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COMPLETE SPECIFICATION

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APPARATUS FOR CONTROLLING A FLOW OF FLUID

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We, FORENO TAPWARE (NZ) LIMITED, a New Zealand company of 5 Hewlett Street,
Port Whangarei 0110, New Zealand, hereby declare the invention, for which we
pray that a patent may be granted to us, and the method by which it is to be
performed, to be particularly described in and by the following statement:

FIELD OF THE INVENTION

The invention relates to an apparatus for providing a flow of fluid at a desired temperature or a desired temperature and flow rate. An apparatus according to the present invention is especially useful for providing a flow of temperature controlled water to a shower head or faucet in a domestic plumbing installation.

BACKGROUND TO THE INVENTION

Flow control devices, for example a domestic shower mixer, mix together a flow of hot fluid and a flow of cold fluid to provide an output flow of fluid at a desired temperature. The temperature of the output flow is adjusted by adjusting the proportion of hot and cold fluids being mixed.

A problem with prior art systems or valves for combining a hot fluid supply and a cold fluid supply for providing a flow of fluid at a desired temperature is that the temperature and pressure of the hot and cold water supplies varies between installations.

For example, some installations comprise a high pressure cold supply having a pressure in the order of 500 – 700 kPa and a low pressure hot supply having a pressure in the order of 50 – 70kPa, approximately one tenth that of the cold water supply pressure.

In other installations, the hot and cold supplies may both be low pressures (for example both hot and cold supply pressures at 50 – 70kPa) or both high pressures (for example both hot and cold supply pressures at 500 – 700kPa). However, the actual hot and cold fluid pressures are unique for a given installation. Actual supply pressures are dependent on the hot and cold supply pipe diameters, lengths and path of supply pipes running between the mixing valve and a main supply line or water supply cylinder. Even for 'equal' pressure systems, the hot and cold fluid pressures can be significantly different.

Because the hot and cold fluid inlet pressures are different and unique for each installation, the characteristics of an apparatus for mixing hot and cold supplies accurately for providing an output flow at a desired temperature may not be easily predictable.

For example, for the arrangement described in US 4,757,943, balanced input pressures are required otherwise expected hot and cold water proportions are not achieved. For example, if the pressure of the cold fluid supply is higher than the pressure of the hot fluid supply, then the expected proportions of hot and cold water flowing through the water mixing device will not be as expected. With reference to Table 1 of US 4,757,943, to achieve a temperature midway between the hot and cold water temperatures, a position setting of 32 may be chosen, providing an expected ratio of hot and cold flows of around 1:1. However, where pressure of the cold fluid is higher, a lower proportion of hot water will occur than the predicted portion of 31/63 quoted in Table 1.

Furthermore, where the hot inlet pressure and the cold inlet pressure are significantly different, for example in a typical unequal pressure system (high cold pressure and low hot pressure), complete malfunctioning of the apparatus can occur as the high pressure cold supply can back-flow through the low pressure hot supply when a control valve is opened on the hot low pressure side of the system.

In this specification where reference has been made to patent specifications, other external documents, or other sources of information, this is generally for the purpose of providing a context for discussing the features of the invention. Unless specifically stated otherwise, reference to such external documents is not to be construed as an admission that such documents, or such sources of information, in any jurisdiction, are prior art, or form part of the common general knowledge in the art.

It is an object of the present invention to overcome the above mentioned disadvantages or to at least provide the user with a useful choice.

SUMMARY OF THE INVENTION

In one aspect, the present invention consists in an apparatus for controlling and mixing a flow of hot fluid and a flow of cold fluid to provide an output flow of fluid at a user selectable desired temperature, the apparatus comprising:

a flow control device for controlling and mixing the flow of hot fluid and the flow of cold fluid, the flow control device comprising:

- a hot inlet for receiving the flow of hot fluid,
- a cold inlet for receiving the flow of cold fluid,

an outlet to provide the output flow of fluid,
at least one hot valve connected between the hot inlet and the outlet
to control the flow of hot fluid from the hot inlet to the outlet, and
at least one cold valve connected between the cold inlet and the
outlet to control the flow of cold fluid from the cold inlet to the outlet,
a hot temperature sensor for sensing the temperature of the flow of hot
fluid,
a cold temperature sensor for sensing the temperature of the flow of cold
fluid,
an output temperature sensor for sensing the temperature of the output flow
of fluid, and
a controller receiving signals from the temperature sensors, in a calibration
routine the controller adapted and configured to:
i) set the cold valve to a cold flow rate setting and the hot valve to a hot
flow rate setting,
ii) wait for time period or for the temperature of the output flow of fluid to
stabilise,
iii) determine a measured output temperature, a measured hot temperature
and a measured cold temperature based on signals from the output temperature
sensor, the hot temperature sensor and the cold temperature sensor,
iv) calculate a cold error term and a hot error term that minimise the sum-
of-squares difference between a calculated output power and a calculated input
power wherein the output power equals the measured output temperature
multiplied by the sum of the cold flow rate setting and the hot flow rate setting, and
the input power equals the sum of the hot flow rate setting multiplied by an
effective hot temperature and the cold flow rate setting multiplied by an effective
cold temperature, wherein the effective hot temperature equals the sum of the
measured hot temperature and the hot error term and the effective cold
temperature equals the sum of the measured cold temperature and the cold error
term, and
in an operation mode the controller adapted and configured to control the
cold valve and the hot valve based on the effective hot temperature and the
effective cold temperature to provide the output flow of fluid at the user selected
desired temperature.

In some embodiments, in the operation mode the controller is adapted and
configured to control the cold valve and the hot valve based on the effective hot

temperature and the effective cold temperature only to provide the output flow of fluid at the user selected desired temperature.

5 In some embodiments, the hot valve is connected between the hot inlet and the outlet to control the flow of hot fluid from the hot inlet to the outlet only, and the cold valve is connected between the cold inlet and the outlet to control the flow of cold fluid from the cold inlet to the outlet only, and the controller is adapted and configured to control the cold valve and the hot valve independently.

10 In some embodiments the apparatus is adapted and configured to control and mix the flow of hot fluid and the flow of cold fluid to provide an output flow of fluid at the user selectable desired temperature and a user selectable desired flow rate.

15 In some embodiments, in the calibration routine the controller repeats steps i) to iii) a number of times to determine a plurality of values for each of the cold flow rate setting, the hot flow rate setting, the measured output temperature, the measured hot temperature and the measured cold temperature, and the controller calculates the cold error term and hot error term that minimise the sum-of-squares difference based on the plurality of values.

20 In some embodiments the controller repeats steps i) to iii) at least 5 times. In some embodiments the controller repeats steps i) to iii) at least 10 times. In some embodiments the controller repeats steps i) to iii) at least 20 times.

25 In some embodiments, in step i) the controller sets the hot valve and the cold valve to randomly determined set points.

30 In some embodiments the controller is adapted and configured to compare the temperature of the output flow of fluid to a predetermined temperature and close the hot water valve to isolate the output from the hot input if the temperature of the output flow of fluid is greater than the predetermined temperature.

35 In some embodiments the controller is adapted and configured to enter a degraded mode if the difference between the temperature of the hot flow of fluid and the temperature of the cold flow of fluid is less than a predetermined threshold, in the degraded mode the controller setting the hot valve and the cold valve to predetermined set points.

In some embodiments the predetermined threshold is less than 20°C.

5 In some embodiments, in the degraded mode the controller sets the hot valve and the cold valve to 50% open.

In some embodiments, the apparatus comprises a human machine interface adapted to allow a user to select the desired temperature and the desired flow rate.

10 In some embodiments the controller is adapted and configured to limit the selectable desired temperature based on the temperature of the hot and cold fluid flows.

15 In some embodiments the controller is adapted and configured to limit the selectable flow rate to be less than the product of:

the quotient of:

20 the difference between the temperature of the flow of hot fluid and the temperature of the flow of cold fluid and the maximum of the difference between the temperature of the flow of hot fluid and the temperature of the output flow of fluid and the difference between the temperature of the output flow of fluid and the temperature of the cold flow of fluid, and a maximum flow rate of the cold valve and the hot valve.

25 In some embodiments the flow control device comprises the cold temperature sensor in proximity to the cold inlet, the hot temperature sensor in proximity to the hot inlet, and the output temperature sensor in proximity to the outlet.

30 In some embodiments the apparatus comprises a mixing unit for mixing of the hot and cold fluid flows prior to temperature measurement by the outlet temperature sensor.

In some embodiments the mixing unit comprises a reservoir volume to allow fluid downstream of the hot valve and cold valve to mix or accumulate prior to temperature measurement by the outlet temperature sensor.

35 In some embodiments the reservoir is an output manifold of the flow control device.

In some embodiments the flow control device comprises a bank of solenoid operated cold valves for controlling the flow of cold fluid and a bank of solenoid operated hot valves for controlling the flow of hot fluid, each said solenoid valve switchable between a closed position and an open position, the controller adapted and configured to open a number of hot valves to control the flow of hot fluid and a number of cold valves to control the flow of cold fluid.

In some embodiments the controller controls the cold valve based on a calculated cold flow rate based on the desired flow rate multiplied by the quotient of the difference between the temperature of the flow of hot fluid and the desired temperature and the difference between the temperature of the flow of hot fluid and the temperature of the flow of cold fluid.

In some embodiments the controller controls the hot valve based on a calculated hot flow rate based on the desired flow rate multiplied by the quotient of the difference between the desired temperature and the temperature of the flow of cold fluid and the difference between the temperature of the flow of hot fluid and the temperature of the flow of cold fluid.

The term "comprising" as used in this specification and claims means "consisting at least in part of". When interpreting each statement in this specification and claims that includes the term "comprising", features other than that or those prefaced by the term may also be present. Related terms such as "comprise" and "comprises" are to be interpreted in the same manner.

It is intended that reference to a range of numbers disclosed herein (for example, 1 to 10) also incorporates reference to all rational numbers within that range (for example, 1, 1.1, 2, 3, 3.9, 4, 5, 6, 6.5, 7, 8, 9 and 10) and also any range of rational numbers within that range (for example, 2 to 8, 1.5 to 5.5 and 3.1 to 4.7) and, therefore, all sub-ranges of all ranges expressly disclosed herein are hereby expressly disclosed. These are only examples of what is specifically intended and all possible combinations of numerical values between the lowest value and the highest value enumerated are to be considered to be expressly stated in this application in a similar manner.

As used herein the term "and/or" means "and" or "or", or both.

As used herein "(s)" following a noun means the plural and/or singular forms of the noun.

5 To those skilled in the art to which the invention relates, many changes in construction and widely differing embodiments and applications of the invention will suggest themselves without departing from the scope of the invention as defined in the appended claims. The disclosures and the descriptions herein are purely illustrative and are not intended to be in any sense limiting.

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The invention consists in the foregoing and also envisages constructions of which the following gives examples only.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Preferred embodiments of the invention will be described by way of example only and with reference to the drawings, in which:

Figure 1 is a diagrammatical representation of a system or apparatus according to one embodiment of the present invention.

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Figure 2 is a diagrammatical representation of a human interface.

Figure 3 is a flow diagram illustrating a calibration routine for determining error terms for use in the control of a flow control device to account for unmeasured variables such as fluid pressures.

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Figure 4 is a flow diagram illustrating a control routine for controlling the flow rate of a hot water supply and the flow rate of a cold water supply to provide a regulated output flow at a desired target temperature or a desired temperature and flow rate.

Figure 5 is a chart representing an upper flow rate limit for a user selectable flow rate.

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DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

An apparatus according to the present invention comprises a flow control device for controlling and mixing a hot fluid flow and a cold fluid flow for providing an output flow of fluid at a desired temperature or desired temperature and flow rate.

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Figure 1 represents diagrammatically an apparatus 1 according to one embodiment of the present invention.

The apparatus or system 1 comprises a hot inlet 2 for providing a flow of hot fluid to the system, a cold inlet 3 for providing a flow of cold fluid to the system, and a main output 4 for providing a regulated or controlled output flow of fluid. The system mixes proportions of hot and cold fluid input to the system to achieve an output flow having a desired temperature or a desired temperature and a desired flow rate.

For controlling proportions of hot and cold fluid to achieve an output flow at a desired temperature and/or flow rate, the system comprises a flow control device 5. In one embodiment, the flow control device comprises at least one cold water valve for controlling the flow of the cold water through the flow control device, and at least one hot water valve for controlling the flow of hot water through the flow control device. Hot water flow from the hot water valve is mixed with cold water flow from the cold water valve in a common outlet to provide a regulated flow via the main output.

The system comprises an outlet temperature sensor 6 for sensing the temperature of the outlet flow. The temperature sensor 6 provides an indication of the temperature of the outlet flow and communicates this temperature indication to a controller 10.

The apparatus preferably comprises a human interface 20. The human interface provides input buttons 21, such as membrane touch buttons, and a display screen 22 for displaying user settings and actual operating parameters. A person showering or bathing may enter a desired temperature and/or flow or other parameters such as time of shower via the input buttons. The human interface communicates with the controller 10, so that the controller may control the flow control device 5 to achieve an output flow in accordance with user defined parameters.

The flow control device 5 may comprise, by example, servo assisted solenoid valves, plunger throttling control devices or rotational orifice devices. Based on at least one user defined parameter, the controller 10 controls the flow control device valves via an electronic drive unit 11 which receives control signals from the controller and provides the necessary voltages to operate the flow control device valves. In one embodiment, the flow control device may provide hot and cold fluid flow control and not have the ability to shut off or isolate the hot and cold fluid from

the main outlet 4. In this embodiment, additional shut off or isolation valves may be provided, for example at the hot and cold inlets 2, 3.

In some embodiments, the flow control device comprises a bank of solenoid operated valves for controlling the flow of cold water and a bank of solenoid operated valves for controlling the flow of hot water. Each solenoid valve may be switched between an open position and a closed position. The bank of cold water valves comprises a plurality of cold valves arranged in a parallel configuration, the inlet of each of the plurality of cold valves in communication with a cold inlet of the flow control device, and an outlet of each of the plurality of cold valves in communication with an outlet of the flow control device. The bank of hot water valves comprises a plurality of hot valves arranged in a parallel configuration, the inlet of each of the plurality of hot valves in communication with a hot inlet of the flow control device, and an outlet of each of the plurality of hot valves in communication with the outlet of the flow control device. The controller opens a selected number of hot valves or cold valves or both to achieve an output flow having the desired temperature. In some embodiments, the controller opens a selected number of hot valves or cold valves or both to achieve an output flow having a desired temperature and a desired flow rate.

Where an installation has unequal supply pressures, for example higher pressure cold supply and low pressure hot supply, in some embodiments the system may comprise a pressure boost device 12 for increasing the hot supply pressure to be similar to the cold supply pressure. For example, the pressure boost device may utilise the high cold pressure to boost the low pressure hot supply to near that of the pressure of the cold supply. As an alternative, a pump may be used to pressure boost the low pressure supply. For example, the controller 10 may control the booster pump output pressure based on measured pressure of the cold and/or hot supplies to achieve a hot pressure near that of the cold supply pressure.

In some embodiments the system may comprise a pressure balance unit 13. The pressure balance unit is located in the system between the flow control device 5 and the hot and cold water supplies, or between the pressure boost device 12 and the water supplies, and the flow control device, where a pressure boost device is required.

The pressure balance unit has a cold inlet 3 and a cold outlet 14, and a hot inlet 2A and a hot outlet 15. The pressure balance unit cold and hot outlets 14, 15 communicate with cold and hot inlets 14A and 15A to the flow control device. The pressure balance unit cold and hot outlets may be directly adjacent to the flow control device cold and hot inlets.

The pressure balance unit 13 acts to reduce a pressure difference between the hot and cold water supplies at the flow control device inputs 14A, 15A. For example, the pressure balance unit may comprise a hot supply throttle valve and a cold supply throttle valve. The throttle valves may be servo assisted solenoid valves, plunger throttling control devices or rotational orifice devices or other valve or flow control device. For example, where the cold water pressure is higher than the hot water pressure, to balance the flow control device hot and cold inlet pressures, the cold throttling device of the pressure balance unit is adjusted in a close direction to reduce the cold supply pressure at the inlet of the flow control device until a difference between the pressures of the cold supply and hot supply is within a predetermined limit. In some embodiments, the pressure balance unit may be a mechanical device comprising a balance piston or movable component that adjusts of shifts under the relative action of the hot and cold inlet pressures to reduce the difference between the hot and cold pressures provided to the flow control device.

Flow Control Device

In an apparatus according to the present invention, the controller controls the flow control device to provide an output flow at a desired temperature or desired temperature and flow rate based on the temperature of the hot inlet flow and the temperature of the cold inlet flow. For example, the flow control device may be provided with a temperature sensor 7 at the flow control device cold inlet 14A and a temperature sensor 8 at the flow control device hot inlet 15A. In a preferred embodiment the controller controls the flow control device valves to provide an output flow at a desired temperature and flow rate. When controlling the cold and hot valves to achieve both a desired temperature and a desired output flow rate it is necessary that the controller can open and close the cold valves and the hot valves independently. That is, the controller can open and close the cold valves independently of the hot valves, and can open and close the hot valves independently of the cold valves. In such an embodiment, the hot valves are connected between the hot inlet and the outlet only, and the cold valves are connected between the cold inlet and the outlet only. In other words, the valves

are 2-way valves. In an embodiment where the apparatus provides a flow of fluid at a desired temperature only, the cold and hot valves may not be controlled independently; for example, when a cold valve is opened a corresponding valve is closed. In such an embodiment, the flow control device may comprise 3-way valves, each valve connected to both of the hot inlet and the cold inlet and the outlet. The 3-way valve is switched to let either hot fluid flow to the outlet, or cold fluid flow to the outlet. The flow rate at the outlet may be constant in such an embodiment.

The flow control device may be controlled by temperature measurement of the input flows based on the following mathematical relationships. According to the present invention, pressure measurement is not required.

For the flow control device, based on a conservation of mass:

$$F_c + F_h = F_o \quad \text{Equation 1}$$

where: F_c = the cold fluid inlet flow rate through the flow control device,
 F_h = the hot fluid inlet flow rate through the flow control device, and
 F_o = the regulated output fluid flow from the flow control device.

The following relationship is based on conservation of energy for the flow control device; the temperature and flow rate of fluid input to the flow control device is equal to the flow rate and temperature of fluid output from the flow control device.

This relationship assumes zero temperature loss through the system and so is an approximation:

$$F_c T_c + F_h T_h = F_o T_o \quad \text{Equation 2}$$

where: T_c = the temperature of the cold fluid flow to the flow control device,
 T_h = the temperature of the hot fluid flow to the flow control device,
and
 T_o = the regulated output fluid temperature from the flow control device.

In use, a user selects a target (desired) output temperature T_o . In some embodiments, the user may also select a target (desired) output flow rate F_o . Alternatively a nominal output flow rate may be preset in the apparatus.

5 From the target output temperature and a nominal output flow rate, or from the target output temperature and a target output flow rate, the controller calculates the cold water and hot water inlet flow rates required. Given T_o and F_o and the measured inlet temperatures T_c and T_h the controller calculates flow rates F_c and F_h . Subtracting T_h multiplied by Equation 1 from Equation 2 gives:

$$(T_o - T_h)F_o = (T_c - T_h)F_c$$

which can be rearranged to calculate the required cold water flow rate input to the flow control device:

$$F_c = \frac{T_h - T_o}{T_h - T_c} F_o \quad \text{Equation 3}$$

15 Similarly the required hot water flow rate input to the flow control device may be computed:

$$F_h = \frac{T_o - T_c}{T_h - T_c} F_o \quad \text{Equation 4}$$

Both of these calculations (Equations 3 and 4) require:

$$T_h \neq T_c$$

25 From Equations 3 and 4, the controller determines from the target output temperature and the measured inlet temperatures the hot and cold flow rates required to achieve the target outlet temperature and the target outlet flow rate.

30 The above theory applies when the pressures of the cold and hot water inlet flows are equal. Where the inlet pressures are equal, the flow control device hot and cold valve settings as calculated from Equations 3 and 4 result in the expected or target output temperature and flow rate.

However, where the cold and hot inlet pressures are different, controlling the flow control device hot and cold valves based on equations 3 and 4 may not achieve the target output temperature and flow rate.

- 5 To take into account a difference in inlet pressures and other errors, for example, sensor errors, in some embodiments of the present invention the controller 10 introduces an error term for each of the inlet cold and hot temperatures:

$$T_h = M_h + e_h \quad \text{Equation 5}$$

$$10 \quad T_c = M_c + e_c \quad \text{Equation 6}$$

where: T_c = the effective temperature of the cold fluid flow,
 T_h = the effective temperature of the hot fluid flow,
 M_c = the measured temperature of the cold fluid flow,
15 M_h = the measured temperature of the hot fluid flow,
 e_c = the error term for the cold fluid inlet temperature, and
 e_h = the error term for the hot fluid inlet temperature.

Substituting the error terms into Equation 2 the following relation is derived:

$$20 \quad T_o(F_h + F_c) = (M_c + e_c)F_c + (M_h + e_h)F_h \quad \text{Equation 7}$$

To determine the magnitude of the error terms, the controller may perform a calibration routine. For example, the apparatus may provide a selectable
25 calibration routine for an installer or user to initiate, for example via the human interface.

In the calibration routine, the controller runs a series of experiments. In each experiment the controller chooses a flow rate setting for each of the hot and cold
30 valves of the flow control device, and measures inlet temperatures M_c and M_h and the outlet temperature M_o resulting from the flow control device valve settings.

The controller determines the values of the error terms e_c and e_h that minimise the sum-of-squares difference in the calculated energy input to and output from the
35 flow control device. That is, the controller seeks to find the minimum value of the total error function $E(e_h, e_c)$:

$$E(e_h, e_c) = \sum_i^N [M_{o_i}(F_{h_i} + F_{c_i}) - (M_{c_i} + e_c)F_{c_i} - (M_{h_i} + e_h)F_{h_i}]^2 \quad \text{Equation 8}$$

where N is the number of experiments.

- 5 Equation 8 describes a paraboloid, whose minimum can be found by setting the partial derivatives to zero. Differentiating Equation 8 and collecting constants outside the summation provides Equations 9 and 10:

$$\frac{\partial E}{\partial e_h} = 2[e_h \sum_i^N F_{h_i}^2 + e_c \sum_i^N F_{h_i}F_{c_i} + \sum_i^N F_{h_i}U_i] \quad \text{Equation 9}$$

$$10 \quad \frac{\partial E}{\partial e_c} = 2[e_h \sum_i^N F_{h_i}F_{c_i} + e_c \sum_i^N F_{c_i}^2 + \sum_i^N F_{c_i}U_i] \quad \text{Equation 10}$$

where:

$$U_i = M_{h_i}F_{h_i} + M_{c_i}F_{c_i} - M_{o_i}(F_{h_i} + F_{c_i})$$

- 15 In each experiment (i) in the calibration routine, the controller sets the flow rate setting F_c and F_h for each of the cold and hot valves of the flow control device and determines the measured inlet temperatures M_c and M_h and the measured outlet temperature M_o . From a number N of experiments the controller determines each of the distinct summations appearing in Equations 9 and 10:

$$P = \sum_i^N F_{h_i}^2$$

$$Q = \sum_i^N F_{c_i}^2$$

$$R = \sum_i^N F_{h_i}F_{c_i}$$

$$S = \sum_i^N F_{h_i}U_i$$

$$T = \sum_i^N F_{c_i}U_i$$

- 20 Using these definitions for the distinct sums from Equations 9 and 10, and by setting Equations 9 and 10 to zero, the controller can determine the minimum of Equation 8 as the solution to the following set of simultaneous equations:

$$Pe_h + Re_c + S = 0 \quad \text{Equation 11}$$

$$Re_h + Qe_c + T = 0 \quad \text{Equation 12}$$

The solution to these equations provides the following expressions for the error terms:

$$e_h = \frac{QS - RT}{R^2 - PQ} \quad \text{Equation 13}$$

$$e_c = \frac{PT - RS}{R^2 - PQ} \quad \text{Equation 14}$$

For these expressions to be valid it is necessary that $R^2 \neq PQ$ which is true when $F_{hi} \neq F_{ci}$ for at least one experiment i .

At the termination of the calibration sequence, for example once the controller has performed a set number of experiments, in each experiment the flow control device valves being set at a variety of settings, values for the error terms are determined.

For example, the controller may set the positions of the flow control device hot and cold valves randomly in each experiment, and determine the distinct summations over a total of 20 experiments. At the conclusion of the experiments the controller then determines the error terms. A user or installer (for example a tradesman plumber) may then set the apparatus to operate in a normal operating mode.

Alternatively, at the conclusion of the calibration sequence, the controller may automatically switch into the normal operating mode.

In the operating mode, the controller calculates the required hot and cold inlet flows required to achieve a target output temperature T_o and flow rate F_o selected by the user. The controller calculates the hot and cold inlet flows based on the measured inlet temperatures M_c and M_h and the error terms e_h and e_c determined during the calibration routine using the following relationships derived from Equations 3 to 6:

$$F_c = \frac{(M_h + e_h) - T_o}{(M_h + e_h) - (M_c + e_c)} F_o \quad \text{Equation 15}$$

$$F_h = \frac{T_o - (M_c + e_c)}{(M_h + e_h) - (M_c + e_c)} F_o \quad \text{Equation 16}$$

Thus an apparatus according to the present invention is adapted to provide an output flow at a desired temperature and flow rate by controlling the flow rate of a

hot inlet flow and a cold inlet flow based on the measured temperatures of the inlet flows, even when there is an imbalance in the pressures of the hot and cold inlet flows.

- 5 The above calibration routine is represented in the flow diagram of Figure 3, and normal operation of the apparatus is represented in the flow diagram of Figure 4.

For example, the inventor has found that for an installation comprising a hot water inlet pressure of about 250kPa and temperature of about 60°C, and a cold water
10 inlet pressure of about 600kPa and a temperature of about 20°C, the calibration routine determined error terms e_h and e_c to be 0 and -8.

For the above operation of the controller, in normal operation (operation mode) the controller controls the flow control device valves to achieve a target output
15 temperature without feedback from the output flow temperature. The output flow temperature is used to set the magnitude of the error terms during the calibration routine. Once in the normal operating mode, the output temperature is not used to control the flow control device to achieving the desired target output temperature.

20 In some embodiments, the apparatus comprises a safety shutdown mode. Should an unsafe high temperature be measured at the output of the apparatus or flow control device, the controller initiates an automatic isolation of the hot water supply. For example, the controller may close all hot water valves in the flow control device, or the controller may close all hot water valves and cold water
25 valves in the flow control device, and/or other hot water supply isolation valves. The safety shut down mode is illustrated in Figure 3. The controller compares the measured output temperature M_o with a high temperature limit T_{high} , and proceeds with normal operation mode if the output temperature is less than the limit, or enters the shutdown mode. A reset may be required to allow the apparatus to
30 begin in normal operation. The discontinuous lines in Figure 3 illustrate the safety shut down mode as an addition to the earlier described control of the flow control device. Where the shutdown mode is included, the comparison between the measured output temperature and the high temperature limit may be done prior to the calculation of the effective temperatures as illustrated in Figure 3.

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In some embodiments, the controller compares the hot and cold inlet temperatures T_c and T_h to verify that they are not equal to avoid divide by zero errors. In some

embodiments, the controller compares the hot and cold inlet temperatures T_c and T_h to verify that there is a difference between the inlet temperatures greater than a minimum threshold. In some embodiments the minimum threshold is less than 40°C. In some embodiments the minimum threshold is less than 35°C. In some
5 embodiments the minimum threshold is less than 30°C. In some embodiments the minimum threshold is less than 25°C. In some embodiments the minimum threshold is less than 20°C. For example, the controller ensures the hot inlet flow temperature is greater than the cold inlet flow temperature by a minimum of about 15 °C. In some embodiments, where the difference between the inlet temperatures
10 is not greater than the minimum threshold, the controller automatically enters a degraded mode. In the degraded mode, the controller sets the flow control device valves to preset valve settings. In the degraded mode, the user cannot alter the flow control device. For example, in the degraded mode, the controller sets the cold valves of the flow control device to provide a 50% flow of maximum cold water
15 flow, and the hot valves of the flow control device to provide a 50% flow of maximum hot water flow. The degraded mode is illustrated in Figure 3. The discontinuous lines in Figure 3 illustrate the degraded mode as an addition to the earlier described control of the flow control device. Where the degraded mode is included, the comparison between the input temperatures may be done prior to the
20 calculation of the cold and hot valve settings as illustrated in Figure 3.

The apparatus may enter the degraded mode when the flow control device has not been operated for some time. For example, where the flow control device has been
25 unused overnight, hot water sitting in the supply pipe work to the flow control device may cool to have the same or similar temperature to the water in the cold supply pipe work to the flow control device. In this instance, when a user operates the flow control device to provide a flow of water, the initial temperatures of the cold and hot inlet flows to the flow control device are the same or similar, and the controller enters the degraded mode to provide a flow of water with the flow control
30 device valves set to preset settings. Once hot water from a hot water source replenishes the water in the hot water supply pipe and reaches the flow control device, the controller exits the degraded mode and enters the normal operating mode, at which time the controller commences control of the flow control device valves in accordance with Equations 3 and 4 or 15 and 16, as illustrated in Figure 3.

35 In some embodiments, the output temperature that a user may select, for example using the human interface, is limited to being between the hot and cold inlet

temperatures T_h and T_c . For example, where a user selects the minimum temperature being the cold water inlet temperature, the controller shuts the hot valve or valves of the flow control device and controls the cold valves to achieve the desired flow rate. The apparatus may limit the settable output temperature range to be narrower than the range defined by the inlet temperatures. For example, the output temperature settable by a user may be limited to a maximum temperature, for example 40°C, that is less than the temperature of the hot water inlet flow which may be significantly higher, for example 55°C.

In some embodiments, the controller determines a limit for the maximum outlet flow rate that a user can select based on the nominal maximum flow rate of the flow control device hot and cold valves. For example, in one configuration, the maximum flow rate of the hot valve or valves may be 12.5L/min and the maximum flow rate of the cold valves may be 12.5L/min. Therefore, the maximum flow rate that the flow control device can provide is when all hot and cold valves of the flow control device are open, providing a maximum flow rate of 25L/min. In this scenario, assuming the pressures of the hot and cold inlet flows are the same, the temperature of the output flow from the flow control device will be the average of the hot and cold inlet temperatures.

The maximum outlet flow rate achievable is also dependent on the inlet temperatures and the desired or target outlet temperature. From Equation 3 we can define a first constraint based on the maximum cold flow from the flow control device:

$$F_c = \frac{T_h - T_o}{T_h - T_c} F_o < F_{maxc} \quad \text{Equation 17}$$

where F_{maxc} is the maximum cold flow rate of the cold valve or valves of the flow control device. Rearranging Equation 17 defines a limit for the output flow based on the maximum cold flow, inlet temperatures and outlet temperature:

$$F_o \leq \frac{T_h - T_c}{T_h - T_o} F_{maxc} \quad \text{Equation 18}$$

Similarly, from equation 4 we can define a limit for the output flow based on the maximum hot flow F_{maxh} of the hot valve or valves of the flow control device, the inlet temperatures and the outlet temperature:

$$F_o \leq \frac{T_h - T_c}{T_o - T_c} F_{maxh} \quad \text{Equation 19}$$

Equations 18 and 19 require the target output temperature to not equal the hot or cold inlet temperatures. In a preferred embodiment the maximum flow for the cold valves and the hot valves of the flow control device is the same, that is $F_{maxh} = F_{maxc} = F_{max}$. Assuming the hot inlet temperature T_h is greater than the cold inlet temperature T_c , Equations 18 and 19 can be combined to give Equation 20 defining the limits for the output flow rate from the flow control device:

$$F_o \leq \frac{T_h - T_c}{\max(T_h - T_o, T_o - T_c)} F_{max} \quad \text{Equation 20}$$

For example, for a flow control device having a maximum flow rate of 12.5L/min for the hot valves and 12.5L/min for the cold valves, and given a cold water inlet temperature of 15°C and a hot water inlet temperature of 65°C, the maximum possible output flow rate that may be provided by the flow control device calculated from Equation 20 is displayed in the graph of Figure 5.

The present invention is particularly useful where a flow control device is used to provide control of temperature or temperature and flow rate in a predicted way, even where there is an imbalance in the inlet pressures.

In one embodiment of the present invention, a sensor calibration routine or method is used to calibrate the temperature sensors relative to one of said temperature sensors, for example the outlet temperature sensor. To calibrate the temperature sensors, the cold valves of the flow control device are open and the hot valves of the flow control device are fully closed or flow through the hot side of the flow control device is prevented, by for example, an upstream isolation valve. In this state, the cold fluid inlet temperature sensor 8 measures the same temperature as the outlet temperature sensor 6. Any difference between the measured temperatures can be accounted for by the controller applying an offset to, for example, the cold temperature sensor signal.

Once the cold inlet temperature sensor and the outlet temperature sensor has been compared, the hot valves of the flow control device are opened and the cold valves of the flow control device are fully closed or flow through the cold side of the flow

control device is prevented, by for example, an upstream isolation valve. In this state, the hot fluid inlet temperature sensor 7 measures the same temperature as the outlet temperature sensor 6. Any difference between the measured temperatures can be accounted for by the controller applying an offset to the hot inlet temperature sensor signal.

The above temperature sensor calibration method ensures the water flow provided by the flow control device can be accurately controlled based on comparison of the temperature sensor signals. The temperature sensor calibration method allows the system to operate effectively with a requirement to accurately calibrate only one temperature sensor in absolute terms, for example the cold temperature sensor. The other two temperatures sensors can be set relatively by reference to the calibrated cold inlet temperature sensor. Preferably the calibrated temperature sensor is factory calibrated by a manufacturer.

In some embodiments, the apparatus comprises a mixing unit 16. The mixing unit ensures complete mixing of the hot and cold fluid flows prior to temperature measurement by the main outlet temperature sensor 6. The mixing unit may comprise a reservoir volume to allow fluid downstream of the flow control device valves to thoroughly mix or accumulate prior to temperature measurement and supply to a shower head or faucet. For example, the reservoir is an output manifold of the flow control device sufficiently sized to have enough volume to prevent temperature spikes in the outlet flow.

In this specification, hot and cold are used relatively, for example, in a system comprising a hot inlet and a cold inlet, the hot inlet is for receiving a flow of fluid having a higher temperature than a flow of fluid being received by the cold inlet. The terms hot and cold are not intended to reflect any particular temperatures or temperature ranges. Similarly, high and low are used relatively and are not intended to reflect any particular pressure ranges. Furthermore, the terms 'hot valve' and 'cold valve' are used to reference a valve located in the hot side of the flow control device and a valve located in the cold side of the flow control device, and are not intended to reflect any other difference (the same type of valve may be used in both the hot and cold sides of the flow control device).

The foregoing description of the invention includes preferred forms thereof. Modifications may be made thereto without departing from the scope of the invention as defined by the accompanying claims.

CLAIMS

1. An apparatus for controlling and mixing a flow of hot fluid and a flow of cold fluid to provide an output flow of fluid at a user selectable desired temperature, the apparatus comprising:

a flow control device for controlling and mixing the flow of hot fluid and the flow of cold fluid, the flow control device comprising:

a hot inlet for receiving the flow of hot fluid,

a cold inlet for receiving the flow of cold fluid,

an outlet to provide the output flow of fluid,

at least one hot valve connected between the hot inlet and the outlet to control the flow of hot fluid from the hot inlet to the outlet, and

at least one cold valve connected between the cold inlet and the outlet to control the flow of cold fluid from the cold inlet to the outlet,

a hot temperature sensor for sensing the temperature of the flow of hot fluid,

a cold temperature sensor for sensing the temperature of the flow of cold fluid,

an output temperature sensor for sensing the temperature of the output flow of fluid, and

a controller receiving signals from the temperature sensors, in a calibration routine the controller adapted and configured to:

i) set the cold valve to a cold flow rate setting and the hot valve to a hot flow rate setting,

ii) wait for time period or for the temperature of the output flow of fluid to stabilise,

iii) determine a measured output temperature, a measured hot temperature and a measured cold temperature based on signals from the output temperature sensor, the hot temperature sensor and the cold temperature sensor,

iv) calculate a cold error term and a hot error term that minimise the sum-of-squares difference between a calculated output power and a calculated input power wherein the output power equals the measured output temperature multiplied by the sum of the cold flow rate setting and the hot flow rate setting, and the input power equals the sum of the hot flow rate setting multiplied by an effective hot temperature and the cold flow rate setting multiplied by an effective cold temperature, wherein the effective hot temperature equals the sum of the measured hot temperature and the hot error term and the effective cold

temperature equals the sum of the measured cold temperature and the cold error term, and

in an operation mode the controller adapted and configured to control the cold valve and the hot valve based on the effective hot temperature and the effective cold temperature to provide the output flow of fluid at the user selected desired temperature.

2. An apparatus as claimed in claim 1 wherein in the operation mode the controller is adapted and configured to control the cold valve and the hot valve based on the effective hot temperature and the effective cold temperature only to provide the output flow of fluid at the user selected desired temperature.

3. An apparatus as claimed in claim 1 or claim 2 wherein the hot valve is connected between the hot inlet and the outlet to control the flow of hot fluid from the hot inlet to the outlet only, and the cold valve is connected between the cold inlet and the outlet to control the flow of cold fluid from the cold inlet to the outlet only, and the controller is adapted and configured to control the cold valve and the hot valve independently.

4. An apparatus as claimed in claim 3 wherein the apparatus is adapted and configured to control and mix the flow of hot fluid and the flow of cold fluid to provide an output flow of fluid at the user selectable desired temperature and a user selectable desired flow rate.

5. An apparatus as claimed in any one of claims 1 to 4 wherein in the calibration routine the controller repeats steps i) to iii) a number of times to determine a plurality of values for each of the cold flow rate setting, the hot flow rate setting, the measured output temperature, the measured hot temperature and the measured cold temperature, and the controller calculates the cold error term and hot error term that minimise the sum-of-squares difference based on the plurality of values.

6. An apparatus as claimed in claim 5 wherein the controller repeats steps i) to iii) at least 5 times.

7. An apparatus as claimed in claim 6 wherein the controller repeats steps i) to iii) at least 10 times.

8. An apparatus as claimed in claim 7 wherein the controller repeats steps i) to iii) at least 20 times.
9. An apparatus as claimed in claim any one of claims 2 to 8 wherein in step i) the controller sets the hot valve and the cold valve to randomly determined set points.
10. An apparatus as claimed in any one of claims 1 to 9, in the operation mode the controller adapted and configured to compare the temperature of the output flow of fluid to a predetermined temperature and close the hot water valve to isolate the output from the hot input if the temperature of the output flow of fluid is greater than the predetermined temperature.
11. An apparatus as claimed in any one of claims 1 to 10 wherein in the operation mode the controller is adapted and configured to enter a degraded mode if the difference between the temperature of the hot flow of fluid and the temperature of the cold flow of fluid is less than a predetermined threshold, in the degraded mode the controller setting the hot valve and the cold valve to predetermined set points.
12. An apparatus as claimed in claim 11 wherein the predetermined threshold is less than 20°C.
13. An apparatus as claimed in claim 11 wherein in the degraded mode the controller sets the hot valve and the cold valve to 50% open.
14. An apparatus as claimed in any one of claims 1 to 13 wherein the apparatus comprises a human machine interface adapted to allow a user to select the desired temperature.
15. An apparatus as claimed in claim 14 wherein the controller is adapted and configured to limit the selectable desired temperature based on the temperature of the hot and cold fluid flows.
16. An apparatus as claimed in claim 14 or 15 wherein the controller is adapted and configured to limit the selectable flow rate to be less than the product of:

the quotient of:

the difference between the temperature of the flow of hot fluid and the temperature of the flow of cold fluid and the maximum of the difference between the temperature of the flow of hot fluid and the temperature of the output flow of fluid and the difference between the temperature of the output flow of fluid and the temperature of the cold flow of fluid, and
a maximum flow rate of the cold valve and the hot valve.

17. An apparatus as claimed in any one of claims 1 to 16 wherein the flow control device comprises the cold temperature sensor in proximity to the cold inlet, the hot temperature sensor in proximity to the hot inlet, and the output temperature sensor in proximity to the outlet.

18. An apparatus as claimed in any one of claims 1 to 17 wherein the apparatus comprises a mixing unit for mixing of the hot and cold fluid flows prior to temperature measurement by the outlet temperature sensor.

19. An apparatus as claimed in claim 18 wherein the mixing unit comprises a reservoir volume to allow fluid downstream of the hot valve and cold valve to mix or accumulate prior to temperature measurement by the outlet temperature sensor.

20. An apparatus as claimed in claim 19 wherein the reservoir is an output manifold of the flow control device.

21. An apparatus as claimed in any one of claims 1 to 20 wherein the flow control device comprises a bank of solenoid operated cold valves for controlling the flow of cold fluid and a bank of solenoid operated hot valves for controlling the flow of hot fluid, each said solenoid valve switchable between a closed position and an open position, the controller adapted and configured to open a number of hot valves to control the flow of hot fluid and a number of cold valves to control the flow of cold fluid.

22. An apparatus as claimed in any one of claims 1 to 21 wherein the controller controls the cold valve based on a calculated cold flow rate based on the desired flow rate multiplied by the quotient of the difference between the temperature of the flow of hot fluid and the desired temperature and the difference between the temperature of the flow of hot fluid and the temperature of the flow of cold fluid.

23. An apparatus as claimed in any one of claims 1 to 22 wherein the controller controls the hot valve based on a calculated hot flow rate based on the desired flow rate multiplied by the quotient of the difference between the desired temperature and the temperature of the flow of cold fluid and the difference between the temperature of the flow of hot fluid and the temperature of the flow of cold fluid.

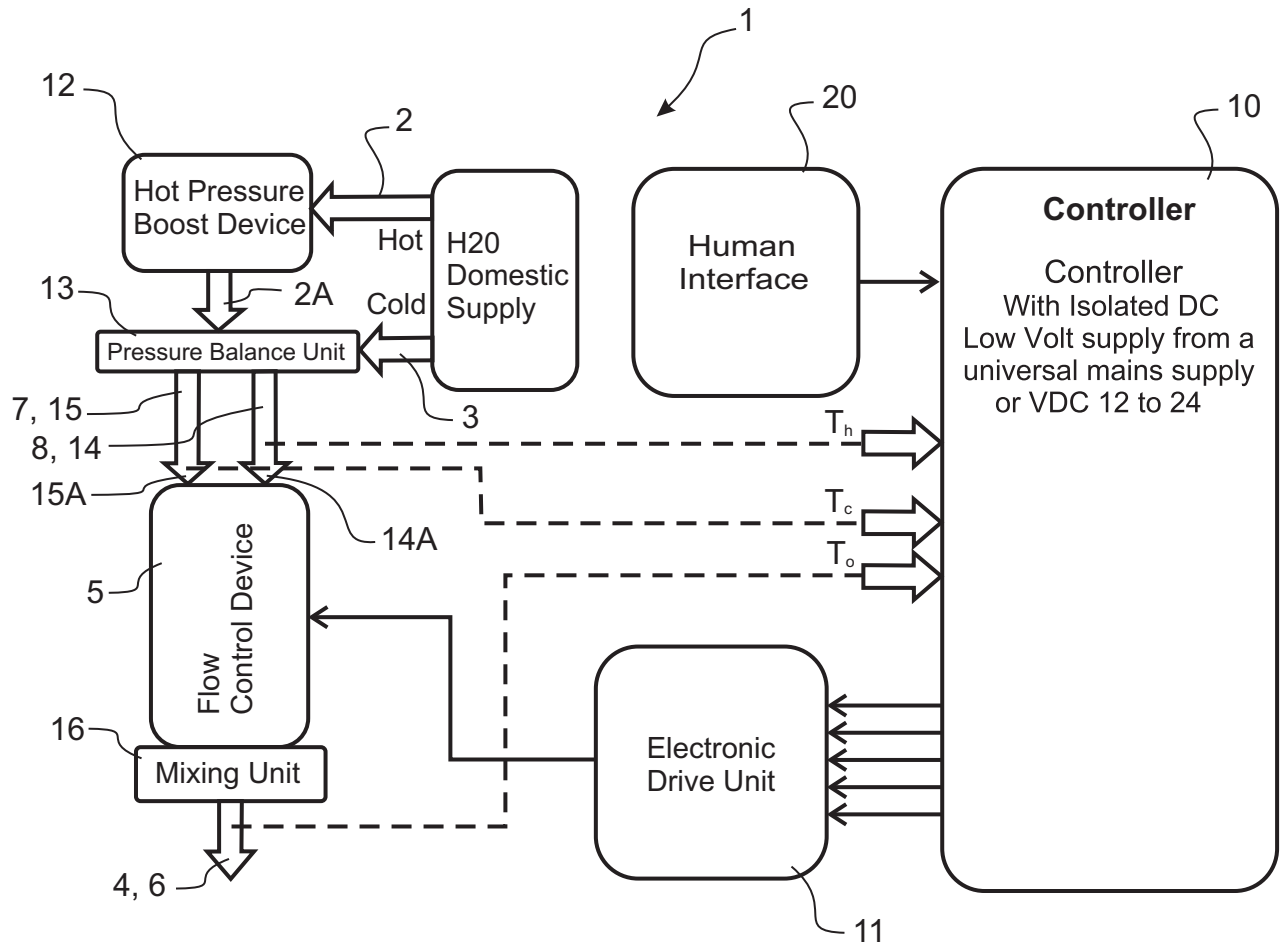
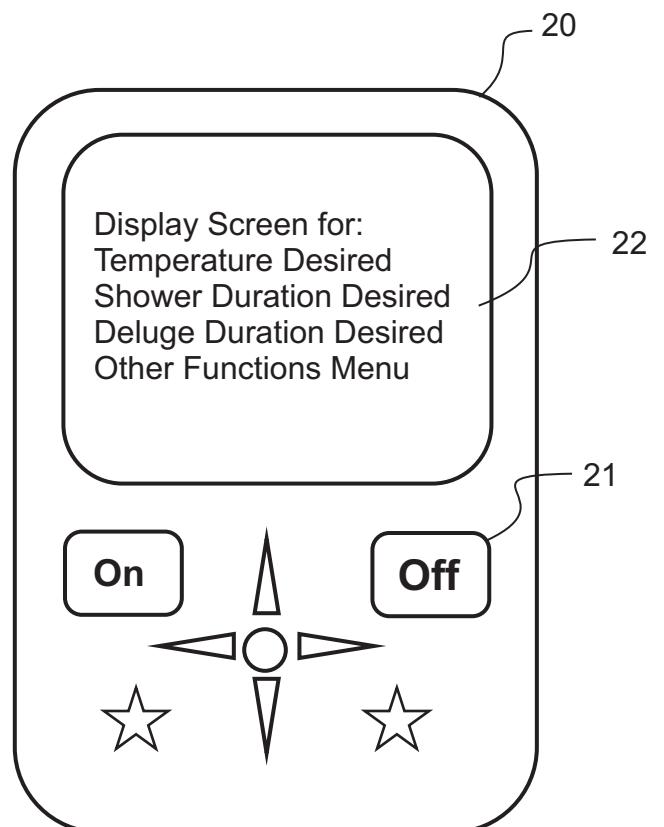


FIGURE 1

FIGURE 2



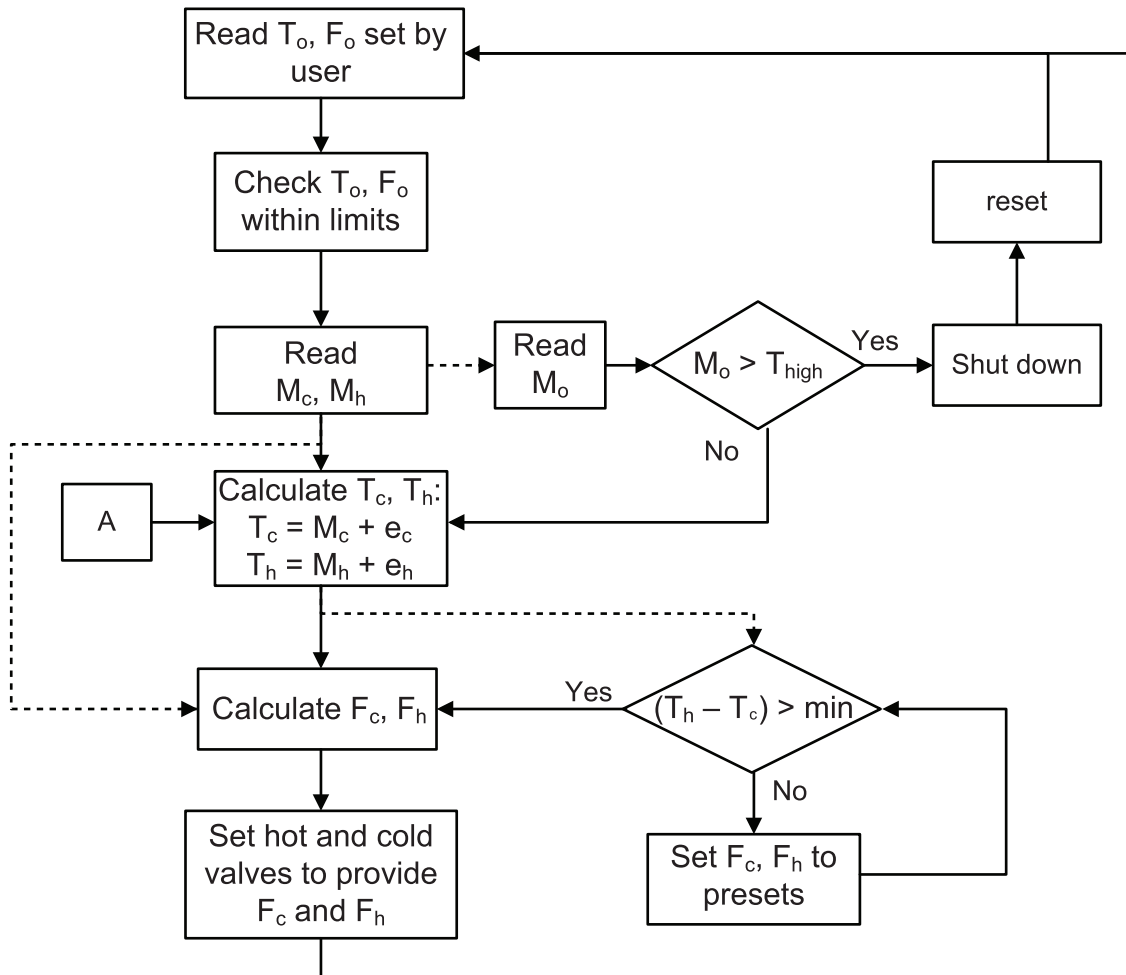
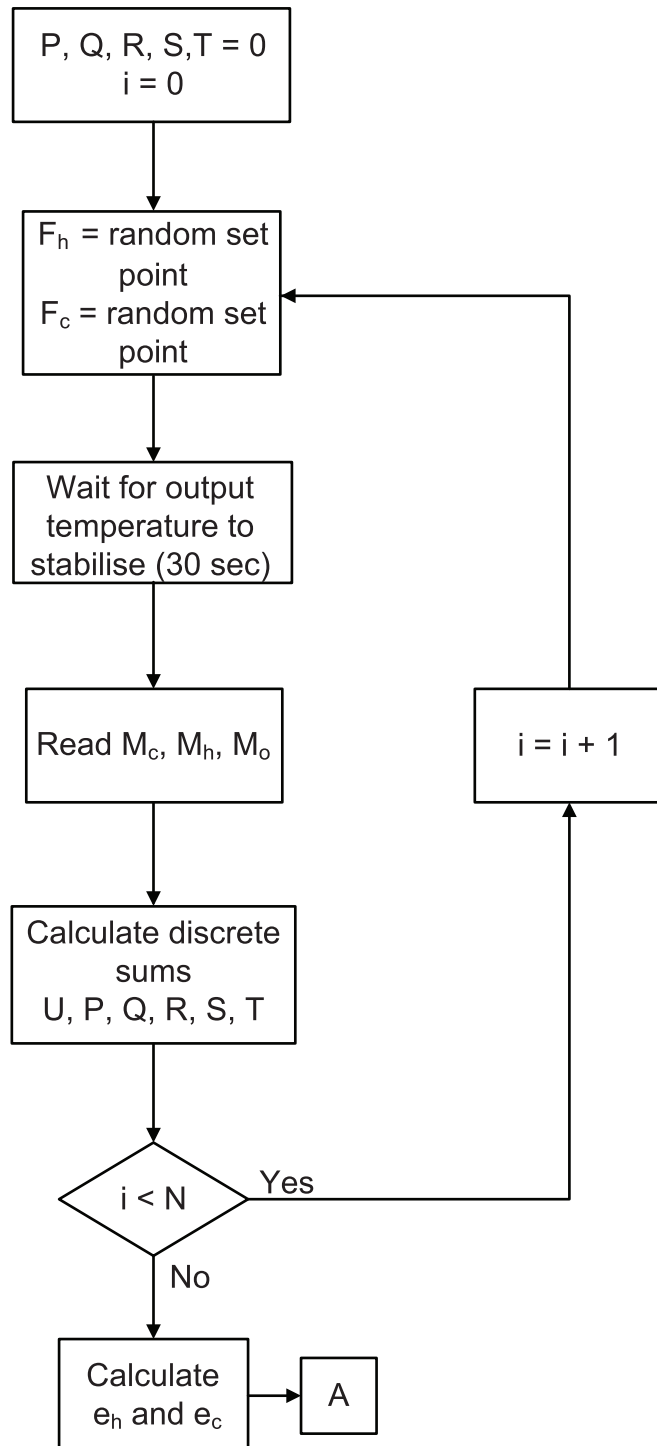
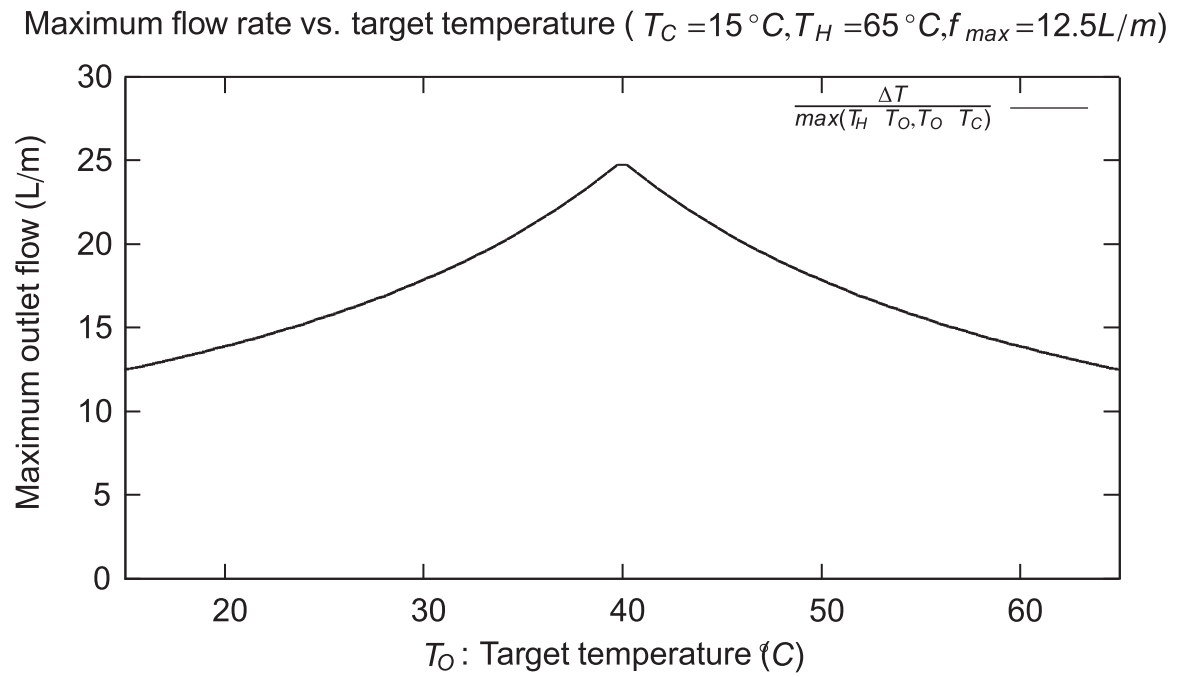


FIGURE 3

**FIGURE 4**

**FIGURE 5**