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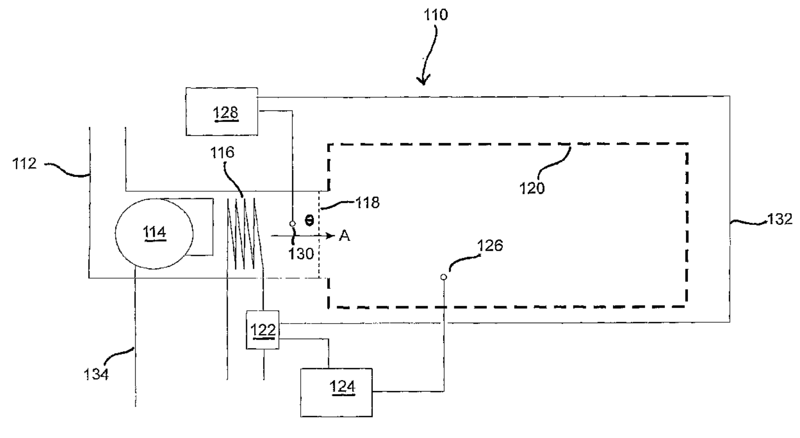

FIGURE 2

(57) Abstract: A method of controlling a space forced convection (air flow) cooling or heating system comprising starting a means of heating or chilling; periodically measuring the temperature of the air (θ) downstream and close to said means of heating or chilling and when θ is less than a predetermined value θ_1 periodically estimating the rate of change of θ with time (dθ/dt) and when the absolute value of said rate of change of temperature with time (dθ/dt) is equal to or less than a user preset value (β_1) interrupting the means of heating or chilling

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Heat Transfer System Controller

The invention relates to a programmable controller and to a method of use for control of a space chilling or heating system.

Space chilling systems typically use a heat pump comprising a closed system containing refrigerant and having an evaporator, a condenser an expansion valve and a fluid circulation pump. When used in chilling systems the evaporator usually takes the form of a heat exchanger located either in the space to be cooled or within a duct through which air is blown into the space to be cooled, this air being chilled by said evaporator heat exchanger.

The operation of such refrigeration systems typically have a primary control system that provide safety interlocks that are either electrical or mechanical or electro-mechanical in operation. In addition, secondary control systems typically include a controller, and thermostats located within the space to be chilled.

The location installation of the thermostat or thermostats within the controlled area does not follow absolute rules and each thermostat location installation is subject to constraints imposed by (but not limited to); internal architecture, area specific furniture, point of delivery of the air, and the location and number of persons within the controlled area.

By the operation of the thermostat or thermostats within the controlled area the heating or chilling process is normally started and stopped, subject to the safety interlocks, and the amount of heat or cold contained within any specific quantity of air delivered to the controlled area is altered once the air has passed over at least one heat exchanger; typically located within an air duct with an outlet in the controlled area. The thermostats operational starting and stopping switching functions relative to set point temperature affect the values of the achieved temperatures within the controlled area. Typically, for cooling the thermostat will operate the chiller when the detected space temperature is slightly above the set point and continue cooling until the detected temperature is a pre-determined value below the set point. This pre-determined value varies appreciably between different manufacturers of thermostats.

The time period required for the heating/chilling system to reach the desired set point value from initial start up value is commonly referred to as the process lag, the value of which is generally a function of:- (a) the volume of air delivered to the controlled area relative to the volume of the controlled area; (b) the physical distance of, constructional material of, thermal insulation applied to, the duct carrying the air to the controlled area: (c) the number of heat sources within the controlled area at any one time in the operation of the heat transfer process; (d) the amount of re-circulated air by volume of the controlled area when compared to any volume of fresh air that is introduced and like volume of controlled area extract air removed; (e) the rated heat transfer maximum capacity - known as duty - of the heat transfer process system compared to the amount of heat or cold required to be transferred to or from the controlled area; and (f) the inability of the heat transfer unit to reduce its duty when the applied load is below the duty achieved at the time of operation of the heat transfer unit.

The effect of the process lag in addition to thermostat location and operation is commonly to cause the air temperatures in some areas of the controlled area to be locally over cooled or locally under heated, depending on the heat transfer process in action. This lag typically results in temperature overshoot (for heating systems) and undershoot (for cooling systems) by comparison to set point. The difference in mean achieved temperature local to the thermostat or devices compared to the set point value is commonly referred to as the set point offset. This temperature disparity commonly leads to controlled area occupant discomfort, a consequence of the continued operation of the heat transfer unit during the set point overshoot/undershoot is that the operational energy consumption of the heating/chilling device is greater than it need be. In part, this undesirable situation results from the practical need to oversize (in respect of average thermal duty) the heater or chiller so that it can meet peak design demand.

One objective of the present invention is to provide apparatus and a control method that allows the overall energy consumption of the heating/chilling unit to be reduced. Another objective is to provide apparatus and a control method that will result in improved user comfort as a result of better temperature control within the space being heated or chilled.

In one aspect the invention comprises a method of controlling a space forced convection cooling or heating system wherein the system comprises: means of heating or chilling; a local first temperature sensor located downstream and close to said means of heating or chilling;

wherein a programmable controller in cooperation with said first temperature sensor measures the temperature of the air (θ) downstream and close to said means of heating or chilling; wherein the method comprises the following steps: (i) start said means of heating or chilling; periodically record the temperature θ and use processing means within the programmable controller to periodically estimate the rate of change of θ with time ($d\theta/dt$); (ii) store a first user preset value (β_1) within the programmable controller and when said rate of change of temperature with time ($d\theta/dt$) or absolute value of ($d\theta/dt$) is equal to or less than said first user preset value (β_1) interrupt said means of heating or chilling.

Following start or restart of said means of heating or chilling means a time delay step may be introduced prior to starting steps (i) and (ii). Following initial power-up of the programmable controller a user preset time delay or a predetermined time delay the length of which is derived as a programmable controller function may be introduced prior to first starting said means of chilling or heating. This advantageously reduces power surge following start up (restart) of multiple systems following a general power supply failure.

In another aspect the invention comprises a method of controlling a space forced convection cooling or heating system wherein the system comprises: means of heating or chilling; a local first temperature sensor located downstream and close to said means of heating or chilling; wherein a programmable controller in cooperation with said first temperature sensor measures the temperature of the air (θ) downstream and close to said means of heating or chilling; wherein the method comprises the following steps: (i) following power-up and system internal health checks for programmable controller; measure initial temperature of the air (θ) downstream and close to said means of heating or chilling; calculate θ_1 according to the formula: $\theta_1 = [fn(\theta)*(D-E)]+E$; wherein D and E are user preset values and $fn(\theta)$ is a value calculated from other user preset values and the value of θ; (ii) start means of heating or chilling and for chilling when θ is less than θ_1 proceed to step (iii) or; for heating when θ is greater than θ_1 proceed to step (iii); (iii) periodically record the temperature θ and use processing means within the programmable controller to periodically estimate the rate of change of θ with time ($d\theta/dt$); store a first user preset value (β_1) within the programmable controller and when said rate of change of temperature with time ($d\theta/dt$) or absolute value of ($d\theta/dt$) is equal to or less than said first user preset value (β_1) interrupt said means of heating or chilling.

Delaying measurement of rate of change of temperature ($d\theta/dt$) (and testing against β_1) until the θ_1 test is satisfied avoids possible premature interruption of heating/chilling owing to thermal lag; for example, lag following start up of the means of chilling (refrigerator compressor).

In another aspect the invention comprises a method of controlling a space forced convection cooling or heating system wherein the system comprises: means of heating or chilling; a local first temperature sensor located downstream and close to said means of heating or chilling; wherein a programmable controller in cooperation with said first temperature sensor measures the temperature of the air (θ) downstream and close to said means of heating or chilling; wherein the method comprises the following steps: (i) following power-up and system internal health checks for programmable controller; measure initial temperature of the air (θ) downstream and close to said means of heating or chilling; calculate θ_1 according to the formula: $\theta_1= [fn(\theta)*(D-E)]+E$; wherein D and E are user preset values and $fn(\theta)$ is a value calculated from other user preset values; (ii) start means of heating or chilling; set time counter T_1 to zero; and for chilling when θ is less than θ_1 proceed to step (iii) or; for heating when θ is greater than θ_1 proceed to step (iii); (iii) periodically record the temperature θ and use processing means within the programmable controller to periodically estimate the rate of change of θ with time ($d\theta/dt$); store a first user preset value (β_1) within the programmable controller and when said rate of change of temperature with time ($d\theta/dt$) or absolute value of ($d\theta/dt$) is equal to or less than said first user preset value (β_1) and T_1 is greater than a user input value T_{MN} interrupt said means of heating or chilling. Introducing time delay T_{MN} is advantageous particularly for applications utilising a refrigerant compressor as it helps avoid short cycling of the chiller system which can lead to mechanical damage of the compressor.

The value of $fn(\theta)$ may be calculated by the formula: $fn(\theta)= (\theta-C)/(B-C)$ or $fn(\theta)= \theta/(B-C)$; where B and C are user preset values.

In another aspect the invention comprises a method of controlling a space forced convection cooling or heating system wherein the system comprises: means of heating or chilling; a local first temperature sensor located downstream and close to said means of heating or chilling; wherein a programmable controller in cooperation with said first temperature sensor measures the temperature of the air (θ) downstream and close to said means of heating or chilling;

wherein the method comprises the following steps: (i) Start said means of heating or chilling; measure temperature of the air (θ) downstream and close to said means of heating or chilling; for chilling when θ is less than a user preset value θ_1; proceed to step (ii) or; for heating when θ is greater than θ_1 proceed to step (ii); (ii) periodically record the temperature θ and use processing means within the programmable controller to periodically estimate the rate of change of θ with time (dθ/dt); store a first user preset value (β_1) within the programmable controller and when said rate of change of temperature with time (dθ/dt) or absolute value of (dθ/dt) is equal to or less than said first user preset value (β_1) interrupt said means of heating or chilling

In another aspect the invention comprises a method of controlling a space forced convection cooling or heating system wherein the system comprises: means of heating or chilling; a local first temperature sensor located downstream and close to said means of heating or chilling; wherein a programmable controller in cooperation with said first temperature sensor measures the temperature of the air (θ) downstream and close to said means of heating or chilling; wherein the method comprises the following steps: (i) Start said means of heating or chilling (16); set time counter T_1 to zero; measure temperature of the air (θ) downstream and close to said means of heating or chilling; for chilling when θ is less than a user preset value θ_1; proceed to step (ii) or; for heating when θ is greater than θ_1 proceed to step (ii); (ii) periodically record the temperature θ and use processing means within the programmable controller to periodically estimate the rate of change of θ with time (dθ/dt); store a first user preset value (β_1) within the programmable controller and when said rate of change of temperature with time (dθ/dt) or absolute value of (dθ/dt) is equal to or less than said first user preset value (β_1) and T_1 is greater than T_{MN} where T_{MN} is a user input value, interrupt said means of heating or chilling.

The method of the invention may also comprise the following step:(iv) continue to periodically measure the temperature (θ) of the air leaving the vicinity of the heater or chiller and when this value (for heating) is less than a preset/predetermined value (θ_2) stored in the programmable controller or (for chilling) or is greater than said preset/predetermined value (θ_2) stored in the programmable controller restart said heating or chilling. Testing θ against θ_2 advantageously helps the system to restart the heater/chiller at the optimum temperature (θ) and thereby contributes to both user comfort and system efficiency.

Preferably; for cooling θ_2 is predetermined as the lower of: (F+G), H or (A-J); and for heating θ_2 is predetermined as the higher of: (F+G), H or (A+J); where G, H and J; where G, H and J are user input values, F is the value of θ at the time that the means of heating or chilling was last interrupted and A is the value of θ at the time θ_1 was last calculated. Testing θ against a calculated θ_2 value advantageously assists the system to restart the heater/chiller at the maximum practical load whilst still achieving user comfort.

When a refrigerant compressor system is utilised, an advantage of maximum practical load operation, with the applied load closer to the system maximum duty, is that it maintains the achieved Coefficient Of Performance of the system closer to the system rated value for longer, whilst the instantaneous COP is also raised due to the raised refrigerant pressure as a consequence of the elevated operational temperatures.

The method of the invention may also comprise the following step:(v) continue to periodically record the temperature θ and use processing means within the programmable controller to periodically estimate the rate of change of θ with time ($d\theta/dt$); store a user preset value (β_2) within the programmable controller and when said rate of change of temperature with time ($d\theta/dt$) or absolute value of ($d\theta/dt$) is equal to or less than user preset value (β_2) stored in the programmable controller restart said heating or chilling. Testing $d\theta/dt$ against β_2 advantageously helps the system to restart the heater/chiller at the optimum time and thereby contributes to both user comfort and system efficiency.

Preferably, the heating or chilling is only restarted when T_2 is greater than T_{MF}, where T_{MF} is a user preset value; and T_2 is a time counter set at zero when means of interrupting chilling or heating was last activated. Introducing time delay T_{MF} is advantageous particularly for chilling applications utilising a refrigerant compressor as it helps avoid short cycling of the chiller system which can lead to mechanical damage of the compressor.

Optionally, at the time of calculating θ_1 a counter (§) is set to zero and then incremented by 1 each time chilling or heating means is interrupted wherein if § is greater than a user input integer value §1 the program returns to the step where θ_1 is calculated but otherwise returns to the following step where the chilling or heating means is initiated.

The method of the invention may be used to provide both heating and chilling comprising a second temperature sensor and wherein the first temperature sensor has a temperature range appropriate for use with a chiller and the second sensor has a temperature range appropriate for use with a heater.

User preset values may be set or adjusted remotely using communication means. The communication means may include a internet link, infrared link or wireless link.

At least one of the following: current sensor value (θ); stored values of θ over a given period; output "on" time, performance error reporting; or, connected device malfunction data, may be actively or passively communicated through wires or wireless to an external device.

In another aspect the invention comprises a method of controlling a space forced convection (air flow) cooling or heating system comprising starting a means of heating or chilling; periodically measuring the temperature of the air (θ) downstream and close to said means of heating or chilling and when θ is less than a predetermined value θ_1 periodically estimating the rate of change of θ with time ($d\theta/dt$) and when the absolute value of said rate of change of temperature with time ($d\theta/dt$) is equal to or less than a user preset value (β_1) interrupting the means of heating or chilling.

A space forced convection cooling or heating system using the method of the invention may include a chilling or heating means located within a duct or located within a vented enclosure within the space to be cooled or heated. The chilling or heating means may comprise one or more heat exchangers through which cooling or heating fluid flow.

In another aspect the invention comprises a programmable controller: for use with a space forced convection cooling or heating system having means of heating or chilling and a local first temperature sensor located downstream and close to said means of heating or chilling; that uses any of the above method steps of the invention.

DESCRIPTION of INVENTION

Preferred embodiments of the invention will now be described by reference to the following diagrammatic figures in which:

Figure 1 shows the main components of a chilling system having a control system according to the present invention;

Figure 2 shows the main components of a chilling system according to a preferred embodiment of the invention;

Figure 3 shows a basic logic flow diagram for a method (chilling mode) according to the invention;

Figure 4 shows a logic flow diagram (chilling mode) for a preferred embodiment of the invention; and

Figure 5 shows how measured temperatures may vary with time for the chilling system of Figure 2.

With reference to Figure 1 a typical heating/chilling system 10, for use in a space 20, with a control system according to the present invention comprises: a heat exchanger 16 at least partly located within a casing 12 through which air is drawn by a fan or the like 14 (powered by line 34) and passed over heat exchanger 16. Heat exchanger 16 typically represents the evaporator of a conventional refrigeration system or is merely an exchanger provided with a cold fluid from an external source; for example chilled water. Alternatively, when the invention is applied to a heating system it may be the condenser of a closed circuit heat pump or hot water from a boiler or external water heater. Means 22 are provided to interrupt the supply of hot or cold fluid to exchanger 16; for example as determined by a standard controller 24 that typically measures the temperature at one or more points in the space 20 under temperature control, using one or more temperature sensors 26. Thus, when used conventionally controller 24 and temperature sensor 26, which typically include a thermostat will start or stop supply of heat or cold to exchanger 16 by means of device 22 which typically comprises a control valve or means of interrupting the action of a refrigeration cycle compressor, boiler etc..

The control apparatus of the present invention comprises a temperature probe 30 located downstream (with respect to airflow) of exchanger 16. The invention further comprises a programmable controller 28 that provides an on/off signal to device 22 in part by measuring the temperature θ of air flowing past temperature probe 30 combined with an advanced programme logic (see below). When an off signal is sent to device 22 via line 32 the supply of heat/cold to exchanger 16 is interrupted irrespective of the state of standard controller 24, but the air fan 14 is not interrupted so that air continues to flow over exchanger 16 into space 20.

Figure 2 shows a preferred embodiment of the invention as used to provide space heating/chilling. Chilling system 110 for use in a space 120 has a control system according to the present invention and comprises: a duct 112 through which air is drawn by a fan or the like 114 and passed over heat exchanger 116. Heat exchanger 116 typically represents one or more evaporator(s) of a conventional refrigeration system or is merely an exchanger provided with a cold fluid from an external source; for example chilled water. Alternatively, when the invention is applied to a heating system it may be the condenser of a closed circuit heat pump or hot water from a boiler or external water heater. Means 122 are provided to interrupt the supply of hot or cold fluid to exchanger 116 as determined for example by a known controller 124 that typically measures the temperature at one or more points in the space 120 under temperature control, using one or more temperature sensors 126. Thus, when used conventionally controller 124 and temperature sensor 126, which typically include a thermostat will start or stop supply of heat or cold to exchanger 116 by means of device 122 which typically comprises a control valve or means of interrupting the action of a refrigeration cycle compressor, boiler etc..

The control apparatus of the present invention comprises a temperature probe 130 located just downstream of exchanger 116 and at a point prior to the inlet 118 of heated or chilled air to space 120. The invention further comprises a programmable controller 128 that provides an on/off signal via line 132 to conventional device 122 in part by measuring the temperature θ of air flowing past temperature probe 130 combined with an advanced programme logic (see below). When an off signal is sent to device 122 the supply of heat/cold to exchanger 116 is interrupted but the air fan 114 is not interrupted so that air continues to flow over exchanger 116 into space 120. While this air may be entirely fresh air; it normally comprises a mixture of recycled air and fresh air. Thus, typically air is extracted from some location within space 120 (not shown) to provide such recycled air. This air will normally flow through an air duct system and typically the energy required to provide this flow will be provided by fan 114 or a further fan or the like (not shown).

As mentioned above controller 128 includes a programmable microprocessor or the like upon which is loaded a control program and into which various user determined input values are entered.

Figure 3; shows a basic logic flow diagram for a control program used in the method (chilling mode) of the invention and run on a programmable controller 28, 128. Naturally, the controller 28 may comprise a conventional thermostat combined with a separate programmable controller (not shown). Alternatively the programmable controller may be provided as part of a modified controller 24 (not shown). In either case the programmable controller includes a processor unit capable of accepting computer program code or the like.

When a system using the present invention is switched on power is provided to thermostat 26, programmable controller 28 and in addition fan 14 is activated, and providing thermostat 26 is calling for cold/heat this is supplied by heat exchanger 16 activated via means 22. At this moment elapsed time counter T_1 is set to zero [301] and then incremented according to lapsed time thereafter. For example, 5 minutes after the programmable controller signal to start flow of refrigerant or heating fluid through heat exchanger 16 the value of T_1 will be 5. For a chilling system; controller 24 will typically energise the compressor of a refrigeration circuit, resulting in cool fluid entering exchanger 16; the temperature of the cool fluid may fall from the initial value over a period of time of system operation.

Temperature sensor 30 sends a signal to programmable controller 28 which is converted by known electronic means to a digital signal that represents the temperature θ of air downstream of exchanger 16 in °C or °F. This allows the temperature θ of air downstream of exchanger 16 to be periodically measured and recorded, and thus the change in θ with time ($d\theta/dt$) also to be estimated. If θ is less than a preset or predetermined value θ_1 [302] and the absolute value of dθ/dt falls below a user input value of β_1 [303] then when T_1 is greater than T_{MN} [304]; (where β_1 and T_{MN} are user input values); then controller sends 28 an off signal via line 32 to conventional interruption device 22 that results in the supply of further cold or heat to exchanger 16 being interrupted by the action of device 22 [305]. At this moment elapsed time counter T_2 is set to zero and then incremented according to lapsed time thereafter. For example; 8 minutes after the interruption of flow of refrigerant or heating fluid through heat exchanger 16 the value of T_2 will be 8. The interruption of the supply of further cold or heat to exchanger 16 continues until θ reaches a value greater than θ_2 [306]; where θ_2 is a user input value. When T_2 is greater than T_{MF} [307]; where T_{MF} is a user input value, means 22 is activated so that interruption of fluid flow to exchanger 16 ceases. This is achieved by returning to the earlier point [301] (see Figure 3) where T_1 is reset as zero and the above cycle is then repeated until either conventional controller 24 and thermostat 26 has reached the set point or the system has been powered-down.

Figure 4; shows a more detailed logic flow diagram for a program used in the method (chilling mode) of the invention and run on a programmable controller 28, 128. Naturally, the controller 128 may comprise a conventional thermostat combined with a separate programmable controller (not shown). Alternatively the programmable controller may be provided as part of a modified controller 124 (not shown). In either case the programmable controller includes a processor unit capable of accepting computer program code or the like.

For a chilling system; when the overall system is switched on, fan 114 is activated and controller 124 will initially energise the compressor of a refrigeration circuit (not shown) providing the temperature measured by thermostat 126 is greater than the set point temperature of controller 124. This results in cool fluid entering exchanger 116; the temperature of the cool fluid may fall from the initial value over a period of time of system operation. When the overall system is switched on power is also provided to programmable controller 128. Temperature sensor 130 sends a signal to programmable controller 128 which is converted by known electronic means to a digital signal that represents the temperature θ of air downstream of exchanger 116 in °C (or °F). Controller 128 then instigates several internal health self-checks [401] before it sets an integer counter (§) at zero; measures the temperature θ of the air downstream of exchanger 116 and sets calculation variable A= θ [402]. The program logic then calculates a value for θ_1 [402] where θ_1 = [A/(B-C)*(D-E)] +E and B, C, D and E are user input constant values (see Table 1); then, providing thermostat 126 is calling for cold/heat this is supplied by controller 128 activating (opening) interruption device 122 so that fluid flows through exchanger 116. At this moment elapsed time counter T_1 is set to zero [403] and then incremented according to lapsed time thereafter. For example, 5 minutes after the programmable controller signal to start of flow of refrigerant or heating fluid through heat exchanger 116 the value of T_1 will be 5.

Controller 128 continues to periodically measure the temperature θ of air downstream of exchanger 116 in °C (or °F etc.), and at the point in time that θ is less than θ_1 [404] the program logic starts to estimate the rate of change in θ with time (dθ/dt). If the absolute value of dθ/dt falls below a user input value of β_1 [405] and if T_1 is greater than T_{MN} [406]; where β_1 and T_{MN} are user input values (see Table 1); then controller 128 sends an off signal via line 132 to interruption device 122 that results in the supply of further cold or heat to exchanger 116 being interrupted [407] by the action of device 122. At this moment elapsed time counter T_2 and T_3 are set to zero and then incremented according to lapsed time thereafter. For example; 3 minutes after the interruption of flow of refrigerant or heating fluid through heat exchanger 116 the value of T_2 will be 3. At this time, the program logic measures the temperature θ of the air downstream of exchanger 116 and sets calculation variable F= θ; increments the value of counter § by one (§=§+1) and also calculates a value for θ_2 where θ_2 = the lower of (F+G), H or (A-J) where G, H and J are user input values (see Table 1). During the interruption of the supply of further cold or heat to exchanger 116 θ continues to be periodically measured and when either; (a) θ reaches a value greater than θ_2 [408] or (b), when T_3 is greater than T_{DE} [409] (a user input value - see Table 1) and the estimated absolute value of the rate of change of θ with time (dθ/dt) is less than $ß_2$ [410] where $ß_2$ is a user input value (see Table 1), when T_2 is greater than T_{MF} [411] the program logic performs up to two further checks [412-413] before returning to an earlier point in the logic [403] (see Figure 4). These two further checks (in time order) are; is § greater than $§_1$ [412] where $§_1$ is a user input value (see Table 1) and is T_4 greater than T_W [413] where T_W is a user input value (see Table 1) and T4 is a time counter set at zero following step [412]. When the answer to all of these tests is yes then the above cycle is repeated (by going to the A=θ step - see Figure 4) [402] until either conventional controller 124 and thermostat 126 has reached the set point or, the system has been powered-down. When answer to the second check (is § GT $\S_1$) [412] is no, then the next step is to return to the "start 22 via line 32" point [403] (see Figure 4).

Figure 5 illustrates (see lower pair of graphs) how the temperature θ of air downstream of exchanger 116 typically varies in a cyclic manner (over a period of 60) min when the system of the invention is not operating (black line) and when the system of the invention is operating (lighter line). Initially following start-up θ rapidly decreases; the rate of decrease of θ then steadily deceases until (in the case where the invention is not in use) it levels off to a steady value after (in this illustration) about 18 min. In contrast, when the invention is in operation supply of chilling via exchanger 116 is interrupted much earlier (after about 9 min) and subsequently the system cycles between chiller activated mode and chiller interrupted mode at a higher frequency. This characteristic of the invention results in the variation of the air temperature immediately upstream of the exchanger 116 (which in this case is indicative of the controlled room temperature) being advantageously much less when the invention is in use (see Figure 5 - upper lighter line graph) than when not in use (see Figure 5 - upper black line graph) and the temperature immediately upstream of the exchanger 116 is also much closer to the desired space set point temperature. This provides more comfortable environment within the space 120 being chilled and also reduces chiller energy consumption, in part, as a result of not over-chilling the controlled space 120.

The rate of change of θ with time can in practice only be estimated. Individual measurements of θ are subject to a variety of errors that in combination mean that a good estimate of dθ/dt cannot in general be obtained by calculating the difference between successive values of θ measured over a short time period of say 0.01 min. Thus, in a preferred embodiment of the invention multiple measurements of θ are made during a first time period and an (first) average value of θ for that time period calculated. Multiple measurements are also made over a successive (second) time period of equal length to the first time period and again an (second) average value of θ calculated. The value of dθ/dt is then estimated as being: (first average value θ- second average value θ)/length of time period.

Within the embodiment of the invention consideration can be given to the format of the physical embodiment of the switching device used for the interrupting of the means of chilling or heating. by maintaining continuity of line 132 to means 22 when power to the invention has been removed thus ensuring that controller 24 can still operate correctly to means 22 while the invention is out of use.

The invention can have the ability to provide any combination of the following; current sensor value (θ), stored values for a given period for the sensor value (for trend logging), output "on" time; performance error reporting; connected device malfunction data, to be actively or passively communicated through wires or wireless to an external device. This advantageously allows analysis of past performance; for example, by a service engineer.

Table 1 - Typical User Input Values

Variable Title	Value for Cooling	Value for Heating	Description of value
β_1 (°/min)	0.6	1	Delta temperature value for process system stop
β_2 (°/min)	3	5	Delta temperature value for process system start
θ_1 (°C)	16	30	Threshold temperature before first delta temperature test (for stopping).
θ_2 (°C)	22	35	Threshold temperature before second delta temperature test (for starting).
T_{MN} (min)	4	5	Minimum process system run period
T_{MF} (min)	3	3	Minimum process system stop period
T_{DE} (min)	0.7	1	Pause period system duration before β_2 process enable test
T_W (min)	6	6	Process pause period duration for "A" variable update
B (min)	24	22	Supply air maximum non operational temperature
C (min)	18	15	Supply air minimum non operational temperature
D (°C)	17	60	Supply air maximum operational temperature
E (°C)	8	30	Supply air minimum operational temperature
G (°C)	10	-15	System start offset from process system stop
H (°C)	21	55	Maximum constant temperature allowed for process system start
J (°C)	5	15	Offset for calculation of maximum variable temperature allowed for process system start
$\S_1$	5	5	Maximum number of process system operational cycles before "A" variable is updated.

Table 1- Notes

(i) Supply air maximum process system non-operational temperature – this is an application and geography specific value and is the maximum value for controlled area supply air with the heat transfer process not operating that the user wishes to use with this application for the calculation purposes (i.e. for direct expansion application in Europe use value of 24).

(ii) Supply air minimum process system non-operational temperature – this is an application and geography specific value and is the minimum value for controlled area supply air with the heat transfer process not operating that the user wishes to use with this application for the calculation purposes (i.e. for direct expansion application in Europe use value of 18).

(iii) Supply air maximum process system operational temperature – this is a set application and geography specific value and is the maximum value for controlled area supply air with the heat transfer process operating that the user wishes to use with this application for the calculation purposes (i.e. for direct expansion application in Europe use value of 17).

(iv) Supply air minimum process system operational temperature – this is a set application and geographic specific value and is the minimum value for controlled area supply air with the heat transfer process operating that the user wishes to use with this application for the calculation purposes (i.e. for direct expansion application in Europe use value of 8).

CLAIMS

1. A method of controlling a space forced convection cooling or heating system wherein the system comprises: means of heating or chilling (16); a local first temperature sensor (30) located downstream and close to said means of heating or chilling; wherein a programmable controller (28) in cooperation with said first temperature sensor (30) measures the temperature of the air (θ) downstream and close to said means of heating or chilling; wherein the method comprises the following steps:

(i) start said means of heating or chilling (16); periodically record the temperature θ and use processing means within the programmable controller (28) to periodically estimate the rate of change of θ with time (dθ/dt);

(ii) store a first user preset value (β_1) within the programmable controller (28) and when said rate of change of temperature with time (dθ/dt) or absolute value of (dθ/dt) is equal to or less than said first user preset value (β_1) interrupt said means of heating or chilling (16).

2. A method of controlling a space forced convection cooling or heating system wherein the system comprises: means of heating or chilling (16); a local first temperature sensor (30) located downstream and close to said means of heating or chilling; wherein a programmable controller (28) in cooperation with said first temperature sensor (30) measures the temperature of the air (θ) downstream and close to said means of heating or chilling; wherein the method comprises the following steps:

(i) following power-up and system internal health checks for programmable controller (28); measure initial temperature of the air (θ) downstream and close to said means of heating or chilling; calculate θ_1 according to the formula: $\theta_1 = [fn(\theta)*(D-E)]+E$; wherein D and E are user preset values and fn(θ) is a value calculated from other user preset values and the value of θ;

(ii) start means of heating or chilling (16) and for chilling when θ is less than θ_1 proceed to step (iii) or; for heating when θ is greater than θ_1 proceed to step (iii);

(iii) periodically record the temperature θ and use processing means within the programmable controller (28) to periodically estimate the rate of change of θ with time (dθ/dt); store a first user preset value (β_1) within the programmable controller (28) and when said rate of change of temperature with time (dθ/dt) or absolute value of (dθ/dt) is equal to or less than said first user preset value (β_1) interrupt said means of heating or chilling.

3. A method of controlling a space forced convection cooling or heating system wherein the system comprises: means of heating or chilling (16); a local first temperature sensor (30) located downstream and close to said means of heating or chilling; wherein a programmable controller (28) in cooperation with said first temperature sensor (30) measures the temperature of the air (θ) downstream and close to said means of heating or chilling; wherein the method comprises the following steps:

(i) following power-up and system internal health checks for programmable controller (28); measure initial temperature of the air (θ) downstream and close to said means of heating or chilling; calculate θ_1 according to the formula: $\theta_1 = [fn(\theta)*(D-E)]+E$; wherein D and E are user preset values and fn(θ) is a value calculated from other user preset values;

(ii) start means of heating or chilling (16); set time counter T_1 to zero; and for chilling when θ is less than θ_1 proceed to step (iii) or; for heating when θ is greater than θ_1 proceed to step (iii);

(iii) periodically record the temperature θ and use processing means within the programmable controller (28) to periodically estimate the rate of change of θ with time (dθ/dt); store a first user preset value (β_1) within the programmable controller (28) and when said rate of change of temperature with time (dθ/dt) or absolute value of (dθ/dt) is equal to or less than said first user preset value (β_1) and T_1 is greater than a user input value T_{MN} interrupt said means of heating or chilling.

4. A method of controlling a space forced convection cooling or heating system wherein the system comprises: means of heating or chilling (16); a local first temperature sensor (30) located downstream and close to said means of heating or chilling; wherein a programmable controller (28) in cooperation with said first temperature sensor (30) measures the temperature of the air (θ) downstream and close to said means of heating or chilling; wherein the method comprises the following steps:

(i) Start said means of heating or chilling (16); measure temperature of the air (θ) downstream and close to said means of heating or chilling; for chilling when θ is less than a user preset value θ_1; proceed to step (ii) or; for heating when θ is greater than θ_1 proceed to step (ii);

(ii) periodically record the temperature θ and use processing means within the programmable controller (28) to periodically estimate the rate of change of θ with time (dθ/dt); store a first user preset value (β_1) within the programmable controller (28) and when said rate of change of temperature with time (dθ/dt) or absolute value of (dθ/dt) is equal to or less than said first user preset value (β_1) interrupt said means of heating or chilling

5. A method of controlling a space forced convection cooling or heating system wherein the system comprises: means of heating or chilling (16); a local first temperature sensor (30) located downstream and close to said means of heating or chilling; wherein a programmable controller (28) in cooperation with said first temperature sensor (30) measures the temperature of the air (θ) downstream and close to said means of heating or chilling; wherein the method comprises the following steps:

(i) Start said means of heating or chilling (16); set time counter T_1 to zero; measure temperature of the air (θ) downstream and close to said means of heating or chilling; for chilling when θ is less than a user preset value θ_1; proceed to step (ii) or; for heating when θ is greater than θ_1 proceed to step (ii);

(ii) periodically record the temperature θ and use processing means within the programmable controller (28) to periodically estimate the rate of change of θ with time (dθ/dt); store a first user preset value (β_1) within the programmable controller (28) and when said rate of change of temperature with time (dθ/dt) or absolute value of (dθ/dt) is equal to or less than said first user preset value (β_1) and T_1 is greater than T_{MN} where T_{MN} is a user input value, interrupt said means of heating or chilling.

6. A method according to any of Claims 2 or 3 where fn(θ) is calculated by the formula:

fn(θ)= (θ-C)/(B-C) or fn(θ)= θ/(B-C); where B and C are user preset values.

7. A method according to Claim 1-6 further comprising the following step:

(iii) continue to periodically measure the temperature (θ) of the air leaving the vicinity of the heater or chiller and when this value (for heating) is less than a preset/predetermined value (θ_2) stored in the programmable controller (28) or (for chilling) or is greater than said preset/predetermined value (θ_2) stored in the programmable controller (28) restart said heating or chilling.

8. A method according to Claim 7 wherein; for cooling θ_2 is predetermined as the lower of: (F+G), H or (A-J); and for heating θ_2 is predetermined as the higher of: (F+G), H or (A+J); where G, H and J; where G, H and J are user input values, F is the value of θ at the time that the means of heating or chilling (16) was last interrupted and A is the value of θ at the time θ_1 was last calculated.

9. A method according to any of Claims 1-8 further comprising the following step:

(iii) continue to periodically record the temperature θ and use processing means within the programmable controller (28) to periodically estimate the rate of change of θ with time (dθ/dt); store a user preset value (β_2) within the programmable controller 28 and when said rate of change of temperature with time (dθ/dt) or absolute value of (dθ/dt) is equal to or less than user preset value (β_2) stored in the programmable controller (28) restart said heating or chilling.

10. A method according to any of Claims 6 to 9 where said heating or chilling is only restarted when T_2 is greater than T_{MF}, where T_{MF} is a user preset value; and T_2 is a time counter set at zero when means of interrupting chilling or heating (16) was last activated.

11. A method according to any of Claims 4 to 10 wherein at the time of calculating θ_l a counter (§) is set to zero and then incremented by 1 each time chilling or heating means (16) is interrupted wherein if § is greater than a user input integer value §1 the program returns to the step where θ_l is calculated but otherwise returns to the following step where the chilling or heating means (16) is initiated.

12. A method according to any preceding claim used to provide both heating and chilling comprising a second temperature sensor and wherein the first temperature sensor has a temperature range appropriate for use with a chiller and the second sensor has a temperature range appropriate for use with a heater.

13. A method according to any preceding claim wherein user preset values can be set or adjusted remotely using communication means.

14. A method according to Claim 13 wherein the communication means includes a internet link, infrared link or wireless link.

15. A method according to Claim 1 wherein following start or restart of said means of heating or chilling means (16) a time delay step is introduced prior to starting steps (i) and (ii).

16. A method according to any preceding claim where at least one of the following: current sensor value (θ); stored values of θ over a given period; output "on" time, performance error reporting; or, connected device malfunction data, are actively or passively communicated through wires or wireless to an external device.

17. A method according to Claim 1 wherein following initial power-up of the programmable controller (28) a user preset time delay or a predetermined time delay the length of which is derived as a programmable controller function is introduced prior to first starting said means of chilling or heating (16).

18. A method of controlling a space forced convection (air flow) cooling or heating system comprising starting a means of heating or chilling; periodically measuring the temperature of the air (θ) downstream and close to said means of heating or chilling and when θ is less than a predetermined value θ_1 periodically estimating the rate of change of θ with time ($d\theta/dt$) and when the absolute value of said rate of change of temperature with time ($d\theta/dt$) is equal to or less than a user preset value (β_1) interrupting the means of heating or chilling

19. A space forced convection cooling or heating system using the method of any preceding claim wherein the chilling or heating means (16) is located within a duct or located within a vented enclosure within said space.

20. A space forced convection cooling or heating system using the method of any preceding claim wherein the chilling or heating means (16) comprises one or more heat exchangers through which cooling or heating fluid flow.

21. A programmable controller (28): for use with a space forced convection cooling or heating system having means of heating or chilling and a local first temperature sensor located downstream and close to said means of heating or chilling; that uses method steps according to any preceding claim.

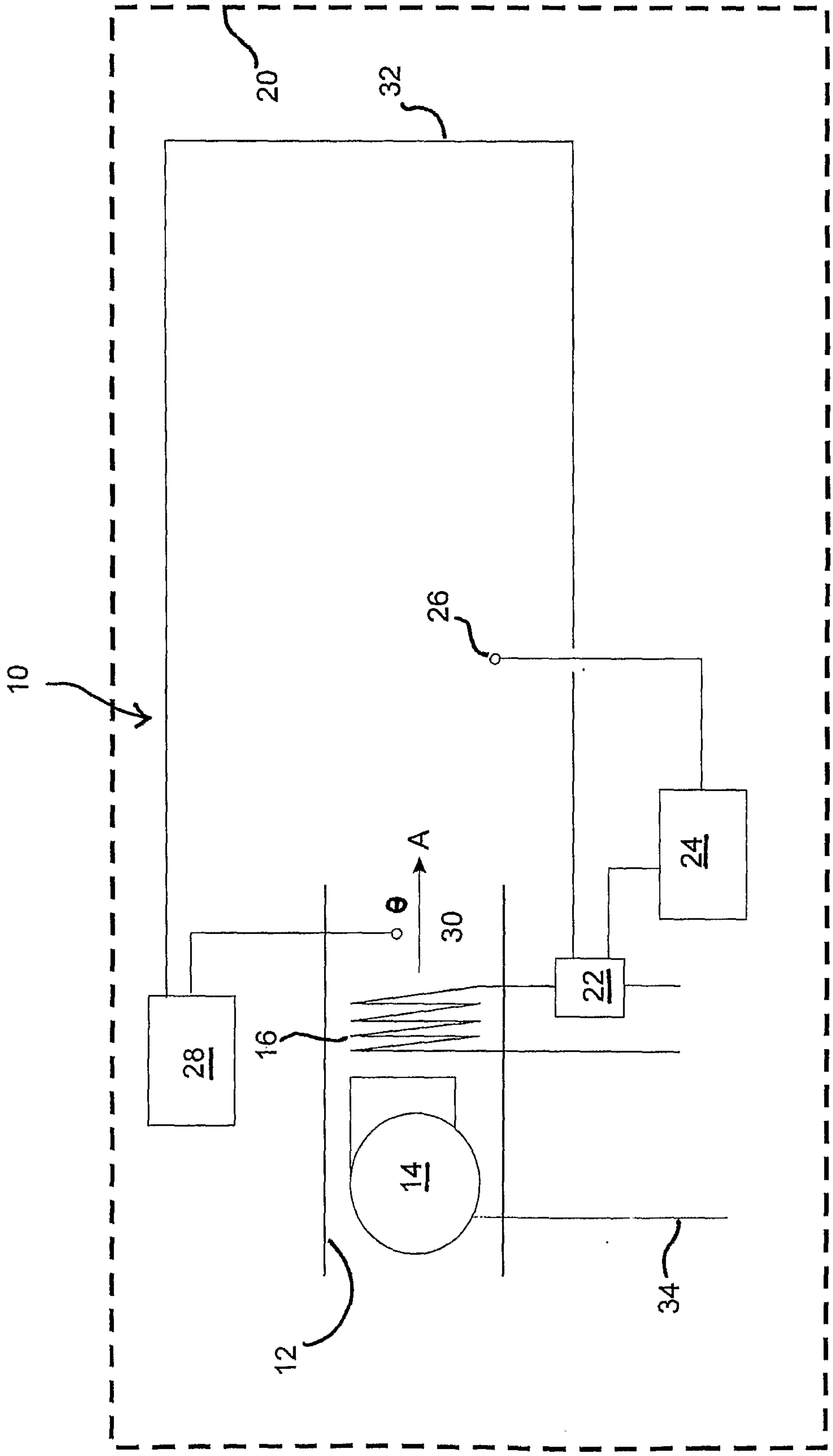

FIGURE 1

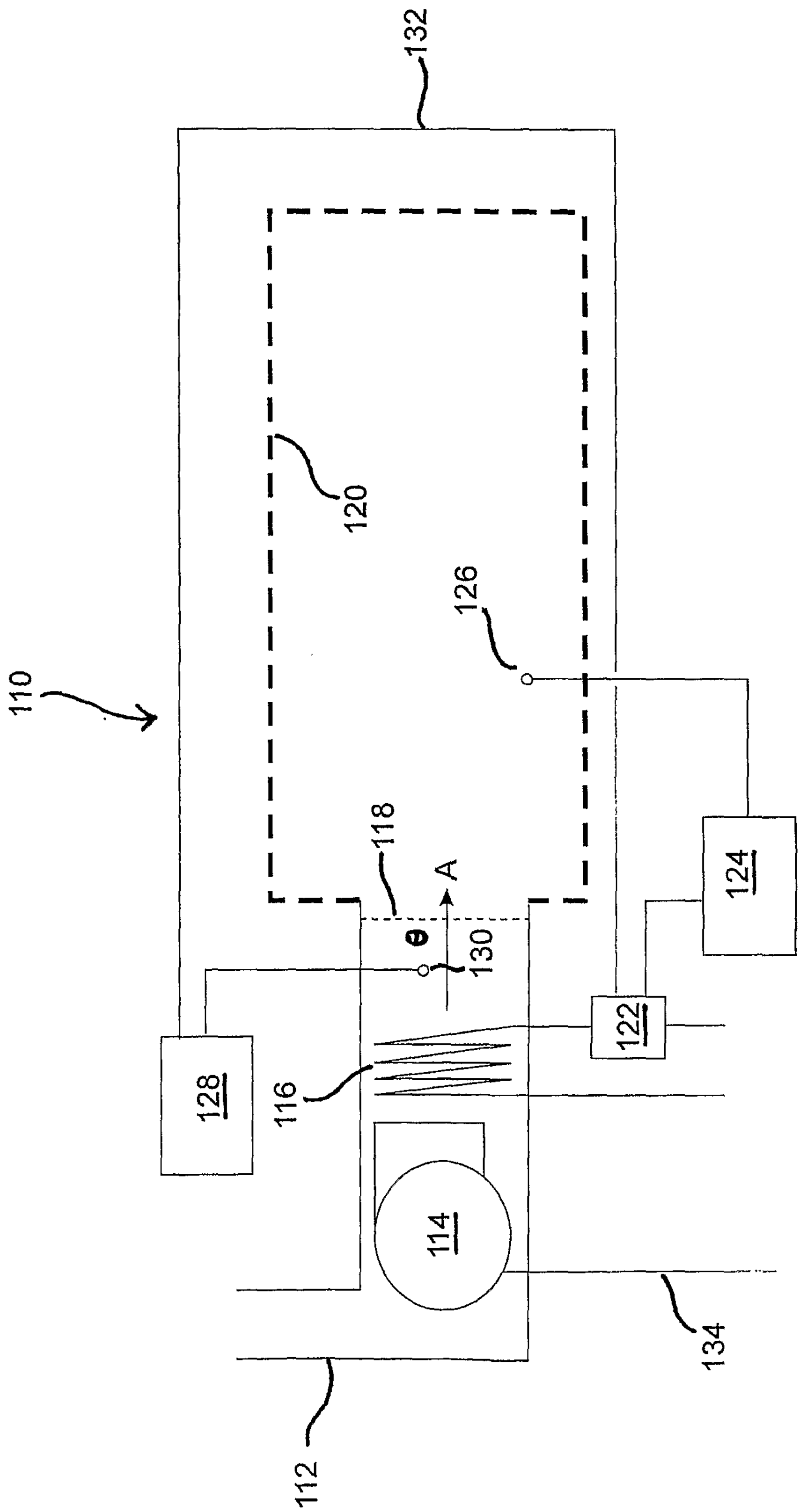

FIGURE 2

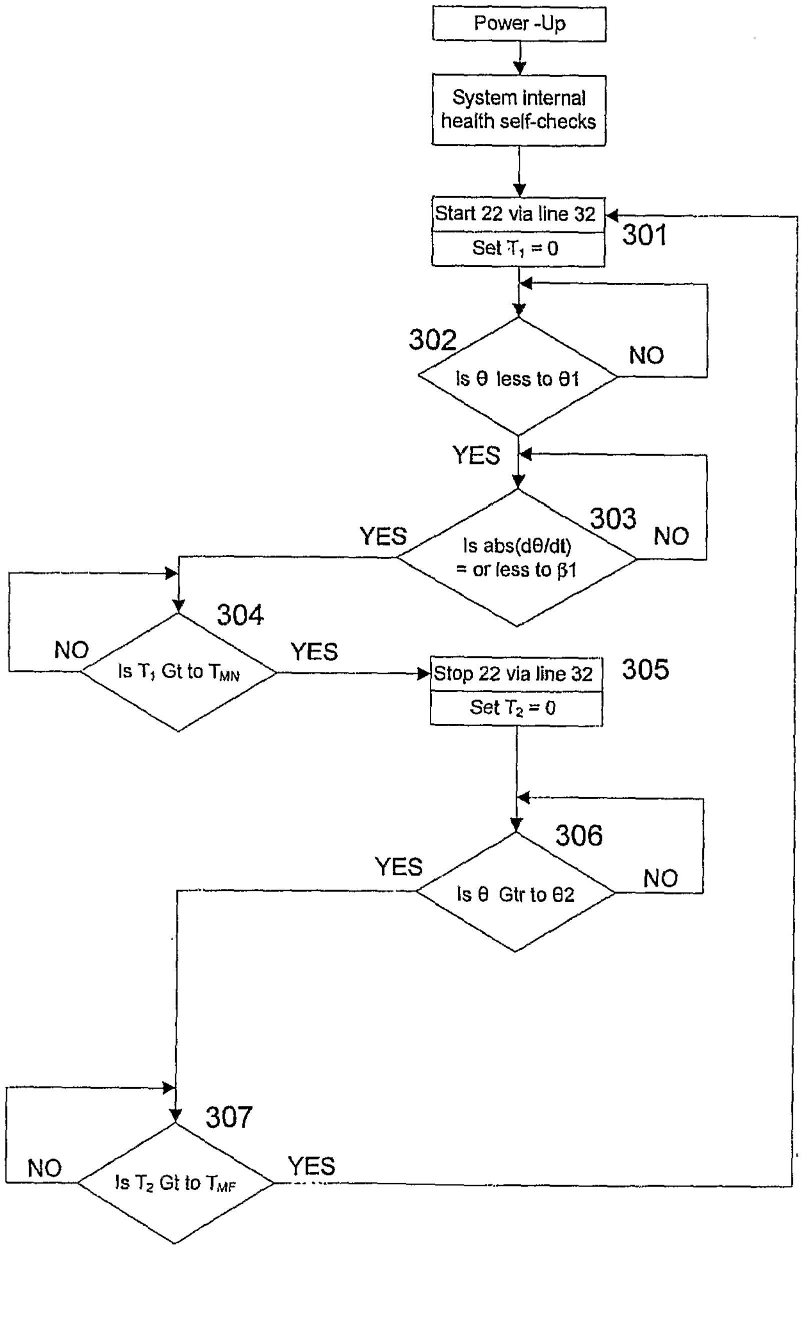
Power -Up
System internal health self-checks
Start 22 via line 32
Set T1 = 0
301
302
Is θ less to θ1
NO
YES
303
Is abs(dθ/dt) = or less to β1
NO
YES
304
Is T1 Gt to TMN
NO
YES
Stop 22 via line 32
Set T2 = 0
305
306
Is θ Gtr to θ2
YES
NO
307
Is T2 Gt to TMF
NO
YES

FIGURE 3

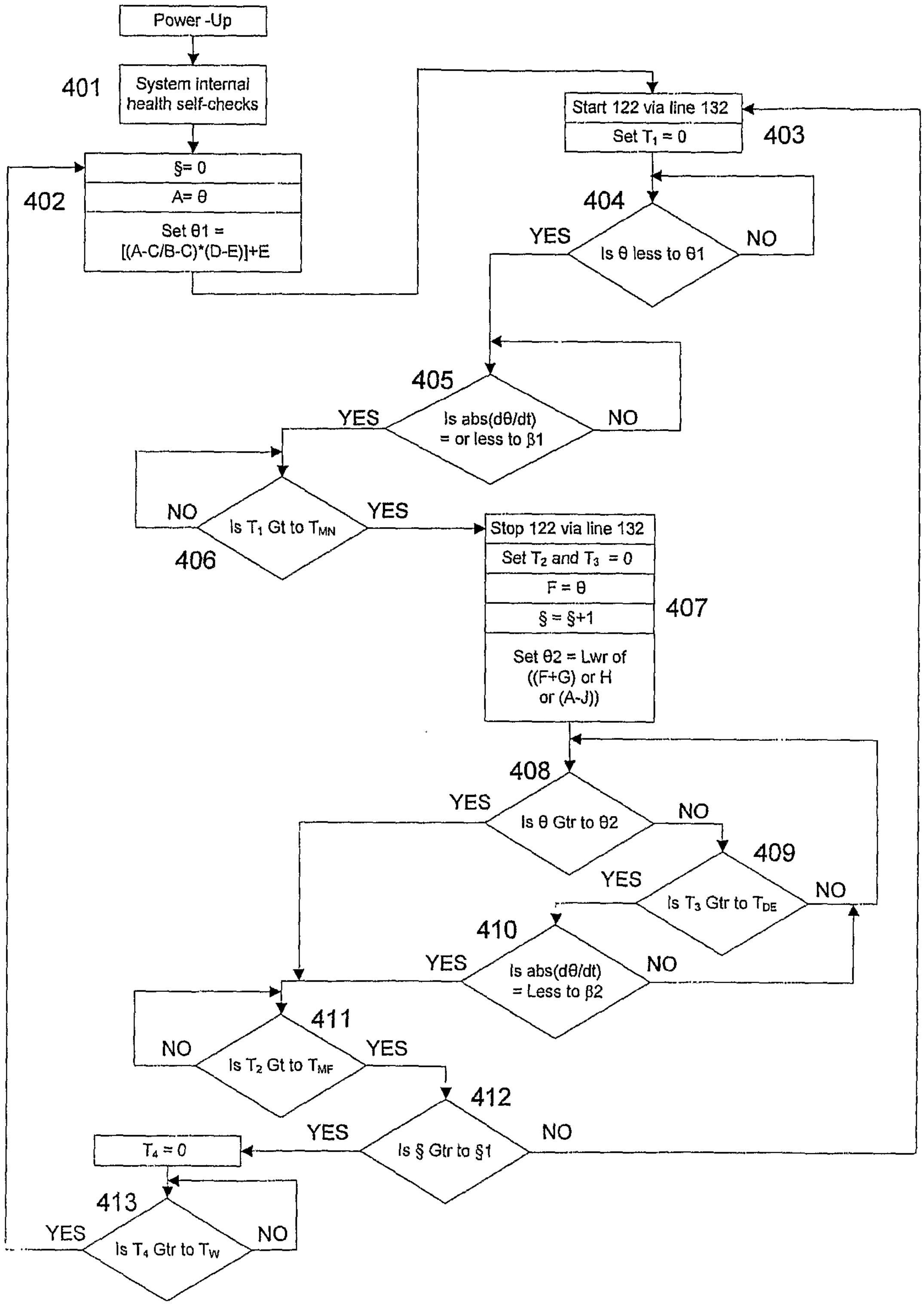
Power -Up
401
System internal health self-checks
402
§= 0
A= θ
Set θ1 = [(A-C/B-C)*(D-E)]+E
Start 122 via line 132
Set T1 = 0
403
404
YES
Is θ less to θ1
NO
405
YES
Is abs(dθ/dt) = or less to β1
NO
NO
Is T1 Gt to TMN
YES
406
Stop 122 via line 132
Set T2 and T3 = 0
F = θ
§ = §+1
Set θ2 = Lwr of ((F+G) or H or (A-J))
407
408
YES
Is θ Gtr to θ2
NO
409
YES
Is T3 Gtr to TDE
NO
410
YES
Is abs(dθ/dt) = Less to β2
NO
411
NO
Is T2 Gt to TMF
YES
412
YES
Is § Gtr to §1
NO
T4 = 0
413
YES
Is T4 Gtr to TW
NO

FIGURE 4

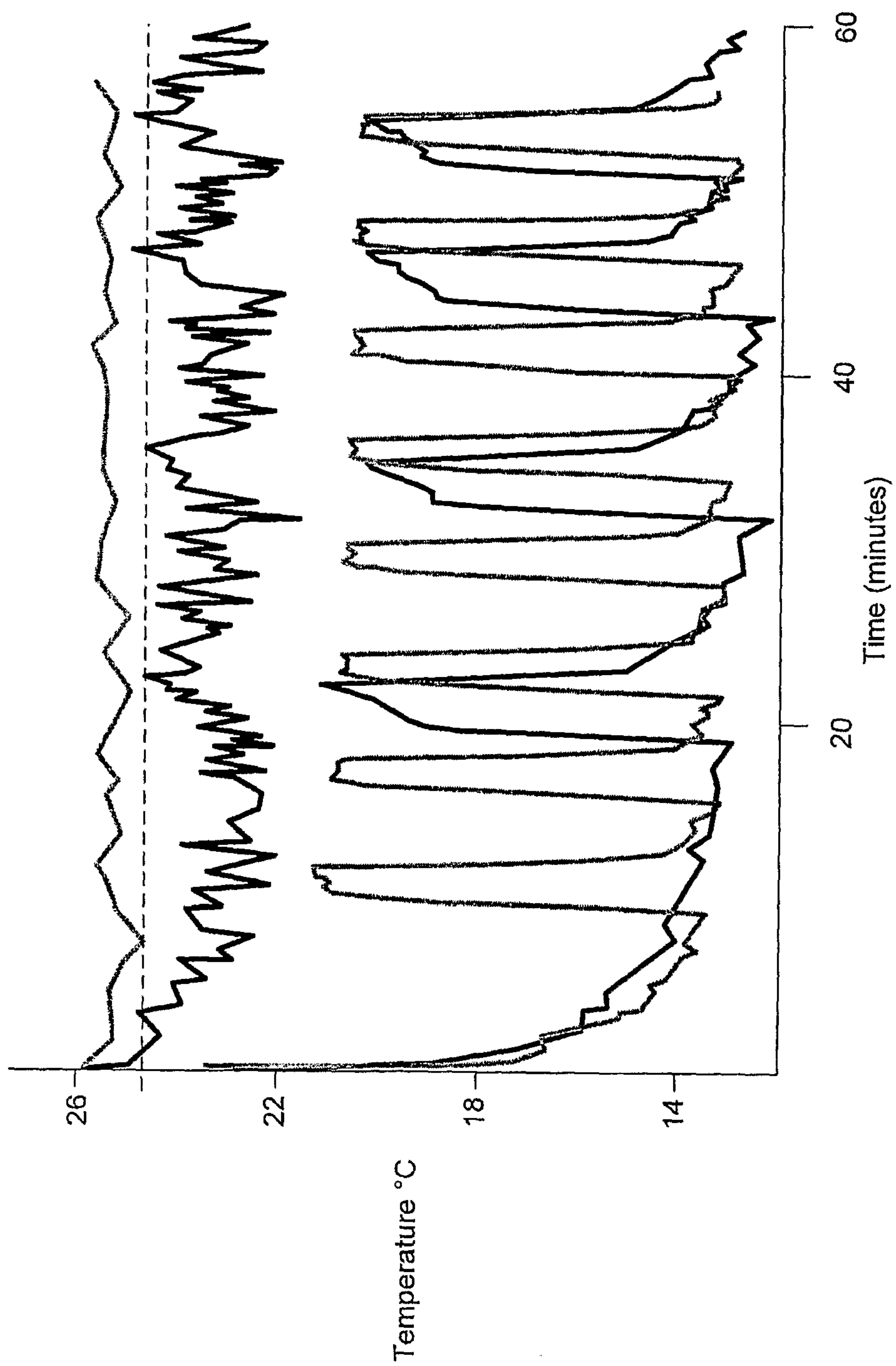

FIGURE 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2008/002368

A. CLASSIFICATION OF SUBJECT MATTER
INV. F24F11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F24F F25B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 176 436 B1 (GAUTHIER DALE A [US] ET AL) 23 January 2001 (2001-01-23) the whole document	1-21
X	US 5 678 758 A (TAKEGAWA HIROZO [JP] ET AL) 21 October 1997 (1997-10-21) the whole document	1-21
A	EP 0 415 747 A (SHAW ALLAN [AU]; LUXTON RUSSELL ESTCOURT [AU]; LUMINIS PTY LTD [AU]) 6 March 1991 (1991-03-06) abstract	1-21

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search: 6 November 2008

Date of mailing of the international search report: 21/11/2008

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2008/002368

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			JP	3099150	A	24-04-1991
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			US	5058388	A	22-10-1991