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(54) **Method for estimating the thermal load of a circuit for a service fluid at outlet from a refrigerating machine**

Verfahren zur Schätzung der Wärmebelastung einer Leitung für eine Betriebsflüssigkeit am Auslass einer Kühlmaschine

Procédé d'estimation de la charge thermique d'un circuit pour un fluide de service à la sortie d'une machine de refroidissement

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Description

[0001] The present invention relates to a method for estimating the thermal load of a circuit for a service fluid at outlet from a refrigerating machine, a control device for implementing this method and a refrigerator machine with such a device.

[0002] In particular, the present invention finds advantageous, though not exclusive, application in the estimation of the thermal load of a hydronic circuit of centralized air-conditioning systems, to which the ensuing description will make explicit reference, without this implying any loss of generality.

[0003] As is known, a centralized air-conditioning system for control of ambient temperature of a building comprises a plurality of fan coils, which are appropriately distributed inside the building and are connected to one another via a hydraulic circuit, and a centralized refrigerating machine designed to cool a service fluid, and in particular a liquid coolant substantially constituted by water, and to convey said service fluid to the various fan coils through said hydraulic circuit.

[0004] Said refrigerating machine, commonly referred to as "chiller", comprises an internal circuit, circulating in which is an working fluid constituted by a refrigerant fluid, an output circuit, which closes on the hydraulic circuit of the air-conditioning system in an area corresponding to an inlet and an outlet of the refrigerating machine, a heat exchanger traversed by the internal circuit and by the output circuit for heat exchange between the working fluid and the service fluid, and one or more compressors for actuating a refrigerating cycle on the working fluid via compression of the working fluid itself. The hydraulic circuit of the air-conditioning system and the output circuit of the refrigerating machine form a so-called hydronic circuit.

[0005] Moreover known are electronic control systems for controlling turning-on and turning-off of the compressors in such a way that the temperature of the service fluid at inlet to or outlet from the refrigerating machine, i.e. the return temperature or the delivery temperature, respectively, of the service fluid, will reach a pre-determined set point.

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

[0007] The control systems referred to above present intrinsic limits due to temporal constraints between the instants of turning-on and turning-off of the compressors for the purpose of lengthening the service life thereof. Said constraints in effect limit the differential between the temperature thresholds to a minimum value, below which the compressors are forced to operate in technically prohibitive conditions of operation that can cause damage thereto. More in general, said temporal constraints mean that the control systems mentioned above do not enable, on the one hand, a good degree of precision of regulation of the temperature of the service fluid and, on the other hand, maximization of the energy efficiency of the air-conditioning system.

[0008] Document JP-A-10 300 163 discloses a method for estimating a cooling capacity by measuring, via a pair of temperature sensors, a delivery temperature of the service fluid at outlet from the refrigerating machine and a return temperature of the service fluid at inlet to the refrigerating machine.

[0009] The aim of the present invention is to provide a method for estimating the thermal load of a hydronic circuit of an air-conditioning system governed by a refrigerating machine and to provide a control device for the refrigerating machine implementing said method that will enable regulation of the delivery temperature in a precise way, and maximization of the energy efficiency of the system, and, at the same time, will be easy and inexpensive to produce.

[0010] Provided according to the present invention are a method for estimating the thermal load of a service circuit for a service fluid at outlet from a refrigerating machine, a control device for a refrigerating machine, and a refrigerating machine in accordance with the annexed claims.

[0011] The present invention will now be described with reference to the annexed drawings, which illustrate a non-limiting example of embodiment thereof and in which:

- Figure 1 illustrates a block diagram of an air-conditioning system comprising a refrigerating machine provided with a control device in accordance with the present invention;
- Figures 3 to 7 illustrate a flowchart of the method for estimating the thermal load of a circuit for a service fluid at outlet from the refrigerating machine of Figure 1 in accordance with the present invention; and
- Figure 2 and Figures 8a to 9b illustrate calculation curves and tables of parameters used in the flowchart of Figures 3 to 7.

[0012] In Figure 1, designated as a whole by 1 is an air-conditioning system comprising a plurality of fan coils 2 appropriately distributed inside a building (not illustrated) of which it is intended to control the ambient temperature, and a refrigerating machine 3 designed to cool and cause circulation, along a hydraulic circuit 4 that connects the fan coils 2 to the refrigerating machine 3 itself, of a service fluid 5, and in particular a liquid coolant substantially constituted by water.

[0013] The refrigerating machine 3 typically comprises an internal circuit 6, circulating in which is an working fluid 7 constituted by a refrigerant fluid, and an output circuit 8, which closes on the hydraulic circuit 4 of the system 1 in an area corresponding to an inlet 9 and an outlet 10 of the refrigerating machine 3. Set along the internal circuit 6 are a

series of devices for actuating a refrigerating cycle on the working fluid 7, and in particular: a first heat exchanger 11 traversed by the internal circuit 6 and by the output circuit 8 functioning as evaporator, i.e., for causing evaporation at low pressure of the working fluid 7 by absorbing heat from the service fluid 5; a compressor 12, preferably of a scroll type, for performing an adiabatic compression on the working fluid 7 in the vapour state; a second heat exchanger 13 functioning as condenser, i.e., for causing condensation of the working fluid 7 in such a way that it can release on the outside the heat previously absorbed; and an expansion valve 14 for cooling and causing partial evaporation of the working liquid 7 in such a way 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, comprising a delivery branch 16, along which the service fluid 5 circulates in a direction D oriented 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. The circulation of the service fluid 5 in the direction D is guaranteed by a pump 18 set along the return branch 17.

[0015] The refrigerating machine 3 is provided with a storage tank 19 set along the delivery branch 16 at a short distance from the heat exchanger 11 for producing a thermal inertia in the hydronic circuit 15 that slows down the dynamics of the system 1 in such a way as to prevent undesirable phenomena of oscillation in the regulation valves (not illustrated) of the fan coils 2. The presence of the storage tank 19 is optional.

[0016] The refrigerating machine 3 further comprises a control device 20 for controlling turning-on and turning-off of the compressor 12 as a function of a delivery temperature TDLV of the service fluid 5.

[0017] In greater detail, the control device 20 comprises a first temperature sensor 21 set along the delivery branch 16 at output from the storage tank 19, i.e., at the outlet 10 of the refrigerating machine 3, for measuring the delivery temperature TDLV of the service fluid 5, a second temperature sensor 22 set along the return branch 17 in an area corresponding to the inlet 9 of the refrigerating machine 3 for measuring the return temperature TRET of the service fluid 5, which corresponds to a desired value of the temperature of evaporation of the working fluid 7 in the heat exchanger 11, a keypad 23 for receiving commands imparted by a user, and an electronic control unit 24 connected to the sensors 21 and 22, to the keypad 23 and to the compressor 12.

[0018] The electronic control unit 24 is designed to control turning-on and turning-off of the compressor 12 as a function of the comparison between the delivery temperature TDLV and a pair of delivery-temperature thresholds in such a way that the delivery temperature TDLV will converge on a delivery-temperature set point TSET comprised between the two delivery-temperature thresholds.

[0019] The electronic control unit 24 implements a method for estimating the thermal load of the hydronic circuit 15 in accordance with the present invention, said method being described in detail hereinafter for the case where the service fluid 5 is cooled for cooling the environments in which the fan coils 2 are arranged.

[0020] In addition, the electronic control unit 24 is designed to regulate the delivery temperature TDLV by adapting the set point TSET and the temperature thresholds to the thermal load estimated.

[0021] The temperature thresholds comprise a lower threshold TLOW and an upper threshold THIG linked to the set point TSET on the basis of the relations:

$$THIG = TSET + DM \cdot R; \quad (1)$$

$$TLOW = TSET - DM \cdot (1 - R), \quad (2)$$

where DM is a temperature differential between the delivery-temperature thresholds, hereinafter referred to more simply as "delivery differential", and R is a parameter, hereinafter referred to as "dividing ratio", comprised between 0 and 1 that defines the ratio with which the delivery differential DM is divided between the two thresholds so as to be able to render them asymmetrical with respect to the set point TSET.

[0022] As may be noted, corresponding to a regulation of the set point TSET, due to the adaptation to the thermal load, is a regulation of the same sign of the lower threshold TLOW and upper threshold THIG. Typically, in controls on the delivery temperature TDLV, the lower threshold TLOW and upper threshold THIG are maintained symmetrical with respect to the set point TSET; i.e., they are linked to the set point TSET via a dividing ratio R of 0.5. However, the lower threshold TLOW and upper threshold THIG can be adjusted irrespective of the set point TSET by acting on the delivery differential DM and on the dividing ratio R.

[0023] To a first approximation, the thermal load of the hydronic circuit 15 corresponds to the thermal load offered by the environment to be cooled. The more the thermal load decreases, the lower the heat exchange between the environment and the fan coils 2, and the less the need to cool the service fluid 5. Consequently, adaptation of the set point TSET envisages increase of the set point TSET as the thermal load decreases. Since the coefficient of performance

(COP) of a refrigerating machine 3 increases as the evaporation temperature in the exchanger increases, it follows that the increase of the set point TSET as the thermal load decreases leads to an increase in the overall efficiency of the system 1.

[0024] The estimated thermal load is given in terms of fraction of load FL, i.e., in terms of ratio between the power that the refrigerating machine 3 must supply to cool the environment and the maximum refrigerating power that can be delivered by the refrigerating machine 3 in given nominal conditions.

[0025] Turning-on or turning-off of the compressor 12 must respect precise temporal constraints between successive events of turning-on and/or turning-off in order to safeguard the integrity of the compressor 12 itself, i.e., it must respect a minimum time Δt_{ON_min} between turning-on and turning-off, a minimum time Δt_{OFF_min} between turning-off and turning-on, and a minimum time $\Delta t_{ON_ON_min}$ between two successive turning-on events. In order to respect said temporal constraints, the compressor 12 should, during an on-off cycle defined between two successive turning-on events, remain on and remain off, respectively, for a theoretical on time Δt_{ON} and a theoretical off time Δt_{OFF} depending upon the estimated fraction of thermal load FL as follows:

$$\Delta t_{ON} = \begin{cases} \Delta t_{ON_min} & FL < FL1 \\ \Delta t_{ON_ON_min} \cdot FL & FL1 \leq FL \leq FL2 \\ \Delta t_{OFF_min} \cdot \frac{FL}{1-FL} & FL > FL2 \end{cases} \quad (3)$$

$$\Delta t_{OFF} = \begin{cases} \Delta t_{ON_min} \cdot \frac{1-FL}{FL} & FL < FL1 \\ \Delta t_{ON_ON_min} \cdot (1-FL) & FL1 \leq FL \leq FL2 \\ \Delta t_{OFF_min} & FL > FL2 \end{cases} \quad (4)$$

where: $FL1 = \frac{\Delta t_{ON_min}}{\Delta t_{ON_ON_min}}$; $FL2 = \frac{\Delta t_{OFF_min}}{\Delta t_{ON_ON_min}}$.

[0026] Figure 2 shows the graph of the theoretical on and off times Δt_{ON} and Δt_{OFF} as the fraction of load FL varies in the case of the following temporal constraints:

- $\Delta t_{ON_min} = 60$ s;
- $\Delta t_{OFF_min} = 180$ s; and
- $\Delta t_{ON_ON_min} = 360$ s.

[0027] The asymptotic evolutions at the extremes of the range of variation of the fraction of load FL mean that the compressor 12 remains on or off for extremely long times at points corresponding, respectively, to fractions of load FL close to 1 or 0.

[0028] Figure 3 illustrates a flowchart that describes the regulation of the delivery temperature TDLV as a function of the estimate of the thermal load.

[0029] With reference to Figure 3, upon turning-on of the refrigerating machine 3, the method envisages a step of initialization of variables (block 100), in which:

- the set point TSET is set to a minimum value TSETmin of 7°C, which corresponds to the value that the set point TSET ideally assumes at a point corresponding to the maximum load in such a way that the refrigerating machine 3 will immediately start cooling to maximum to cope with a possibly high initial load;
- the delivery differential DM is set to a default value DMdef of 4.8°C;
- the dividing ratio R is set to a default value Rdef of 0.5; and
- two variables t_{ON} and t_{OFF} , referred to hereinafter as "turning-on instant" and "turning-off instant", respectively, of the compressor 12, are set to 0; and
- a variable τ_{WAIT} , referred to hereinafter as "wait time", is set to 0.

[0030] The delivery temperature TDLV and the return temperature TRET are measured via the respective sensors 21 and 22 (block 101).

[0031] Periodically, a measurement of the delivery temperature TDLV is compared with the lower threshold TLOW (block 102) and the upper threshold THIG (block 103). If the delivery temperature TDLV is lower than or equal to the lower threshold TLOW, then the compressor 12 is turned off (block 104). Instead, if the delivery temperature TDLV is higher than or equal to the upper threshold THIG, then the compressor 12 is turned on (block 105). The instants of time of the events of turning-off and turning-on are stored in the respective variables turning-off instant t_{OFF} (block 106) and turning-on instant t_{ON} (block 107). In addition, at each turning-on event a counter N_{ON} for counting the number of turning-on events is incremented (block 108).

[0032] The turning-on event determines start of the on-off cycle of the compressor 12, and at a point corresponding to said event a series of calculations is triggered, which leads to the estimation of the thermal load and to the adaptation of the set point TSET and of the thresholds TLOW and THIG to the estimated thermal load.

[0033] In particular, on the basis of the turning-on instant t_{ON} and turning-off instant t_{OFF} , an effective on time Δt_{ON_real} , an effective off time Δt_{OFF_real} , and an effective cycle time Δt_{TOT_real} of the compressor 12 are determined, the latter being equal to the sum $\Delta t_{ON_real} + \Delta t_{OFF_real}$ (block 109), and a mean delivery temperature TDLVmean is determined by averaging the measurements of delivery temperature TDLV over the effective cycle time Δt_{TOT_real} (block 110).

[0034] In accordance with the present invention, the thermal load is estimated as a function of the measurements of delivery temperature TDLV and return temperature TRET and is supplied, as mentioned previously, in terms of an estimated fraction of load FL (block 111).

[0035] Once the estimation of the fraction of load FL has been performed, the theoretical on time Δt_{ON} and the theoretical off time t_{OFF} are calculated, respectively, via Eq. (3) and Eq. (4) and a theoretical cycle time Δt_{TOT} , equal to the sum $\Delta t_{ON} + \Delta t_{OFF}$, is calculated (block 112).

[0036] At this point, the set point TSET is adjusted via an adaptation thereof to the fraction of load FL (block 113). However, the adaptation of the set point TSET to the fraction of load FL is enabled only after verification of the fact that the number of turning-on events N_{ON} has reached a minimum number of turning-on events N_{ON_min} , preferably equal to 4 (block 114). This control has the purpose of enabling a sufficient stabilization of the process of estimation of the fraction of load FL in so far as the process of estimation is perturbed by the regulation of the set point TSET.

[0037] After the regulation of the set point TSET, the wait time τ_{WAIT} is set to a value calculated by applying the following formula:

$$\tau_{WAIT} = 2.5 \cdot \Delta TSET \cdot (\Delta t_{TOT}), \quad (5)$$

where $\Delta TSET$ is a set-point step produced by the regulation of the set point TSET with respect to the previous value assumed by the set point TSET itself, as will be explained hereinafter, and a down count is activated starting from said value of wait time τ_{WAIT} (block 115). Only at the end of said down count is the regulation of the set point TSET enabled again (block 116). Also this solution has the purpose of enabling a sufficient stabilization of the process of estimation of the fraction of load FL.

[0038] Next, the lower threshold TLOW and upper threshold THIG are adjusted as a function of the fraction of load FL, of the mean delivery temperature TDLVmean, and of the set point TSET (block 117).

[0039] Figure 4 illustrates a portion of flowchart regarding block 111 of Figure 3, which illustrates the substeps regarding determination of the fraction of load FL of the hydronic circuit 15 in accordance with the present invention.

[0040] The method is based upon the hypothesis that the system constituted by the air-conditioning system 1 and by the environment to be cooled is a thermally insulated system, for which it is possible to write an energy-balance equation in terms of temperature of the type:

$$\Delta TQ = TDLV - TRET + k \cdot \frac{dTRET}{dt} \quad (6)$$

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

[0041] In particular, with reference to Figure 4, the method for estimating the thermal load envisages estimating the

system parameter k to tune a subsequent estimation of the fraction of load FL with the characteristics of capacity and mass flowrate of the hydronic circuit 15 (block 200), and subsequently of acquiring samples of delivery temperature $TDLV(n)$ and return temperature $TRET(n)$ by 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 samples of delivery temperature $TDLV(n)$ and return temperature $TRET(n)$ via a discrete Kalman filter (block 202) that expresses Eq. (6) as system in the discrete state space (DSS) according to the following matrix form:

$$\begin{cases} x(n+1) = F \cdot x(n) + G \cdot u(n) \\ y(n) = H \cdot x(n) + J \cdot u(n) \end{cases} \quad (7)$$

where $u(n)$, $x(n)$ and $y(n)$ are, respectively, the vector of the inputs, of the states, and of the outputs of the system at the discrete instant n , and where

$$u(n) = \begin{bmatrix} TDLV(n) \\ TRET(n) \end{bmatrix}, \quad x(n) = y(n) = \begin{bmatrix} \Delta TQ(n) \\ TRET(n) \end{bmatrix} \quad (8)$$

$$F = \begin{bmatrix} 1 & 0 \\ \frac{ts}{k} & 1 - \frac{ts}{k} \end{bmatrix}, \quad G = \begin{bmatrix} 0 \\ \frac{ts}{k} \end{bmatrix}, \quad H = [0 \quad 1], \quad J = [0]. \quad (9)$$

[0042] The transformation of Eq. (6) into the system defined by Eqs. (7), (8) and (9) is based upon the further hypothesis that the thermal power that the environment transfers to the system 1 is constant during the sampling period ts . Hence, the estimation of the difference of temperature ΔTQ is supplied in discrete form $\Delta TQ(n)$.

[0043] The difference of temperature ΔTQ estimated undergoes a low-pass filtering (block 203), for example via a first-order Chebyshev filter with a cut-off pulsation of 0.003 rad/s and a peak pass-band ripple of 3dBp, and is then processed to obtain a mean value ΔTQ_{mean} over the measured cycle time Δt_{CYCLE} (block 204).

[0044] Finally, there is calculated a mean value ΔTCH_{mean} of a difference of temperature ΔTCH between the temperatures $TDLV$ and $TRET$ over the portion of the cycle time Δt_{CYCLE} corresponding to the period in which the compressor 12 is turned on in so far as the difference of temperature ΔTCH is zero when the compressor 12 is turned off (block 205), and the fraction of load FL sought is calculated as ratio between the mean values ΔTQ_{mean} and ΔTCH_{mean} (block 206),

$$FL = \frac{\Delta TQ_{mean}}{\Delta TCH_{mean}} \quad (10)$$

[0045] Eq. (10) follows directly from the definition of fraction of load given previously.

[0046] Figure 5 illustrates a portion of flowchart that describes in greater detail the step of estimation of the system parameter k indicated in block 200 in Figure 4.

[0047] The system parameter k is estimated on the basis of a formula obtained from an energy-balance equation in terms of temperature similar to Eq. (6) and expressed as a function of temperatures of which measurements are available, i.e., of the delivery temperature $TDLV$ and of the return temperature $TRET$. Said formula has the following form:

$$k(t) = \frac{TDLV(t - \frac{\tau_1}{2}) - TRET(t + \frac{\tau_1}{2}) - TDLV(t + \tau_2) + TRET(t)}{\frac{dTDLV}{dt}(t + \tau_2)} \quad (11)$$

where τ_1 and τ_2 are the heat-propagation delays introduced, respectively, by the pipes of the hydronic circuit 15 and by the storage tank 19, assuming the outlet of the heat exchanger 11 as origin of a thermal variation, and t is an instant of time in which the system parameter k is estimated.

[0048] With reference to Figure 5, during each on-off cycle of the compressor 12, the effective on time Δt_{ON_real} and off time Δt_{OFF_real} are compared with one another (block 300): if the duration Δt_{ON_real} is greater than the

duration Δt_{OFF_real} , then the system parameter k will be estimated just before turning-off of the compressor 12, namely, $t = t_{OFF} - \varepsilon$ (block 301); otherwise, the system parameter k will be estimated just before turning-on of the compressor 12, namely, $t = t_{ON} - \varepsilon$ (block 302). The deviation time ε is preferably five seconds.

[0049] The heat-propagation delay τ_2 due to the storage tank 19 is determined as a difference between the turning-on instant t_{ON} and a first sing-inversion instant, in which the first derivative of the delivery temperature TDLV passes from a positive value to a negative value (block 303). By calculating, instead, the difference between the turning-on instant t_{ON} and a second sing-inversion instant, in which the first derivative of the return temperature TRET passes from a positive value to a negative value, there is obtained a heat-propagation delay τ_3 for the entire hydronic circuit 15, i.e., between the outlet and the inlet of the exchanger (block 304). Hence, the heat-propagation delay τ_1 due to the pipes is given by $\tau_1 = \tau_3 - \tau_2$ (block 305).

[0050] It is clear that, in the absence of the storage tank 19, we will not obtain the corresponding heat-propagation delay τ_2 , and the delay of propagation τ_1 due to the pipes would be equal to τ_3 .

[0051] At this point, it is possible to apply Eq. (11) for calculating a value of the system parameter k at the instant of time t (block 306).

[0052] The estimation of the system parameter k in the way described above corresponds to an estimation of the characteristics of capacity and mass flowrate of the hydronic circuit 15 that enables automatic tuning of the estimation of the fraction of load FL to the characteristics of the system 1. This operation is certainly necessary upon initial turning-on of the refrigerating machine 3 after it has been connected to a new system 1, but also during normal operation of the system 1 itself for identifying variations of load due to de-activation of one or more fan coils 2.

[0053] Figure 6 illustrates a portion of flowchart that describes in greater detail the step of regulation of the set point TSET indicated in block 113 in Figure 3.

[0054] This step envisages calculation of a new value of the set point TSET using a formula that expresses the temperature of set point TSET as a function of the estimated fraction of load FL (block 400) :

$$TSET = \begin{cases} TSET_{max} & \text{if } FL \leq FLI \\ TSET_{min} + (TSET_{max} - TSET_{min}) \cdot \frac{(1 - FL)}{(1 - FLI)} & \text{otherwise} \end{cases} \quad (12)$$

where TSETmin is the minimum value of the set point TSET corresponding to the fraction of maximum load equal to unity, TSETmax is a maximum value of the set point TSET corresponding to the fraction of load that is equal to zero, and FLI is a value of fraction of load that separates the relation into a first portion in which the set point TSET is constant and a second portion in which the set point TSET decreases linearly as the fraction of load FL varies.

[0055] Eq. (12) is considered for three different sets of values of the parameters TSETmin, TSETmax and FLI gathered together in the table appearing in Figure 8a. Figure 8b represents the three different versions of Eq. (12) via three respective curves plotted in the plane TSET, FLI and designated by C1, C2 and C3.

[0056] The three sets of parameters TSETmin, TSETmax and FLI, and hence the three curves C1, C2 and C3, correspond to three different modes of operation of the refrigerating machine 3 which can be selected by the user.

Corresponding to the curve C1 is a default mode of operation, which ensures the best compromise between energy efficiency of the refrigerating machine 3 and precision of regulation of the delivery temperature TDLV, in so far 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 of fractions of load FL , i.e., from 0.3 to 1. Corresponding to the curve C2, instead, is a mode of operation that ensures the best energy efficiency, in so far as the new value of the set point TSET is equal to a high value (TSETmax) for a wide range of values of fractions of load FL , i.e., from 0 to 0.6, thus maximizing the coefficient of performance of the refrigerating machine 3. Finally, corresponding to the curve C3 is a mode of operation that ensures the best control of humidity in so far 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.

[0057] After the new value of the set point TSET has been calculated, a set-point step $\Delta TSET$ is determined by calculating the difference between the value just calculated and the preceding value of the set point TSET and setting an upper limit for the step $\Delta TSET$ at a maximum value $\Delta TSET_{max}$ preferably of 4°C (block 401), and the set point TSET is updated by applying instantaneously the set-point step $\Delta TSET$ to the preceding set point TSET (block 402).

[0058] Figure 7 illustrates a portion of flowchart that describes in greater detail the step of regulation of the lower threshold TLOW and upper threshold THIG indicated in block 117 in Figure 3.

[0059] This step envisages calculation of a first error parameter $E\delta t$, which defines the relative error between the effective cycle time Δt_{TOT_real} and the theoretical cycle time Δt_{TOT} (block 500), as follows:

$$E\Delta t = \frac{\Delta t_{TOT_real} - \Delta t_{TOT}}{\Delta t_{TOT}} \quad (13)$$

[0060] If it is found that the error $E\Delta t$ is negative (block 501), it means that the delivery differential DM is too small, i.e., it does not enable respect of the temporal constraints between successive turning-on and/or turning-off events, and hence it is necessary to increase it by an amount ΔDM , preferably of 0.2°C (block 502); otherwise, a new value of delivery differential DM is determined in such a way that said error $E\Delta t$ tends to zero (block 503). In particular, the new value of delivery differential DM is determined using a numeric method for search for the zeroes of a function, known as chord method or secant method, by applying it to a target function constituted by the error $E\Delta t$ as a function of the delivery differential DM. This regulation has the purpose of maximizing the number of turning-on events of the compressor 12 per hour in due respect of the aforesaid temporal constraints.

[0061] In addition, a second error parameter ETDLV is calculated, which defines the relative error between the mean delivery temperature TDLVmean and the set point TSET (block 504),

$$ETDLV = \frac{TDLV_{mean} - TSET}{TSET} \quad (14)$$

and a new value of dividing ratio R is determined in such a way that said error ETDLV tends to zero (block 504). In a way similar to that adopted for the delivery differential DM, the chord method or secant method is used applying it to a target function constituted by the error ETDLV as a function of the dividing ratio R. This regulation has the purpose of speeding up convergence of the delivery temperature TDLV towards the set point TSET.

[0062] At this point, the lower threshold TLOW and the upper threshold THIG are calculated as a function of the dividing ratio R, of the delivery differential DM, and of the set point TSET applying Eq. (1) and Eq. (2), respectively (block 506).

[0063] The dependency of the theoretical cycle time Δt_{TOT} upon the fraction of load FL causes the delivery differential DM, and hence the position of the lower threshold TLOW and upper threshold THIG with respect to the set point TSET, to be in effect adapted to the fraction of load FL.

[0064] It should be noted that the working diagram of the refrigerating machine 3 illustrated in Figure 1 can generically describe also a machine designed to heat the service fluid 5 in order to heat the environments in which the fan coils 2 are set, for example, a refrigerating machine 3 of the type operating as heat pump. In said type of refrigerating machine 3, the compressor 12 is configured so as to carry out the refrigerating cycle in a reverse mode with respect to what was described previously, i.e., in such a way that the heat exchanger 11 functions as condenser for transferring heat from the working fluid 7 to the service fluid 5, and the heat exchanger 13 functions as evaporator.

[0065] The method for estimating the thermal load in accordance with the present invention is hence applicable also to the case where the refrigerating machine 3 is designed to heat the service fluid 5, it being sufficient simply to reverse the mechanism of some of the steps described and change the value of some parameters, and in particular:

- upon turning-on of the heat pump, the set point TSET is set to a maximum value TSETmax of 45°C , which corresponds to the value that the set point TSET assumes ideally at a point corresponding to the maximum thermal load in such a way that the heat pump will immediately start to heat to the maximum to cope with a possibly high initial load; in fact, there is an increase of efficiency as the condensation temperature decreases;
- if the measurement of the delivery temperature TDLV exceeds the upper threshold THIG, then the compressor 12 is turned off;
- if the measurement of the delivery temperature TDLV is below the lower threshold TLOW, then the compressor 12 is turned on;
- the set point TSET is decreased when the thermal load decreases, that is, the new set point TSET is expressed as a linear increasing function of the fraction of load FL of the type:

$$TSET = \begin{cases} TSET_{min} & \text{if } FL \leq FLI \\ TSET_{max} + (TSET_{min} - TSET_{max}) \cdot \frac{(1 - FL)}{(1 - FLI)} & \text{otherwise} \end{cases} \quad (15)$$

- Eq. (14) is considered for three different sets of values of the parameters TSETmin, TSETmax and FLI gathered in the table appearing in Figure 9a and generating the curves C1, C2 and C3 illustrated in Figure 9b;
- the maximum value $\Delta TSET_{max}$ at which the amplitude of regulation of the set point TSET is to be limited is preferably

5°C; and

- the default value DMdef of the differential DM is preferably 6°C.

[0066] The main advantage of the method for estimating the thermal load of a hydronic circuit 15 described above as compared to the known art is that it increases the overall efficiency of the system 1 albeit maintaining a good precision of regulation of the delivery temperature TDLV of the service fluid 5 in the hydronic circuit 15.

[0067] In fact, the adaptation of the set point TSET to the thermal load of the hydronic circuit 15 enables the refrigerating machine 3 to respond promptly to the variations of thermal load of the environment of which it is intended to control the temperature in such a way that the evaporation temperature can increase in the case where the machine is configured for cooling the service fluid 5, or in such a way that the condensation temperature can decrease in the case where the machine is configured for heating the service fluid 5, thus maximizing the coefficient of performance in all the operating conditions.

[0068] In addition, the adaptation of the two delivery-temperature thresholds TLOW and THIG to the estimated fraction of load FL enables maximization of the number of turning-on events of the compressor 12 per hour within the limit imposed by the temporal constraints between successive turning-on and/or turning-off events via regulation of the delivery differential DM and enables speeding up of the convergence of the delivery temperature TDLV to the set point TSET via the regulation of the dividing ratio R.

[0069] Another advantage is that it enables automatic adaptation of the refrigerating machine 3 to the type of system 1 in which it is installed and rapid identification of variations of thermal load due to de-activation of one or more fan coils 2, thanks to the operation of estimation of the system parameter k that expresses the characteristics of capacity and flowrate of the system 1.

[0070] Finally, the possibility of switching from regulation for a service fluid to be cooled to that for a service fluid to be heated by simply varying some parameters renders the method easy to implement in the electronic control unit 24 of any refrigerating machine 3 of a reversible type, i.e. one provided with an reverse valve arranged along the internal circuit 6 to be able to reverse the refrigerating cycle so as to enable an operation in cooling mode or in heating mode.

Claims

1. A method for estimating the thermal load of a service circuit (15) for a service fluid (5) at outlet from a refrigerating machine (3) of an air-conditioning system (1); the refrigerating machine (3) comprising a compressor (12), and the air-conditioning system comprising fan-coil means (2); the service circuit (15) comprising a delivery branch (16) for circulation of the service fluid (5) from the refrigerating machine (3) to the fan-coil means (2), and a return branch (17) for return of the service fluid (5) at input to the refrigerating machine (3); wherein the method comprises:

- measuring (101), via a pair of temperature sensors (21, 22), a delivery temperature (TDLV) of the service fluid (5) at outlet from the refrigerating machine (3) and a return temperature (TRET) of the service fluid (5) at inlet to the refrigerating machine (3); and

- supplying (106, 107, 109, 111) an estimate of the thermal load (FL) by processing, via a Kalman filtering, the measurements of the delivery temperature (TDLV) and of the return temperature (TRET).

2. The method according to Claim 1, wherein said estimate of the thermal load is supplied (106, 107, 109, 111) in terms of fraction of load (FL) referred to a maximum power that can be delivered by said refrigerating machine (3).

3. The method according to Claim 1 or Claim 2, wherein supplying (106, 107, 109, 111) an estimate of the thermal load (FL) comprises:

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

4. The method according to any one of the preceding claims, wherein supplying (106, 107, 109, 111) an estimate of the thermal load (FL) comprises:

- acquiring (201) samples of delivery temperature (TDLV(n)) and of return temperature (TRET(n)) according to a given sampling period (ts); and

- estimating (202) a first difference of temperature (ΔTQ) defined between the inlet and the outlet of the fan-coil means (2) by processing the samples of delivery temperature (TDLV(n)) and return temperature (TRET(n)) via a discrete Kalman filter that expresses an energy balance of said air-conditioning system (1) as a system in the

discrete state space.

5. The method according to Claim 4, wherein supplying (106, 107, 109, 111) an estimate of the thermal load (FL) comprises:

- calculating (204-206) a fraction of thermal load (FL) referred to a maximum power that can be delivered by said refrigerating machine (3) and as a function of said first difference of temperature (ΔTQ) and of a second difference of temperature (ΔTCH) defined as a difference between said delivery temperature (TDLV) and said return temperature (TRET).

6. The method according to Claim 5, wherein calculating (204-206) a fraction of thermal load (FL) comprises:

- calculating (204, 205) a mean value (ΔTQ_{mean}) of said first difference of temperature (ΔTQ) and a mean value (ΔTCH_{mean}) of said second difference of temperature (ΔTCH); and
- calculating (206) the fraction of load as ratio between the mean value (ΔTQ_{mean}) of the first difference of temperature (ΔTQ) and the mean value (ΔTCH_{mean}) of the second difference of temperature (ΔTCH).

7. The method according to Claim 6, wherein said mean value (ΔTQ_{mean}) of said first difference of temperature (ΔTQ) is calculated over an on-off cycle of said compressor (12), and said mean value (ΔTCH_{mean}) of said second difference of temperature (ΔTCH) is calculated over the portion of said cycle where the compressor (12) is turned on.

8. The method according to any one of Claims 4 to 7, wherein supplying (106, 107, 109, 111) an estimate of the thermal load (FL) comprises:

- carrying out (203) a low-pass filtering of said first estimated difference of temperature (ΔTQ).

9. The method according to any one of Claims 4 to 8, wherein said discrete Kalman filter has: input variables comprising a discrete series constituted by said samples of delivery temperature (TDLV(n)) and a discrete series constituted by said samples of return temperature (TRET(n)); output variables coinciding with the state variable and comprising the series of samples of return temperature (TRET(n)) and a series of values of first difference of temperature ($\Delta TQ(n)$); and matrices for processing the input and state variables, the elements of which are a function of a system parameter (k) that depends upon characteristics of capacity and mass flowrate of said service circuit (15).

10. The method according to any one of Claims 3 to 9, wherein tuning the estimate of the thermal load (FL) as a function of an estimate of characteristics of capacity and mass flowrate of said service circuit (15) comprises:

- estimating (106, 107, 109, 200) a system parameter (k) proportional to a density (ρ) of the service fluid (5), proportional to a total volume (V_{tot}) of said service circuit (15), and inversely proportional to a mass flowrate (m) of said service circuit (15).

11. The method according to Claim 10, wherein estimating (106, 107, 109, 200) the system parameter (k) comprises:

- determining (109), for each on-off cycle of said compressor (12), an effective on time (Δt_{ON_real}) and an effective off time (Δt_{OFF_real}) of the compressor (12);
- determining (300-302) an estimation instant (t) as a function of the result of a comparison between the effective on time (Δt_{ON_real}) and the effective off time (Δt_{OFF_real}); and
- calculating (306) a value of the system parameter (k) at the estimation instant (t).

12. The method according to Claim 10 or Claim 11, wherein estimating (106, 107, 109, 200) the system parameter (k) comprises:

- determining (303-305) heat-propagation delays (τ_1 , τ_2 , τ_3) introduced by said service circuit (15);
- calculating (306) a value of the system parameter (k) as a function of said delivery temperature (TDLV), of a return temperature (TRET) of said service fluid (5) at inlet to the refrigerating machine (3), and of the heat-propagation delays (τ_1 , τ_2 , τ_3).

13. The method according to any one of Claims 10 to 12, wherein estimating (106, 107, 109, 200) the system parameter (k) comprises:

- storing (106, 107), for each on-off cycle of said compressor (12), a turning-on instant (t_{ON}) and a turning-off instant (t_{OFF}) of the compressor (12);

determining (300-302) an estimation instant (t) comprising:

- in the case where said effective on time (Δt_{ON_real}) is longer than said effective off time (Δt_{OFF_real}), calculating (301) the estimation instant (t) as a difference between the turning-off instant (t_{OFF}) and a given deviation time (ϵ);
- otherwise, calculating (302) the estimation instant (t) as a difference between the turning-on instant (t_{ON}) and the deviation time (ϵ).

14. The method according to Claim 12 or Claim 13, wherein estimating (106, 107, 109, 200) said system parameter (k) comprises:

- storing (107), for each on-off cycle of said compressor (12), a turning-on instant (t_{ON}) of the compressor (12); determining (303-305) heat-propagation delays (τ_1 , τ_2 , τ_3) introduced by said service circuit (15) comprising:
- determining (307) a first heat-propagation delay (τ_3) as a function of said turning-on instant (t_{ON}) of the compressor (12) and of a first instant in which the first derivative of said return temperature (TRET) passes from a positive value to a negative value.

15. The method according to Claim 14, wherein said refrigerating machine (3) comprises means for storage (19) of said service fluid (5) set along a delivery branch (16) of said service circuit (15) for producing a thermal inertia; determining (303-305) heat-propagation delays (τ_1 , τ_2 , τ_3) introduced by said service circuit (15) comprising:

- determining (305) a second heat-propagation delay (τ_2) as a function of said turning-on instant (t_{ON}) of the compressor (12) and of a second instant in which the first derivative of said delivery temperature (TRET) passes from a positive value to a negative value; and
- determining (305) a third heat-propagation delay (τ_1) as a function of the first heat-propagation delay (τ_3) and of the second heat-propagation delay (τ_2).

16. The method according to any one of the preceding claims, comprising:

- turning on and turning off (102-105) said compressor (12) as a function of a measurement of the delivery temperature (TDLV) in such a way that the delivery temperature (TDLV) itself will converge to a delivery-temperature set point (TSET); and
- using said estimate of the thermal load (FL) for regulating said delivery temperature (TDLV) by adapting the delivery-temperature set point (TSET) to the estimate of the thermal load (FL) itself.

17. The method according to any one of the preceding claims, comprising:

- comparing (102, 103) a measurement of said delivery temperature (TDLV) with a pair of delivery-temperature thresholds (TLOW, THIG) set in a given way with respect to a delivery-temperature set point (TSET); and
- using said estimate of the thermal load (FL) for regulating said delivery temperature (TDLV) by adapting the position of the thresholds (TLOW, THIG), with respect to said set point (TSET), to the estimate of the thermal load (FL) itself.

18. A control device for a refrigerating machine (3), the control device (20) comprising first temperature-sensor means (21) for measuring a delivery temperature (TDLV) of a service fluid (5) at outlet from the refrigerating machine (3) and a control unit (24) designed to control the refrigerating machine (3) in such a way that the delivery temperature (TDLV) will converge to a set point (TSET), and being **characterized in that** it comprises second temperature-sensor means (22) for measuring a return temperature (TRET) of the service fluid (5) at inlet to the refrigerating machine (3) and **in that** the control unit (24) implements the method according to any one of Claims 1 to 17.

19. A refrigerating machine (3) comprising a compressor (12) and a control device (20) for turning on and turning off the compressor (12) as a function of a measurement of delivery temperature (TDLV) of a service fluid (5) at outlet from the refrigerating machine (3), and **characterized in that** the control device (20) is according to Claim 18.

Patentansprüche

1. Verfahren zum Schätzen der Wärmebelastung eines Betriebskreislaufs (50) für ein Betriebsfluid (5) am Auslass einer Kühlmaschine (3) einer Klimaanlage (1), wobei die Kühlmaschine (3) einen Kompressor (12) umfasst und die
 5 Klimaanlage eine Gebläsekonvektor-Einrichtung (2) umfasst; wobei der Betriebskreislauf (15) umfasst einen Zulieferzweig (16) für die Zirkulation des Betriebsfluids (5) von der Kühlmaschine (3) zu der Gebläsekonvektor-Einrichtung (2) und einen Rückführzweig (17) für die Rückführung des Betriebsfluids (5) am Einlass zur Kühlmaschine (3); wobei das Verfahren umfasst:
 - 10 - Messen (101), über ein Paar Temperatursensoren (21, 22), einer Zuliefertemperatur (TDLV) des Betriebsfluids (5) am Auslass aus der Kühlmaschine (3) und einer Rückführtemperatur (TRET) des Betriebsfluids (5) am Einlass zur Kühlmaschine (3); und
 - Liefern (106, 107, 109, 111) einer Schätzung der Wärmebelastung (FL) durch ein Verarbeiten, über eine Kalman-Filterung, der Messungen der Zuliefertemperatur (TDLV) und der Rückführtemperatur (TRET).
- 15 2. Verfahren nach Anspruch 1, in welchem die Schätzung der Wärmebelastung geliefert wird (106, 107, 109, 111) als Teil der Last (FL) in Bezug auf eine maximale Leistung, die durch die Kühlmaschine (3) zugeführt werden kann.
- 20 3. Verfahren nach Anspruch 1 oder 2, in welchem das Liefern (106, 107, 109, 111) einer Schätzung der Wärmebelastung (FL) umfasst:
 - Einstellen (106, 107, 109, 111) der Schätzung der Wärmebelastung (FL) als eine Funktion einer Schätzung der Eigenschaften von Kapazität und des Mengendurchsatzes des Betriebskreislaufs (15).
- 25 4. Verfahren nach einem der vorstehenden Ansprüche, in welchem das Liefern (106, 107, 109, 111) eine Schätzung der Wärmebelastung (FL) umfasst:
 - Beschaffen (201) von Proben der Zuliefertemperatur (TDLV(n)) und der Rückführtemperatur (TRET(n)) entsprechend einer gegebenen Beprobungsdauer (ts); und
 - 30 - Schätzen (202) einer ersten Temperaturdifferenz (ΔTQ), welche zwischen dem Einlass und dem Auslass der Gebläsekonvektor-Einrichtung (2) gebildet wird, durch Verarbeiten der Proben der Zuliefertemperatur (TDLV(n)) und der Rückfuhrtemperatur (TRET(n)) über ein diskretes Talmann-Filter, das ein Energiegleichgewicht der Klimaanlage (1) als ein System im diskreten Zustandsraum ausdrückt.
- 35 5. Verfahren nach Anspruch 4, in welchem das Liefern (106, 107, 109, 111) einer Schätzung der Wärmebelastung (FL) umfasst:
 - Berechnen (204-206) eines Teils der Wärmebelastung (FL) in Bezug auf eine Maximalleistung, die durch die Kühlmaschine (3) geliefert werden kann, und als eine Funktion der ersten Temperaturdifferenz (ΔTQ) und einer
 - 40 zweiten Temperaturdifferenz (ΔTCH), die als eine Differenz zwischen der Zuliefertemperatur (TDLV) und der Rückführtemperatur (TRET) gebildet wird.
6. Verfahren nach Anspruch 5, in welchem das Berechnen (204-206) eines Teils der Wärmebelastung (FL) umfasst:
 - 45 - Berechnen (204, 205) eines Mittelwerts (ΔTQ_{mean}) der ersten Temperaturdifferenz (ΔTQ) und eines Mittelwerts (ΔTCH_{mean}) der zweiten Temperaturdifferenz (ΔTCH); und
 - Berechnen (206) des Teils der Last als Verhältnis zwischen dem Mittelwert (ΔTQ_{mean}) der ersten Temperaturdifferenz (ΔTQ) und des Mittelwerts (ΔTCH_{mean}) der zweiten Temperaturdifferenz (ΔTCH).
- 50 7. Verfahren nach Anspruch 6, in welchem der Mittelwert (ΔTQ_{mean}) zu der ersten Temperaturdifferenz (ΔTQ) über einen Ein/Aus-Zyklus des Kompressors (12) berechnet wird und der Mittelwert (ΔTCH_{mean}) der zweiten Temperaturdifferenz (ΔTCH) über den Bereich des Zyklus berechnet wird, in welchem der Kompressor (12) eingeschaltet ist.
- 55 8. Verfahren nach einem der Ansprüche 4 bis 7, in welchem das Liefern (106, 107, 109, 111) einer Schätzung der Wärmebelastung (FL) umfasst:
 - Ausführen (203) eines Niederpass-Filtervorgangs der ersten geschätzten Temperaturdifferenz (ΔTQ).

9. Verfahren nach einem der Ansprüche 4 bis 8, in welchem das diskrete Kalman-Filter hat: Eingangsvariablen mit einer diskreten Reihe, die durch die Proben der Zuliefertemperatur (TDLV(n)) gebildet wird, und einer diskreten Reihe, die durch die Proben der Rückführtemperatur (TERT(n)) gebildet wird; Ausgangsvariablen, die mit dem variablen Zustand zusammenfallen und die Probenreihen der Rückführtemperatur (TART(n)) und einer Reihe von Werten der ersten Temperaturdifferenz ($\Delta TQ(n)$) umfassen; und Matrizes zum Verarbeiten der Eingangs- und Zustandsvariablen, deren Elemente eine Funktion eines Systemparameters (κ) sind, der von den Eigenschaften der Kapazität und des Mengendurchsatzes des Betriebskreislaufs (15) abhängig ist.

10. Verfahren nach einem der Ansprüche 3 bis 9, in welchem das Einstellen der Schätzung der Wärmebelastung (FL) als eine Funktion einer Schätzung von Eigenschaften der Kapazität und des Mengendurchsatzes des Betriebskreislaufs (15) umfasst:

- Schätzen (106, 107, 109, 200) eines Systemparameters (κ) proportional zu einer Dichte (p) des Betriebsfluids (5), proportional zum Gesamtvolumen (Vtot) des Betriebskreislaufs (15) und umgekehrt proportional zu einem Mengendurchsatz (m) des Betriebskreislaufs.

11. Verfahren nach Anspruch 10, in welchem das Schätzen (106, 107, 109, 200) des Systemparameters (κ) umfasst:

- Bestimmen (109) für jeden Ein/Aus-Zyklus des Kompressors (12) einer effektiven Ein-Zeit (Δt_{ON_real}) und einer effektiven Aus-Zeit (Δt_{OFF_real}) des Kompressors (12);
- Bestimmen (300-302) eines Schätzung-Zeitpunkts (t) als eine Funktion des Ergebnisses eines Vergleichs zwischen der effektiven EIN-Zeit (Δt_{ON_real}) und der effektiven AUS-Zeit (Δt_{OFF_real}); und
- Berechnen (306) eines Wertes des Systemparameters (κ) zum Schätzung-Zeitpunkt (t).

12. Verfahren nach Anspruch 10 oder Anspruch 11, in welchem das Schätzen (106, 107, 109, 200) des Systemparameters (κ) umfasst:

- Bestimmen (303-305) von Wärme-Ausbreitungsverzögerungen auf (τ_1, τ_2, τ_3), die im Betriebskreislauf (15) verursacht werden;
- Berechnen (306) eines Wertesystemparameters (κ) als eine Funktion der Zuliefertemperatur (TDLV), einer Rückführtemperatur (TRET) des Betriebsfluids (5) vom Einlass zur Kühlmaschine (3) und der Wärme-Ausbreitungsverzögerungen (τ_1, τ_2, τ_3).

13. Verfahren nach einem der Ansprüche 10 bis 12, in welchem das Schätzen (106, 107, 109, 200) des Systemparameters (κ) umfasst:

- Speichern (106, 107) für jeden Ein/Aus-Zyklus des Kompressors (12) eines Einschalt-Zeitpunkts (t_{ON}) und eines Ausschalt-Zeitpunkts (t_{OFF}) des Kompressors (12);
- Bestimmen (300-302) eines Schätzung-Zeitpunkts (t) mit:
 - in dem Falle, in welchem die effektive EIN-Zeit (Δt_{ON_real}) länger ist als die effektive AUS-Zeit (Δt_{OFF_real}), berechnen (301) des Schätzungs-Zeitpunkts (t) als eine Differenz zwischen dem Ausschalt-Zeitpunkt (t_{OFF}) und einer gegebenen Abweichzeit (ϵ);
 - Andernfalls berechnen (302) des Schätzungs-Zeitpunkts (t) als eine Differenz zwischen dem Einschalt-Zeitpunkt (t_{ON}) und der Abweichzeit (ϵ).

14. Verfahren nach Anspruch 12 oder Anspruch 13, in welchem das Schätzen (106, 107, 109, 200) des Systemparameters (κ) umfasst:

- Speichern (107) für jeden Ein-Aus-Zyklus des Kompressors (12) eines Einschalt-Zeitpunkts (t_{ON}) des Kompressors (12);
- Bestimmen (303-305) von Wärme-Ausbreitungsverzögerungen (τ_1, τ_2, τ_3), die durch den Betriebskreislauf (15) verursacht werden, mit:
- Bestimmen (307) einer ersten Wärme-Ausbreitungsverzögerung (τ_3) als eine Funktion des Einschalt-Zeitpunkts (t_{ON}) des Kompressors (12) und eines ersten Zeitpunkts, in welchem die erste Ableitung der Rückführungstemperatur (TRET) von einem positiven Wert zu einem negativen Wert übergeht.

15. Verfahren nach Anspruch 14, in welchem die Kühlmaschine (3) Mittel zur Speicherung (19) des Betriebsfluids (5)

umfasst, die entlang eines Zulieferzweigs (16) des Betriebskreislauf (15) angeordnet sind, um eine Wärmeträgheit zu produzieren;

- Bestimmen (303, 305) von Wärme-Ausbreitungsverzögerung (τ_1 , τ_2 , τ_3), die durch den Betriebskreislauf (15) verursacht werden, mit:
- Bestimmen (305) einer zweiten Wärme-Ausbreitungsverzögerung (τ_2) als eine Funktion des Einschalt-Zeitpunkts (t_{ON}) des Kompressors (12) und eines zweiten Zeitpunkts in welchem die erste Ableitung der Zuliefertemperatur (TRET) von einem positiven Wert zu einem negativen Wert übergeht; und
- Bestimmen (305) einer dritten Wärme-Ausbreitungsverzögerung (τ_1) als eine Funktion der ersten Wärme-Ausbreitungsverzögerung (τ_3) und der zweiten Wärme-Ausbreitungsverzögerung (τ_2).

16. Verfahren nach einem der vorstehenden Ansprüche, mit:

- Einschalten und Ausschalten (102-105) des Kompressors (12) als eine Funktion einer Messung der Zuliefertemperatur (TDLV) in der Weise, dass sich die Zuliefertemperatur (TDLV) selbst einem Zuliefertemperatur-Einstellpunkt (TSET) annähert; und
- Verwenden der Schätzung der Wärmebelastung (FL) zum Regulieren der Zuliefertemperatur (TDLV), in dem der Zuliefertemperatur-Einstellpunkt (TSET) an die Schätzung der Wärmelast (FL) angepasst wird.

17. Verfahren nach einem der vorstehenden Ansprüche, mit:

- Vergleichen (102, 103) einer Messung der Zuliefertemperatur (TDLV) mit einem paar Zuliefertemperatur-Schwellenwerten (TLOW, THIG), die in einer gegebenen Weise in Bezug auf einen Zuliefertemperatur-Einstellpunkt (TSET) gesetzt werden; und
- Verwenden der Schätzung der Wärmebelastung (FL) zum Regulieren der Zuliefertemperatur (TDLV), in dem die Position der Schwellenwerte (TLOW, THIG) in Bezug auf den Einstellpunkt (TSET) angepasst wird, um die Wärmebelastung (FL) zu schätzen.

18. Steuervorrichtung für eine Kühlmaschine (3), wobei die Steuervorrichtung (20) umfasst eine erste Temperatursensor-Einrichtung (21) zum Messen einer Zuliefertemperatur (TDLV) eines Betriebsfluids (5) am Auslass der Kühlmaschine (3) und eine Steuereinheit (24), die so ausgelegt ist, dass diese die Kühlmaschine (3) in der Weise steuert, dass die sich die Zuliefertemperatur (TDLV) einem Einstellpunkt (TSET) annähert und **dadurch gekennzeichnet, dass** diese eine zweite Temperatursensor-Einrichtung (22) zum Messen einer Rückföhrtemperatur (TRET) des Betriebsfluids (5) am Einlass der Kühlmaschine (3) umfasst und dass die Steuereinheit (24) das Verfahren gemäß einem der Ansprüche 1 bis 17 implementiert.

19. Kühlmaschine (3) mit einem Kompressor (12) und einer Steuervorrichtung (20) zum Einschalten und Ausschalten des Kompressors (12) als eine Funktion einer Messung der Zuliefertemperatur (TDLV) eines Betriebsfluids (5) an einem Auslass der Kühlmaschine (3) und **dadurch gekennzeichnet, dass** die Steuervorrichtung (20) Anspruch 18 entspricht.

Revendications

1. Procédé permettant d'estimer la charge thermique d'un circuit de service (15) pour un fluide de service (5) à la sortie d'une machine frigorifique (3) d'un système de climatisation (1) ; la machine frigorifique (3) comprenant un compresseur (12) ; et le système de climatisation comprenant un moyen ventilo-convecteur (2) ; le circuit de service (15) comprenant une branche de distribution (16) pour la circulation du fluide de service (5) de la machine frigorifique (3) au moyen ventilo-convecteur (2), et une branche de retour (17) pour le retour du fluide de service (5) à l'entrée de la machine frigorifique (3) ; où le procédé comprend le fait :

- de mesurer (101), par l'intermédiaire d'une paire de capteurs de température (21, 22), une température de distribution (TDLV) du fluide de service (5) à la sortie de la machine frigorifique (3) et une température de retour (TRET) du fluide de service (5) à l'entrée de la machine frigorifique (3) ; et
- de fournir (106, 107, 109, 111) une estimation de la charge thermique (FL) par traitement, par l'intermédiaire d'un filtrage de Kalman, des mesures de la température de distribution (TDLV) et de la température de retour (TRET).

2. Procédé selon la revendication 1, dans lequel ladite estimation de la charge thermique est fournie (106, 107, 109, 111) en termes de fraction de charge (FL) en référence à une puissance maximale qui peut être distribuée par ladite machine frigorifique (3).

3. Procédé selon la revendication 1 ou 2, dans lequel la fourniture (106, 107, 109, 111) d'une estimation de la charge thermique (FL) comprend le fait :

- de régler (106, 107, 109, 200) l'estimation de la charge thermique (FL) en fonction d'une estimation de caractéristiques de capacité et de débit massique dudit circuit de service (15).

4. Procédé selon l'une quelconque des revendications précédentes, dans lequel la fourniture (106, 107, 109, 111) d'une estimation de la charge thermique (FL) comprend le fait :

- d'acquérir (201) des échantillons de température de distribution (TDLV(n)) et de température de retour (TRET(n)) selon une période d'échantillonnage donnée (ts) ; et
- d'estimer (202) une première différence de température (ΔTQ) définie entre l'entrée et la sortie du moyen ventilateur-convecteur (2) par traitement des échantillons de température de distribution (TDLV(n)) et de température de retour (TRET(n)) par l'intermédiaire d'un filtre de Kalman discret qui exprime un bilan énergétique dudit système de climatisation (1) comme étant un système dans l'espace d'états discret.

5. Procédé selon la revendication 4, dans lequel la fourniture (106, 107, 109, 111) d'une estimation de la charge thermique (FL) comprend le fait :

- de calculer (204-206) une fraction de charge thermique (FL) en référence à une puissance maximale qui peut être distribuée par ladite machine frigorifique (3) et en fonction de ladite première différence de température (ΔTQ) et d'une deuxième différence de température (ΔTCH) définie comme étant une différence entre ladite température de distribution (TDLV) et ladite température de retour (TRET).

6. Procédé selon la revendication 5, dans lequel le calcul (204-206) d'une fraction de charge thermique (FL) comprend le fait :

- de calculer (204, 205) une valeur moyenne (ΔTQ_{mean}) de ladite première différence de température (ΔTQ) et une valeur moyenne (ΔTCH_{mean}) de ladite deuxième différence de température (ΔTCH) ; et
- de calculer (206) la fraction de charge en tant que rapport entre la valeur moyenne (ΔTQ_{mean}) de la première différence de température (ΔTQ) et la valeur moyenne (ΔTCH_{mean}) de la deuxième différence de température (ΔTCH).

7. Procédé selon la revendication 6, dans lequel ladite valeur moyenne (ΔTQ_{mean}) de ladite première différence de température (ΔTQ) est calculée sur un cycle marche-arrêt du compresseur (12), et ladite valeur moyenne (ΔTCH_{mean}) de ladite deuxième différence de température (ΔTCH) est calculée sur la partie dudit cycle où le compresseur (12) est mis en marche.

8. Procédé selon l'une quelconque des revendications 4 à 7, dans lequel la fourniture (106, 107, 109, 111) d'une estimation de la charge thermique (FL) comprend le fait :

- de réaliser (203) un filtrage passe-bas de ladite première différence estimée de température (ΔTQ).

9. Procédé selon l'une quelconque des revendications 4 à 8, dans lequel ledit filtre de Kalman discret a : des variables d'entrée comprenant une série discrète constituée par lesdits échantillons de température de distribution (TDLV(n)) et une série discrète constituée par lesdits échantillons de température de retour (TRET(n)) ; des variables de sortie coïncidant avec la variable d'état et comprenant la série d'échantillons de température de retour (TRET(n)) et une série de valeurs de première différence de température ($\Delta TQ(n)$) ; et des matrices pour traiter les variables d'entrée et d'état, dont les éléments sont une fonction d'un paramètre de système (k) qui dépend de caractéristiques de capacité et de débit massique dudit circuit de service (15).

10. Procédé selon l'une quelconque des revendications 3 à 9, dans lequel le réglage de l'estimation de la charge thermique (FL) en fonction d'une estimation de caractéristiques de capacité et de débit massique dudit circuit de service (15) comprend le fait :

- d'estimer (106, 107, 109, 200) un paramètre de système (k) proportionnel à une densité (ρ) du fluide de service (5), proportionnel à un volume total (V_{tot}) dudit circuit de service (15), et inversement proportionnel à un débit massique (m) dudit circuit de service (15).

5 11. Procédé selon la revendication 10, dans lequel l'estimation (106, 107, 109, 200) du paramètre de système (k) comprend le fait :

- de déterminer (109), pour chaque cycle marche-arrêt dudit compresseur (12), un temps de marche effectif (Δt_{ON_real}) et un temps d'arrêt effectif (Δt_{OFF_real}) du compresseur (12) ;
- 10 - de déterminer (300-302) un instant d'estimation (t) en fonction du résultat d'une comparaison entre le temps de marche effectif (Δt_{ON_real}) et le temps d'arrêt effectif (Δt_{OFF_real}) ; et
- de calculer (306) une valeur du paramètre de système (k) à l'instant d'estimation (t).

12. Procédé selon la revendication 10 ou 11, dans lequel l'estimation (106, 107, 109, 200) du paramètre de système (k) comprend le fait :

- de déterminer (303-305) des retards de propagation de chaleur (τ_1 , τ_2 , τ_3) introduits par ledit circuit de service (15) ;
- de calculer (306) une valeur du paramètre de système (k) en fonction de ladite température de distribution (TDLV), d'une température de retour (TRET) dudit fluide de service (5) à l'entrée de la machine frigorifique (3), et des retards de propagation de chaleur (τ_1 , τ_2 , τ_3).

13. Procédé selon l'une quelconque des revendications 10 à 12, dans lequel l'estimation (106, 107, 109, 200) du paramètre de système (k) comprend le fait :

- de stocker (106, 107), pour chaque cycle marche-arrêt dudit compresseur (12), un instant de mise en marche (t_{ON}) et un instant de mise à l'arrêt (t_{OFF}) du compresseur (12) ;

la détermination (300-302) d'un instant d'estimation (t) comprenant le fait :

- dans le cas où ledit temps de marche effectif (Δt_{ON_real}) est plus long que ledit temps d'arrêt effectif (Δt_{OFF_real}), de calculer (301) l'instant d'estimation (t) comme étant une différence entre l'instant de mise à l'arrêt (t_{OFF}) et un temps d'écart donné (ε) ;
- sinon, de calculer (302) l'instant d'estimation (t) comme étant une différence entre l'instant de mise en marche (t_{ON}) et le temps d'écart (ε).

14. Procédé selon la revendication 12 ou 13, dans lequel l'estimation (106, 107, 109, 200) dudit paramètre de système (k) comprend le fait :

- de stocker (107), pour chaque cycle marche-arrêt dudit compresseur (12), un instant de mise en marche (t_{ON}) du compresseur (12) ;

la détermination (303-305) des retards de propagation de chaleur (τ_1 , τ_2 , τ_3) introduits par ledit circuit de service (15) comprenant le fait :

- de déterminer (307) un premier retard de propagation de chaleur (τ_3) en fonction dudit instant de mise en marche (t_{ON}) du compresseur (12) et d'un premier instant où la première dérivée de ladite température de retour (TRET) passe d'une valeur positive à une valeur négative.

15. Procédé selon la revendication 14, dans lequel ladite machine frigorifique (3) comprend un moyen pour le stockage (19) dudit fluide de service (5) situé le long d'une branche de distribution (16) dudit circuit de service (15) pour produire une inertie thermique ; la détermination (303-305) des retards de propagation de chaleur (τ_1 , τ_2 , τ_3) introduits par ledit circuit de service (15) comprenant le fait :

- de déterminer (305) un deuxième retard de propagation de chaleur (τ_2) en fonction dudit instant de mise en marche (t_{ON}) du compresseur (12) et d'un deuxième instant où la première dérivée de ladite température de distribution (TRET) passe d'une valeur positive à une valeur négative ; et

- de déterminer (305) un troisième retard de propagation de chaleur (τ_1) en fonction du premier retard de propagation de chaleur (τ_3) et du deuxième retard de propagation de chaleur (τ_2).

16. Procédé selon l'une quelconque des revendications précédentes, comprenant le fait :

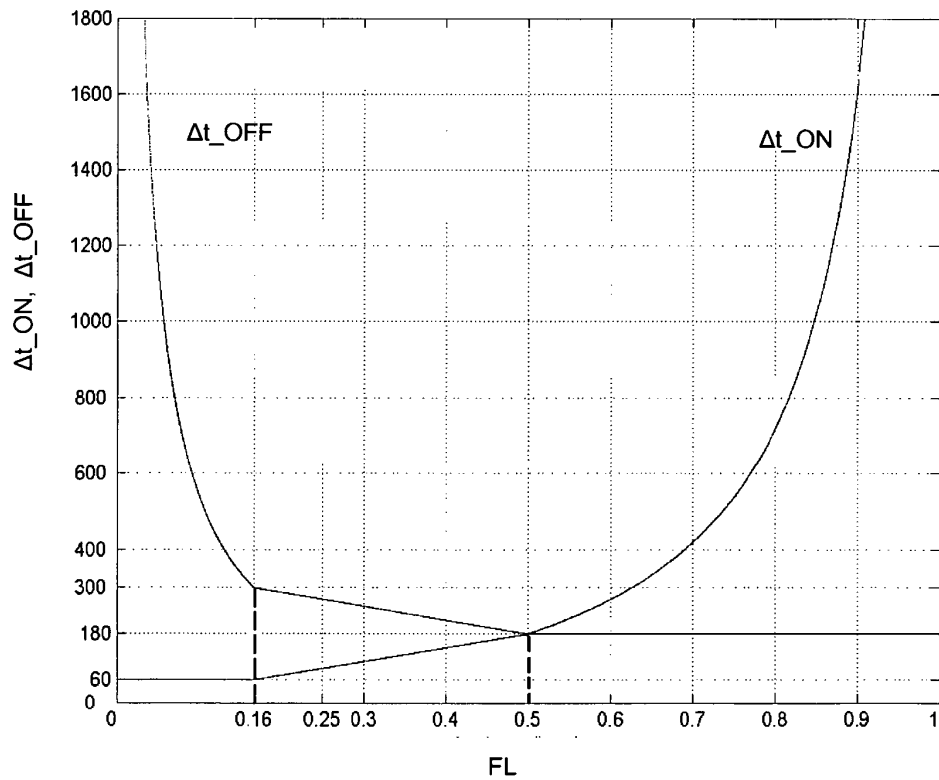
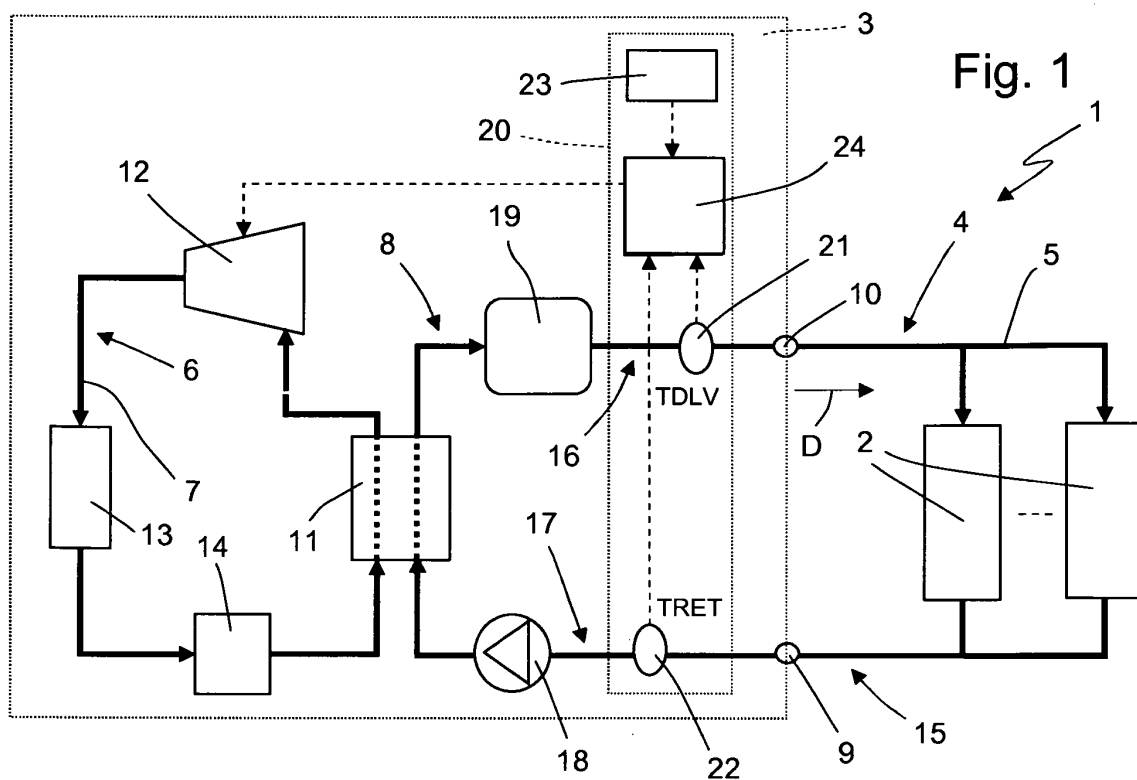
- de mettre en marche et de mettre à l'arrêt (102-105) ledit compresseur (12) en fonction d'une mesure de la température de distribution (TDLV) de sorte que la température de distribution (TDLV) elle-même convergera vers un point de consigne de température de distribution (TSET) ; et
- d'utiliser ladite estimation de la charge thermique (FL) pour réguler ladite température de distribution (TDLV) par adaptation du point de consigne de température de distribution (TSET) à l'estimation de la charge thermique (FL) elle-même.

17. Procédé selon l'une quelconque des revendications précédentes, comprenant le fait :

- de comparer (102, 103) une mesure de ladite température de distribution (TDLV) à une paire de seuils de température de distribution (TLOW, THIG) définis d'une façon donnée par rapport à un point de consigne de température de distribution (TSET) ; et
- d'utiliser ladite estimation de la charge thermique (FL) pour réguler ladite température de distribution (TDLV) par adaptation de la position des seuils (TLOW, THIG), par rapport audit point de consigne (TSET), à l'estimation de la charge thermique (FL) elle-même.

18. Dispositif de commande pour une machine frigorifique (3), le dispositif de commande (20) comprenant un premier moyen de détection de température (21) pour mesurer une température de distribution (TDLV) d'un fluide de service (5) à la sortie de la machine frigorifique (3) et une unité de commande (24) conçue pour commander la machine frigorifique (3) de sorte que la température de distribution (TDLV) convergera vers un point de consigne (TSET), et étant **caractérisé en ce qu'il** comprend un deuxième moyen de détection de température (22) pour mesurer une température de retour (TRET) du fluide de service (5) à l'entrée de la machine frigorifique (3) et **en ce que** l'unité de commande (24) met en oeuvre le procédé selon l'une quelconque des revendications 1 à 17.

19. Machine frigorifique (3) comprenant un compresseur (12) et un dispositif de commande (20) pour mettre en marche et mettre à l'arrêt le compresseur (12) en fonction d'une mesure de température de distribution (TDLV) d'un fluide de service (5) à la sortie de la machine frigorifique (3), et **caractérisée en ce que** le dispositif de commande (20) est conforme à la revendication 18.



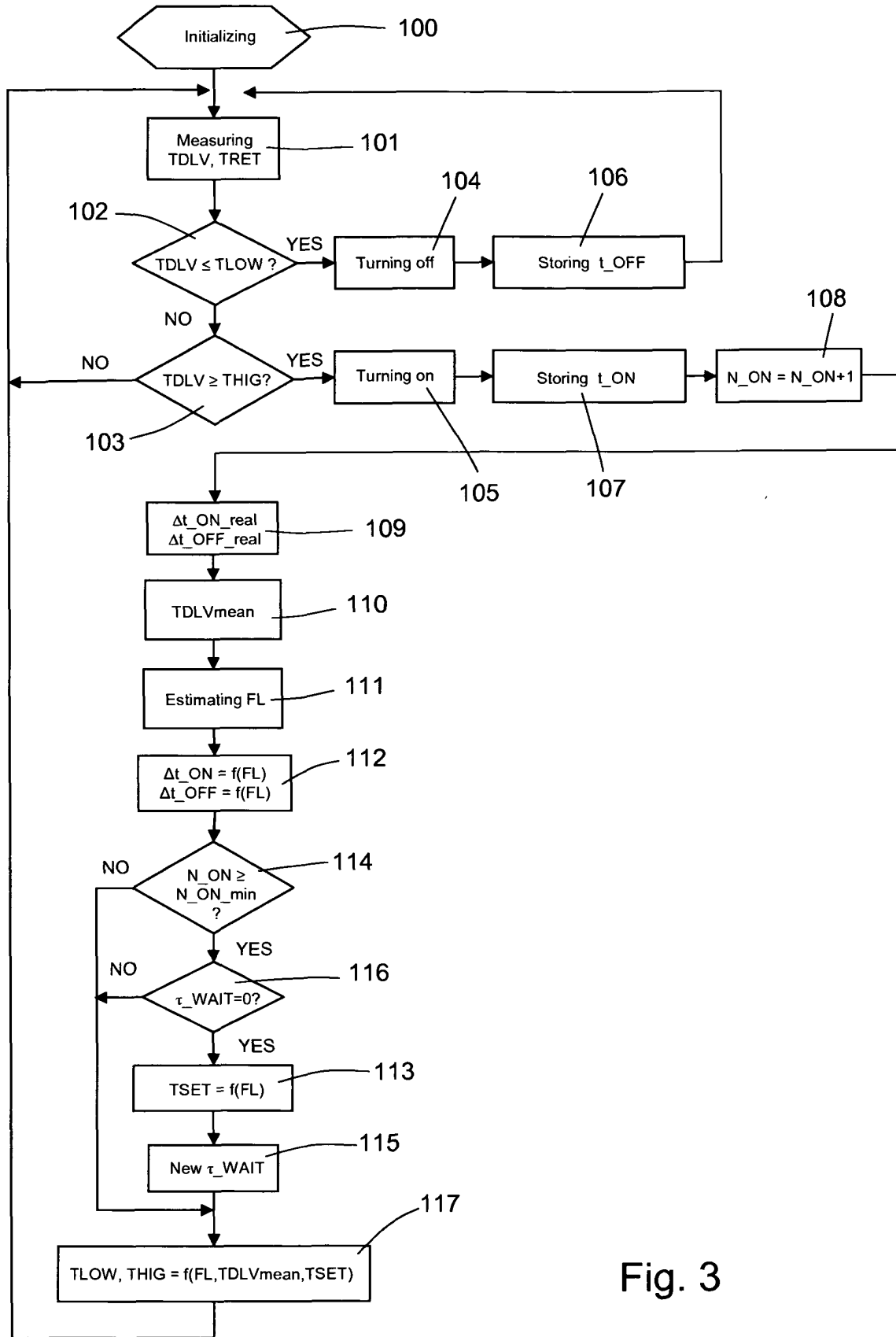


Fig. 3

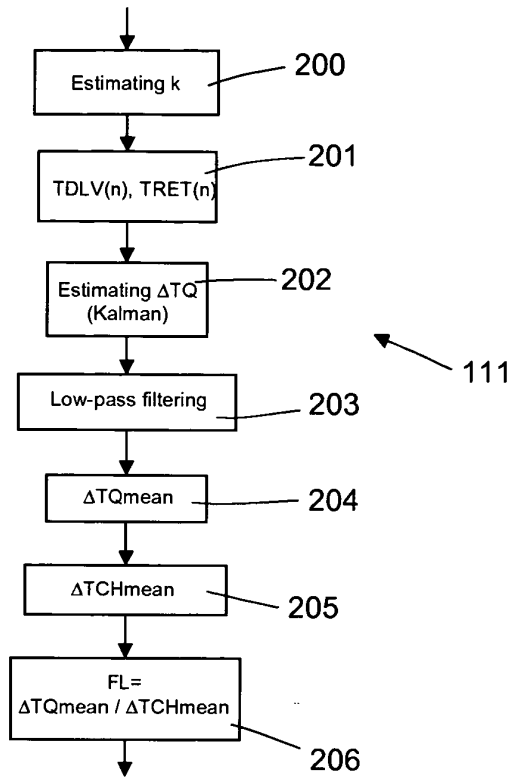


Fig. 4

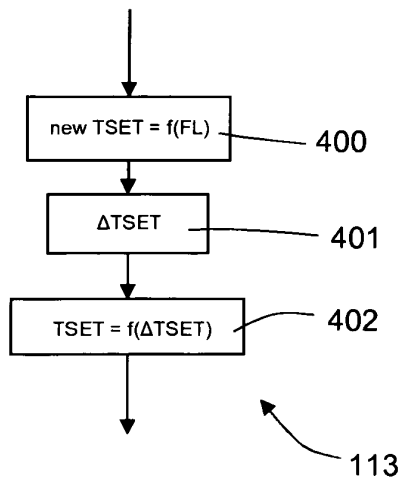


Fig. 6

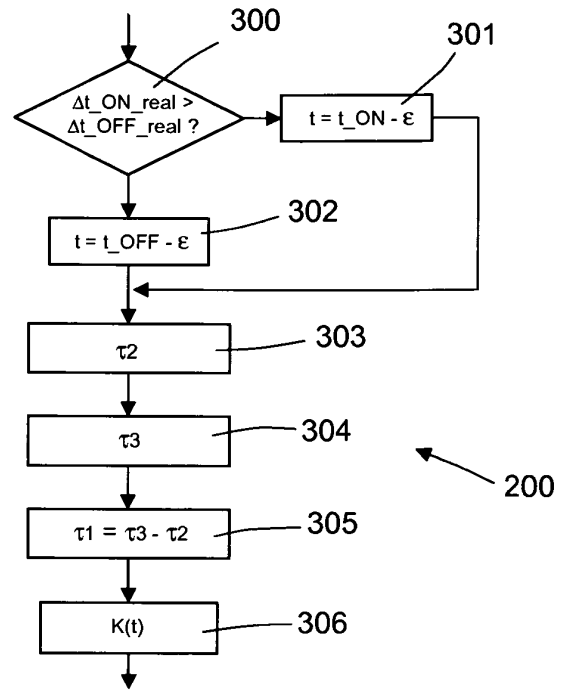


Fig. 5

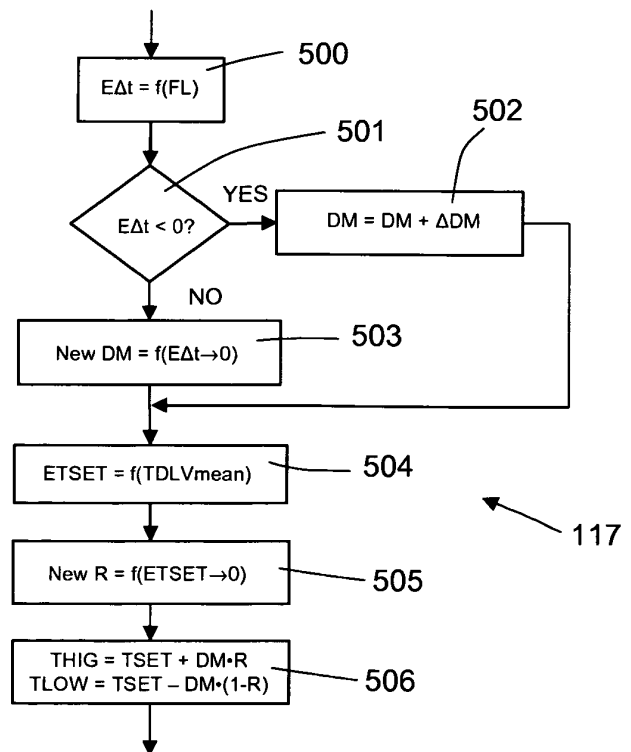


Fig. 7

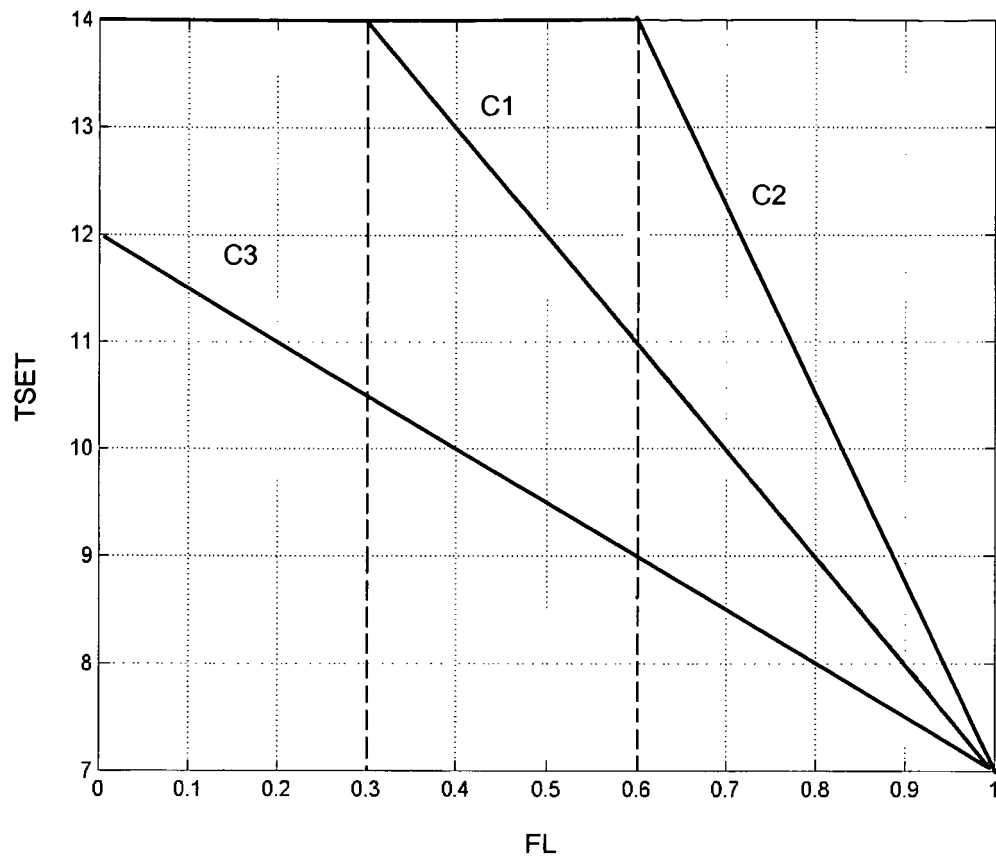


Fig. 8a

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

Fig. 8b

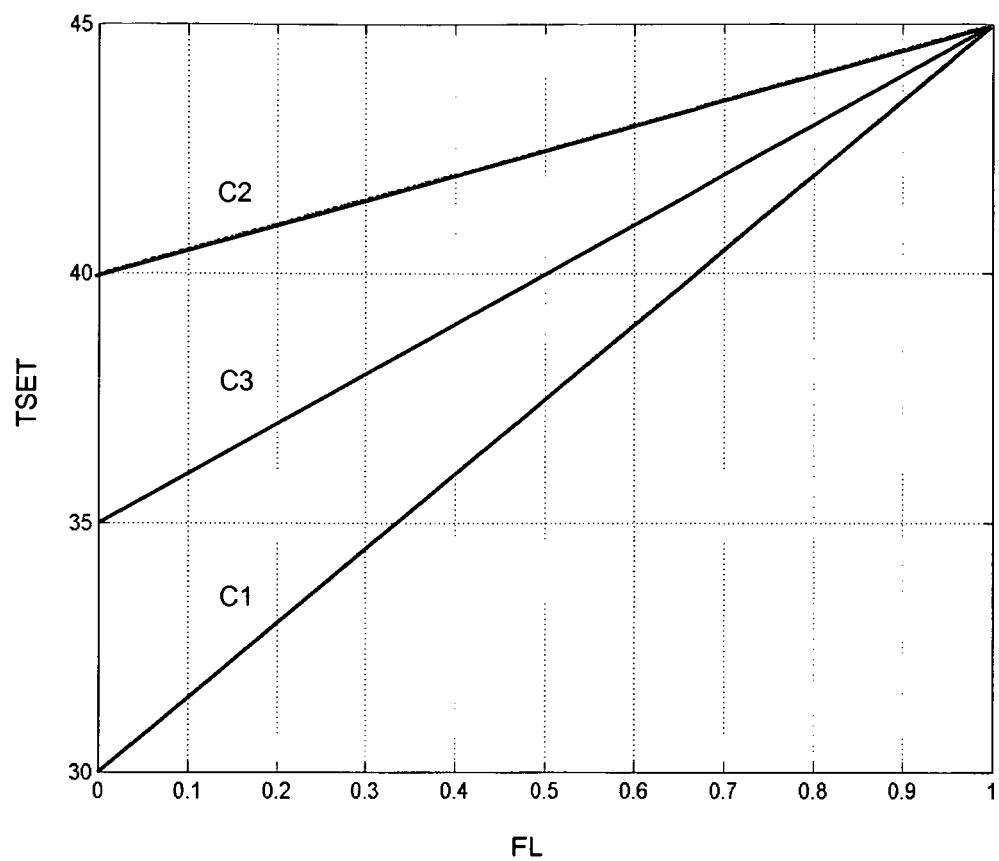


Fig. 9a

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

Fig. 9b

REFERENCES CITED IN THE DESCRIPTION

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