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(54) **Method for regulating the delivery temperature of a service fluid in output from a refrigerating machine**

(57) In a refrigerating machine (3) for an air-conditioning system (1), which is equipped with one or more fan coils (2) and a hydronic circuit (15) having a delivery branch (16) for the circulation of a service fluid (5) from the refrigerating machine (3) to the fan coils (2) and a return branch (17) for the return of the service fluid (5) in input to the refrigerating machine (3), the compressor (12) of the machine (3) is switched on and off (102-105) as a function of a measurement of the delivery temperature (TDLV) such that the same delivery temperature (TDLV) converges to a set point temperature (TSET), and this set point temperature (TSET) is adapted (106-115) to an estimate of the cooling/heating load (FL) of the hydronic circuit (15).

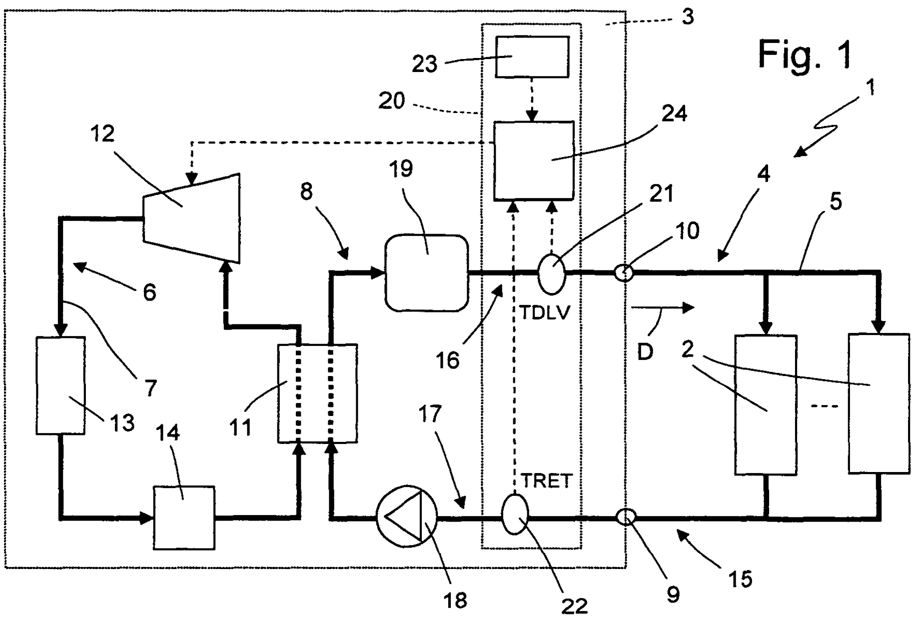

Fig. 1

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Description

[0001] The present invention concerns a method for regulating the delivery temperature of a service fluid in output from a refrigerating machine.

[0002] In particular, the present invention finds useful, but not exclusive, application in the regulation of the delivery temperature of a service fluid in output from a water chiller for centralized air-conditioning systems, to which the following description shall make explicit reference without, however, any loss of generality.

[0003] As is known, a centralized air-conditioning system for the control of the ambient temperature in a building comprises a plurality of fan coils, which are opportunely distributed inside the building and connected with each other via a hydraulic circuit, and a centralized refrigerating machine suited to cool a service fluid, and in particular a coolant liquid substantially composed of water, and to convey this service fluid to the various fan coils via said hydraulic circuit.

[0004] This refrigerating machine, normally indicated by the term "chiller", comprises an internal circuit in which a working fluid consisting of a refrigerant circulates, a heat exchanger through which the internal circuit passes and that is connected to the hydraulic circuit of the air-conditioning system in correspondence to the refrigerating machine's inlet and outlet for heat exchange between the working fluid and the service fluid, and one or more compressors for implementing a refrigeration cycle on the working fluid through compression of the working fluid itself.

[0005] Electronic control systems are also known of for controlling the switching on and off of the compressors such that the temperature of the service fluid in input to or output from the refrigerating machine, namely the return temperature or, respectively, the delivery temperature of the service fluid, reaches a predetermined set point value.

[0006] These control systems essentially implement a proportional type of control logic in which the switching on and off of the compressors is carried out on the basis of a direct comparison between a measurement of the return or delivery temperature of the service fluid and a pair of temperature thresholds.

[0007] The above-mentioned control systems exhibit intrinsic limits due to the time constraints between the moments of switching the compressors on and off for the purpose of extending their life. In actual fact, these constraints limit the differential between the temperature thresholds to a minimum value, below which the compressors would operate in technically prohibitive running conditions that could damage them. More in general, on the one hand these time constraints prevent the mentioned control systems from achieving a good level of precision in regulating the temperature of the service fluid and, on the other, from maximizing the energy efficiency of the air-conditioning system.

[0008] Furthermore, the control carried out on the basis of the return temperature is not very precise because a different quantity is controlled from that which is effectively involved by the heat exchange in the fan coils.

[0009] The object of the present invention is to provide a method for regulating the delivery temperature of a service fluid in output from a refrigerating machine for an air-conditioning system and to create a control device for a refrigerating machine embodying this method, which permit regulation of the delivery temperature in a precise manner and maximization of the system's energy efficiency and, at the same time, are of straightforward and economic embodiment.

[0010] According to the present invention, a method for regulating the delivery temperature of a service fluid in output from a refrigerating machine, a control device for a refrigerating machine and a refrigerating machine in accordance with the attached claims are provided.

[0011] The present invention shall now be described with reference to the attached drawings, which illustrate a non-limitative example of embodiment, in which:

- Figure 1 shows a block diagram of an air-conditioning system including a refrigerating machine equipped with a control device in accordance with the present invention;
- Figures 3 to 6 show a flow chart of the method for regulating delivery temperature set point for a service fluid in output from the refrigerating machine in Figure 1 in accordance with the present invention;
- Figures 2, 7a and 7b show calculation curves and a table of the parameters utilized in the flow chart in Figures 3 to 6; and
- Figures 8a and 8b show a calculation curve and a table of the parameters utilized in the flow chart in Figures 3 a 6 in accordance with a further embodiment of the present invention.

[0012] In Figure 1, reference numeral 1 generally designates a block diagram showing the principles of an air-conditioning system comprising a plurality of fan coils 2 opportunely distributed inside a building (not shown) for which it is wished to control the ambient temperature, and a refrigerating machine 3 suited to cool a service fluid 5, in particular a coolant liquid substantially composed of water, and make it circulate through a hydraulic circuit 4 that connects the fan coils 2 to the refrigerating machine 3 itself.

[0013] Typically, the refrigerating machine 3 comprises an internal circuit 6, in which a working fluid 7 consisting of a refrigerant circulates, and an output circuit 8, which connects to the hydraulic circuit 4 of the system 1 in correspondence to an inlet 9 and an outlet 10 of the refrigerating machine 3. A series of devices are arranged along the internal circuit 6 to implement a refrigeration cycle on the working fluid 7, and in particular, a first heat exchanger 11, through which the internal circuit 6 and the output circuit 8 pass and which functions as an evaporator to make the working fluid 7 evaporate at low pressure by absorbing heat from the service fluid 5; a compressor 12, preferably of the scroll type, to carry out adiabatic compression on the working fluid 7 in the vapour state; a second heat exchanger 13 functioning as a condenser, that is to make the working fluid 7 condense so as to release the previously absorbed heat to the outside; and an expansion valve 14 to cool the working fluid 7 and make it partially evaporate so that it is ready for another cycle.

[0014] The hydraulic circuit 4 of the system 1 and the output circuit 8 of the refrigerating machine 3 form a so-called hydronic circuit 15, including a delivery branch 16, along which the service fluid 5 circulates in a direction D from the heat exchanger 11 to the fan coils 2, and a return branch 17, along which the service fluid 5 returns to the heat exchanger 11. Circulation of the service fluid 5 in direction D is guaranteed by a pump 18 placed along the return branch 17.

[0015] The refrigerating machine 3 is equipped with a storage tank 19 placed along the delivery branch 16 at a short distance from the heat exchanger 11 to produce thermal inertia in the hydronic circuit 15, which slows the dynamics of the system 1 so as to avoid undesired oscillation phenomena in the regulator valves (not shown) of the fan coils 2. The presence of the storage tank 19 is optional.

[0016] In addition, the refrigerating machine 3 comprises a control device 20 to control the switching on and off of the compressor 12 based on the delivery temperature TLDV of the service fluid 5.

[0017] More in detail, the control device 20 comprises a first temperature sensor 21 placed along the delivery branch 16 at the outlet of the storage tank 19, or rather at the outlet 10 of the refrigerating machine 3, to measure the delivery temperature TDLV of the service fluid 5, a second temperature sensor 22 placed along the return branch 17 in correspondence to the inlet 9 of the refrigerating machine 3 to measure the return temperature TRET of the service fluid 5, a keypad 23 to accept commands given by a user, and an electronic control unit 24 connected to the sensors 21 and 22, the keypad 23 and the compressor 12.

[0018] The electronic control unit 24 is suited to control the switching on and off of the compressor 12 based on a comparison between a measurement of the delivery temperature TDLV and a pair of delivery temperature thresholds such that the delivery temperature TDLV converges to a delivery temperature set point TSET between the two delivery temperature thresholds.

[0019] The electronic control unit 24 is configured to implement the method for regulating the delivery temperature TDLV of the service fluid 5 in accordance with the present invention, which method is described below for the case in which the service fluid 5 is chilled to cool the environments where the fan coils 2 are placed.

[0020] The underlying principle of this method is to adapt the set point TSET to an estimate of the cooling load produced by the environment to be cooled and surrendered to the hydronic circuit 15. In particular, the set point TSET is increased when the cooling load diminishes. Indeed, the more the cooling load drops, the less the heat exchange between the environment and the fan coils 2, and less is the need to cool the service fluid 5. Since the coefficient of performance (COP) of a refrigerating machine 3 increases as the evaporation temperature in the heat exchanger rises, it follows that the rise in the set point TSET as the cooling load drops results in an increase in the overall efficiency of the system 1.

[0021] The estimated cooling load is defined in terms of fraction of load FL, that is as the ratio between the power that the refrigerating machine 3 must deliver to cool the environment and the maximum refrigeration power that the refrigerating machine 3 can deliver under given nominal conditions.

[0022] Switching on and off of the compressor 12 takes place respecting precise time constraints between successive switch-ons and/or switch-offs in order to safeguard the integrity of the compressor 12, or rather respecting a minimum time Δt_ON_min between switch-on and switch-off, a minimum time Δt_OFF_min between switch-off and switch-on and a minimum time Δt_ON_ON_min between two successive switch-ons. To fulfil these time constraints, during an on-off cycle defined between two successive switch-on events, the compressor 12 should remain switched on and switched off for a theoretical operational period Δt_ON and a theoretical stoppage period Δt_OFF respectively, these periods depending on the estimated fraction of cooling load FL in the following manner:

$$\Delta t\_ON = \begin{cases} \Delta t\_ON\_min & FL < FL1 \\ \Delta t\_ON\_ON\_min \cdot FL & FL1 \le FL \le FL2 \\ \Delta t\_OFF\_min \cdot \dfrac{FL}{1-FL} & FL > FL2 \end{cases} \qquad (1)$$

$$\Delta t\_OFF = \begin{cases} \Delta t\_ON\_min \cdot \dfrac{1-FL}{FL} & FL < FL1 \\ \Delta t\_ON\_ON\_min \cdot (1-FL) & FL1 \le FL \le FL2 \\ \Delta t\_OFF\_min & FL > FL2 \end{cases} \quad (2)$$

where:

$$FL1 = \frac{\Delta t\_ON\_min}{\Delta t\_ON\_ON\_min} \text{ and } FL2 = \frac{\Delta t\_OFF\_min}{\Delta t\_ON\_ON\_min}.$$

[0023] Figure 2 illustrates the trends of the theoretical periods Δt_ON and Δt_OFF as the fraction of load FL changes for the following time constraints:

- Δt_ON_min = 60 s;
- Δt_OFF_min = 180 s; and
- Δt_ON_ON_min = 360 s.

[0024] The asymptotic trends at the ends of the change interval in the fraction of load FL mean that the compressor 12 remains switched on or off for very long periods corresponding to fractions of load FL close to 1 or 0 respectively.

[0025] Figure 3 shows a flow chart that describes to steps followed by the method for regulating the delivery temperature TDLV of the service fluid 5 in accordance with the present invention. With reference to Figure 3, at the moment of switching on the refrigerating machine 3, the method provides a variables initialization phase (block 100), in which:

- the set point TSET is set to a minimum value TSETmin equal to 7 °C, which corresponds to the value that the set point TSET ideally assumes at maximum load, so that the refrigerating machine 3 immediately starts to cool to the maximum to meet a possibly high initial load;
- two variables, t_ON and t_OFF, henceforth referred to respectively as the switch-on time and switch-off time of the compressor 12, are set to 0; and
- a variable τ_WAIT, henceforth referred to as the wait time, is set to 0.

[0026] The delivery temperature TDLV and the return temperature TRET are measured via the respective sensors 21 and 22 (block 101).

[0027] Periodically, a measurement of the delivery temperature TDLV is compared with the previously mentioned pair of delivery temperature thresholds, in particular with a lower threshold TLOW lesser than the set point TSET (block 102) and with an upper threshold THIG greater than the set point TSET (block 103). If the delivery temperature TDLV is less than or equal to the lower threshold TLOW, then the compressor 12 is switched off (block 104). Instead, if the delivery temperature TDLV is greater or equal to the upper threshold THIG, then the compressor 12 is switched on (block 105).

[0028] The values of the lower TLOW and upper THIG thresholds are linked to the value of the set point TSET. Hence, for an adjustment to the set point TSET there is a corresponding adjustment of the same sign to the thresholds TLOW and THIG. Typically, in the checks made on the delivery temperature TDLV, the lower TLOW and upper THIG thresholds are kept symmetrical with respect to the set point TSET.

[0029] The times of the switch-off and switch-on events are stored in the respective variables switch-off time t_OFF (block 106) and switch-on time t_ON (block 107). In addition, on every switch-on event, a counter N_ON of the number of switch-ons is incremented (block 108).

[0030] The switch-on event starts the on-off cycle of the compressor 12 and a series of calculations are triggered in correspondence to this event that result in an estimate of the cooling load and the adjustment of the set point TSET and the thresholds TLOW and THIG to the estimated cooling load.

[0031] In particular, based on the switch-on t_ON and switch-off t_OFF times, a real operational period Δt_ON_real, a real stoppage period Δt_OFF_real and a real cycle period Δt_TOT_real, the latter equal to the sum Δt_ON_real + Δt_OFF_real, are calculated for the compressor 12 (block 109).

[0032] The cooling load is estimated in function of the measurements of the delivery TDLV and return TRET temperatures and is provided, as previously disclosed, in terms of an estimated fraction of load FL (block 110).

[0033] Once the estimate of the fraction of load FL is made, the theoretical operational period Δt_ON and the theoretical stoppage period t_OFF are calculated by relations (1) and (2) respectively, and a theoretical cycle period Δt_TOT calculated as the sum Δt_ON + Δt_OFF (block 111).

[0034] At this point, the set point TSET is adjusted by adapting it the estimated fraction of load FL (block 112). However, the adjustment of the set point TSET to the fraction of load FL is only enabled after having checked that the number of switch-ons N_ON has reached a minimum number of switch-ons N_ON_min, preferably equal to 4 (block 113). The purpose of this check is to allow adequate stabilization of the estimation process for the fraction of load FL, as the estimation process is perturbed by adjustment of the set point TSET.

[0035] After adjustment of the set point TSET, the wait time τ_WAIT is set to a value calculated with the following formula:

$$\tau\_WAIT = 2.5 \cdot \Delta TSET \cdot (\Delta t\_TOT), \qquad (3)$$

where ΔTSET is a set point step produced by adjustment of the set point TSET with respect to the previous value of the same set point TSET, as shall be explained further on. A countdown is activated starting from this wait time value τ_WAIT (block 114). Adjustment of the set point TSET is only re-enabled when the countdown expires (block 115). This expedient also has the purpose of allowing sufficient stabilization of the fraction of load FL estimation process.

[0036] Figure 4 shows a portion of the flow chart regarding block 110 of Figure 3 that shows the sub-phases concerning the calculation of the fraction of load FL of the hydronic circuit 15.

[0037] The method is based on the assumption that the system constituted by the system 1 and the environment to be cooled is a thermally insulated system, for which an energy balance equation can be written in terms of temperature of the type:

$$\Delta TQ = TDLV - TRET + k \cdot \frac{dTRET}{dt} \qquad (4)$$

where ΔTQ is the temperature difference between the inlet and outlet of the group of fan coils 2 produced by the thermal power that the environment supplies to the system 1, and k is a parameter, henceforth referred to as the installation parameter, which depends on the capacity and mass flow characteristics of the hydronic circuit 15, and in particular $k = \rho \cdot Vtot/m$, where ρ is the density of the service fluid 5 expressed in kg/m^3, Vtot is the volume of the entire hydronic circuit 15 expressed in m^3 and m is the mass flow of the hydronic circuit 15 expressed in kg/s.

[0038] In particular, with reference to Figure 4, the method provides for estimating the installation parameter k to tune a successive estimate of the fraction of load FL with the capacity and mass flow characteristics of the hydronic circuit 15 (block 200), and to subsequently acquire samples of delivery TDLV(n) and return TRET(n) temperatures, sampling the outputs of the sensors 21 and 22 with a sampling period ts (block 201) and estimating the temperature difference ΔTQ by processing the delivery TDLV(n) and return TRET(n) temperature samples via a discrete Kalman filter (block 202) that expresses equation (4) as a system in discrete state space (DSS) according to the matrix form

$$\begin{cases} x(n+1) = F \cdot x(n) + G \cdot u(n) \\ y(n) = H \cdot x(n) + J \cdot u(n) \end{cases} \qquad (5)$$

where u(n), x(n) and y(n) are respectively the vectors of the inputs, the states and the outputs of the system at discrete time n, and in which

$$u(n)=\begin{bmatrix} TDLV(n) \\ TRET(n) \end{bmatrix},\quad x(n)=y(n)=\begin{bmatrix} \Delta TQ(n) \\ TRET(n) \end{bmatrix} \tag{6}$$

$$F=\begin{bmatrix} 1 & 0 \\ \frac{ts}{k} & 1-\frac{ts}{k} \end{bmatrix},\quad G=\begin{bmatrix} 0 \\ \frac{ts}{k} \end{bmatrix},\quad H=\begin{bmatrix} 0 & 1 \end{bmatrix},\quad J=\begin{bmatrix} 0 \end{bmatrix} \tag{7}$$

[0039] The transformation of equation (4) in the system defined by (5), (6) and (7) is based on the further assumption that the thermal power released by the environment to the system 1 is constant during the sampling period ts. Therefore, the estimate of the temperature difference ΔTQ is provided in a discrete form ΔTQ(n).

[0040] The estimated temperature difference ΔTQ undergoes low-pass filtering (block 203), for example, via a first order Chebyshev filter having a cutoff angular frequency of 0.003 rad/s and peak band-pass ripple of 3dB, and is successively processed to obtain a mean value ΔTQmean for the measured cycle time ΔtCYCLE (block 204).

[0041] Finally, a mean value ΔTCHmean is calculated for the temperature difference ΔTCH between the TDLV and TRET temperatures on the part of the cycle time ΔtCYCLE regarding the period when the compressor 12 is on, as the temperature difference ΔTCH is null when the compressor 12 is off (block 205), and the fraction of load FL being sought is calculated as the ratio between the mean values ΔTQmean and ΔTCHmean (block 206),

$$FL=\frac{\Delta TQmean}{\Delta TCHmean}\,. \tag{8}$$

[0042] The formula (8) follows directly from the previously given definition of fraction of load.

[0043] Figure 5 shows a portion of a flow chart that describes the phase of estimating the installation parameter k, indicated by block 200 in Figure 4, in greater detail.

[0044] The installation parameter k is estimated on the basis of a formula obtained from an energy balance equation in terms of temperature similar to equation (4) and expressed as a function of temperatures for which there are measurements, or rather of the delivery temperature TDLV and the return temperature TRET. This formula has the following form:

$$k(t)=\frac{TDLV(t-\frac{\tau 1}{2})-TRET(t+\frac{\tau 1}{2})-TDLV(t+\tau 2)+TRET(t)}{\frac{dTDLV}{dt}(t+\tau 2)}, \tag{9}$$

where τ1 and τ2 are the heat propagation delays respectively introduced by the conductors of the hydronic circuit 15 and storage tank 19, assuming the outlet of the heat exchanger 11 as the source of a heat variation and t is the time at which the installation parameter k is estimated.

[0045] With reference to Figure 5, during each on-off cycle of the compressor 12, the real periods of operation Δt_ON_real and stoppage Δt_OFF_real are compared with each other (block 300). If the Δt_ON_real period is greater than the Δt_OFF_real period, then the installation parameter k will be estimated just before switching off the compressor 12, or rather t = t_OFF - ε (block 301); otherwise, the installation parameter k will be estimated just before switching on the compressor 12, or rather t = t_ON - ε (block 302). The time shift ε is preferably equal to 5 seconds.

[0046] The heat propagation delay τ2 due to the storage tank 19 is calculated as the difference between the time of switching on t_ON and a first inversion time in which the first derivate of the delivery temperature TDLV passes from a positive value to a negative value (block 303). Instead, by calculating the difference between the time of switching on t_ON and a second inversion time in which the first derivate of the return temperature TRET passes from a positive value to a negative value, a heat propagation delay τ3 regarding the entire hydronic circuit 15 is obtained, or rather between the outlet and the inlet of the heat exchanger (block 304). Therefore, the heat propagation delay τ1 due to the conductors is given by τ1 = τ3 - τ2 (block 305).

[0047] It is evident that in the absence of the storage tank 19, we shall not have the related heat propagation delay τ2 and the propagation delay τ1 due to the conductors will be equal to τ3.

[0048] At this point, it is possible to apply formula (9) to calculate a value for the installation parameter k at time t (block 306).

[0049] Estimation of the installation parameter k in the above-described manner corresponds to an estimate of the capacity and mass flow characteristics of the hydronic circuit 15, which allows the estimate of the fraction of load FL to be automatically tuned to the characteristics of the system 1. This operation is without doubt necessary for the first switch-on of the refrigerating machine 3 after it has been connected to a new system 1, but also during normal operation of the same system 1 to identify load variations due to the deactivation of one or more fan coils 2.

[0050] Figure 6 shows a portion of flow chart that describes the adjustment phase of the set point TSET, indicated by block 112 in Figure 3, in greater detail.

[0051] This phase provides for the calculation of a new set point TSET value via a formula that expresses the temperature of the set point TSET as a function of the estimated fraction of load FL (block 400) :

$$TSET = \begin{cases} TSET\max & if\ FL \leq FLI \\ TSET\min + (TSET\max - TSET\min)\cdot\dfrac{(1-FL)}{(1-FLI)} & otherwise \end{cases} \qquad (10)$$

where TSETmin is the minimum value of the set point TSET corresponding to the maximum fraction of load equal to 1, TSETmax is the maximum value of the set point TSET corresponding to the null fraction of load and FLI is a value of the fraction of load that separates the relationship between a first segment in which the set point TSET is constant and a second segment in which the set point TSET decreases in a linear manner as the fraction of load FL changes.

[0052] Formula (10) is considered for three different sets of values of the parameters TSETmin, TSETmax and FLI, listed in the table shown in Figure 8a. Figure 8b shows the three different versions of formula (10) via three respective curves traced in the TSET - FLI plane and indicated as C1, C2 and C3.

[0053] The three sets of parameters TSETmin, TSETmax and FLI, and therefore the three curves C1, C2 and C3, correspond to three different, user-selectable operating modes of the refrigerating machine 3. A default operating mode corresponds to curve C1 that ensures the best compromise between energy efficiency of the refrigerating machine 3 and regulating precision of the delivery temperature TDLV, as the new value of the set point TSET can vary between the minimum value TSETmin and the maximum value TSETmax for a wide range of values for the fraction of load FL, i.e. between 0.3 and 1. Instead, an operating mode corresponds to curve C2 that ensures the best energy efficiency, as the new value of the set point TSET is equal to a high value (TSETmax) over a wide range of values of fractions of load FL, namely between 0 and 0.6, in this way maximizing the coefficient of performance of the refrigerating machine 3. Finally, an operating mode corresponds to curve C3 that ensures the best humidity control, as the new value of the set point TSET is different for each value of fraction of load FL and can assume a maximum value TSETmax that is lower than that of the other curves C1 and C2.

[0054] After the new value for the set point TSET has been calculated, a set point step ΔTSET is determined by calculating the difference between the value just calculated and the previous value of the set point TSET and upwardly limiting the step ΔTSET to a maximum value ΔTSETmax preferably equal to 4 °C (block 401), while the set point TSET is updated by immediately applying the set point step ΔTSET to the previous set point TSET value (block 402).

[0055] It is worthwhile to note that the diagram of the principle of the refrigerating machine 3 shown in Figure 1 can also generically describe a machine suited to heat the service fluid 5 for the purpose of heating the environments in which the fan coils 2 are placed, for example a refrigerating machine 3 of the type operating as a heat pump. In this type of refrigerating machine 3, the compressor 12 is configured so as to perform the refrigeration cycle in the opposite sense to that previously described, or rather in a manner for which the heat exchanger 11 functions as a condenser to transfer heat from the working fluid 7 to the service fluid 5 and the heat exchanger 13 functions as an evaporator.

[0056] The method for regulating the delivery temperature TDLV of the service fluid 5 in accordance with the present invention is therefore also applicable in the case in which the refrigerating machine 3 is suited to heat the service fluid 5, it being sufficient to simply invert the mechanism of some of the described phases and change the value of some parameters, and in particular:

- when the heat pump is switched on, the set point TSET is set to a maximum value TSETmax equal to 45 °C, which corresponds to the value that the set point TSET ideally assumes at maximum heating load, so that the heat pump immediately starts to heat to the maximum to meet a possibly high initial load; indeed, efficiency increases as the condensation temperature decreases;
- if the measurement of the delivery temperature TDLV exceeds the upper threshold THIG, then the compressor 12 is switched off;
- if the measurement of the delivery temperature TDLV is less than the lower threshold TLOW, then the compressor 12 is switched on;
- the set point TSET is decreased when the heating load drops, that is to say the new set point TSET value is expresses as an increasing linear function of the fraction of load FL of the type:

$$TSET = \begin{cases} TSET\min & if\ \ FL \leq FLI \\ TSET\max + (TSET\min - TSET\max) \cdot \dfrac{(1-FL)}{(1-FLI)} & otherwise \end{cases} \qquad (11)$$

- formula (11) is considered for three different sets of values for the parameters TSETmin, TSETmax and FLI, listed in the table shown in Figure 8a and generating the curves C1, C2 and C3 shown in Figure 8b; and
- the maximum value ΔTSETmax with which to limit the amplitude of adjustment of the set point TSET is preferably equal to 5 °C.

[0057] The main advantage of the above-described method for regulating the delivery temperature TDLV with respect to known art is to increase the overall efficiency of the system 1, whilst still maintaining good precision in regulating the delivery temperature TDLV itself. In fact, the adaptation of the set point TSET to the cooling/heating load of the hydronic circuit 15 allows the refrigerating machine 3 to promptly respond to variations in the cooling/heating load of the environment for which it is wished to control the temperature, so that the evaporation temperature can increase in the case where the machine is configured to cool the service fluid 5, or so that the condensation temperature can drop in the case where the machine is configured to heat the service fluid 5, thus maximizing the coefficient of performance in all working conditions.

[0058] Another advantage is to allow the automatic adaptation of the refrigerating machine 3 to the type of system 1 in which it is installed and to rapidly identify cooling/heating load variations due to the deactivation of one or more fan coils 2, thanks to the estimation operation of the installation parameter k that expresses the capacity and flow characteristics of the system 1.

[0059] Finally, the possibility of switching from the regulation of a service fluid to be cooled to that of a service fluid to be heated by simply changing certain parameters, renders the method easy to implement in the electronic control unit 24 of any refrigerating machine 3 of the reversible type, i.e. fitted with an reverse valve placed along the internal circuit 6 for reversing the refrigeration cycle so as to allow cooling mode or heating mode operation.

Claims

1. Method for regulating the delivery temperature (TDLV) of a service fluid (5) in output from a refrigerating machine (3) of an air-conditioning system (1), which comprises fan coils means (2) and a service circuit (15) comprising a delivery branch (16) for the circulation of the service fluid (5) from the refrigerating machine (3) to the fan coils means (2) and a return branch (17) for the return of the service fluid (5) in input to the refrigerating machine (3); the refrigerating machine (3) comprising a compressor (12); the method comprising:

    - switching the compressor (12) on and off (102-105) as a function of a measurement of the delivery temperature (TDLV) in a manner such that the same delivery temperature (TDLV) converges to a delivery temperature set point (TSET);

    and being **characterized in that** it further comprises:

    - adapting (106-115) the set point (TSET) to an estimate of the cooling/heating load (FL) of the service circuit (15).

2. Method according to claim 1, in which said adaptation (106-115) of the set point (TSET) to an estimate of the cooling/heating load (FL) takes place in correspondence to a switch-on event of the compressor (12).

3. Method according to claim 1 or 2, in which adapting (106-115) said set point (TSET) to an estimate of the cooling/heating load (FL) comprises:

- calculating (400) a new value for the set point (TSET) based on the estimated cooling/heating load (FL); and
- updating (401, 402) the set point (TSET) based on the new value and a previous value of the set point (TSET).

4. Method according to claim 3, in which adapting (106-115) the set point (TSET) to an estimate of the cooling/heating load (FL) comprises:

- enabling (113) said calculation (400) of a new value for the set point (TSET) after a minimum number of switch-ons (N_ON_min) of the compressor (12).

5. Method according to claim 3 or 4, in which updating (401 and 402) the set point (TSET) comprises:

- determining (401) a set point step ΔTSET by calculating the difference between said new value and previous value of the set point (TSET) and upwardly limiting this difference to a maximum set point step value (ΔTSETmax); and
- updating (401) the set point (TSET) by immediately applying the set point step (ΔTSET) to the previous value of the set point (TSET).

6. Method according to claim 5, in which adapting (106-115) the set point (TSET) to an estimate of the cooling/heating load (FL) comprises:

- activating (114) a countdown for a wait time (τ_WAIT) proportional to said set point step (ΔTSET); and
- enabling (115) said calculation (400) of a new value for the set point (TSET) at the expiry of said countdown.

7. Method according to claim 6, in which adapting (106-115) the set point (TSET) to an estimate of the cooling/heating load (FL) comprises:

- determining (111) a theoretical cycle period (Δt_TOT) of the compressor (12) in an on-off cycle of the latter as a function of the estimated cooling/heating load (FL);

said wait time (τ_WAIT) also being proportional to the theoretical cycle period (Δt_TOT).

8. Method according to one of the claims 3 to 7, in which adapting (106-115) the set point (TSET) to an estimate of the cooling/heating load (FL) comprises:

- providing (110) an estimate of fraction of load (FL) with reference to a maximum deliverable power of the said refrigerating machine (3).

9. Method according to claim 8, in which said refrigerating machine (3) is suited to cool said service fluid (5); calculating (400) a new value for the set point (TSET), including:

- in the case where the estimated fraction of load (FL) is less than or equal to an intermediate fraction of load value (FLI), assuming a constant equal to a maximum set point value (TSETmax) as the new value;
- otherwise calculating this new value as a decreasing function of the estimated fraction of load (FL).

10. Method according to claim 9, in which said decreasing function of the fraction of load (FL) is linear.

11. Method according to claim 10, in which said linear decreasing function is defined by an angular coefficient equal to the difference between said maximum set point value (TSETmax) and a minimum set point value (TSETmin) corresponding to a fraction of load (FL) equal to 1; the maximum set point value (TSETmax) being equal to 14 °C, the minimum set point value (TSETmin) being equal to 7 °C and the intermediate fraction of load value (FLI) being equal to 0.6.

12. Method according to one of the claims 9 to 11, in which updating (401, 402) the set point (TSET) comprises:

- determining (401) a set point step ΔTSET by calculating the difference between said new value and the previous value of the set point (TSET) and upwardly limiting this difference to a maximum set point step value (ΔTSETmax) equal to 4 °C.

13. Method according to claim 8, in which said refrigerating machine (3) is suited to heat said service fluid (5); said new value for the set point (TSET) being calculated (400) as an increasing function of the estimated fraction of load (FL).

14. Method according to claim 13, in which said increasing function of the fraction of load (FL) is linear.

15. Method according to claim 14, in which said linear increasing function is defined by an angular coefficient equal to the difference between a minimum set point value (TSETmin) corresponding to a fraction of load (FL) equal to 0 and a maximum set point value (TSETmax) corresponding to a fraction of load (FL) equal to 1; the minimum set point value (TSETmax) being equal to 40 °C and the maximum set point value (TSETmin) being equal to 45 °C.

16. Method according to one of the claims 13 to 15, in which updating (401, 402) the set point (TSET) comprises:

- determining (401) a set point step ΔTSET by calculating the difference between said new value and the previous value of the set point (TSET) and upwardly limiting this difference to a maximum set point step value (ΔTSETmax) equal to 5°C.

17. Method according to one of the previous claims, in which adapting (106-115) the set point (TSET) to an estimate of the cooling/heating load (FL) comprises:

- estimating (110) the cooling/heating load in terms of fraction of load (FL) with reference to a maximum deliverable power of the refrigerating machine (3), by processing, via Kalman filtering, measurements of said delivery temperature (TDLV) and measurements of a return temperature (TRET) of said service fluid (5) in input to said refrigerating machine (3).

18. Method according to claim 17, in which estimating (110) the cooling/heating load in terms of fraction of load (FL) comprises:

- acquiring (201) delivery (TDLV(n)) and return (TRET(n)) temperature measurement samples according to a sampling period (ts);
- estimating (202) a first temperature difference (ΔTQ) defined between the inlet and outlet of said fan coils means (2), processing said measurement samples (TDLV(n), TRET(n)) via a discrete Kalman filter that expresses an energy balance of said air-conditioning system (1) as a system in discrete state space; and
- calculating (204-206) the fraction of load (FL) as a function of said first temperature difference (ΔTQ) and a second temperature difference (ΔTCH) defined as the difference between said delivery temperature (TDLV) and said return temperature (TRET).

19. Method according to one of the previous claims, in which adapting (106-115) the set point (TSET) to an estimate of the cooling/heating load (FL) comprises:

- tuning (106, 107, 109 and 200) the estimate of the cooling/heating load (FL) as a function of an estimate of capacity and mass flow characteristics of said service circuit (15).

20. Method according to claim 19, in which tuning the estimate of the cooling/heating load (FL) comprises:

- estimating (106, 107, 109 and 200) an installation parameter (k) proportional to the density (p) of the service fluid (5) and the volume (Vtot) of said service circuit (15) and inversely proportional to the mass flow (m) of said service circuit (15).

21. Control device for a refrigerating machine (3), the control device (20) including first temperature sensor means (21) to measure the delivery temperature (TDLV) of a service fluid (5) in output from the refrigerating machine (3) and a control unit (24) suited to control the refrigerating machine (3) in a manner such that the delivery temperature (TDLV) converges to a set point (TSET), and being **characterized in that** it comprises second temperature sensor means (22) to measure the return temperature (TRET) of the service fluid (5) in input to the refrigerating machine (3) and **in that** the control unit (24) is configured to implement the method in accordance with one of the claims 1 to 20.

22. Refrigerating machine (3) including a compressor (12) and a control device (20) for switching the compressor (12) on and off, based on a measurement of the delivery temperature (TDLV) of a service fluid (5) in output from the refrigerating machine (3), and **characterized in that** the control device (20) is of the type claimed by claim 21.

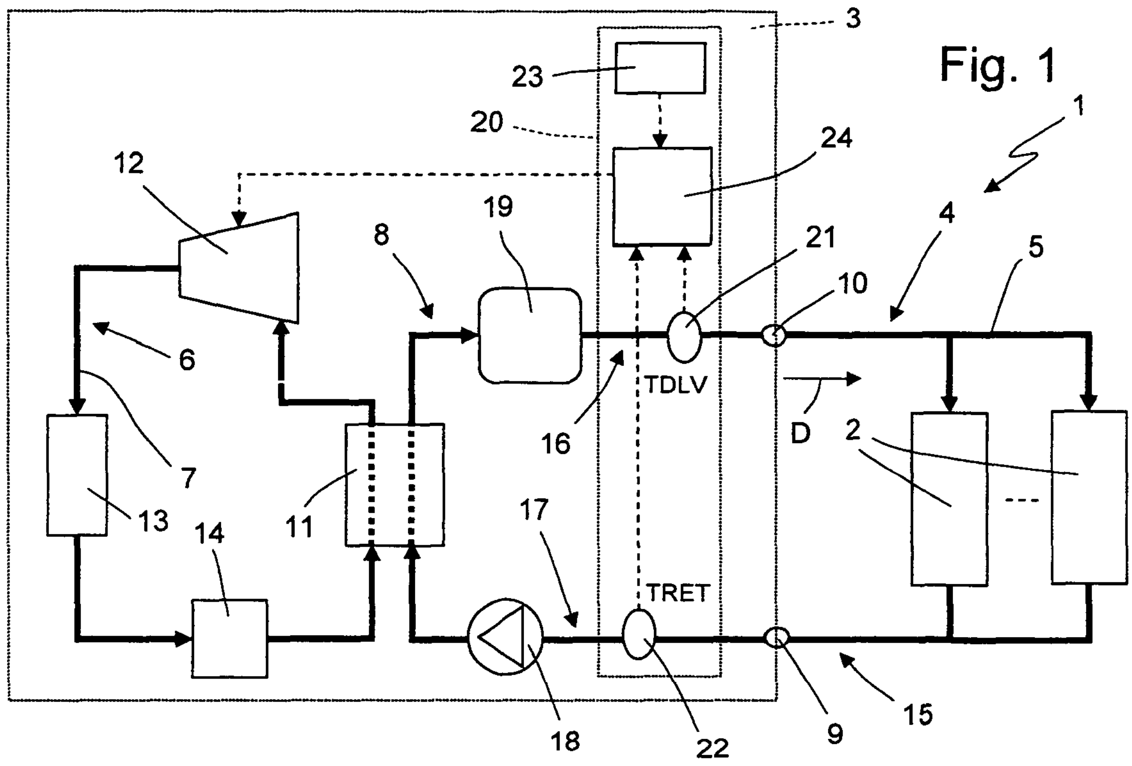
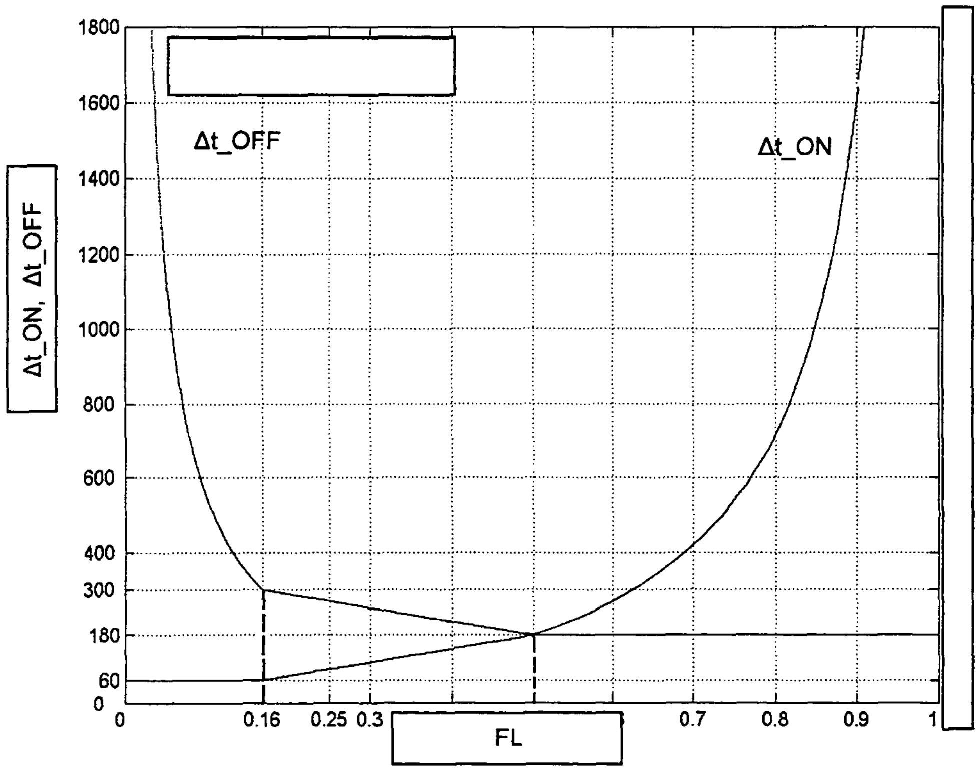

3
23
20
24
12
19
8
21
10
1
4
5
6
TDLV
16
D
2
7
13
14
11
17
TRET
18
22
9
15

Fig. 1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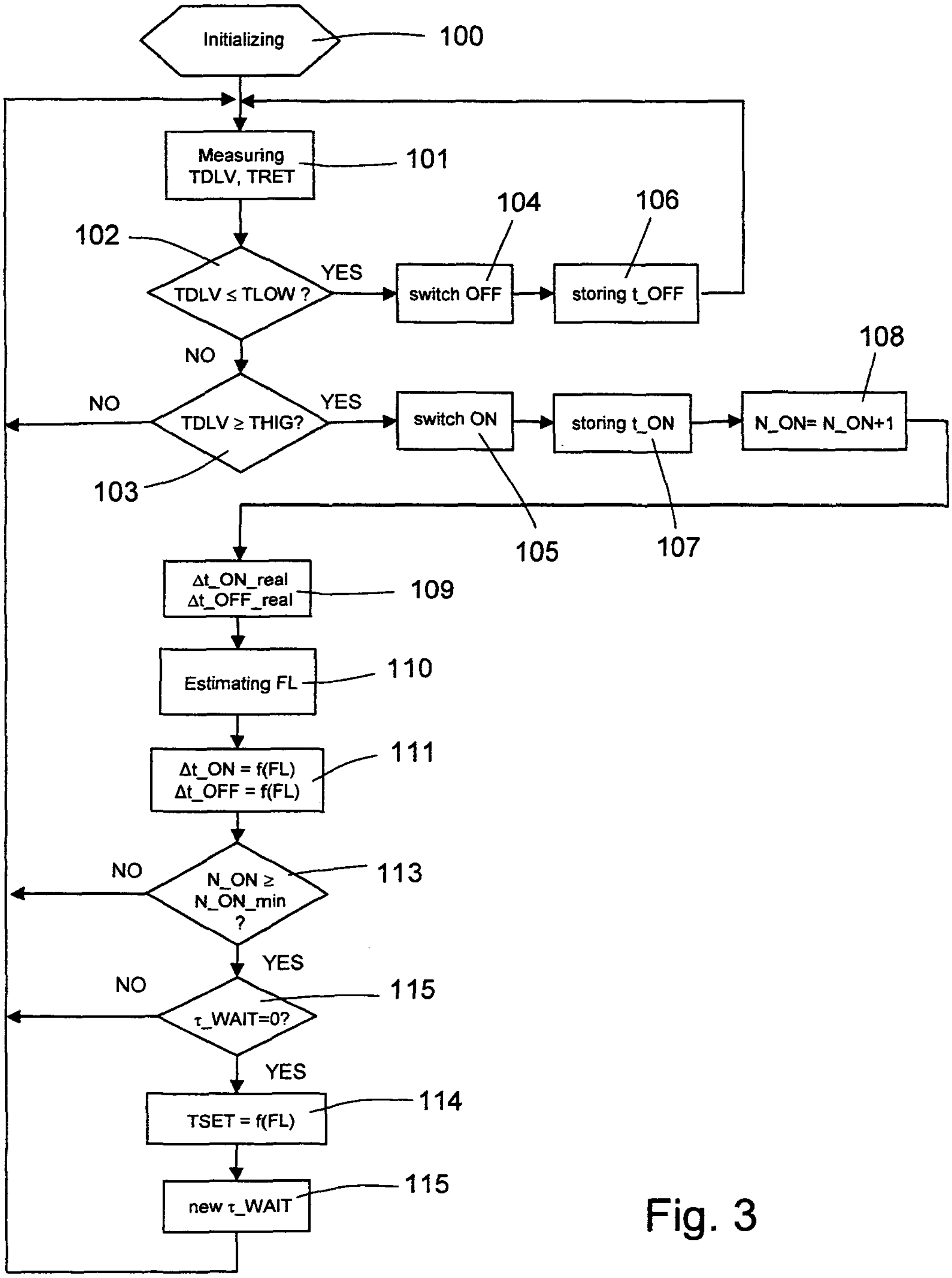
1600
1400
1200
1000
800
600
400
300
180
60
0
0
0.16
0.25
0.3
0.7
0.8
0.9
1
Δt_OFF
Δt_ON
Δt_ON, Δt_OFF
FL

Fig. 2



Initializing
100
Measuring TDLV, TRET
101
102
TDLV ≤ TLOW ?
YES
NO
switch OFF
104
storing t_OFF
106
TDLV ≥ THIG?
YES
NO
103
switch ON
105
storing t_ON
107
N_ON= N_ON+1
108
Δt_ON_real Δt_OFF_real
109
Estimating FL
110
Δt_ON = f(FL) Δt_OFF = f(FL)
111
N_ON ≥ N_ON_min ?
113
NO
YES
τ_WAIT=0?
115
NO
YES
TSET = f(FL)
114
new τ_WAIT
115

Fig. 3

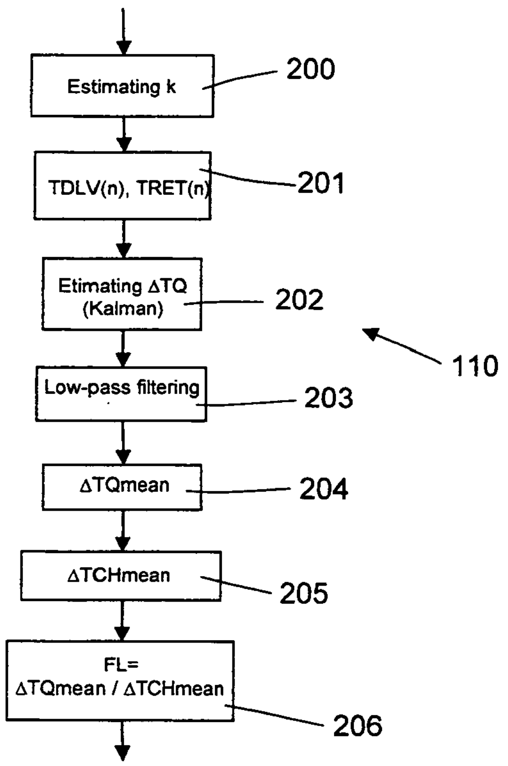


Fig. 4

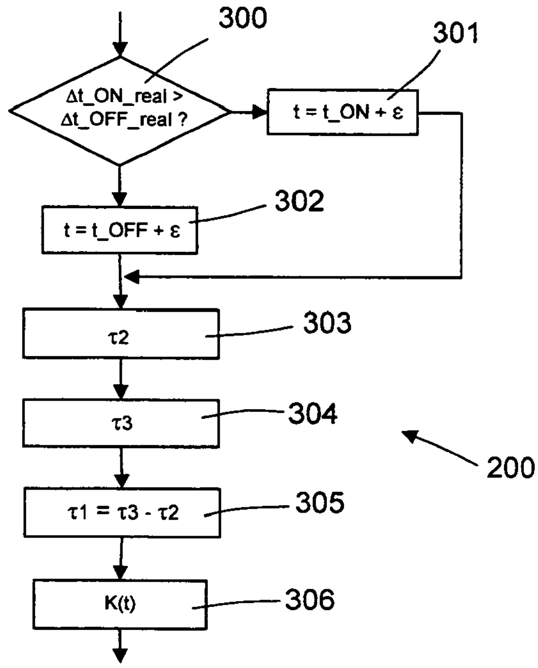


Fig. 5

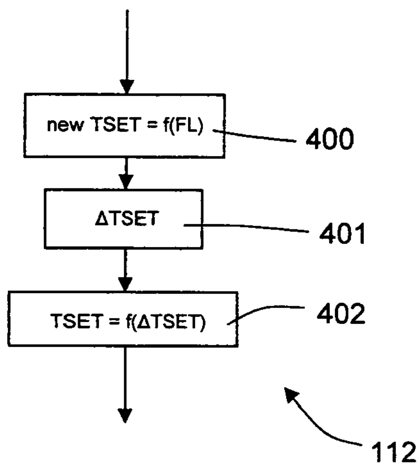


Fig. 6

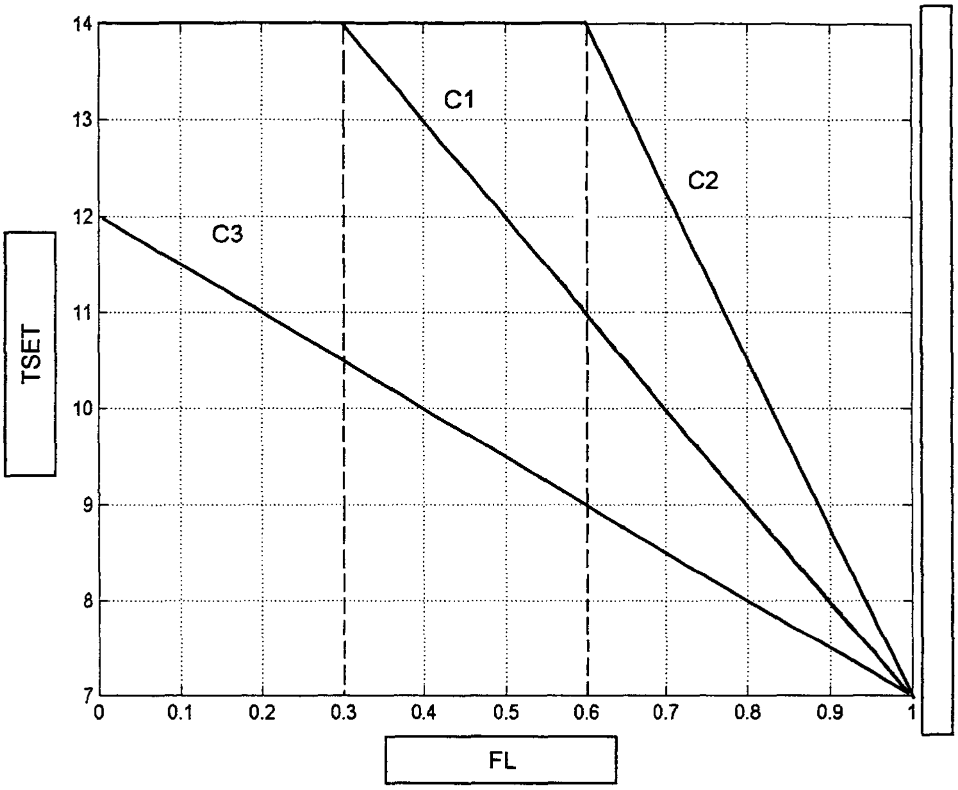


Fig. 7a

curve	TSETmin (°C)	TSETmax (°C)	FLI
C1	7	14	0,3
C2	7	14	0,6
C3	7	12	0

Fig. 7b

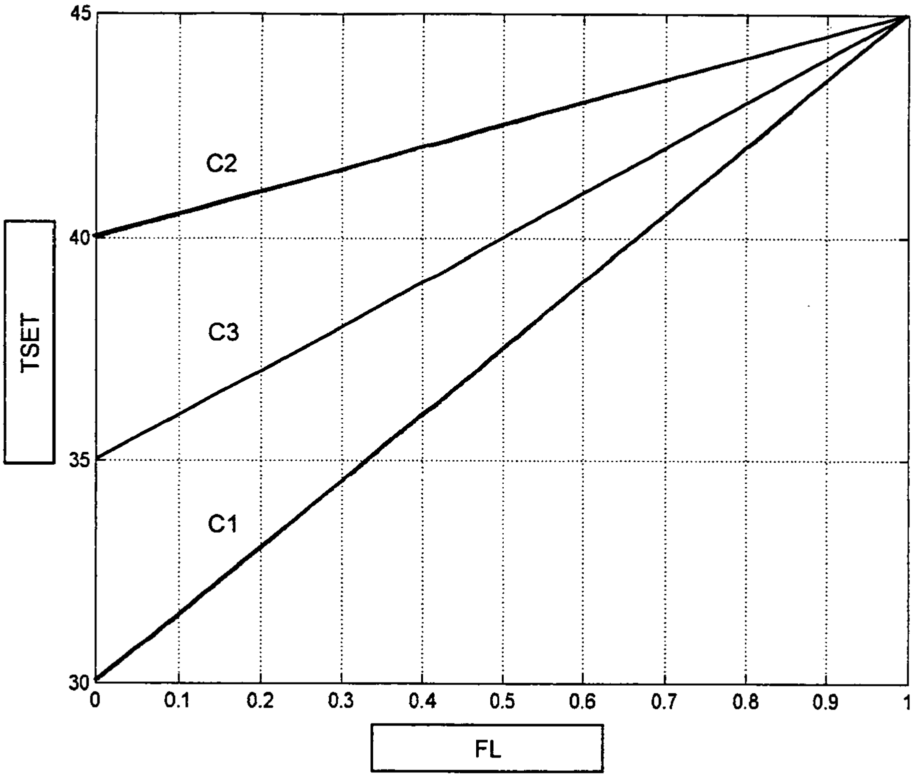


Fig. 8a

curve	TSETmin (°C)	TSETmax (°C)	FLI
C1	30	45	0
C2	40	45	0
C3	35	45	0

Fig. 8b

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 07 42 5349

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	11 January 2008	de Graaf, Jan Douwe

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EUROPEAN SEARCH REPORT

Application Number
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The present search report has been drawn up for all claims

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