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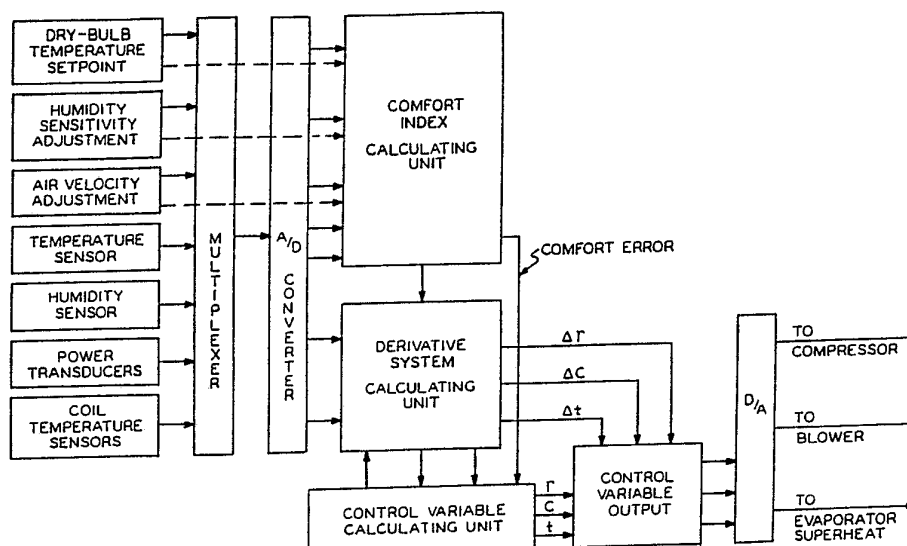
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(54) Title: A METHOD FOR THE OPTIMAL COMFORT AND EFFICIENCY CONTROL OF VARIABLE SPEED HEAT PUMPS AND AIR CONDITIONERS



## (57) Abstract

A controller and a related method that maintains thermal comfort in an occupied space at a user-defined level while simultaneously maximizing the efficiency of the space conditioning equipment. The controller determines the setting of heating/cooling capacity, indoor airflow rate, evaporator superheat and other system parameters such that a comfort constraint is satisfied. The comfort index may be any arbitrarily-defined relationship of measured or inferred quantities such as air temperature, relative humidity, air velocity, mean radiant temperature, CO<sub>2</sub> concentration, etc. The controller ensures that the error between comfort index and the comfort setpoint is zero while the energy consumed by the space conditioning equipment is minimized.

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A METHOD FOR THE OPTIMAL COMFORT AND EFFICIENCY CONTROL  
OF VARIABLE SPEED HEAT PUMPS AND AIR CONDITIONERS

The invention relates to a method for the optimal  
comfort and efficiency control of variable speed heat  
5 pumps and air conditioners.

BACKGROUND OF THE INVENTION

Up to the present time, residential heating and cooling  
equipment has primarily been controlled by temperature-  
sensing thermostats. In recent years, some manufacturers  
10 have incorporated humidity sensing in their controls. Humidi-  
ty control has most often been accomplished through a "dehumi-  
difying cycle" or through "humidity reset" (adjustment of the  
temperature setpoint) rather than through an integrated com-  
fort control strategy. As attention in the HVAC industry be-  
15 comes increasingly focused on providing greater comfort, the  
need for continuous control of humidity, as well as other en-  
vironmental parameters (such as relative air velocity, mean  
radiant temperature, CO<sub>2</sub> concentration and air contaminants)  
becomes more critical.

20 The advent of AC inverter technology has made relatively  
low-cost variable-speed compressors, fans and blowers possible  
in residential heat pumps and air conditioners. In addition  
to heat pumps and air conditioners, variable-capacity opera-  
tion is becoming possible with conventional heating-only

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systems. Variable-capacity operation allows greater flexibility as to how the equipment is controlled. The goal therefore becomes not only maintaining adequate comfort, but also doing so in the most energy efficient manner.

5           Not only is it desirable to control the thermal parameters described above, but due to the increased emphasis placed on controlling indoor air quality, it becomes necessary to also control air contaminants such as CO<sub>2</sub>, VOC's and particulates. Conventional, single-variable control strategies are not appropriate for this more advanced level of control. There-  
10           fore a more sophisticated approach is required.

#### SUMMARY OF THE INVENTION

With the advent of microcomputer-based type thermostats, more sophisticated control functionality is possible by  
15           utilizing the memory that accompanies the micro-computer to implement a control program.

20           The main objective of the present invention is to provide a new and improved method for controlling, as a minimum, the compressor speed, indoor fan speed and evaporator superheat of a heat pump or air conditioner in such a manner that human thermal comfort is maintained and plant (space conditioning equipment) efficiency is maximized.

          The sensor means, microcomputer means, memory means and actuator means allow a microcomputer-based thermostat to

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measure necessary thermal and air quality conditions within a space and from these measurements and user inputs to: construct a comfort setpoint, construct a comfort index, determine the space conditioning plant efficiency, identify the sensitivity of the measured comfort parameters to changes in the controlled system parameters, compute the changes in space conditioning parameters necessary to eliminate any error between the measured comfort index and the desired comfort level while insuring maximally efficient operation, and output these system operating parameters as control signals to the space conditioning equipment. The control program ensures maximum plant efficiency while providing the desired level of comfort.

Since this strategy results in optimal control, any other choice of compressor speed, blower speed and evaporator superheat will result in either increased energy consumption or reduced comfort.

In a typical variable-capacity system, the compressor speed is controlled based on the air temperature in the conditioned space, while the blower speed is controlled based on the compressor speed and the evaporator superheat is generally controlled by some arbitrary, preest value. The desired temperature will be maintained, however, depending upon the conditions in the space, other variables

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such as humidity, air velocity, etc. may result in unacceptable comfort. It is possible that this comfort deviation will result in increased energy consumption (for example, over-dehumidification).

5           In addition to dry bulb temperature control, it is possible to compensate for latent effects by incorporating humidity measurements into the controller. This compensation can be done by either incrementally adjusting the dry-bulb setpoint (humidity reset) or by periodically  
10           switching between dry-bulb and humidity control. The problem with these and other existing approaches is that no mechanisms exist for independently specifying the values of the manipulated or control variables (compressor speed, blower speed, evaporator superheat) that will maintain  
15           precise comfort control while maximizing efficiency. The present invention provides a means of accomplishing this objective.

          The control system according to the present invention provides a comfort control means, including: microcomputer  
20           means including real time clock means and memory means; data input means for specifying desired comfort level; multiple sensor means for measuring all parameters that comprise the comfort index as well as energy efficiency and key temperatures of the space conditioning system;

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actuator means for outputting control variable signals;  
said microcomputer means and said memory means including  
optimal comfort control program means which is memory  
means providing control means of multiple sensory data,  
5 calculation means to construct a single index representa-  
tive of comfort, and control means of multiple outputs  
such that plant efficiency is maximized and said comfort  
index equals the comfort setpoint.

The above and other objects, features and advantages  
10 of the invention will become more apparent from the en-  
suing detailed description taken in conjunction with the  
accompanying drawings and the appended claims.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1 to 4 are graphs showing the variation of  
15 latent and sensible capacity and coefficient of perform-  
ance (COP) as a function of compressor speed, blower speed  
and evaporator superheat for a specific heat pump installa-  
tion;

Fig. 5 is a block diagram showing an embodiment of  
20 the optimal control system according to the invention;

Fig. 6 is a flowchart showing the basic operation of  
the device; and

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Figs. 7 to 9 show the performance of the device in a specific application.

#### DESCRIPTION OF THE PREFERRED EMBODIMENT

In Figs. 1 to 4, the performance of a specific air conditioning plant (in this instance a heat pump) is given in terms of sensible capacity, latent capacity and coefficient of performance (COP) as a function of compressor speed, indoor air flow rate and evaporator superheat which are the manipulated variables.

Fig. 1 shows the variation of latent cooling capacity as a function of evaporator superheat for minimum compressor speed and four indoor airflow rates. This figure indicates that under normal operating conditions, there is no latent cooling for full indoor airflow. The latent capacity can be dramatically increased by lowering the indoor air flow rate or increasing the evaporator superheat (by constricting the expansion valve). Both of these actions serve to lower the evaporating temperature. Figs. 2 and 3 show the variation of latent cooling capacity and total cooling capacity, respectively, for a range of indoor airflow rates and compressor speeds. The evaporator superheat is a constant 50°F. Fig. 4 shows the variation of COP with indoor air flow rate and compressor speed. It



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may be noted that the highest COPs do not always occur at full air flow. This will depend on the power consumption characteristics of the variable-speed indoor blower.

A complex relationship exists between the manipulated variables, comfort and COP. Only one combination of the manipulated variables exists such that the space conditioning equipment will consume the least amount of power (i.e., maximum COP) while simultaneously providing the desired level of comfort. In the following description, a control means is disclosed for systematically determining the proper manipulated or control variable values to achieve this optimal operating input.

A preferred embodiment of an optimal comfort control system of the invention will now be described with reference to Fig. 5. As shown in Fig. 5, multiple temperature sensor means, humidity sensor means and the like (e.g., mean radiant temperature, CO<sub>2</sub>, particulate, VOC sensing means) and power transducer means are provided for comfort sensing and power consumption sensing elements, respectively. The comfort sensing elements are provided at suitable locations in the conditioned space. The power transducer elements and additional temperature sensor elements are provided at suitable locations in the space conditioning plant (i.e., heat pump, air conditioner,

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etc.) Data input means are provided for establishing a comfort setpoint.

Analog outputs from the comfort sensing elements and data input means are converted into respective digital signals by an A/D converter. The data inputs may also be digital signals and therefore not require A/D conversion. These digital signals are supplied to a microcomputer. In the microcomputer, said comfort index calculating means computes a comfort setpoint using the dry-bulb temperature setpoint plus the humidity sensitivity adjustment plus the air velocity sensitivity adjustment.

The comfort index calculating means is also responsive to the outputs from comfort sensing elements for effecting a calculation of the instantaneous comfort index. The outputs of the comfort index calculation means are the discrepancy between the comfort setpoint and the instantaneous comfort index itself. The system derivative calculating means is responsive to the outputs from the comfort index calculation means and the power transducer elements and temperature sensing means for establishing a relationship between the comfort index, plant efficiency and changes to the control variables. The system derivative calculating means is also responsive to the output of the control variable calculation means. The control variable calcu-

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lating update means is responsive to the output of the system derivative calculation means and the output of the comfort index calculating means for effecting the calculation of the values of each of the manipulated variables.

5 The control variable output means is responsive to the output of the control variable update calculating means and the system derivative calculating means for effecting the actual control variable command signals. The control variable command signals are converted to analog outputs  
10 by a D/A converter. Each analog output is supplied to the appropriate actuator in the space conditioning equipment.

In the discussion below, a more detailed description of the comfort index calculating means, the system derivative calculating means and control variable update calculating means is given.  
15

In general, comfort is a function of many physical properties of the conditioned space including non-thermal factors, such as air contaminants. While this invention is not dependent on the functional relationships that define comfort, the preferred embodiment utilizes Fanger's  
20 Predicted Mean Vote, or PMV, as a measure of comfort<sup>1</sup>.

The PMV is based on an energy balance imposed on the human body. The PMV reflects human thermal comfort. Conditions that result in a PMV of 0 are considered

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comfortable for 95 percent of a given population. In this invention, the comfort index (CI) is taken to be a non-linear function of sensed temperatures, humidity and air velocity. Thus the comfort index is given by:

$$5 \qquad \qquad \qquad CI = CI(T,w,V) \qquad \qquad \qquad (1)$$

where

T = Sensed temperatures,  
w = Humidity  
V = Air velocity

10           At this point, it should be emphasized that the choice of a comfort constraint relation is purely arbitrary. Any function incorporating terms for temperature, humidity, velocity, etc., CO<sub>2</sub> concentration, particulates and other air contaminants is suitable.

15           The comfort setpoint is not a parameter that can be easily specified by a typical human occupant. Therefore a mechanism is required to construct the comfort setpoint from parameters that are readily specified by the user. There are many ways that this can be accomplished. In the  
20           preferred embodiment of this invention, the user sets the desired dry-bulb temperature and the comfort index calculating unit assumes default values for all other parameters appearing in the comfort index relationship. Said

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unit then calculates the desired comfort setpoint. It is realized that the default values assumed will not in general satisfy the comfort demands of the population at large, therefore means are provided to adjust any and all other parameters appearing in the comfort index relationship. In the preferred embodiment, these means are provided by a mechanism to incrementally adjust the assumed default values such as humidity and air velocity. Therefore the comfort setpoint ( $CI_{set}$ ) is given by:

$$CI_{set} = CI(T_{set}, w_{def} + \Delta w, V_{def} + \Delta V) \quad (2)$$

where

$T_{set}$  = dry-bulb temperature setpoint

$w_{def}$  = default humidity

$\Delta w$  = incremental humidity adjustment

$V_{def}$  = default air velocity

$\Delta V$  = incremental air velocity adjustment

The default values are typically not constants. It should be noted that the sensed temperatures, humidity, air velocity, etc. will in general be a function of the control variables. Therefore, the comfort index can also be expressed as:

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$$CI = CI(r, c, t) \quad (3)$$

where

r = compressor speed  
 c = blower speed  
 t = evaporator superheat

The discrepancy between the comfort setpoint and the instantaneous comfort index is the comfort error, CE.

This comfort error is given by:

$$CE = CI_{\text{set}} - CI \quad (4)$$

The comfort error along with the comfort index are the outputs of the comfort index calculating unit.

The system derivative calculating unit relates the comfort index and space conditioning performance efficiency to changes in the manipulated variables. To accomplish this the controller must monitor the performance efficiency. For a heat pump the performance efficiency (PE) or coefficient of performance (COP) is given by:

$$COP = COP(r, c, t) = \frac{Q_{\text{evap}}}{W_{\text{compr}} + W_{\text{fans}}} \quad (5)$$

Since  $Q_{\text{evap}}$  is difficult to measure directly, the preferred embodiment determines the performance efficiency from the following relationship:

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$$PE = PE(r, c, t) = \frac{T_2 \cdot W_{\text{compr}}}{(T_1 - T_2) (W_{\text{compr}} + W_{\text{fans}})} \quad (6)$$

In equations (5) and (6) the following definitions apply:

$Q_{\text{evap}}$  = cooling capacity

5  $W_{\text{compr}}$  = power input to compressor

$W_{\text{fans}}$  = power input to blower and outdoor fan

$T_2$  = temperature of evaporator coil

$T_1$  = temperature of condensor coil

As is the case with CI, the performance efficiency of the space conditioning system is also a nonlinear function of  $r$ ,  $c$  and  $t$ . A complex relationship exists between these parameters and the CI. The coupling is established through the space conditioning system and the conditioned environment. The capacity of the system (both sensible and latent) along with the ambient conditions establish the internal conditions that in turn dictate CI.

A systematic mechanism is required to establish the appropriate values of  $r$ ,  $c$  and  $t$  that simultaneously satisfy the comfort setpoint and maximize COP. There are several ways of performing this task. In the preferred embodiment of the present invention, this task is accomplished by performing a dynamic nonlinear optimization.

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To do this, it is convenient to relate the two functions, PE and CE, through the Hamiltonian, H, which is given by:

$$H = L(x,u) + \lambda^T f(x,u) \quad (7)$$

where

- 5             $L(x,u)$  = performance index
- $f(x,u)$  = constraint relation(s)
- $\lambda$  = Langrangian multiplier(s)
- $x$  = state parameters
- $u$  = decision vector

10           Thus for this problem, the Hamiltonian becomes

$$H = PE + \lambda \cdot CE \quad (8)$$

The solution to the optimization problem, called a stationary point, is where  $dL=0$  for arbitrary  $du$ , while holding  $df=0$  (letting  $dx$  change as it will). The necessary conditions for a stationary value of  $L(x,u)$  are:

15

$$f(x,u) = 0 ; \frac{\partial H}{\partial x} = 0 ; \frac{\partial H}{\partial u} = 0 \quad (9)$$

Since the choice of which variables to designate as decision parameters is not unique, it is only a matter of convenience to make a distinction between decision and state parameters. Here we select the decision vector to be composed of all the manipulated variables, namely  $r$ ,

20



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c and t. With this formulation, there are four unknowns (r, c, t and  $\lambda$ ), hence four equations are need to obtain a solution. The following four functions are derived from Equations (8) and (9):

$$5 \quad f_1 = \frac{\partial H}{\partial \lambda} = CE \quad (10)$$

$$f_2 = \frac{\partial H}{\partial r} = \frac{\partial PE}{\partial r} + \frac{\partial CE}{\partial r} \quad (11)$$

$$f_3 = \frac{\partial H}{\partial c} = \frac{\partial PE}{\partial c} + \frac{\partial CE}{\partial c} \quad (12)$$

$$f_4 = \frac{\partial H}{\partial t} = \frac{\partial PE}{\partial t} + \frac{\partial CE}{\partial t} \quad (13)$$

The problem now becomes one of finding values of r, c, t and  $\lambda$  such that functions  $f_1$  through  $f_4$  vanish. These values are then the solution to the optimization problem.

Unfortunately, in typical space conditioning applications, function  $f_1$  through  $f_4$  are not directly measurable and they are generally time-dependent. Thus, the system to be controlled must be identified. In the present invention, the system is identified by observing how  $f_1$  through  $f_4$  change with respect to each of the control variables and  $\lambda$ . The derivatives of  $f_1$  through  $f_4$  are determined by periodically perturbing the control variables and about their current values. After these perturbations are complete, the derivatives may be written in matrix form as

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the Jacobian,  $J$ , which is:

$$J = \begin{bmatrix} \frac{\partial f_1}{\partial \lambda} & \frac{\partial f_1}{\partial r} & \frac{\partial f_1}{\partial c} & \frac{\partial f_1}{\partial t} \\ \frac{\partial f_2}{\partial \lambda} & \frac{\partial f_2}{\partial r} & \frac{\partial f_2}{\partial c} & \frac{\partial f_2}{\partial t} \\ \frac{\partial f_3}{\partial \lambda} & \frac{\partial f_3}{\partial r} & \frac{\partial f_3}{\partial c} & \frac{\partial f_3}{\partial t} \\ \frac{\partial f_4}{\partial \lambda} & \frac{\partial f_4}{\partial r} & \frac{\partial f_4}{\partial c} & \frac{\partial f_4}{\partial t} \end{bmatrix} \quad (14)$$

The Jacobian and functions  $f_1$  through  $f_4$  are outputs of the system derivative calculating means and are required by the control variable update calculating means.

The control variable update calculating means is used to establish the values of the control variables and  $\lambda$  necessary to satisfy the comfort setpoint and simultaneously minimize energy consumption. The update is given by:

$$\begin{bmatrix} \lambda \\ r \\ c \\ t \end{bmatrix}_{\text{new}} = \begin{bmatrix} \lambda \\ r \\ c \\ t \end{bmatrix}_{\text{old}} + J^{-1} \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{bmatrix} \quad (15)$$

Constraints on the control variables are handled by removing the constrained control variable from the update

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procedure and assigning it the value of the constraint.  
Note that the algorithm given by Equation (15) is completely generic. That is, no assumptions have been made about the type of conditioned space conditioning equipment being controlled nor have any assumptions been made about the environment.

In order to further explain the operation of the present device, the optimal comfort control executive flow-chart is disclosed in Fig. 6. At block 80 the parameters are initilized and at 81 the registers are cleared. The output of 81 is fed to a check start initialization device at 82 which provide a "no" indication at 83, or can continue at 84. If the sequence is continued at 84 then the major control loop is entered. The stage mode flag at 85 is made available from an auxiliary element such as a conventional multistage thermostat not described in the current invention. At 86 the stage mode is checked which can provide a "no" indication at 87 or can continue with the sequence at 88. If the current mode is modulating and not on/off then mode = 2 and the sequence continues at 89 where the user inputs are read, these values are then stored and the sequence continues at 90 where the sensors are read as is the real time clock. With this information the data flow is to 91 where CI is calculated.

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The output of 91 is fed to a check Jacobian calculating device which can provide a "no" output at 93 or a "yes" output at 92. If "yes", the Jacobian is reevaluated and data flow proceeds to 95 where a series of perturbations on each control variable is initiated. At 96 the results of the control variable perturbation is read from the sensor inputs. The output of 96 is fed to 97 where the performance efficiency (PE) and comfort error (CE) are computed. At 98 the current value of each control variable ( $\lambda$ , PE and CE) is stored. The output of 98 enters a check device to determine if each control variable and has been perturbed. 98 can provide either a "yes" at 102 or a "no" at 100. If no the sequence continues at 101 where the perturbation continues. If yes data flows to 103 where  $f_2$  through  $f_4$  are calculated as are the second derivatives necessary to form the Jacobian. The output of 103 is fed to 104 where the Jacobian is inverted. At 105 the results of the inversion along with  $f_2 - f_4$  are stored. With this information the data flow is on to 104 which can also be reached from 93 if the result of the Jacobian recalculation check was "no". At 104 the new control variables are determined based on either the old or new Jacobian and the current value of the comfort error and the old value of the control

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variables. The output of 106 proceeds to 107 where the new value of the control variables are output to the space calculating system.

The performance of this controller for a typical residence operating during the cooling season is shown in Figs. 7, 8 and 9. In these figures the space conditioning plant is a heat pump. For this system the comfort error is given in terms of PMV and the performance efficiency is given in terms of COP. The control variables are compressor speed,  $r$ , indoor blower speed,  $c$ , and evaporator superheat,  $t$ . A thermal load is imposed on the space and the control variables are initialized at some arbitrary initial value. The algorithm is then allowed to proceed. The nominal operating range is:

- o 500 to 1800 compressor speed
- o 600 to 1200 indoor air flow
- o 0 to 50°f evaporator superheat

The control moves needed to obtain optimal conditions are shown in Fig. 7. The optimal solution was obtained in only 6 updates. In this figure the control variables have been normalized using the ranges enumerated above. The corresponding impact these moves have on comfort and heat pump performance is shown in Fig. 8.

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This figure shows that by the sixth update the comfort error is indeed zero and the COP is 3.97. The optimal control vector at this point in time is given from the previous figure as  $r = 592$ ,  $c = 993$  and  $t = 5$ . To show  
5 that this control does indeed result in an optimum COP, performance contours can be plotted in a three dimensional  $r, c, t$  space. The peak value of the COP on the zero pmv surface will define the optimal value of  $r, c$  and  $t$ . Fig. 8 shows this information. For clarity only  
10 a two dimensional space is shown ( $r$ - $c$  space). The COP along the zero PMV contour is projected on both the  $r$  and  $c$  axis. The optimum value is seen to be 3.97 and this corresponds to  $r = 592$  and  $c = 993$ , precisely the values obtained by the optimal controller.

15 A summary of the features of the invention is as follows:

The basis for the invention is an optimal control device for variable capacity air conditioning equipment which simultaneously controls a plurality of states within  
20 the conditioned environment while at the same time maximizing efficiency or minimizing power consumption of said conditioning equipment. The control device constructs a single index from a plurality of sensed variables and based on this index simultaneously adjusts all manipulated

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variables to the space conditioning equipment such that the index is maintained at the desired level set of the user and that said equipment operates in a maximally efficient manner. The index is automatically calculated by the control device to be indicative of comfort conditions in the conditioned environment. A setpoint of the comfort index is determined automatically by the control device in terms of input means adjusted by the user. The input means allows the user to input desired conditions on each parameter to be controlled in the environment. These inputs are automatically converted to a comfort index setpoint by the controller.

While a control device was described as controlling a thermal comfort index called a PMV the device is not limited to a particular comfort index. Indeed it is envisioned that the device will be used to control not only thermal parameter such as temperatures, humidity and air velocity but also air quality parameters such as CO<sub>2</sub>, VOC's, particulates, etc. Similarly the device is not limited to adjusting only the manipulated variables described above (r, c, t) but typically any manipulatable variable which can effect a change in the controlled variable (i.e. damper position, filter setting and the like).

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Finally, the control device is not limited to the specific means for determining the updates on the manipulated variables. While the perturbation method utilizing the Jacobian search is the preferred approach, 5 other methods such as brute force searches are also possible.



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It is claimed:

1. A method for operating a system having variable speed equipment such as heat pumps and air conditioners while (1) achieving optimal comfort conditions in an air conditioned space and (2) maximizing the coefficient of performance (COP) of said equipment;

said equipment being characterized by having controls for varying parameters thereof including compressor speed (r), indoor air flow rate (c), and evaporator superheat (t);

said system having multiple sensory inputs from which variable comfort influencing data parameters transmitted from said space to said equipment includes drybulb temperature (T), humidity ratio (w) and air velocity (V);

said method comprising the steps of:

providing a nonlinear measure of comfort function CI (T,w,V) based on said data parameters;

setting one of said data parameters and calculating default values for the other of said data parameters;

calculating a setpoint value for said comfort function;

expressing said function CI (T,w,V) in terms of said equipment parameters as a function of CI (r,c,t);

calculating a comfort error (CE) value which is said setpoint value of CI (T,w,V) minus said CI (r,c,t);

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selecting a nonlinear coefficient of performance function  $PE(r, c, t)$  based on said equipment parameters which is desired to be maximized and which is based on the same variables as said  $CI(r, c, t)$ ; and

5       maximizing said  $PE(r, c, t)$  function while attempting to maintain said  $(CE)$  value at said zero value.

2. A method according to claim 1 wherein said maximizing step is performed by relating said functions through a performance index  $(H)$  wherein

10       
$$H = PE + \lambda CE$$

with said  $\lambda$  being a Lagrangian multiplier.

3. A method according to claim 2 including the steps of representing said  $PE$  function as a performance index  $L(x, u)$  and representing said  $CE$  function as a constraint function  $f(x, u)$  so that

15

$$H = L(x, u) + \lambda^T \cdot f(x, u)$$

with said  $x$  being state parameters  $(r, c, t)$  and said  $u$  being a decision vector; and

finding values of said state parameters  $(r, c, t, \lambda)$  at a stationary value of said  $L(x, u)$  wherein  $dL = 0$  for arbitrary  $du$  while holding  $df = 0$ .

20

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4. A method as set forth in claim 1 wherein said comfort influencing data parameters include CO<sub>2</sub> concentration, particulates and other air contaminants.

5. A method as set forth in claim 1 wherein said  
5 temperature (T) is set.

6. A method as set forth in claim 5 wherein said other of said data parameters are initially adjustable to provide a bias thereon.

7. A method for operating a system having variable  
10 speed equipment such as heat pumps and air conditioners while (1) achieving optimal comfort conditions in an air conditioned space and (2) maximizing the coefficient of performance (COP) of said equipment;

said equipment being characterized by having con-  
15 trols for varying parameters thereof;

said system having multiple sensory inputs from which variable comfort influencing data parameters are transmitted from said space to said equipment;

said method comprising the steps of:

20 providing a nonlinear measure of comfort function CI (data) based on said data parameters;

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setting one of said data parameters and calculating default values for the other of said parameters;

calculating a setpoint value for said comfort function;

5       expressing said function CI (data) in terms of said equipment parameters as a function CI (manipulated control variables);

calculating a comfort error (CE) value which is said setpoint value of CI (data) minus said CI (manipulated control variables);

10

selecting a nonlinear performance function PE (manipulated control variables) based on said equipment parameters which is desired to be maximized and which is based on the same variables as said CI (manipulated control variables); and

15

maximizing said PE (manipulated control variables) function while attempting to maintain said (CE) value at said zero value.

20       8. A method according to claim 7 wherein said maximizing step is performed by relating said functions through a performance index (H) wherein

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$$H = PE + \lambda CE$$

with said  $\lambda$  being a Lagrangian multiplier.

9. A method according to claim 7 wherein said comfort error (CE) and said setpoint value are  
5 continuously updated.

10. A method for operating a space conditioning system having equipment characterized by variable operating parameters which both (1) achieves desired comfort conditions in the conditioned space and  
10 (2) maximizes the performance efficiency of said equipment, said equipment being characterized by controls for varying operating parameters thereof, said system having multiple sensory inputs from which a plurality of actual time-variable comfort influencing  
15 data parameter values are transmitted from said conditioned space to said equipment on a real-time basis; said system also having user-determined desired data parameter values; said method comprising the steps of:

20 constructing a single measure of comfort function based on the data parameter values; and

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adjusting the variable operating parameters of  
the equipment based on said measure of  
comfort function in a manner such that the  
user-adjustable parameters are approached  
and maintained at the desired level by the  
most efficient operation of the equipment.

11. A method as set forth in claim 10 wherein  
said data paramters comprise air quality parameters.

12. A method as set forth in claim 11, wherein  
said data parameters include the concentration of one or  
more smoke-related irritants.

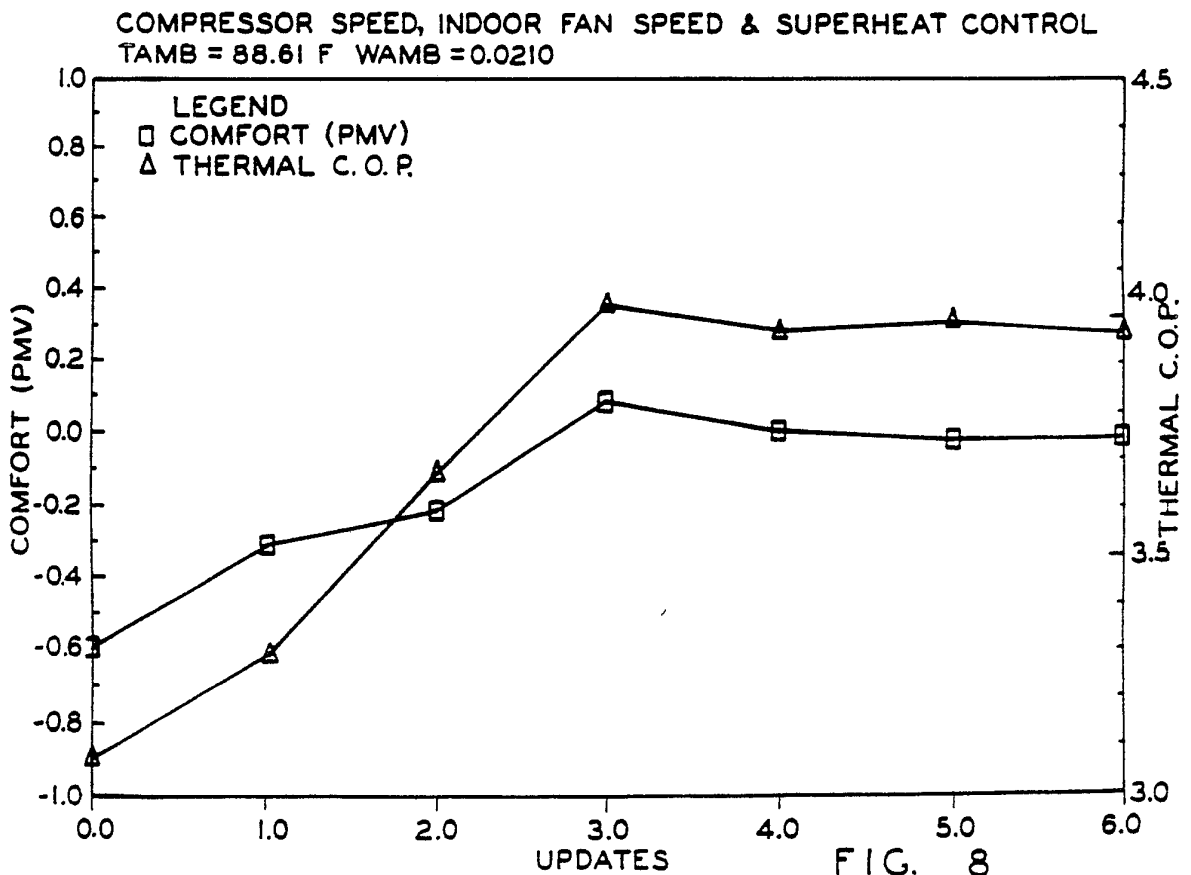
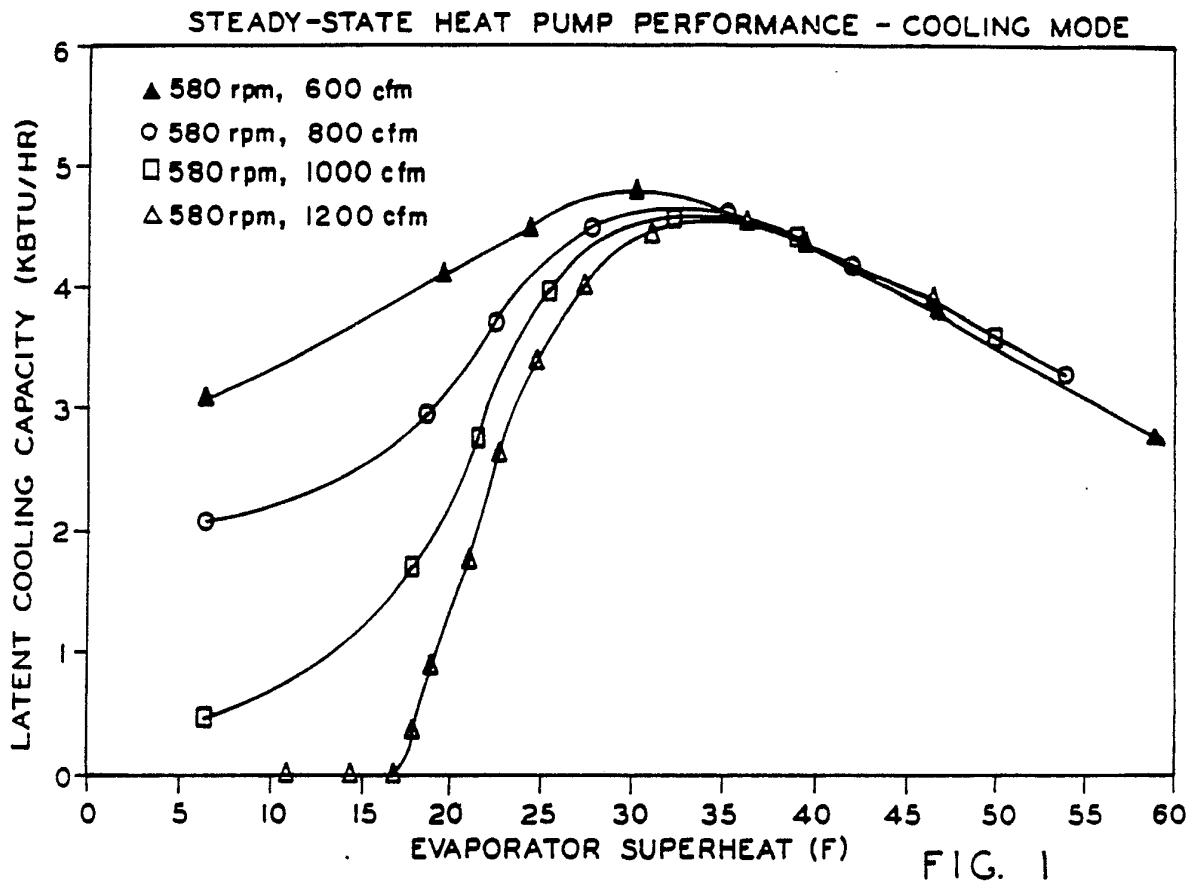
13. A method as set forth in claim 11 wherein  
said data paramters include CO<sub>2</sub>.

14. A method as set forth in claim 11 wherein  
said data paramters comprise particulates.

15. A method as set forth in claim 12 wherein  
said data paramters comprise particulates.

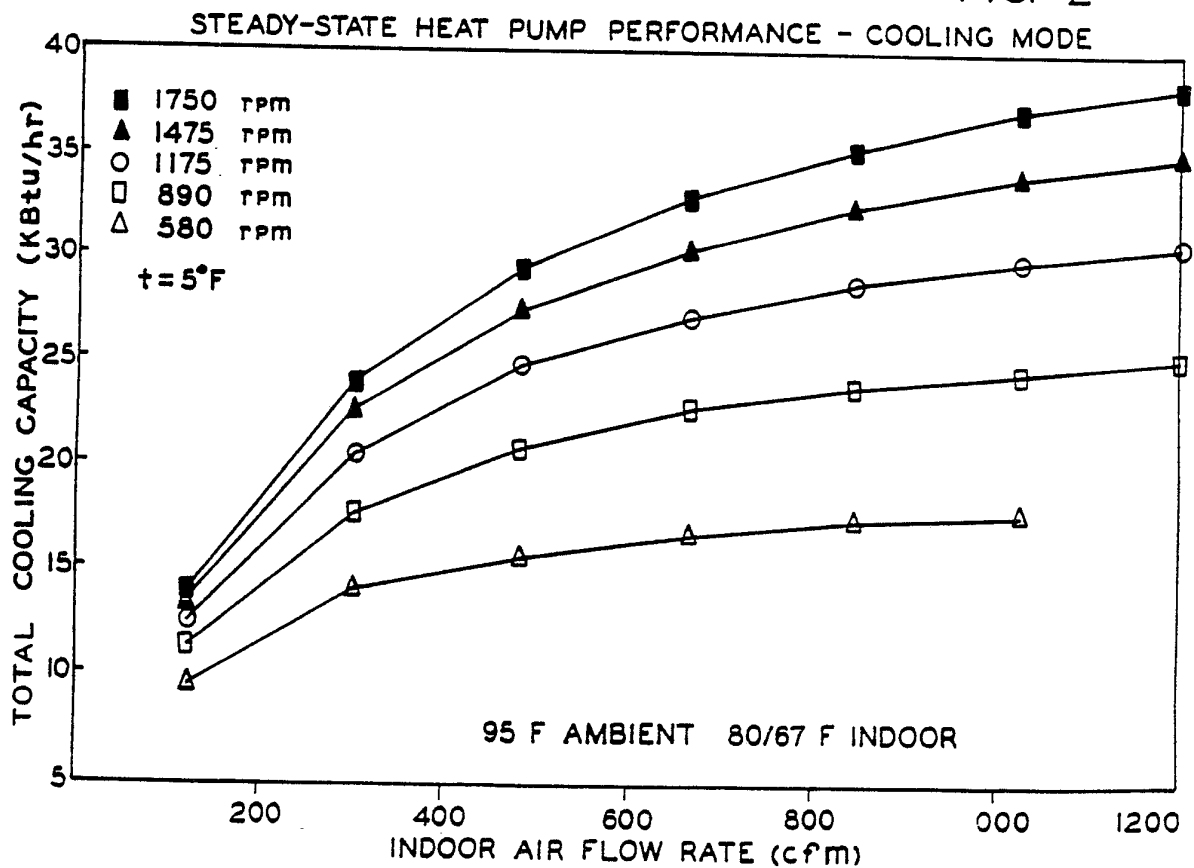
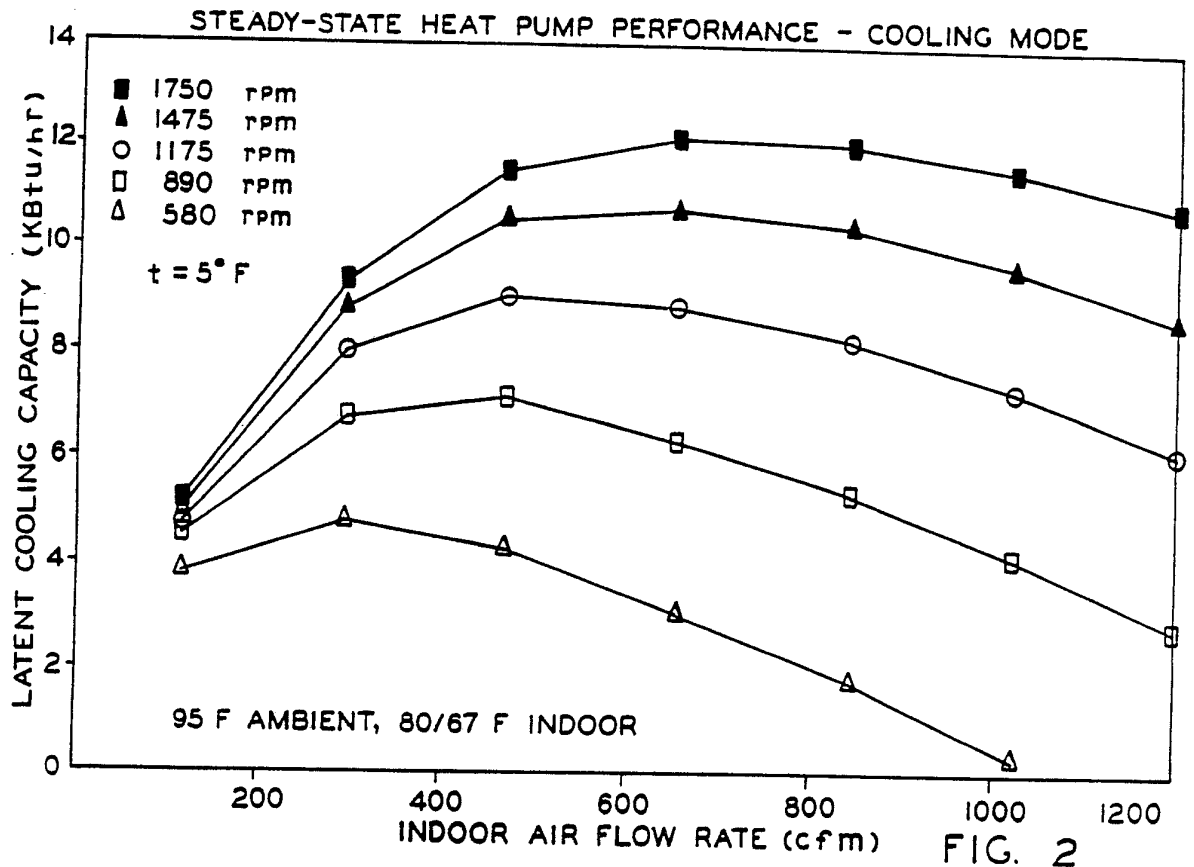
16. A method as set forth in claim 10 wherein  
said data paramters comprise thermal parameters.

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SUBSTITUTE SHEET

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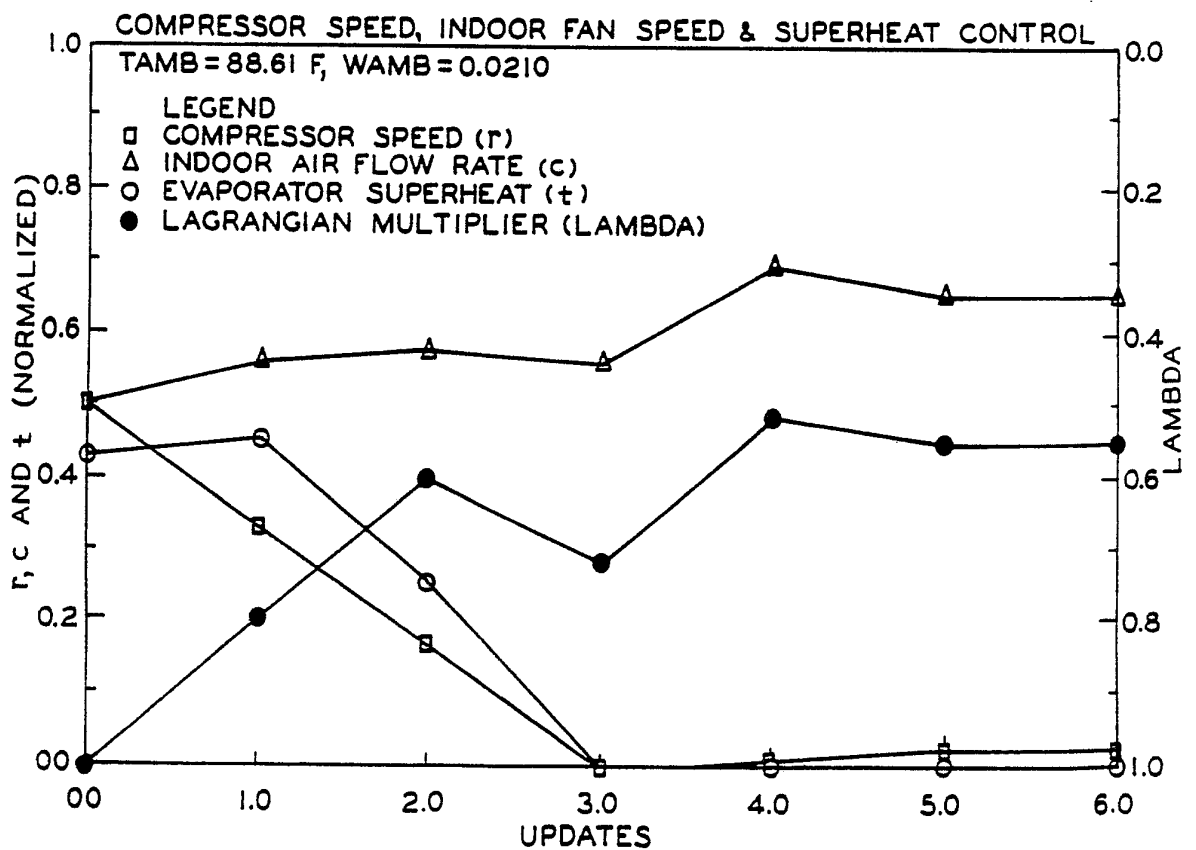
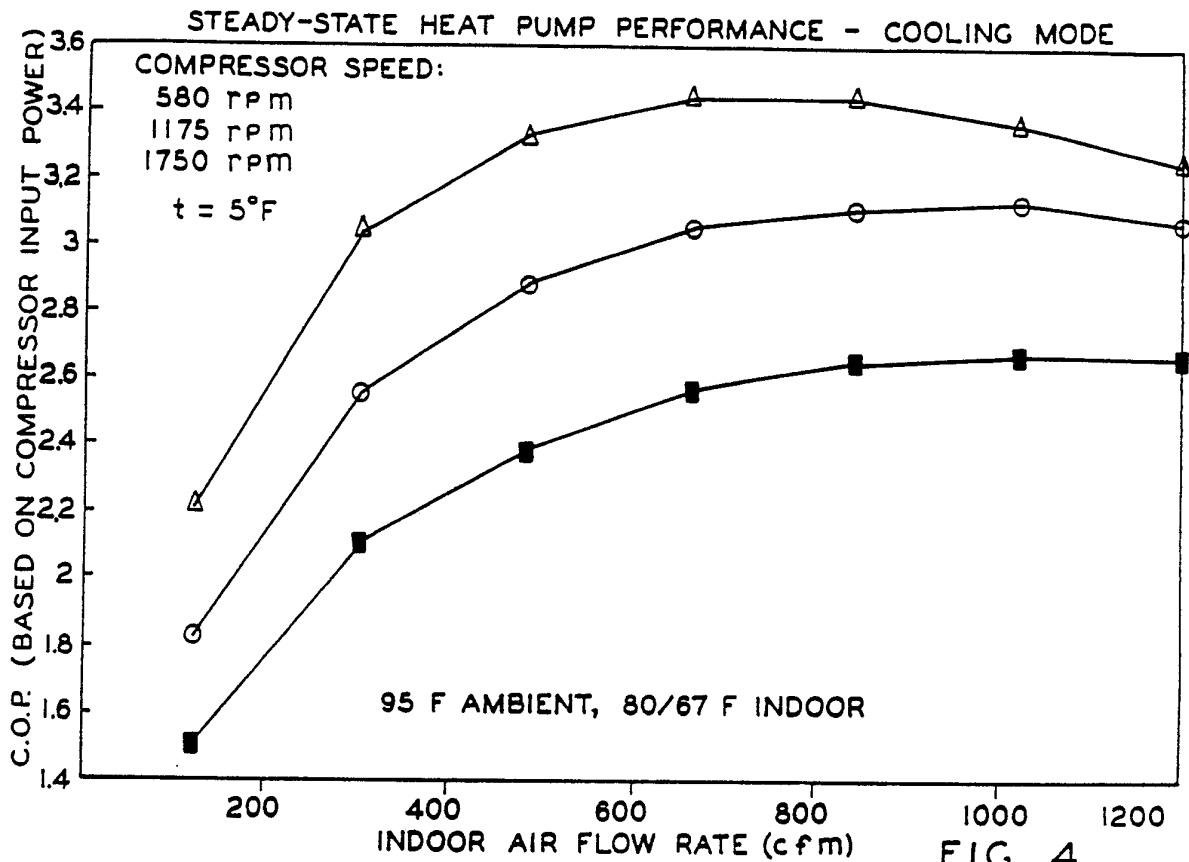


FIG. 7

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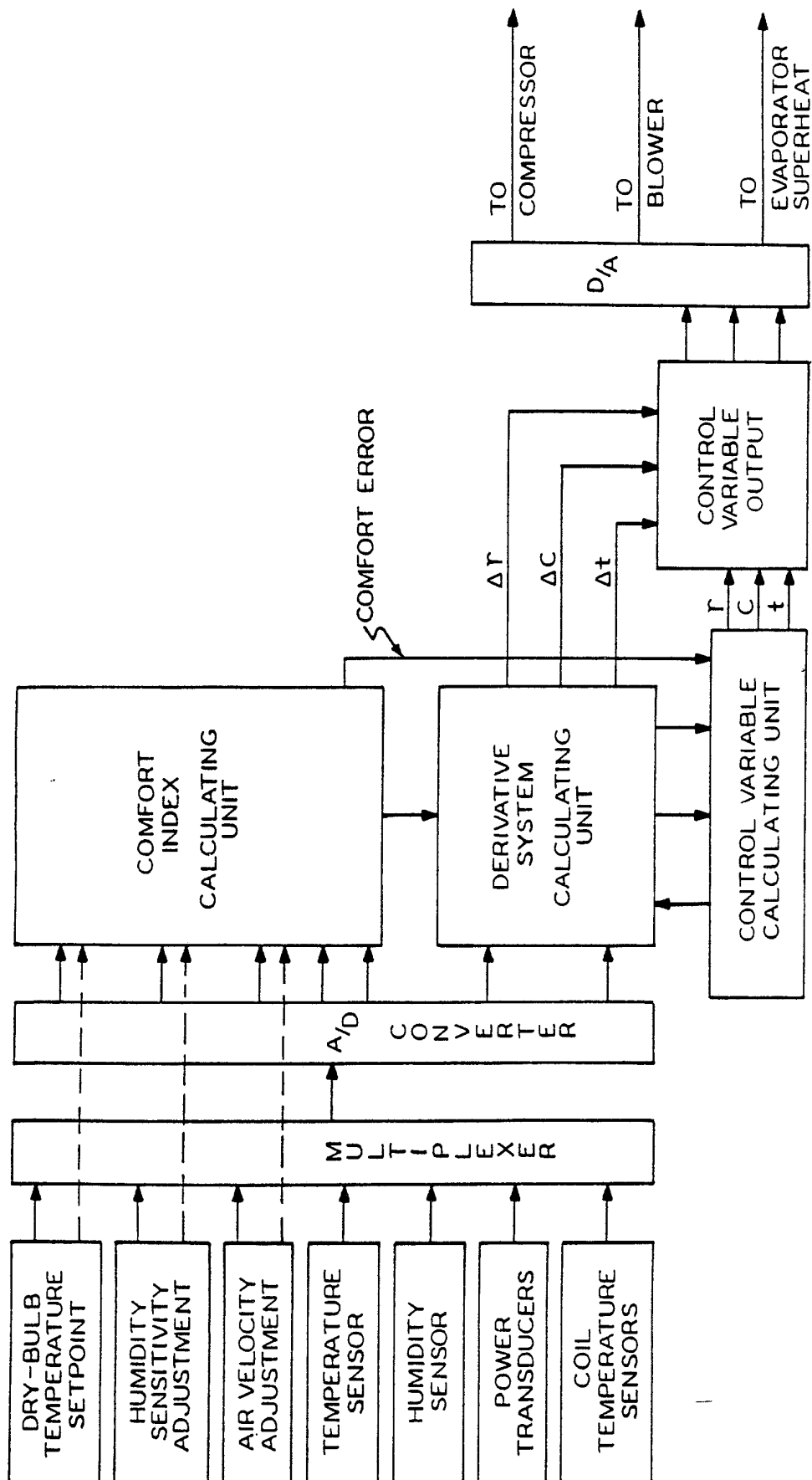
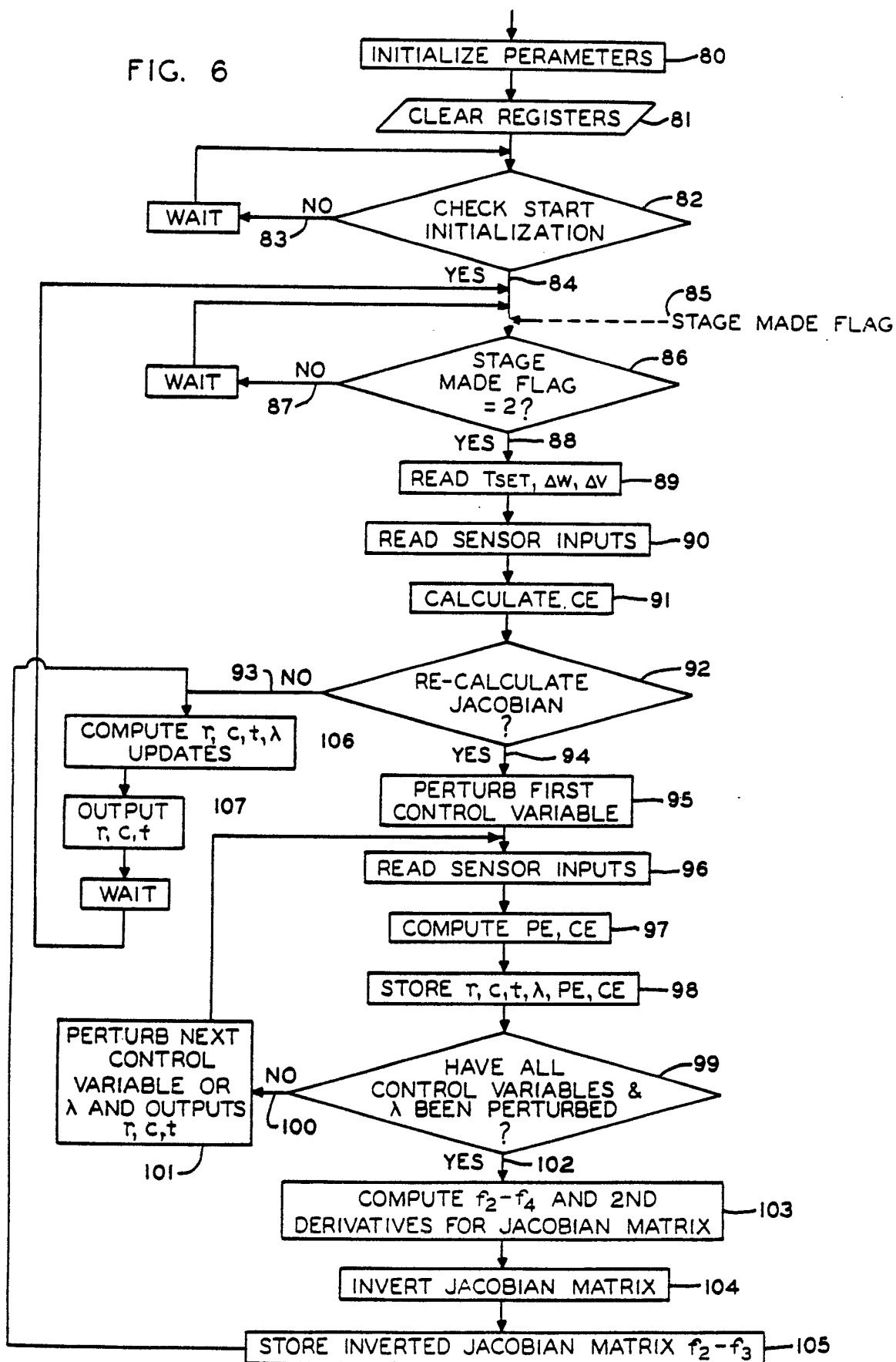


FIG. 5

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FIG. 6



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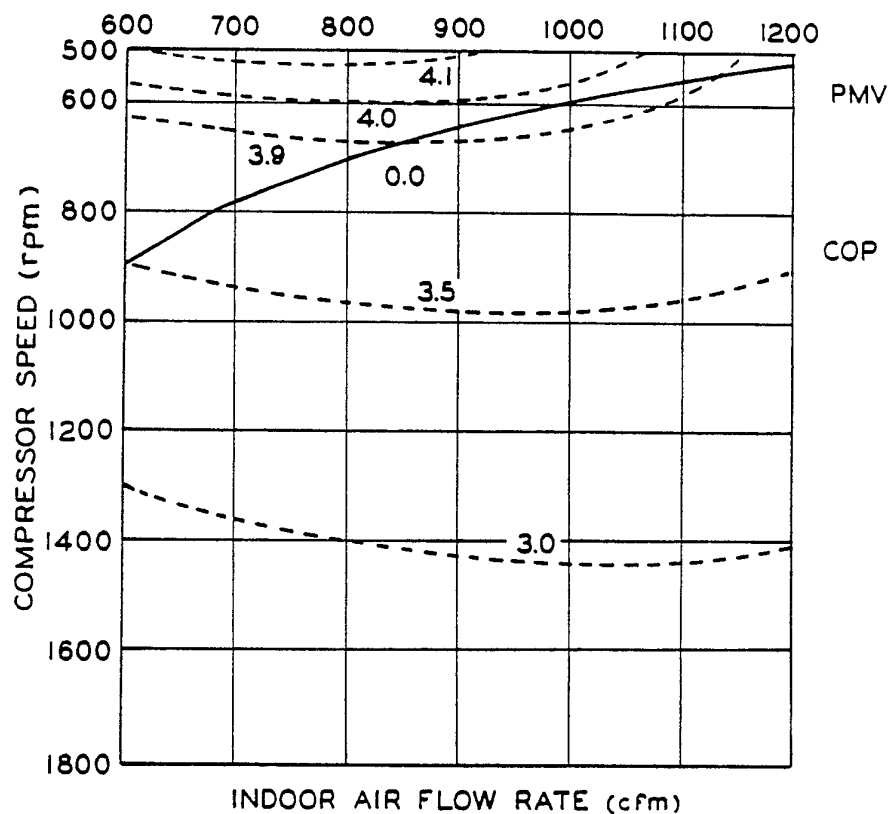


FIG. 9A

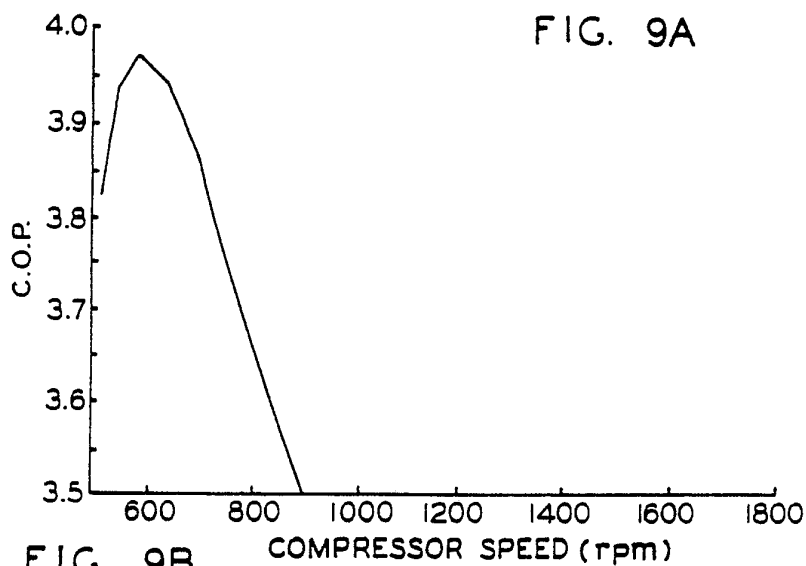


FIG. 9B

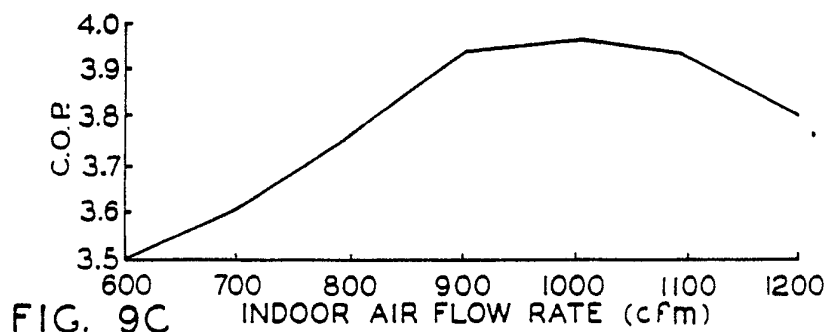


FIG. 9C

# INTERNATIONAL SEARCH REPORT

International Application No. PCT/US89/02451

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC IPC(4) G05D23/24; F24F 3/14 US. CL. 62/150, 204, 209; 165/12, 22; 364/148, 149, 505		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>7</sup>		
Classification System	Classification Symbols	
US	62/150, 204, 209; 165/12, 22 364/148, 149, 505	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT</b> <sup>9</sup>		
Category *	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
A	US, A, 4,024,725 (UCHIDA ET AL.) 24 May 1977 See entire document.	1-16
A	US, A, 4,257,795 (SHAW) 24 March 1981. See entire document.	1-16
A	US, A, 4,616,325 (HECKENBACH ET AL.) 07 October 1986. See entire document.	1-16
A	US, A, 4,720,982 (SHIMIZU ET AL.) 26 January 1988. See entire document.	1-16
A	US, A, 4,725,001 (CARNEY ET AL.) 16 February 1988. See entire document.	1-16
A	US,N, Thermal Comfort, Analysis and Application in Environmental Engineering Textbook by P.O. Fanger, McGraw-Hill issued 1970 pages 37-42 of interest.	1-16
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>* Special categories of cited documents: <sup>10</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&amp;" document member of the same patent family</p> </div> </div>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
22 AUGUST 1989	19 SEP 1989	
International Searching Authority	Signature of Authorized Officer	
ISA/US	Felix Gruber <i>Felix Gruber</i>	