

Controlling a booster pump in a distributed-pump hydronic heating or cooling system

TECHNICAL FIELD

The present invention relates to distributed-pump hydronic systems for heating or cooling that include multiple pumps. In particular, the present invention relates to a method for controlling a booster pump in such a system and to a pump configured to perform such control.

BACKGROUND

10 In hydronic systems with distributed pumps, multiple pumps are used to pump fluid through the system. For example, in such a distributed pump setting, pumps may be used in a hydronic system for controlling air temperatures in air handling units (AHUs) or for local pressure control for supplying branches of fan coils (FCs), chilled beams, or radiators. The hydronic system may carry a cooling load, hence chilled water may be pumped from a chiller bank to various terminal units. Distributed pumps are also used in heating systems, where water is heated by a boiler or through a heat exchanger and is fed to heating units such as AHUs or radiators by the distributed pump setup. Further examples of hydronic systems include district energy systems.

20 Hydronic systems for heating or cooling typically include a supply line for feeding fluid from a source, e.g. from a chiller bank, a boiler or a heat exchanger, to various parts of a building or of another structure to be heated or cooled or otherwise to various consumers. Similarly, the system typically includes a return line for returning fluid to the source. The system typically further includes a plurality of branch lines that fluidly connect respective terminal units, such as air handling units, fan coils, radiators or the like, with the main supply line and the return line, respectively. Branch pumps are typically installed in the branch lines for feeding fluid through the respective terminal units. In the case of a district energy system, the terminal units may be substations, such as individual houses, flat stations or the like.

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In heating installations or other hydronic systems of large buildings or other complex constructions, a multitude of pumps may be installed in order to reliably supply the individual parts of the installation with fluid or heat. If a multitude of such pumps cooperate in an installation, be it by way of parallel connection, series connection or a
5 combination thereof, then a complex hydraulic network results. It may thus be a challenging task to operate these pumps such that, as a sum, they run in an at least approximately energy-optimized manner.

It is thus generally desirable to provide a system that is suitable even for large buildings
10 or other structures, such as airports, large healthcare facilities, large office or research facilities, hotels, large apartment complexes buildings etc.

It is further generally desirable to provide a system that facilitates retrofitting and/or expansion of existing installations.

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In a distributed pump system, it is beneficial to use maintenance free pumps at the AHUs and the FCs, such as canned centrifugal pumps. Maintenance free pumps are beneficial in such installations as there are many of them and they are distributed throughout the system. Accordingly, if pumps are employed that do require regular
20 maintenance, maintenance procedures for such pumps tend to be complicated. However, maintenance-free pumps often have a limited flow and pressure range. In particular, the pressure range can be a problem at the branches in large systems, hence other types of pumps, which may require maintenance, are often required in prior art systems, which in turn increases maintenance costs.

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WO2011088983A1 discloses a distributed pump system including branch pumps and additional booster or pilot pumps, which support the branch pumps, because they allow the pressure increase along a supply line to be distributed. This prior art system proposes communication of dedicated signals between the branch- and booster-pumps
30 in order to ensure energy-optimal operation of the combined pump system. While facilitating a reduction of the maintenance costs, the above prior art system requires setting up communication between the pumps, which is often complicated and time

consuming, in particular in large buildings or structures, and therefore can be a barrier for using booster pumps in a distributed pump setup.

SUMMARY

5 Thus, it remains desirable to provide a hydronic system that solves one or more of the above problems and/or that has other benefits, or that at least provides an alternative to existing solutions. In particular, it is desirable to provide distributed control of the pumps of a distributed-pump hydronic heating or cooling system, in particular of the booster pumps of such a system, without the need for communication between the
10 pumps or communication to a SCADA or BMS system.

According to one aspect, disclosed herein are embodiments of a hydronic system for heating and/or cooling a target structure, the system comprising:

- at least one supply line,
- 15 - at least one return line,
- a plurality of branch lines, each branch line fluidly connecting at least one terminal unit with the supply line or with the return line,
- a plurality of branch pumps, each configured to pump fluid through a respective one of the plurality of branch lines,
- 20 - at least one booster pump configured to pump fluid through the supply line or the return line, the at least one booster pump being arranged in series with one or more of the plurality of branch pumps, the at least one booster pump being operable at a controllable booster pump speed, wherein the booster pump speed is controllable to be larger than a minimum booster pump speed,
- 25 wherein the at least one booster pump comprises a booster pump controller configured to:
 - receive one or more pressure sensor signals indicative of a differential pressure between the supply line and the return line,
 - 30 - determine a booster pump control error indicative of a difference between a reference pressure and the differential pressure,

- stop pump operation of the booster pump responsive to the booster pump operating at the minimum booster pump speed and the differential pressure exceeding the reference pressure.

5 Accordingly, the system provides a distributed pump control where the booster pumps are controlled individually without the need for communication with the other booster pumps, with the branch pumps or with a central system for being able to perform an efficient pump control. Stopping the pump operation responsive to the booster pump operating at the minimum booster pump speed and the differential pressure exceeding
10 the reference pressure prevents the booster pump from unnecessarily pushing fluid through the branch pumps it supports, without the need for the booster pump to receive any communication about the status of the branch pump. The pumps are hydraulically interconnected via the supply, return and branch lines, and this hydraulic interconnection is sufficient for a suitable operation and control of the booster pumps,
15 thereby providing a simple and low-cost installation and/or commissioning of the system. It will be appreciated that, in some embodiments, it may be desirable to provide such communication for other purposes, but such communication is not necessary for the purpose of controlling the booster pumps.

20 Embodiments of the system allows a distributed pump control to be efficiently operated even in large buildings or other large systems, which thereby may benefit from the advantages of a distributed design, such as the provision of an auto-balanced system, energy savings and/or the ability to provide distributed control / intelligence.

25 In some embodiments, the booster pump controller is further configured to re-start pump operation of the booster pump responsive to the booster pump control error exceeding a predetermined pressure threshold, thereby providing a start/stop control of the pump that does not require any communicative connection to other pumps or to a central control system.

30 The supply line may be configured to transport fluid from a source, in particular a source of heated or cooled fluid, such as a chiller bank, a boiler, a heat exchanger, etc. to

respective parts of a building, of another structure or to respective nodes of a network of consumers. The branch lines branch off from the supply line and/or return line at respective branch or end points or are otherwise fluidly connected to the supply line and/or return line. The terminal units and the associated branch pumps are arranged in parallel with each other along the supply line and the return line. The use of booster pumps in the supply line and/or the return line, which are thus operated in series with one or more of the branch pumps, support the branch pumps, thereby facilitating the use of small centrifugal pumps as branch pumps while still allowing to supply even a large system. The use of centrifugal branch pumps, in particular, maintenance-free centrifugal pumps, such as canned centrifugal pumps, reduces maintenance costs.

As the system utilizes one or more booster pumps that support multiple branch pumps, a modular system design is facilitated. For example, various sections of a building can easily be supplied by corresponding groups of branch pumps and by accompanying one or more booster pumps. Similarly, an existing system can easily be retrofit by adding one or more booster pumps and/or expanded by adding a group of branch pumps with associated one or more booster pumps. For example, respective groups of floors, e.g. every five floors, in a building may have allocated a booster pump in the main supply line that supplies all floors. The booster pumps then support the respective group of floors they are allocated to.

Embodiments of the system further help to avoid starvation in remote branches of a system, in particular of large system and they facilitate utilization of maintenance-free, distributed pumps to operate in operational ranges that have high efficiency.

Generally, the branch pumps are those pumps of the system that are directly assigned to a terminal unit or a group of terminal units, i.e. pumps whose entry or exit is typically directly assigned to a terminal unit or group of terminal units. Generally, terminal units may be regarded as consumers of the hydronic system where thermal energy is exchanged between the liquid of the hydronic system and the target structure, in particular the air inside the target structure. Examples of a terminal unit include an AHU, an FC, a radiator, a substation of a district energy network, or the like. In the majority of

cases, the branch pumps are typically arranged upstream of the associated terminal unit, but they may however also lie downstream of the associated terminal unit, i.e. they are then branch pumps which connect to the terminal unit or group of terminal units at the suction side. In some embodiments, a branch pump may be directly assigned to a group of terminal units, e.g. to a bank of radiators arranged in parallel to one another. Branch pumps are thus all the pumps which directly connect to a terminal unit or group of terminal units, be it on the suction side or on the pressure side. The branch pumps are generally arranged in parallel with the other branch pumps. The branch pumps generally control a value related to the operation of the terminal unit they are associated with, such as a differential pressure, a temperature, a flow rate, etc., e.g. the air temperature of a heat exchanger or the pressure over a set of fan coils. A branch pump may be a pump that is directly connected to the input or output of a terminal unit without any other pump arranged in series between the branch pump and the terminal unit.

The booster pumps are arranged along the supply line or the return line from which the branch lines branch off or are otherwise fluidly connected to. Each of the booster pumps is arranged in series with at least one or more of the branch pumps. Booster pumps generally do not control the pressure over individual terminal units but rather the supply pressure to a set of one or more branch pumps. In embodiments with more than one booster pump, the booster pumps may be arranged in series with one or more other booster pumps. The at least one booster pump is operationally coupled to the supply line or the return line and is typically not assigned to a particular consumer but rather supports multiple branch pumps in respective branch lines. The booster pumps may thus be considered subordinate to the branch pumps. The booster pumps may be positioned in the supply line and/or the return line.

Generally, a pump suitable as a booster pump and/or as a branch pump may be a centrifugal pump or another suitable type of pump, in particular a speed-controllable centrifugal pump or another type of speed-controllable pump. A pump suitable as booster pump and/or as a branch pump may comprise an electric motor for driving the pump. The pump may further comprise a pump controller for controlling operation of

the pump, in particular for controlling a pump speed. The controllable pump speed may be the rotational speed of the pump, such as the speed of an impeller of the pump or the speed of the motor driving the impeller. The pump controller may include a frequency converter or a rotational speed controller as well as suitable control and regulation electronics.

The at least one booster pump is operable at a controllable booster pump speed, the controllable booster pump speed being controllable above a minimum booster pump speed, i.e. the booster pump may be operable at speeds above a minimum booster pump speed, which may be specific to a particular pump or a particular type of pump. The booster pump may be operable to create a minimum pressure when operating at the minimum booster pump speed and at zero fluid flow. In some embodiments, the pressure threshold used in the pump control may be selected to be at least said minimum pressure, i.e. equal to, or higher than, said minimum pressure, thereby avoiding pressure oscillations. However, in other embodiments other thresholds may be used, including e.g. a pressure threshold slightly smaller than the minimum pressure of the booster pump. It will be appreciated that each of the branch pump may also have a corresponding minimum branch pump speed and an associated minimum pressure.

In some embodiments, the booster pump controller is further configured to control the controllable booster pump speed during operation of the booster pump so as to reduce the booster pump control error, thereby providing a gradual pump control in addition to an ON/OFF control of the pump operation. For example, the booster pump controller may be configured to implement a proportional-integral (PI) controller for controlling the controllable booster pump speed, thus providing an efficient pump control.

In some embodiments, the system comprises at least one pressure sensor operatively connected to the booster pump controller and configured to provide said one or more pressure sensor signals, thereby providing accurate and, preferably, real-time input pressure sensor signals and facilitating reliable pump control. The at least one pressure sensor may comprise a differential pressure sensor for measuring the differential pressure between the supply and return lines, in particular between respective

measurement locations along the supply and return lines, and for providing a pressure sensor signal indicative of the measured differential pressure to the booster pump controller. Alternatively the at least one pressure sensor comprises at least two pressure sensors for measuring fluid pressures in the supply line and in the return line,
5 respectively. Accordingly, the booster pump controller may then be configured to determine the differential pressure from pressure sensor signals from the at least two pressure sensors. Generally, a differential pressure sensor may include capillary pipes connected to the respective measurement locations and a sensor for measuring a pressure difference between the capillary pipes. Alternatively, individual pressure
10 sensors may be arranged at the measurement locations where the sensors are electrically or otherwise communicatively connected so as to determine a differential pressure between the measurement locations.

The at least one pressure sensor may be directly or indirectly communicatively coupled
15 to the booster pump controller to allow the booster pump controller to receive the pressure sensor signal from the at least one pressure sensor. The coupling may be by a wired or wireless connection. In some embodiments at least one pressure sensor may be integrated into the booster pump.

20 From a control point of view, it is often beneficial to use a pressure measured at a measurement location displaced from the booster pump, e.g. at a measurement location along the supply line, which is downstream from the booster pump, as input to the pump controller. This may particularly be useful when the booster pump is installed at a large distance along the supply or return line from the branch or end points where
25 the branch lines with the branch pumps supported by the booster pump branch off the supply or return line. Accordingly, in some embodiments, the at least one pressure sensor may thus be arranged displaced from the booster pump, e.g. in a downstream direction along the supply line, e.g. proximal to a branch or end point where one of the branch lines branches off the supply or return line. On the other hand, from an
30 installation point of view, it may often be preferable to position the at least one pressure sensor in relative proximity to the booster pump, which is to receive and use the pressure sensor signal provided by the pressure sensor. This way, any wiring may be

kept short and signals may be less prone to be affected by communication noise or range-limitations of wireless communication. Accordingly, in some embodiments, the at least one pressure sensor is configured to provide one or more pressure sensor signals indicative of a measured differential pressure between respective measurement

5 locations along the supply line and the return line, and the booster pump controller is configured to determine a modified differential pressure from the measured differential pressure. The modified differential pressure may be indicative of an estimated differential pressure between respective locations along the supply line and the return line, one or both of which locations are displaced from the respective measurement

10 locations. The booster pump controller may thus be configured to use the determined modified differential pressure for controlling stop and re-start of the booster pump operation. Thereby, the pump control may be based on an estimated pressure value at a position displaced, e.g. downstream, from the booster pump, where the estimated pressure is determined based on a pressure measurement made in close proximity to

15 the booster pump. In particular, determining the modified differential pressure may be based on the measured differential pressure, on a loss parameter and on a determined fluid flow through the supply or return line, i.e. on a normally known design parameter of the system and on a quantity which the pump controller may estimate based on operational parameters of the pump that can easily be determined. For example, the

20 booster pump controller may be configured to estimate the fluid flow from one or more observable operational parameters of the booster pump.

In some embodiments, one or more of the branch pumps may also be controlled by a local control process, which does not require communication with the booster pump(s) or with other branch pumps, thereby providing a high degree of distributed control. To

25 this end, in some embodiments, at least one of the plurality of branch pumps is operable at a controllable branch pump speed, wherein the branch pump speed is controllable to be larger than a minimum branch pump speed. The at least one branch pump may comprise a branch pump controller configured to:

- 30 - receive one or more sensor signals indicative of a performance parameter, wherein performance of the pump affects the performance parameter in a first

- direction, in particular either increases or decreases the performance parameter,
- determine a branch pump control error indicative of a difference between a reference performance value and the performance parameter,
- 5 - stop pump operation of the branch pump responsive to the branch pump operating at the minimum branch pump speed and the performance parameter deviating from the reference performance value by more than a first threshold error in said first direction.
- 10 In some embodiments, the branch pump controller is further configured to re-start pump operation of the branch pump responsive to the performance parameter deviating from the reference performance value by more than a second threshold error in a second direction opposite the first direction.
- 15 The combination of the distributed control of the booster pumps and the distributed control of the branch pumps according to this embodiment has been found to provide a particular reliable and efficient distributed control of the hydronic system.
- Generally, operation of the branch pump, i.e. pumping fluid through the branch line and
- 20 associated terminal unit affects the control parameter in a one direction only, i.e. either increases or decreases the control parameter. Whether operation of the pump increases or decreases the control parameter depends on the control parameter and the type of hydronic system. For example, in a heating system, operation of a branch pump generally increases the return temperature from a radiator or other terminal unit.
- 25 Conversely, in a cooling system, operation of a branch pump generally decreases the return temperature from an AHU. This is because a pump can generally only control by applying positive pressure at the branch. The branch pump control error therefore is a signed number. Accordingly, when the performance parameter deviates from the reference performance value in the same direction as operation of the branch pump
- 30 alters the control parameter, the branch pump would need to lower its speed in order to reduce the absolute value of the branch pump control error. However, if the branch

pump already operates at its minimum speed, a further reduction of the branch pump speed is no longer possible.

5 In some embodiments, the branch pump controller is further configured to control the controllable branch pump speed during operation of the branch pump so as to reduce the branch pump control error, thereby providing a gradual pump control in addition to an ON/OFF control of the pump operation. In some embodiments, the branch pump controller is configured to implement a PI controller for controlling the controllable branch pump speed, thereby provide an efficient control.

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The branch pump(s) may be controlled based on a variety of control parameters, e.g. dependent on the desired control paradigm, existing system design, etc. In particular, in some embodiments, the performance parameter is chosen from the group of performance parameters consisting of: a fluid temperature of the fluid in the branch line
15 in a proximity of the branch pump, a fluid flow rate in the branch line in a proximity of the branch pump, a fluid pressure in the branch line in a proximity of the branch pump, an air temperature, an air flow temperature in an air handling unit, a differential air temperature, a differential fluid temperature, a differential pressure. It will be appreciated that other embodiments may use other performance parameters.

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The present disclosure relates to different aspects including the system described above and in the following, corresponding apparatus, systems, methods, and/or products, each yielding one or more of the benefits and advantages described in connection with one or more of the other aspects, and each having one or more embodiments corresponding to
25 the embodiments described in connection with one or more of the other aspects and/or disclosed in the appended claims.

In particular, according to another aspect, disclosed herein are embodiments of a pump for use as a booster pump of a hydronic system for heating and/or cooling a target
30 structure, the hydronic system comprising at least one supply line, at least one return line, a plurality of branch lines, each branch line fluidly connecting a terminal unit with the supply line or with the return line, and a plurality of branch pumps, each configured

to pump fluid through a respective one of the plurality of branch lines. The pump is configurable to pump fluid through the supply line or the return line when arranged in series with one or more of the plurality of branch pumps. The pump is operable at a controllable booster pump speed, wherein the booster pump speed is controllable to be
5 larger than a minimum booster pump speed.

Various embodiments of the pump comprise a pump controller configured to:

- receive one or more pressure sensor signals indicative of a differential pressure between the supply line and the return line,
- 10 - determine a booster pump control error indicative of a difference between a reference pressure and the differential pressure,
- stop pump operation of the pump responsive to the pump operating at the minimum booster pump speed and the differential pressure exceeding the reference pressure.

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Embodiments of the pump are suitable for operation in a hydronic system as disclosed herein, or otherwise. The pump controller may be or comprise a frequency converter or another suitable pump control circuit, in particular a control circuit for controlling a pump speed of the pump. Similarly, the branch pump controller of a branch pump may
20 comprise a frequency converter or another suitable pump control circuitry.

According to another aspect, disclosed herein are embodiments of a method for controlling operation of a booster pump of a hydronic system for heating and/or cooling a target structure, the hydronic system comprising at least one supply line, at least one
25 return line, a plurality of branch lines, each branch line fluidly connecting a terminal unit with the supply line or with the return line, a plurality of branch pumps, each configured to pump fluid through a respective one of the plurality of branch lines, and at least said booster pump, the booster pump being configured to pump fluid through the supply line or the return line, the booster pump being arranged in series with one or more of the
30 plurality of branch pumps, the booster pump being operable at a controllable booster pump speed, wherein the booster pump speed is controllable to be larger than a minimum booster pump speed. Various embodiments of the method comprise:

- receiving one or more pressure sensor signals indicative of a differential pressure between the supply line and the return line,
- determining a booster pump control error indicative of a difference between a reference pressure and the differential pressure,
- 5 - stopping pump operation of the booster pump responsive to the booster pump operating at the minimum booster pump speed and the differential pressure exceeding the reference pressure.

10 Embodiments of the method may be implemented by a pump controller of a booster pump or otherwise. For example, in embodiments where the booster pump controller of the booster pump comprises a frequency converter, embodiments of the method may be implemented by the digital frequency converter electronics of the frequency converter.

15 BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments will be described in more detail in connection with the appended drawings, where

- FIG. 1 schematically shows an embodiment of a hydronic system.
- 20 FIG. 2 schematically shows another embodiment of a hydronic system.
- FIG. 3 schematically illustrates an embodiment of a pump suitable as a booster pump or a branch pump in a hydronic system as disclosed herein
- FIG. 4 schematically shows a state diagram of an embodiment of a process for controlling a branch pump of a hydronic system.
- 25 FIG. 5 schematically shows a flow diagram of an embodiment of a process for controlling a branch pump of a hydronic system.
- FIG. 6 illustrates an example of pump curves for a centrifugal pump.
- FIG. 7 schematically shows a state diagram of an embodiment of a process for controlling a booster pump of a hydronic system.
- 30 FIG. 8 schematically shows a flow diagram of an embodiment of a process for controlling a booster pump of a hydronic system.
- FIG. 9 schematically shows another embodiment of a hydronic system.

FIGs. 10A-D illustrate simulation results of the operation of the system of FIG. 9 when controlled by an embodiment of the control process described herein.

DETAILED DESCRIPTION

- 5 FIG. 1 schematically shows an embodiment of a hydronic system generally designated by reference numeral 1, in particular a chilled water system. The system comprises a source 10, which in this embodiment may be a chiller bank for supplying chilled water or another suitable fluid, which is pumped to a number terminal units 40-1, 40-2 and 40-3, respectively. In the present example, terminal units 40-1 and 40-2 are air handling units
10 (AHUs) while terminal unit 40-3 is a group of fan coils (FC). However, it will be appreciated that alternative embodiments may include alternative or additional types of terminal units, such as chilled beams or radiators that may serve as cooling loads in addition or instead of the air handling units and/or fan coils. It will further be appreciated that the number of terminal units of a hydronic system may vary
15 considerably. While FIG. 1 shows three terminal units for purposes of simple illustration, it will be appreciated that other embodiments will typically include considerably more terminal units which may be distributed throughout a building or similar structure to be cooled.
- 20 The chilled water is distributed from the source 10 to the respective terminal units via a network of pipes or other suitable conduits. For the purpose of the present description the pipes or conduits are simply referred to as lines. In particular, the system comprises a supply line 20 for feeding chilled water from the source 10 to respective parts of the building or structure to be cooled. The system further comprises a return line 30 for
25 returning water from terminal units in respective parts of the building or structure back to the source 10, in particular for renewed chilling.
- In the embodiment of FIG. 1, the system includes a main pump 95, which may be operationally coupled to the supply line 20 close to the source 10, and which pumps the
30 chilled water through the supply line 20. The system further comprises a bypass line 25, which fluidly connects the supply line 20 with the return line 30.

The terminal units 40-1 through 40-3 are fluidly connected to the source in parallel to each other. To this end, each of the terminal units 40-1 through 40-3 is connected to the supply line 20 and to the return line 30 by respective branch lines. In particular, each of the terminal units 40-1 through 40-3 is connected to the supply line 20 by a respective
5 feed branch line 50-1 through 50-3, respectively. The feed branch lines thus feed chilled water from the supply line 30 to an input end of the respective terminal units. Additionally, each of the terminal units 40-1 through 40-3 is connected to the return line 30 by a respective return branch line 60-1 through 60-3, respectively. The return branch lines thus feed water from output ends of the respective terminal units to the return line
10 30. The branch lines branch off from the supply line and return line, respectively, at respective branch or end points.

The system 1 further includes a number of branch pumps 70-1 through 70-3, each associated with a respective one of the terminal units 40-1 through 40-3. To this end,
15 each of the branch pumps is operationally coupled to a respective one of the return branch lines 60-1 through 60-3, respectively, i.e. the branch pumps pump water through the respective return branch lines from the respective terminal units to the return line 30. It will be appreciated that some or all of the branch pumps may be operationally coupled to the respective feed branch lines, instead, i.e. they may pump water from the
20 supply line 20 towards the respective terminal units. Yet further, the system includes non-return valves 55-1 through 55-3 located in the respective branch lines so as to prevent return flow from the return to the supply line through the branch lines. In the example of FIG. 1, all non-return valves 55-1 through 55-3 are located in the respective feed branch lines 50-1 through 50-3. However, it will be appreciated that some or all of
25 the non-return valves may alternatively be located in the respective return branch lines instead, e.g. as illustrated in FIG. 2 below.

The branch pumps are preferably speed-controllable pumps, in particular speed-controllable centrifugal pumps, such as to be able to control the flow of chilled water
30 passing through the associated terminal units. To this end, the system may comprise one or more sensors 80-1 through 80-3 for measuring a suitable performance parameter that may serve as an input to the control of the respective branch pumps. In the

example of FIG. 1, each of the AHUs 40-1 and 40-2 has an associated temperature sensor 80-1 and 80-2, respectively, which may be positioned in the air stream of the AHUs and configured to measure the air flow temperature T of the air blown into the room by the respective AHU. Each temperature sensor is communicatively coupled, e.g. by a wired or wireless connection, to the respective branch pump 70-1 or 70-2, respectively. Accordingly, the branch pumps 70-1 and 70-2 receive respective sensor signals indicative of the air flow temperature in the respective terminal unit, and they use the measured temperature as a performance parameter for controlling their respective pump speed. Alternatively, other sensors may be used, e.g. a temperature sensor measuring the fluid temperature of the supplied fluid to the AHU, or a differential temperature, a flow sensor a pressure sensor, a differential pressure sensor, etc. Generally, such sensors may be integrated into the respective AHU or into the respective branch pump, or they may be provided as separate sensors. An embodiment of a control process for controlling the branch pumps will be described in more detail below.

Similarly, the system comprises a pressure sensor 80-3 configured to measure a differential pressure Δp_b between the feed branch line 50-3 and the return branch line 60-3 associated with the bank of fan coils 40-3. The pressure sensor 80-3 is communicatively coupled, e.g. by a wired or wireless connection, to the corresponding branch pump 70-3 that is associated to the bank of fan coils 40-3. Accordingly, the branch pump 70-3 receives a sensor signal indicative of the differential pressure between the input and output of the bank of fan coils and uses the differential pressure as a performance parameter for controlling its pump speed. It will be appreciated that the branch pump 70-3 may receive sensor signals from separate pressure sensors instead that measure the fluid pressure at the input and output of the bank of fan coils 40-3, respectively.

It will generally be appreciated that the branch pumps 70-1 through 70-3 may receive alternative or additional sensor signals and control their pump speeds based on such alternative or additional sensor signals and/or on alternative or additional performance parameters derivable from such sensor signals. Other examples of suitable performance

parameters include: a fluid temperature of the fluid in the branch line in a proximity of the branch pump, a fluid flow rate in the branch line in a proximity of the branch pump, and a fluid pressure in the branch line in a proximity of the branch pump, an ambient air temperature in a proximity of the terminal unit associated with the branch line.

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The choice of performance parameter may depend on the type of terminal unit, the desired control paradigm, available sensors and/or other factors.

10 In the example of FIG. 1, each branch pump receives sensor signals from a respective sensor. It will be appreciated that, in some embodiments, more than one branch pump may receive sensor signals from a single sensor.

15 The system 1 further comprises a booster pump 90, which is operationally coupled to the supply line 20 and configured to pump fluid through the supply line 20. In the example of FIG. 1, the booster pump 90 is located at a position along the supply upstream from the branch or end points where branch lines 50-2 and 50-3 branch off the supply line 20, i.e. booster pump 90 is arranged in series with each of branch pumps 70-2 and 70-3 and can thus support these branch pumps. While the system illustrated in FIG. 1 only includes a single booster pump, it will be appreciated that other
20 embodiments may include more than one booster pump, which may be distributed along the supply line so as to support respective groups of branch pumps. The provision of such booster pumps in a distributed pump system reduces the operational requirements for the branch pumps, in particular as regards their pressure range, and may be operable to distribute the pressure increase along the supply line.

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For example, in a distributed pump system, e.g. the system of FIG. 1, it is beneficial to use maintenance free branch pumps at the AHU's and the FC's, such as canned centrifugal pumps. Maintenance free pumps are particularly interesting for installations that include many branch pumps distributed across the system, meaning the
30 maintenance procedures are complicated. However, this type of pump has a limited flow and pressure range. In particular, the pressure range can be a problem at the branches in large systems. Accordingly, distributed pump systems using canned

centrifugal pumps as branch pumps may benefit from the provision of additional booster pumps. It will be appreciated, however, that booster pumps as disclosed herein may also be used to advantage in distributed-pump hydronic systems that utilize other types of branch pumps.

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As will be described in greater detail below, the booster pump 90 is controlled based on a differential pressure between the supply line 20 and the return line 30. To this end, the system 1 comprises a pressure sensor 91 configured to measure the differential pressure Δp_m between a measurement point 92 along the supply line 20 and a measurement point 93 of the return line. The pressure sensor 91 is communicatively coupled, e.g. by wired or wireless connection, to the booster pump 90, and the pump controller of the booster pump 90 uses the differential pressure as an input to the control process. An embodiment of a suitable control process for controlling the booster pump will be described in greater detail below.

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FIG. 2 schematically shows another embodiment of a hydronic system 1, in this example a heating system.

The system 1 of FIG. 2 is similar to the system of FIG. 1, in that it comprises a source 10, a supply line 20, a return line 30 and terminal units 40-1 through 40-3. The terminal units 40-1 through 40-2 are connected in parallel to each other the supply and return lines via feed branch lines 50-1 through 50-3 and return branch lines 60-1 through 60-3, all as described in connection with FIG. 1. The system 1 further comprises branch pumps 70-1 through 70-3 operationally coupled to the respective return branch lines 60-1- through 60-3, respectively, also all as described in connection with FIG. 1, except that, in the embodiment of FIG. 2, the source 10 is a heat exchanger, a boiler or the like, and that the terminal units 40-1 and 40-3 are respective banks of radiator. Terminal unit 40-2 is an air handling unit. Yet further, the system 1 further includes non-return valves 55-1 through 55-3 located in the respective branch lines so as to prevent return flow from the return to the supply line through the branch lines, also as described in connection with FIG. 1, except that, in the example of FIG. 2, one non-return valve 55-2 is located in

the corresponding return branch line 60-2, while non-return valves 55-1 and 55-3 are located in the respective feed branch lines 50-1 and 50-3.

Accordingly, in the example of the heating system of FIG. 1, the source 10 provides hot
5 water (or another suitable fluid) which is distribute by the supply line 20 to respective parts of a building or other structure to be heated, or otherwise to different nodes of a network of consumers. As in the embodiment of FIG. 1, the branch pumps receive sensor signals form respective sensors 80-1 through 80-3 and control operation of the branch pumps based on associated performance parameters. In the example of FIG. 2,
10 sensor 80-2 is a temperature sensor, which measures the temperature T of the hot water in the AHU 40-2, while sensors 80-1 and 80-2 are differential pressure sensors measuring the differential pressure between the respective feed branch lines 50-1 and 50-2 and the respective return branch lines 60-1 and 60-2.

15 Yet further, and has also been described in connection with FIG. 1, the system includes a number of booster pumps. In particular, the system of FIG. 2 includes two booster pumps 90-1 and 90-2, respectively, operationally coupled to the supply line 20 at respective locations along the supply line. Booster pump 90-1 is located upstream of all terminal units while booster pump 90-2 is located downstream from terminal unit 40-1
20 and upstream from terminal units 40-2 and 40-3. Each of the booster pumps receives sensor signals from a respective differential pressure sensor 91-1 and 91-2, respectively, which measure the differential pressure between the supply line and the return line at respective measurement locations 92-1 and 92-2 along the supply line and respective measurement locations 93-1 and 93-2 along the return line.

25 It will be appreciated that other examples of hydronic systems may include other types of sources and/or other types of terminal units. Moreover, the number of terminal units, branches, branch pumps and/or booster pumps may vary from embodiment to embodiment. Similarly control of the branch pumps may be based on a variety of
30 performance parameters, e.g. as described above or otherwise.

It will further be appreciated that, instead of the differential pressure from a differential pressure sensor, the booster pumps may receive sensor signals from separate pressure sensors that measure the fluid pressure at respective measurement points along the supply line and the return line, respectively. The pressure sensors may be separate
5 pressure sensors, separate from the booster pump, and coupled to the supply line and the return line, respectively. Alternatively, a booster pump may be provided with an integrated pressure sensor. Generally, in a distributed pump system, the booster pumps should preferably ensure that the differential pressure at the supply line is close to zero in order to efficiently support the branch pumps, while still ensuring room for the
10 branch pumps to control the temperature, flow, or pressure at the branches.

In various embodiments disclosed herein the control of the booster pump does not require any central control system or any communication with the branch pumps, or with any further booster pumps in the system. The control of the booster pump may be performed based entirely on sensor signals from one or more pressure sensors that may
15 be provided in a proximity of the booster pump. Yet further, as described in more detail below, the control of the branch pumps may also be performed locally, based on local sensor data. Accordingly, the system may be controlled in a fully distributed manner without requiring communication to a central control system or communication between the various pumps.

20

FIG. 3 schematically illustrates an embodiment of a pump suitable as a booster pump or a branch pump in a hydronic system as disclosed herein. The pump 100 comprises a fluid displacement mechanism 110 and a pump drive 120. The fluid displacement mechanism 110 may be a centrifugal pump or a different type of pump. The fluid displacement
25 mechanism 110 has an inlet 111 for suction of water or a different fluid, such as of a different liquid. The fluid displacement mechanism 110 also has an outlet 112 for providing the output flow of the pump. The pump drive 120 comprises a motor 121, such as an electrical motor, and a pump controller 122. The pump controller may include a frequency converter for supplying the motor with electrical energy and/or
30 other circuitry for controlling operation of the motor 121. The pump controller may be connectable to a suitable power supply (not shown) in order to supply the pump drive 120 with electric energy. During operation, the motor 121 drives the pump causing the

fluid displacement mechanism to pump fluid from the inlet 111 to the outlet 112 at a flow rate. The pump 100 has an input interface 130, e.g. a wired or wireless interface, for receiving sensor signals from one or more sensors 200, e.g. from one or more pressure sensors, a temperature sensor, a flow sensor and/or the like. The pump controller is configured, e.g. by a suitable software program, to control operation of the pump responsive to the received sensor signals.

In the following, embodiments of pump control processes will be described for the control of a branch pump and a booster pump, respectively, in a hydronic system with distributed pump control. The embodiments of the control process may be implemented by the pump controller of the pump being controlled, e.g. by the pump controller 122 of the pump of FIG. 3.

In particular, an embodiment of a process for controlling a branch pump of a hydronic system, e.g. for controlling one of the branch pumps of the system of FIG. 1 or FIG. 2, will now be described with reference to FIGs. 4 and 5. FIG. 4 schematically shows a state diagram of the process while FIG. 5 shows a corresponding flow diagram of the process. It will be appreciated that each of the branch pumps of the system of FIG. 1 or FIG. 2 may be controlled by their respective pump controllers by implementing an embodiment of the process of FIGs. 4 and 5.

The branch pump is selectively controllable in an ON state S41 or an OFF state S40, as illustrated in FIG. 4. When operated in the ON state S41 (step 51 in FIG. 5), the pump controller controls operation, in particular the pump speed, of the pump so as to control a suitable performance parameter, e.g. the temperature, flow rate or pressure of the fluid being pumped by the branch pump through the branch line. To this end, the pump controller of the branch pump may receive sensor signals indicative of measured values of the performance parameter, e.g. from a temperature sensor, a flow sensor or a pressure sensor, e.g. as described in connection with the branch pumps of the systems of FIGs. 1 and 2. The control of the branch pump may be based on a control error indicative of a difference between the measured performance parameter and a reference value of the performance parameter. The control process may then control

operation of the pump so as to minimize the absolute value of the control error. To this end, the control process may implement a PI controller or another suitable control scheme.

- 5 In the case of temperature control in a cooling system, e.g. in the system of FIG. 1, the control error ϵ may be given by

$$\epsilon = -(T_{ref} - T),$$

Where T designates the measure fluid temperature and T_{ref} represents the reference temperature value. Similarly, in the case of temperature control in a heating system, e.g.

- 10 in the system of FIG. 2, the control error may be given by

$$\epsilon = T_{ref} - T.$$

In the case of flow or pressure control, the control error may be given by

$$\epsilon = q_{ref} - q_b \quad , \quad \epsilon = \Delta p_{ref} - \Delta p_b.$$

Here q_b and Δp_b are the branch-flow and -pressure respectively. In all cases, the

- 15 subscript *ref* denotes the reference value for the control variable.

With the control errors defined as above, the pump is capable of changing the respective performance parameter such, that the control error is decreased by increasing the pump speed. As the control error is a signed quantity, the control error
20 can become negative, in which case the pump speed will typically be decreased. It will be appreciated that other definitions of the control error (e.g. a definition of the error with an opposite sign) may cause operation of the pump to increase the signed control error instead so as to approach zero from below.

- 25 However, many pumps, in particular centrifugal pumps, cannot control to zero pressure, which would correspond to zero pump speed at zero flow. Yet further, the booster pumps are generally not controlled to run in a reverse direction. This is illustrated by FIG. 6, which schematically illustrates an example of an operational area of a pump.

- 30 In particular, FIG. 6 illustrates an example of pump curves for a centrifugal pump. The controllable operational area of the pump is represented by the shaded area 401. The operational area 401 is defined by the minimum and maximum speed of the centrifugal

pump. Here, q and Δp are the flow and pressure of the pump respectively, n_{min} and n_{max} are the minimum and maximum speed of the pump, respectively, and Δp_{min} is the minimum pressure value at zero flow.

- 5 Again referring to FIGs. 4 and 5, the control process of the branch pumps accounts for this limitation in the operating range of the pump by applying an ON/OFF control scheme when the load conditions are low, i.e. under low pump flow conditions.

10 In particular, when, during operation of the branch pump in its ON state S41 using the above control scheme, the pump speed reaches the minimum speed of the pump, i.e. $n = n_{min}$, and if the control error decreases below a predetermined negative threshold, $\epsilon < -\Delta\epsilon$, the pump stops operation (step 52 in FIG. 5), i.e. it enters the OFF state S40. Otherwise, the process continues operation in the ON state S41 and continues to control the pump speed based on the control error.

15

In the OFF state S40, the process continues to monitor the performance parameter and, when the control error again exceeds a positive threshold, $\epsilon > \Delta\epsilon$, the process again initializes the PI controller (step 53 in FIG. 5), in particular the I tem of the PI controller, and enters the ON state S41, to resume speed controlled operation of the pump based on the control error. Accordingly, the ON/OFF control implements a hysteresis gap defined by the threshold error $\Delta\epsilon$. In the present embodiment, the hysteresis gap is symmetric around zero, but it will be appreciated that other embodiments may use an asymmetric hysteresis gap.

20

25 In a system with at least one booster pumps operating in series with a branch pump, the booster pump may still push fluid through the terminal unit, even when the branch pump is stopped. Accordingly, it is desirable to provide a control process for the booster pump that avoids unintended flow through the terminal units.

30

An embodiment of a process for controlling a booster pump of a hydronic system, e.g. for controlling one of the booster pumps of the system of FIG. 1 or FIG. 2, will now be

described with reference to FIGs. 7 and 8. FIG. 7 schematically shows a state diagram of the process while FIG. 8 shows a corresponding flow diagram of the process.

It will be appreciated that each of the booster pumps of the system of FIG. 1 or FIG. 2 may be controlled by their respective pump controllers by implementing an
 5 embodiment of the process of FIGs. 7 and 8.

The booster pump is selectively controllable in an ON state S71 or an OFF state S70, as illustrated in FIG. 7. When operated in the ON state S71 (step 81 in FIG. 8), the pump controller controls operation, in particular the pump speed, of the pump so as to control
 10 the differential pressure along the supply line to zero or to a negative predefined pressure reference value along the supply line, i.e. the performance parameter for the booster pump is the differential pressure and the associated control error for the booster pumps is

$$e = r - \Delta p_m$$

15 Where the pressure reference value r may be set to zero ($r = 0$) or to a negative value.

To this end, the pump controller of the booster pump may receive sensor signals indicative of a measured differential pressure Δp_m in the supply line, or it may receive individual pressure measurements from which the differential pressure can be derived,
 20 e.g. as described in connection with FIGs. 1 and 2. The control process may then control operation of the pump so as to minimize the absolute value of the control error e . To this end, the control process may implement a PI controller or another suitable control scheme.

25 However, as discussed above with reference to FIG. 6, centrifugal pumps cannot control to zero pressure. Moreover, the control process should avoid forcing fluid through terminal units even though the associated branch pumps are currently in their OFF state.

Accordingly, the booster pump control process also implements an ON/OFF scheme. In
 30 particular, when, during operation of the booster pump in its ON state S71 using the above control scheme, the pump speed reaches the minimum speed of the booster pump, i.e. $n = n_{min}$, and if the control error becomes negative, $e < 0$, the booster pump

stops operation (step 82 in FIG. 8), i.e. it enters the OFF state S70. Otherwise, the process continues operation of the booster pump in the ON state S71 and continues to control the booster pump speed based on the above control error e .

- 5 In the OFF state S70, the process continues to monitor the differential pressure Δp and the associated control error e . When the control error fulfils a predetermined start condition, the process again initializes the PI controller (step 83 in FIG. 8), in particular the I term of the PI controller, and enters the ON state S71, to resume speed controlled operation of the booster pump based on the control error.

10

In the present embodiment, the start condition triggering re-start of the booster pump is $e > \Delta p_{th}$, i.e. the control error exceeds a predetermined threshold value Δp_{th} , which is selected to be at least the minimum pressure of the booster pump, i.e. $\Delta p_{th} \geq \Delta p_{min}$. This start condition ensures that booster pump is only re-started when the control error

- 15 is larger than the minimum pressure of the given booster pump Δp_{min} , thereby avoiding pressure oscillations. Otherwise, in the absence of this start condition, if the booster pump delivers a pressure that is higher than the cut-in pressure Δp_{min} , then the PI controller would immediately lower the pump speed to the minimum speed, which would still result in a negative control error e . This would lead to an immediate shut off,
20 followed by another cut-in; hence, the system would oscillate.

- In some embodiments, the differential pressure sensor, which is used for measuring the supply-line differential pressure Δp_m for the booster pump control, is installed immediately after the booster pump. This installation setup avoids the need for remote
25 communication between a sensor placed downstream from the booster pump and the booster pump.

- In some embodiments, it may be desirable to base the booster pump control on a differential pressure downstream from the booster pump, e.g. at a location where the
30 branch line to the terminal unit and branch pump branches off from the supply line, such as at the first downstream branch following the booster pump. In this situation, a

downstream sensor pressure sensor communicatively coupled to the booster pump with a sufficiently robust communication link may be established.

Alternatively to installing the sensor downstream from the pump, a sensor may be installed in the vicinity of the booster pump, at the pump controller may estimate a modified pressure value from the measured pressure value, such that the modified pressure value is an estimate of a corresponding pressure at a downstream location. For example, the downstream location may be at least 10 m downstream from the sensor, such as at least 20 m, such as at least 50 m. Accordingly, the sensor can be considered as being virtually moved downstream. To this end, it is useful to recognize that the pressure at any point between the booster pump and the downstream location (e.g. at the first downstream branch) can be calculated from the pump flow using the pipe loss parameter R of the supply line for the given point according to

$$\Delta \hat{p}_m = \Delta p_m - Rq^2$$

Here, Δp_m is the measured differential pressure measured by the actual pressure sensor in the vicinity of, in particular just after, the pump; q is the pump flow, which the pump controller may estimate from the operational parameters of the pump, and $\Delta \hat{p}_m$ is the pressure estimate of the downstream pressure. The pipe loss parameter R is a predetermined constant that may be stored in the pump controller of the booster upon installation/commissioning. The loss parameter may be pre-calculated based on the pipe dimensions and on the distance between the pump (or the actual pressure sensor, which is assumed to be located in the vicinity of the pump) and the virtual measurement point for which the pressure value is to be determined.

Based on the thus estimated modified pressure value $\Delta \hat{p}_m$, the control error may be defined as

$$e = -\Delta \hat{p}_m$$

(or as $e = r - \Delta \hat{p}_m$ with a suitably selected reference value r , which will typically be selected $r \leq 0$, even though a reference being slight larger than zero may in some embodiments also be possible).

With the above modified pressure, the booster pump control approach disclosed herein can be used with a virtual pressure measurement point by using the pressure $-\Delta\hat{p}_m$ instead of the measured pressure $-\Delta p_m$ in the proposed control. As the flow is typically estimated from pump operation parameters, the flow value is not available when the pump is switch off. However, the worst-case condition, from a pressure control point of view, is when the flow is zero, hence the start condition may still remain unchanged.

For the distributed control to work it is desirable that the branch pumps are configured such that they are able to sufficiently lower the pressure at the booster pumps, in particular such that they are able to lower the pressure at the location of the first upstream booster pump below the minimum pressure $\Delta p_{\min}$ of said first upstream booster pump. For example, this can be ensured by designing the branch pumps to be able to deliver the loop pressure to a virtual bypass (i.e. the point where the booster pump controls the pressure difference between the supply and return lines) plus the minimum pressure $\Delta p_{\min}$.

FIG. 9 schematically shows another embodiment of a hydronic system 1. The system 1 of FIG. 9 is similar to the system of FIG. 2, in that it comprises a source 10, a supply line 20, a return line 30, terminal units 40-1 through 40-3 and booster pumps 90-1 and 90-2, all as described in connection with FIG. 2, except that all terminal units of the system of FIG. 9 are air handling units (AHUs). The AHUs are connected to the supply line 20 by respective feed branch lines 50-1 through 50-3 and the AHUs are connected to the return line by respective return branch lines 60-1 through 60-3, again all as described in connection with FIG. 2. Each of the AHUs has an associated branch pump 70-1 through 70-3, respectively, also as described in connection with FIG. 2, except that the branch pumps 70-1 through 70-3 of FIG. 9 are coupled to the respective feed branch lines 50-1 through 50-3 instead of to the respective return branch lines. The branch pumps are controlled so as to control the air flow temperature of the AHUs 40-1 through 40-3, respectively as measured by respective temperature sensors 80-1 through 80-3 which are communicatively coupled to the respective branch pumps, again all as described in connection with FIG. 2. Yet further, the system 1 further includes non-return valves 55-1

through 55-3 located in the respective return branch lines 60-1 through 60-3 so as to prevent return flow from the return to the supply line through the branch lines.

5 The booster pumps are controlled based on respective differential pressure measurements between the supply and return lines, as measured by pressure sensors 91-1 and 91-2, respectively. The branch pumps are controlled based on the control process of FIGs. 4 and 5 while the booster pumps are controlled based on the control process of FIGs. 7 and 8.

10 FIGs. 10A-D illustrate simulation results of the operation of the system of FIG. 9 when controlled by an embodiment of the control process described herein. To this end an ambient temperature T_{amb} is simulated which forms the load on each of the AHUs.

15 FIG. 10A shows the differential pressures at the branch pumps and the booster pumps, respectively. FIG. 10B shows the flow rates at the branch pumps and the booster pumps, respectively. FIG. 10 C shows the ambient temperature 1001 and the air flow temperatures of the three AHUs. Finally, FIG. 10D shows the pump speeds of the branch pumps and the booster pumps.

20 As will be apparent from FIGs. 10A-D the control process has been found to result in a stable control of the return temperatures for different values of the ambient temperature.

25 Embodiments of the method described herein may be computer-implemented. In particular, embodiments of the method may be implemented by means of hardware comprising several distinct elements, and/or at least in part by means of a suitably programmed data processing system. In the apparatus embodiments enumerating several means, several of these means can be embodied by one and the same element, component or item of hardware: The mere fact that certain measures are recited in 30 mutually different dependent embodiments or described in different embodiments does not indicate that a combination of these measures cannot be used to advantage.

It should be emphasized that the term "comprises/comprising" when used in this specification is taken to specify the presence of stated features, elements, steps or components but does not preclude the presence or addition of one or more other features, elements, steps, components or groups thereof.

CLAIMS

1. A hydronic system for heating and/or cooling a target structure, the system comprising:

- 5 - at least one supply line,
 - at least one return line,
 - a plurality of branch lines, each branch line fluidly connecting a terminal unit with the supply line or with the return line,
 - a plurality of branch pumps, each configured to pump fluid through a respective one of
10 the plurality of branch lines,
 - at least one booster pump configured to pump fluid through the supply line or the return line, the at least one booster pump being arranged in series with one or more of the plurality of branch pumps, the at least one booster pump being operable at a controllable booster pump speed, wherein the booster pump speed is controllable to be
15 larger than a minimum booster pump speed,

wherein the at least one booster pump comprises a booster pump controller configured to:

- 20 - receive one or more pressure sensor signals indicative of a differential pressure between the supply line and the return line,
 - determine a booster pump control error indicative of a difference between a reference pressure and the differential pressure,
 - stop pump operation of the booster pump responsive to the booster pump operating at the minimum booster pump speed and the differential pressure
25 exceeding the reference pressure.

2. The hydronic system according to claim 1, wherein the booster pump controller is further configured to re-start pump operation of the booster pump responsive to the booster pump control error exceeding a predetermined pressure threshold.

30

3. The hydronic system according to claim 2, wherein the at least one booster pump is operable to create a minimum pressure when operating at the minimum booster pump

speed and at zero flow, and wherein the pressure threshold is no smaller than said minimum pressure.

4. The hydronic system according to any one of the preceding claims, wherein the
5 booster pump controller is further configured to control the controllable booster pump speed during operation of the booster pump so as to reduce the booster pump control error.

5. The hydronic system according to claim 4, wherein the booster pump controller is
10 configured to implement a PI controller for controlling the controllable booster pump speed.

6. The hydronic system according to any one of the preceding claims, comprising at least one pressure sensor operatively connected to the booster pump controller and
15 configured to provide said one or more pressure sensor signals.

7. The hydronic system according to claim 6, wherein the at least one pressure sensor comprises a differential pressure sensor for measuring the differential pressure and for providing a pressure sensor signal indicative of the measured differential pressure to the
20 booster pump controller.

8. The hydronic system according to claim 7, wherein the at least one pressure sensor comprises at least two pressure sensors for measuring fluid pressures in the supply line and in the return line, respectively, and wherein the booster pump controller is
25 configured to determine the differential pressure from pressure sensor signals from the at least two pressure sensors.

9. The hydronic system according to any one of claims 6 through 8, wherein the at least one pressure sensor is configured to provide one or more pressure sensor signals
30 indicative of a measured differential pressure between respective measurement locations along the supply line and the return line, and wherein the booster pump controller is configured to determine a modified differential pressure from the

measured differential pressure, the modified differential pressure being indicative of an estimated differential pressure between respective locations displaced from the respective measurement locations, and to use the determined modified differential pressure for controlling stop and re-start of the booster pump operation.

5

10. The hydronic system according to claim 9, wherein determining the modified differential pressure is based on the measured differential pressure, on a loss parameter and on a determined fluid flow.

10 11. The hydronic system according to claim 10, wherein the booster pump controller is configured to estimate the fluid flow from one or more observable operational parameters of the booster pump.

12. The hydronic system according to any one of the preceding claims, wherein at least
15 one of the plurality of branch pumps is operable at a controllable branch pump speed, wherein the branch pump speed is controllable to be larger than a minimum branch pump speed, wherein the at least one branch pump comprises a branch pump controller configured to:

- receive one or more sensor signals indicative of a performance parameter,
20 wherein performance of the pump affects the performance parameter in a first direction, in particular either increases or decreases the performance parameter,
- determine a branch pump control error indicative of a difference between a reference performance value and the performance parameter,
- 25 - stop pump operation of the branch pump responsive to the branch pump operating at the minimum branch pump speed and the performance parameter deviating from the reference performance value by more than a first threshold error in said first direction.

30 13. The hydronic system according to claim 12, wherein the branch pump controller is further configured to re-start pump operation of the branch pump responsive to the

performance parameter deviating from the reference performance value by more than a second threshold error in a second direction opposite the first direction.

14. The hydronic system according to claim 12 or 13, wherein the branch pump
5 controller is further configured to control the controllable branch pump speed during operation of the branch pump so as to reduce the branch pump control error.

15. The hydronic system according to claim 14, wherein the branch pump controller is
10 configured to implement a PI controller for controlling the controllable branch pump speed.

16. The hydronic system according to any one of claims 12 through 15, wherein the
performance parameter is chosen from the group of performance parameters consisting
of: a fluid temperature of the fluid in the branch line in a proximity of the branch pump,
15 a fluid flow rate in the branch line in a proximity of the branch pump, a fluid pressure in the branch line in a proximity of the branch pump, an air temperature, an air flow temperature in an air handling unit, a differential air temperature, a differential fluid temperature, a differential pressure. It will be appreciated that other claims may use other performance parameters.

20
17. A pump for use as a booster pump in a hydronic system for heating and/or cooling a target structure, the hydronic system comprising at least one supply line, at least one return line, a plurality of branch lines, each branch line fluidly connecting a terminal unit with the supply line or with the return line, and a plurality of branch pumps, each
25 configured to pump fluid through a respective one of the plurality of branch lines,

wherein the pump is configurable to pump fluid through the supply line or the return line when arranged in series with one or more of the plurality of branch pumps, the pump being operable at a controllable booster pump speed, wherein the booster pump
30 speed is controllable to be larger than a minimum booster pump speed,

wherein the pump comprises a pump controller configured to:

- receive one or more pressure sensor signals indicative of a differential pressure between the supply line and the return line,
- determine a booster pump control error indicative of a difference between a reference pressure and the differential pressure,
- 5 - stop pump operation of the pump responsive to the pump operating at the minimum booster pump speed and the differential pressure exceeding the reference pressure.

18. The pump according to claim 17, wherein the pump controller is further configured
10 to re-start pump operation of the pump responsive to the pump control error exceeding a predetermined pressure threshold.

19. A method for controlling operation of a booster pump of a hydronic system for heating and/or cooling a target structure, the hydronic system comprising at least one
15 supply line, at least one return line, a plurality of branch lines, each branch line fluidly connecting a terminal unit with the supply line or with the return line, a plurality of branch pumps, each configured to pump fluid through a respective one of the plurality of branch lines, and at least said booster pump, the booster pump being configured to pump fluid through the supply line or the return line, the booster pump being arranged
20 in series with one or more of the plurality of branch pumps, the booster pump being operable at a controllable booster pump speed, wherein the booster pump speed is controllable to be larger than a minimum booster pump speed, wherein the method comprises:

- 25 - receiving one or more pressure sensor signals indicative of a differential pressure between the supply line and the return line,
- determining a booster pump control error indicative of a difference between a reference pressure and the differential pressure,
- stopping pump operation of the booster pump responsive to the booster pump operating at the minimum booster pump speed and the differential pressure
30 exceeding the reference pressure.

20. The method according to claim 19, further comprising re-starting pump operation of the booster pump responsive to the booster pump control error exceeding a predetermined pressure threshold.