of the smart hydronic emitter **371** to control operations of the hydronic system **370** for managing the rate of heat delivery is explained with reference to FIG. **5**.

[0079] The various steps and/or operations of the flow diagram, and combinations of steps/operations in the flow diagram, may be implemented by, for example, hardware, firmware, a processor, circuitry and/or by an apparatus such as the control unit **350** explained with reference to FIGS. **1** to **4**. The method **500** starts at **502**.

[0080] At **502**, the control unit **350** receives sensor data. More specifically, the control unit **350** receives temperature

information (T_1, T_2) from two temperature sensors (see, sensors **372**, **374** in FIG. **3**C) spatially separated in the hydronic system **370**. In general, the temperature measurements are taken across a device/component in the hydronic system **370** in which rate of heat transfer has to be reduced. Further, flow rate f of the fluid across the spatially separated points (P_1, P_2) i.e., the heat transfer device **310** is sensed by a sensor (see, the flow sensor **376** in FIG. **3**C). Therefore, the sensor data includes temperature information (T_1, T_2) and flow rate f of the fluid in the hydronic system **370**. It shall be noted that the sensor data can be received from external sources, for example, databases or third party sources that continuously monitor such information for the hydronic system **370**.

[0081] At **503**, the control unit **350** receives thermal requirements for conditioning an enclosure, for example, an indoor space. The thermal requirements may either be determined based on user input (i.e., temperature setting) or thermostat readings.

[0082] At **504**, the control unit **350** calculates a target rate of heat delivery Q_T for optimal functioning of the hydronic system **370** based on the thermal requirements for effective management and performance of the hydronic system **370**.

[0083] At **506**, the control unit **350** calculates the actual rate of heat delivery Q_A. At **508**, the control unit **350** is configured to compare the actual rate of heat delivery Q_A with the target rate of heat delivery Q_T. If the actual rate of heat delivery is equal to the target rate of heat delivery i.e., $Q_A=Q_T$, the control unit **350** performs no computations and continuously monitors the sensor data at predefined intervals (e.g., every 5 minutes) to determine if there are any differences between the actual rate of heat delivery Q_A and the target rate of heat delivery Q_T.

[0084] At **510**, the control unit **350** is configured to calculate heat delivery rate difference Q_D. If the actual rate of heat delivery is greater than the target rate of heat delivery i.e., $Q_A>Q_T$ or if the actual rate of heat delivery is lesser than the target rate of heat delivery i.e., $Q_A<Q_T$, the control unit **350** determines the heat delivery rate difference $Q_D=Q_A-Q_T$.

[0085] At **512**, the control unit **350** is configured to adapt flow rate f based on heat delivery rate difference Q_D. The control unit **350** is configured to control operations of one or more components (e.g., flow modulator, pump) in the hydronic system **370** to regulate the rate of heat delivery such that $Q_A=Q_T$ based on the heat delivery rate difference Q_D. In one embodiment, the control unit **350** controls a flow modulator (e.g., the flow modulator **330**) by performing steps **514**-**516**. In another embodiment, the control unit **350** controls operations of a pump by performing steps **518**-**520** or steps **522**-**526**.

[0086] At **514**, the control unit **350** is configured to calculate target flow rate f_t based on the heat delivery rate difference Q_D. At **516**, the control unit **350** is configured to operate a flow modulator based on target flow rate f_t.

[0087] At **518**, the control unit **350** is configured to calculate target pumping rate P_t based on the heat delivery rate difference Q_D. At **520**, the control unit **350** is configured to operate the pump based on the target pumping rate P_t.

[0088] At **522**, the control unit **350** is configured to calculate a target first temperature T_{1t} based on the heat delivery rate difference Q_D. At **524**, the control unit **350** is configured to calculate a target pumping rate P_t based on the target first temperature T_{1t}. At **526**, the control unit **350** is configured to operate the pump based on the target pumping rate P_t.

[0089] The sequence of operations of the method **500** need not be necessarily executed in the same order as they are presented. Further, one or more operations may be grouped together and performed in form of a single step, or one operation may have several sub-steps that may be performed in parallel or in a sequential manner.

[0090] FIG. **6** illustrates a flow diagram of a method **600** for managing the rate of heat delivery in the hydronic system **300**/**360**/**370**, in accordance with an example embodiment of the present disclosure. The various steps and/or operations of the flow diagram, and combinations of steps/operations in the flow diagram, may be implemented by, for example, hardware, firmware, a processor, circuitry and/or by an apparatus such as the control unit **350** explained with reference to FIGS. **1** to **4** and/or by a different device associated with the execution of software that includes one or more computer program instructions. The method **600** starts at **602**.

[0091] At operation **602**, the method **600** includes receiving, by a control unit, at least a first temperature (T_1) and a second temperature (T_2) from two spatially separated points in the hydronic system **300**/**360**/**370**. The control unit **350** monitors the temperature at the two spatially separated points for managing the rate of heat delivery in the hydronic system **300**/**360**/**370**. In other words, temperature measurements (T_1, T_2) are used to control the rate of heat delivery across the two spatially separated points. In one embodiment, the two spatially separated points correspond to the inlet of the heat transfer device and outlet of the heat transfer device, respectively. In general, a temperature difference across ends of the heat transfer device is determined. It shall be apparent that temperature measurements can be made across any device or component of the hydronic system **300**/**360**/**370** for managing the rate of heat delivery in the hydronic system **200**. In one embodiment, the hydronic system **370** includes sensors (e.g., sensors S**1**, S**2**) to sense the temperature at respective points. For example, sensor S**1** measures temperature at the inlet of the heat transfer device and the sensor S**2** measures temperature at the outlet of the heat transfer device. In another embodiment, the temperature measurements (T_1, T_2) may be obtained from external sources, for example, devices/systems capable of measuring temperatures (T_1, T_2) at two spatially separated points.

[0092] At operation **604**, the method **600** includes receiving, by the control unit, a flow rate 'f' of fluid pumped from the storage tank to the inlet of the heat transfer device. In one embodiment, the flow rate 'f' of the fluid may be sensed by a flow sensor. In some cases, a flow sensor may be omitted in favor of pre-calibration of the pump. In other words, the pump speed control provides sufficiently accurate knowledge of the flow rate 'f' of the fluid and may not require the use of the flow sensor.

[0093] At operation **606**, the method **600** includes calculating, by the control unit, at a predefined interval a temperature difference between the two spatially separated points in the hydronic system **300**/**360**/**370** based, at least in part on, the first temperature and the second temperature. The change in temperature ΔT affects the rate of heat delivery in hydronic systems and can be determined based on measured temperatures at respective points. To that effect, the change in temperature $\Delta T=T_1-T_2$ across the

spatially separated points is calculated as the temperature difference between the temperatures measured at corresponding points. As such, the control unit **350** is configured to read sensor data (i.e., temperature T_1, T_2 and flow rate f) at predefined intervals, for example, every 2 minutes for managing the rate of heat delivery in the hydronic system **300/360/370**. However, it shall be apparent that depending on application or configuration, the control unit **350** may continuously monitor parameters of the hydronic system **300/360/370** for dynamically managing the rate of heat delivery in the hydronic system **300/360/370**.

[0094] At operation **608**, the method **600** includes calculating, by the control unit, at the predefined interval an actual rate of heat delivery to the heat transfer device based, at least in part, on the flow rate f and the temperature difference ΔT. For example, measurement off and ΔT can determine the rate of heat delivery to (or from) the hydronic system or sub-system in real (or near-real) time as shown below in equations (2), (3) and (4).

$$\frac{dq}{dt} \alpha f \quad \text{Equation (2)}$$

$$\frac{dq}{dt} \alpha (T_1 - T_2) \quad \text{Equation (3)}$$

$$Q = \frac{dq}{dt} = kf(T_1 - T_2) \quad \text{Equation (4)}$$

where,

k is the heat capacity per volume of the fluid, and

$$\frac{dq}{dt}$$

is the rate of heat delivery to the hydronic system.

[0095] In one non-limiting example, if the fluid flow rate f is 0.33 gallons per minute and fluid temperatures (T_1, T_2) at the two spatially separated points are 140° F. and 80° F. and assuming the fluid to be water, the heat capacity is 8.33 BTU/gallon. The actual rate of heat delivery Q_A is 9900 BTU/hour (Q_1=8.33 BTU/gallon*0.33 gallon/minute*(140° F.−80° F.)*60 minute/hour=9900 BTU/hour).

[0096] At operation **610**, the method **600** includes determining, by the control unit, at the predefined intervals a heat delivery rate difference between the actual rate of heat delivery and a target rate of heat delivery. The actual rate of heat delivery Q_A corresponds to rate of heat delivered at a current instant in the hydronic system and the target rate of heat delivery Q_T corresponds to a desired rate of heat delivery in the hydronic system **300**. In one embodiment, the target rate of heat delivery Q_T may be determined based on a thermostat input that manages temperature requirements for conditioning an enclosure, such as, a house. Alternatively, the user can provide user inputs to provide a desired temperature in the enclosure and the target rate of heat delivery Q_T is determined based on the temperature requirements for maintenance of optimal working, fuel efficiency and cost reductions. For example, the user may preset the rate of heat delivery (i.e., target rate of heat delivery Q_T) at 9,500 BTU/hr to optimize usage of fuel in the hydronic system **200**. In one example, if the actual rate of heat delivery (Q_A) is 9,900 BTU/hr, the heat delivery rate difference Q_d is 400 BTU/hr (d=9,900-9,500 BTU/hr=400 BTU/hr).

[0097] At operation **612**, the method **600** includes adapting, by the control unit, at least the flow rate of fluid into the inlet of the heat transfer device based, at least in part, on the heat delivery rate difference Q_d to maintain the target rate of heat delivery Q_T in the heat transfer device. As seen from equation 3, the actual rate of heat delivery Q_A can be regulated to the target rate of heat delivery Q_T by adapting parameters, for example, flow rate for temperatures T_1, T_2. In one embodiment, a target flow rate f_t for maintaining the target rate of heat delivery Q_T is calculated based on the heat delivery rate difference Q_d for adapting the flow rate f More specifically, a flow modulator is configured at the inlet of heat transfer device for modulating/controlling the flow rate of the fluid into the inlet of the heat transfer device. The flow modulator includes one or more valves that may be controlled by a control circuit, for example, the control unit **350** for regulating the rate of heat delivery in the hydronic systems **300/360/370**. Accordingly, the control unit **350** is configured to operate the flow modulator or the valves in the flow modulator to achieve the target flow rate f_t. In another embodiment, the control unit **350** calculates a target pumping rate P_t for achieving the target rate of heat delivery Q_T The target pumping rate P_t is used to adapt the flow rate into the inlet of the heat transfer device by operating a pump that pumps fluid from the storage tank to the heat transfer device.

[0098] As already explained, input/output temperatures (T_1, T_2) at the inlet/outlet of the heat transfer device or temperature difference may be adapted to maintain the target rate of heat delivery Q_t. As such, for adapting the temperature T_2 at the outlet of the heat transfer device, the flow rate f in the heat transfer device has to be suitably adapted. In one embodiment, a target first temperature T_{1t} for achieving the target rate of heat delivery Q_t is calculated by the control unit **350**. The target first temperature T_{1t} is used for calculating the target flow rate f_t into the inlet of the heat transfer device and the flow modulator is suitably adapted based on the target flow rate f_t. Alternatively, a target pumping rate P_t for achieving the target rate of heat delivery Q_T is calculated based on the target first temperature T_{1t}. Thereafter, a pumping rate of the pump is adapted to the target pumping rate P_t for achieving the target rate of heat delivery Q_T. It shall be noted that adapting the parameters that affect the rate of heat delivery (e.g., flow rate f, temperatures T_1, T_2) is an iterative process that requires continuous monitoring of the parameters and dynamically adapting them to achieve the target rate of heat delivery.

[0099] FIG. **7** illustrates a block diagram representation of a server system **700** capable of implementing at least some embodiments of the present disclosure. The server system **700** is configured to host and manage the application **114** that is provided to an electronic device such as the device **104**, in accordance with an example embodiment of the disclosure. An example of the server system **700** is the server system **108** shown and described with reference to FIG. **1**. The server system **700** includes a computer system **705** and a database **710**.

[0100] The computer system **705** includes at least one processor **715** for executing instructions. Instructions may be stored in, for example, but not limited to, a memory **720**. The processor **715** may include one or more processing units (e.g., in a multi-core configuration).

[0101] The memory **720** is a storage device embodied as one or more volatile memory devices, one or more non-volatile memory devices, and/or a combination of one or more volatile memory devices and non-volatile memory devices, for storing micro-contents information and instructions. The memory **720** may be embodied as magnetic storage devices (such as hard disk drives, floppy disks, magnetic tapes, etc.), optical magnetic storage devices (e.g., magneto-optical disks), CD-ROM (compact disc read only memory), CD-R (compact disc recordable), CD-R/W (compact disc rewritable), DVD (Digital Versatile Disc), BD (Blu-ray® Disc), and semiconductor memories (such as mask ROM, PROM (programmable ROM), EPROM (erasable PROM), flash ROM, RAM (random access memory), etc.).

[0102] The processor **715** is operatively coupled to a communication interface **725** such that the computer system **705** is capable of communicating with a mobile device, for example, the device **104** or communicates with any entity within the network **106** via the communication interface **725**.

[0103] The processor **715** may also be operatively coupled to the database **710**. The database **710** is any computer-operated hardware suitable for storing and/or retrieving data, such as, but not limited to, the user input, the temperature data, the load data, data obtained during operation of the system **200**/**300** and the like. The database **710** may include multiple storage units such as hard disks and/or solid-state disks in a redundant array of inexpensive disks (RAID) configuration. The database **710** may include a storage area network (SAN) and/or a network attached storage (NAS) system.

[0104] In some embodiments, the database **710** is integrated within the computer system **705**. For example, the computer system **705** may include one or more hard disk drives as the database **710**. In other embodiments, the database **710** is external to the computer system **705** and may be accessed by the computer system **705** using a storage interface **730**. The storage interface **730** is any component capable of providing the processor **715** with access to the database **710**. The storage interface **730** may include, for example, an Advanced Technology Attachment (ATA) adapter, a Serial ATA (SATA) adapter, a Small Computer System Interface (SCSI) adapter, a RAID controller, a SAN adapter, a network adapter, and/or any component providing the processor **715** with access to the database **710**.

[0105] The processor **715** is communicably coupled with the memory **720** and the communication interface **725**. The processor **715** is capable of executing the stored machine executable instructions in the memory **720** or within the processor **715** or any storage location accessible to the processor **715**. The processor **715** may be embodied in a number of different ways. In an example embodiment, the processor **715** may be embodied as one or more of various processing devices, such as a coprocessor, a microprocessor, a controller, a digital signal processor (DSP), processing circuitry with or without an accompanying DSP, or various other processing devices including integrated circuits such as, for example, an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), a microcontroller unit (MCU), a hardware accelerator, a special-purpose computer chip, or the like. The processor **715** performs various functionalities of the server system **700** as described herein.

[0106] The disclosed methods with reference to FIGS. **1** to **7**, or one or more operations of the flow diagrams **500** and **600** may be implemented using software including computer-executable instructions stored on one or more computer-readable media (e.g., non-transitory computer-readable media, such as one or more optical media discs, volatile memory components (e.g., DRAM or SRAM), or nonvolatile memory or storage components (e.g., hard drives or solid-state nonvolatile memory components, such as Flash memory components)) and executed on a computer (e.g., any suitable computer, such as a laptop computer, net book, Web book, tablet computing device, smart phone, or other mobile computing device). Such software may be executed, for example, on a single local computer or in a network environment (e.g., via the Internet, a wide-area network, a local-area network, a remote web-based server, a client-server network (such as a cloud computing network), or other such network) using one or more network computers. Additionally, any of the intermediate or final data created and used during implementation of the disclosed methods or systems may also be stored on one or more computer-readable media (e.g., non-transitory computer-readable media) and are considered to be within the scope of the disclosed technology. Furthermore, any of the software-based embodiments may be uploaded, downloaded, or remotely accessed through a suitable communication means. Such a suitable communication means includes, for example, the Internet, the World Wide Web, an intranet, software applications, cable (including fiber optic cable), magnetic communications, electromagnetic communications (including RF, microwave, and infrared communications), mobile communications, or other such communication means.

[0107] Various embodiments disclosed herein provide numerous advantages. More specifically, the embodiments disclosed herein suggest techniques for managing rate of heat delivery in hydronic systems. The control unit adapts parameters that affect the rate of heat delivery of the hydronic system to manage the rate of heat delivery. Various embodiments describe adapting different parameters based on a target rate of heat delivery so the rate of heat delivery is regulated to the target rate of heat delivery. Further, feedback to the hydronic system to adjust temperature, flow rate or temperature difference can be used to seek a targeted rate of heat delivery. Moreover, the control circuit ensures nominal performance levels of the hydronic system by establishing a balance of fluid flow and heat delivery for typical conditions. Such adaptation of the parameters of the hydronic system ensures efficient performance and fuel usage thereby reducing the costs associated with operating the hydronic system.

[0108] Various embodiments of the disclosure, as discussed above, may be practiced with steps and/or operations in a different order, and/or with hardware elements in configurations, which are different than those which are disclosed. Therefore, although the disclosure has been described based upon these exemplary embodiments, it is noted that certain modifications, variations, and alternative constructions may be apparent and well within the spirit and scope of the disclosure.

[0109] Although various exemplary embodiments of the disclosure are described herein in a language specific to structural features and/or methodological acts, the subject matter defined in the appended claims is not necessarily

limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as exemplary forms of implementing the claims.

What is claimed is:

1. A hydronic system, comprising:

a control unit for managing a rate of heat delivery across two spatially separated points in the hydronic system, the control unit comprising:

a communication module configured to:

receive at least a first temperature and a second temperature of a fluid from a first point and a second point, respectively in the hydronic system, wherein the first point and the second point correspond to the two spatially separated points; and

receive a flow rate of the fluid across the two spatially separated points;

a memory comprising stored instructions; and

a processing module communicably coupled to the memory and the communication module, the processing module configured to execute the stored instructions to cause the hydronic system to perform at least:

calculating an actual rate of heat delivery in the two spatially separated points based, at least in part, on flow rate and temperature difference of the fluid in the two spatially separated points;

determining a heat delivery rate difference between the actual rate of heat delivery and a target rate of heat delivery; and

adapting at least the flow rate of the fluid flowing between the two spatially separated points based, at least in part, on the heat delivery rate difference to maintain the target rate of heat delivery.

2. The hydronic system as claimed in claim **1**, wherein the first point corresponds to an inlet of a heat transfer device and the second point corresponds to an outlet of the heat transfer device.

3. The hydronic system as claimed in claim **2**, wherein for adapting at least the flow rate of the fluid between the two spatially separated points, the control unit is further configured to calculate a target flow rate based, at least in part, on the heat delivery rate difference.

4. The hydronic system as claimed in claim **3**, further comprising:

at least one flow modulator configured at the inlet of the heat transfer device, wherein the control unit is configured to adapt the flow rate of the fluid into the inlet of the heat transfer device based on the target flow rate.

5. The hydronic system as claimed in claim **2**, wherein for adapting at least the flow rate of the fluid between the two spatially separated points, the control unit is further configured to calculate a target pumping rate based, at least in part, on the heat delivery rate difference.

6. The hydronic system as claimed in claim **5**, further comprising:

at least one pump operatively coupled to a storage tank for pumping the fluid from the storage tank to the heat transfer device, wherein the control unit is configured to modify a pumping rate of the at least one pump based on the target pumping rate.

7. The hydronic system as claimed in claim **2**, wherein for adapting at least the flow rate of the fluid between the two spatially separated points, the control unit is further configured to:

calculate a target first temperature at the outlet of the heat transfer device based, at least in part, on the heat delivery rate difference;

calculate a target pumping rate based, at least in part, on the target first temperature; and

operate at least one pump at the target pumping rate for adapting the flow rate of the fluid into the inlet of the heat transfer device, wherein the at least one pump is operatively coupled to a storage tank for pumping fluid from the storage tank to the heat transfer device.

8. The hydronic system as claimed in claim **2**, wherein the control unit is further configured to:

calculate a target first temperature at the outlet of the heat transfer device based, at least in part, on the heat delivery rate difference;

calculate a target flow rate based, at least in part, on the target first temperature; and

operate at least one flow modulator for adapting the flow rate of the fluid into the inlet of the heat transfer device based on the target flow rate, wherein the at least one flow modulator is configured at the inlet of the heat transfer device.

9. The hydronic system as claimed in claim **1**, wherein the target rate of heat delivery is based, at least in part, on temperature requirements for conditioning an enclosure.

10. A hydronic system, comprising:

a heat transfer device;

at least one pump operatively coupled to a storage tank for pumping fluid from the storage tank to the heat transfer device; and

a control unit operatively coupled to the heat transfer device and the at least one pump, wherein the control unit is configured to perform the following steps at predefined intervals:

receiving at least a first temperature and a second temperature from two spatially separated points in the hydronic system, wherein the first temperature corresponds to temperature of the fluid entering an inlet of the heat transfer device and the second temperature corresponds to temperature of the fluid leaving an outlet of the heat transfer device;

receiving a flow rate of the fluid in the heat transfer device;

calculating a temperature difference between the two spatially separated points in the hydronic system based, at least in part on, the first temperature and the second temperature;

calculating an actual rate of heat delivery in the heat transfer device based, at least in part, on the flow rate and the temperature difference;

determining a heat delivery rate difference between the actual rate of heat delivery and a target rate of heat delivery;

calculating a target pumping rate based, at least in part, on the heat delivery rate difference; and

operating the at least one pump at the target pumping rate for adapting at least the flow rate of the fluid into the inlet of the heat transfer device to maintain the target rate of heat delivery in the heat transfer device.

11. The hydronic system as claimed in claim **10**, wherein for calculating the target pumping rate, the control unit is further configured to:

calculate a target first temperature at the outlet of the heat transfer device based, at least in part, on the heat delivery rate difference; and

calculate the target pumping rate for operating the at least one pump based, at least in part, on the target first temperature.

12. The hydronic system as claimed in claim **10**, wherein a first sensor measures the first temperature and a second sensor measures the second temperature at the two spatially separated points.

13. The hydronic system as claimed in claim **10**, wherein the flow rate of the fluid is measured by a flow sensor configured at the outlet of the heat transfer device.

14. The hydronic system as claimed in claim **10**, wherein the heat transfer device is at least one of:

hydronic panels;

radiators;

air handler; and

radiant floor.

15. A method for controlling rate of heat delivery in a hydronic system, the method comprising:

receiving, by a control unit, at least a first temperature and a second temperature from two spatially separated points in the hydronic system, wherein the two spatially separated points correspond to an inlet of a heat transfer device and an outlet of the heat transfer device;

receiving, by the control unit, a flow rate of fluid in the heat transfer device;

calculating at a predefined interval, by the control unit, a temperature difference between the two spatially separated points in the hydronic system based, at least in part, on the first temperature and the second temperature;

calculating at the predefined interval, by the control unit, an actual rate of heat delivery to the heat transfer device based, at least in part, on the flow rate and the temperature difference;

determining at the predefined interval, by the control unit, a heat delivery rate difference between the actual rate of heat delivery and a target rate of heat delivery; and

adapting, by the control unit, at least the flow rate of the fluid into the inlet of the heat transfer device based, at least in part, on the heat delivery rate difference to maintain the target rate of heat delivery in the heat transfer device.

16. The method as claimed in claim **15**, wherein adapting at least the flow rate of the fluid into the inlet of the heat transfer device comprises:

calculating, by the control unit, a target flow rate based, at least in part, on the heat delivery rate difference.

17. The method as claimed in claim **16**, further comprising:

adapting, by the control unit, the flow rate of the fluid based on the target flow rate, wherein at least one flow modulator is configured at the inlet of the heat transfer device for adapting the flow rate.

18. The method as claimed in claim **15**, wherein adapting at least the flow rate of the fluid into the inlet of the heat transfer device further comprises:

calculating, by the control unit, a target pumping rate for operating at least one pump based, at least in part, on the heat delivery rate difference.

19. The method as claimed in claim **18**, further comprising:

operating, by the control unit, the at least one pump at the target pumping rate for adapting the flow rate of the fluid into the inlet of the heat transfer device, wherein the at least one pump is operatively coupled to a storage tank for pumping the fluid from the storage tank to the heat transfer device.

20. The method as claimed in claim **15**, further comprising:

calculating, by the control unit, a target first temperature at the outlet of the heat transfer device based, at least in part, on the heat delivery rate difference;

calculating, by the control unit, a target pumping rate for operating at least one pump based, at least in part, on the target first temperature; and

operating, by the control unit, the at least one pump at the target pumping rate for adapting the flow rate of the fluid into the inlet of the heat transfer device, wherein the at least one pump is operatively coupled to a storage tank for pumping the fluid from the storage tank to the heat transfer device.

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