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(54) System and method for fan speed control.

(57) The present invention relates to a fan speed controller which may be used in conjunction with heating, cooling and dehumidification air ventilation systems. The fan speed controller regulates ambient temperature and humidity by maintaining constant temperature differentials across the heating and cooling elements of the system. These temperature differentials are repeatedly tested and maintained through a feedback control system which regulates the volume and velocity of air passing through the heating and cooling units by regulating the speed of the fan circulating air through those heating and cooling units.

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SYSTEM AND METHOD FOR FAN SPEED CONTROL

BRIEF SUMMARY OF THE INVENTION

The present invention relates to systems and methods for improving the energy efficiency of a building environmental control system by modulating fan speed in response to determined actual thermal loads.

BACKGROUND OF THE INVENTION

At present, the heating, cooling and dehumidification systems which are commonly employed in large commercial single zone applications (i.e. supermarkets) regulate ambient temperature and humidity by toggling their heating and cooling units on and off. The ventilation fans in these systems run at full speed at all time, even when the heating and cooling units are off. These continuously running fans are sized and designed to handle peak conditions, namely, the conditions presented by the hottest and coldest days of the year. These peak conditions, however, occur only about 2% of the year. Since during the rest of the year these fans operate at full speed, these fans spend the vast majority of their time operating in a region of excess capacity and at a speed in excess of what is required to achieve the desired ambient conditions. This situation results in a substantial waste of energy because the energy consumed by these fan motors accounts for almost 30% of the energy consumed by the heating, cooling and dehumidification systems in which these fans are employed.

The present invention is directed to the conservation of this wasted energy. Instead of operating the air circulation fan at full speed all the time, the present invention varies the speed of this fan so as to move only the amount of air required to achieve the desired ambient conditions. The speed of the fan is adjusted through a feedback control system which monitors and maintains a constant temperature differential across the heating and cooling units in the air circulation system. This feedback control system tracks the actual load on the system and then varies the fan speed and hence the volume and velocity of air moving through the heating and cooling units so as to maintain this constant temperature differential. In this way the desired comfort level is achieved through the use of significantly lower average fan speeds. This results in a vast energy savings because, as previously mentioned, the fan will only be required to run at full speed approximately 2% of the year.

Below is a table depicting actual test data collected during the testing of the present invention. Prior to the installation of the present invention, the fan at the test site ran continuously at its maximum design capacity wherein it moved 24,000 CFM of air at all times consuming 10,220 KWH per month and 122,640 KWH per year.

MONTH	KWH CONSUMED	AVERAGE VOLUME OF AIR MOVED (CFM)
January	1,217	5,000
February	1,107	5,024
March	1,298	5,226
April	1,538	6,176
May	2,107	7,700
June	2,593	10,111
July	2,778	10,458
August	2,857	10,725
September	2,393	9,380
October	1,769	6,850
November	1,210	5,090
December	1,269	5,146

Total KWH consumed during year = 22,136 KWH

Energy saved = (122,640 - 22,136) = 100,504 KWH

Average volume of air moved during year = 7,241 CFM

Table 1. Actual and Calculated Energy Consumptions of a Building

The present invention was employed at the test site in connection with the same fan used previously, however, the speed of the fan was varied and controlled in accordance with the present invention. As the data illustrates, the fan on average ran well below capacity because the fan was designed to move 24,000 CFM of air and on average it only moved 7,241 CFM. Given that the fan speed in revolutions per minute is linearly related to the CFM of air being moved, it is readily clear that the present invention resulted in significantly lower average fan speeds. This reduction in fan speed resulted in an energy savings of 100,504 KWH over the course of the year (or 82% percent of the energy previously used for driving the fan) while maintaining the same comfort level previously achieved.

The energy savings achieved by the present invention is enhanced by the fact that the energy required to drive a fan decreases exponentially as the fan speed decreases linearly. This phenomena is explained in Fan Engineering, An Engineer's Handbook, 7th ed. at pp. 232-233, and is illustrated by the chart and graph depicted below.

SUPPLY BLOWER 20 HP MOTOR

HZ	SCFM	KW
60	21,300	13.3
55	19,700	9.74
50	17,700	7.69
45	15,500	6.40
40	13,000	4.89
35	10,700	3.7
30	8,300	2.86
25	6,200	2.07
20	4,500	1.52
15	3,000	1.06
10	1,800	0.36
5	1,000	0.06

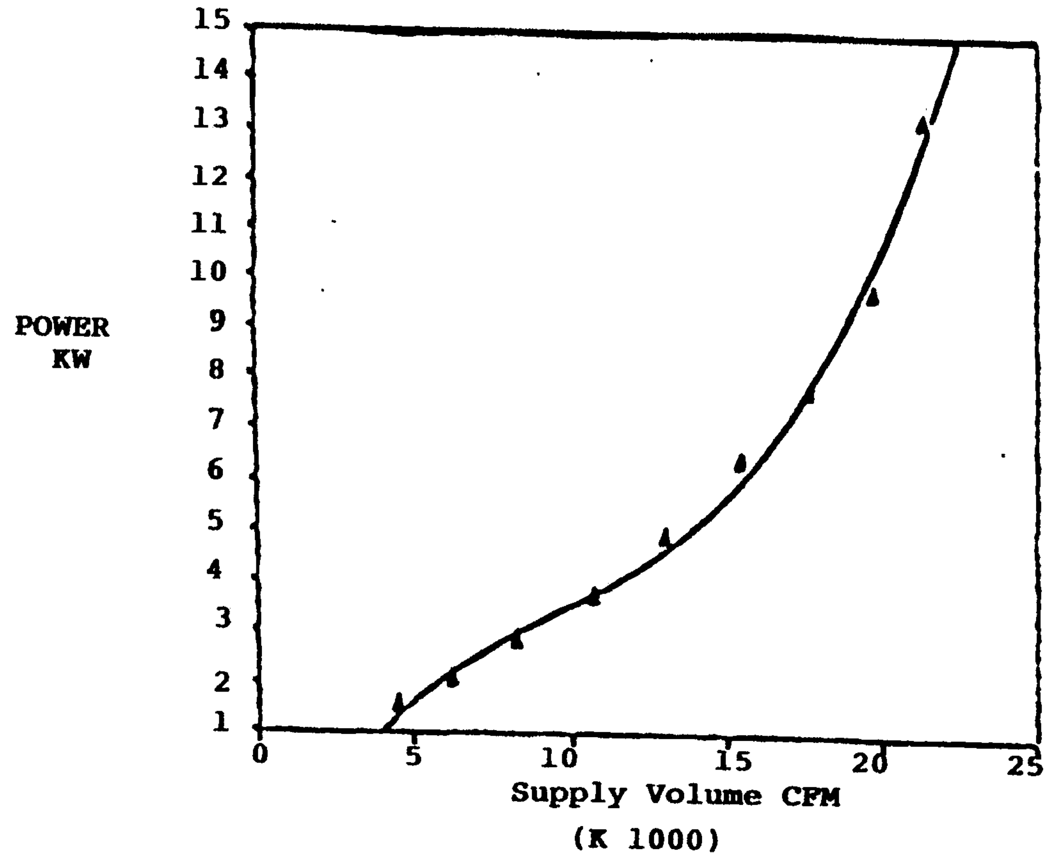

TABLE 2. POWER vs. AIR FLOW VOLUMES FOR A FAN

Extrapolating from the above, it can be seen that near the upper half of the curve, as CFM decreases from maximum to approximately half capacity, the power needed to drive the fan decreases by the cube. In this region of the curve, the power needed to drive the fan can be approximated by the following formula:

$$\text{Power Required to Drive Fan (KWH)} = \text{Power Consumed at Max. Design Speed (KWH)} \times \left(\frac{\text{CFM Actually Moved}}{\text{Max. CFM Capable of Being Moved}}\right)^3$$

Another and a more simple way of explaining this relationship between power required and CFM would simply by to say that it takes substantially more energy to move X CFM through a given system for a half hour, than it takes to move X/2 CFM through that same system for an hour. The present invention, by employing significantly slower fan speeds than those currently in use, takes advantage of this relationship. In addition, by always maintaining a certain predetermined minimum fan speed, the present invention avoids the inefficient and less advantageous lower end of the fan curve.

The relationship between power consumed and CFM also allows the present invention to out perform systems other than those employed in connection with large single zone applications like supermarkets. As previously mentioned, the fans in these systems run continuously. In contrast, the fans in residential systems commonly run only when the heating or cooling units in these systems are on or for a limited period after these heating and cooling units are turned off. The fans in these residential systems, however, are always operated at full speed when they are on. This results in wasted energy because during much if the year these fans could achieve the desired ambient conditions by moving less air and turning more slowly. The present invention results in considerable savings in a residential application by operating the fan only at the speed which is required to achieve the desired conditions, thereby eliminating the excess fan speeds currently in use and taking advantage of the relationship between CFM and KW explained above.

SUMMARY OF THE INVENTION AND ITS CONTRIBUTION TO THE ART

Besides the energy savings described above, the basic fan speed controller of the present invention can be employed in connection with other basic control means or methods so as to achieve a number of other additional features and advantages. As explained above, the basic controller of the present invention employs a feedback control system which varies fan speed and CFM so as to maintain constant temperature differentials across the heating or cooling elements in the system. Once this basic capability for controlling fan speed is employed additional features are readily achievable.

One of these features is air pulsing control which the present invention employs in connection with its heating operation. This feature is designed to identify and correct a situation where warm heated air collects near the ceiling of the room, leaving the lower portion of the room undesirably cold. This situation is depicted in a diagram from p.30.4 of the Ashrae Handbook , reproduced below.

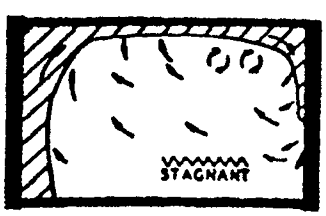

Illustration 1 — Heated Air Stagnation Diagram

This air pulsing feature operates by testing the air temperature at a control point located a few feet above the floor in the room. If this control point temperature is too low, the fan speed controller raises the fan speed to maximum for a few minutes in order to push this hot air off the ceiling and cirulate it through the room.

Another feature of the present invention is its demand period function. The utility of this feature stems from the fact that any given electric bill is a function of two variables, total usage and peak usage. Peak usage is the maximum amount of electricity used within any given cycle window during the billing period. Thus, an entity that can spread its demand for electricity more evenly over time will have a lower electric bill even if its total usage remains constant. In order to take advantage of this billing situation, the present invention employs a control loop which monitors cycle periods equal in duration to the cycle window used by the electric company. During the last few minutes of each cycle period this control loop turns the fan speed down to a minimum fan speed. This operation, while not reducing the total energy already being consumed the basic fan control system, reduces the peak usage of the system thereby significantly cheapening the cost of operation.

Another feature available with the present invention is a night setback function. This feature allows for the adjusting of temperature during the night when the site of the system may not be in use. With the basic controller in place, this feature can be accomplished simply by slowing the circulation fan down to its minimum speed thereby letting the ambient temperature move to the edge of its allowable setback range. This setback temperature is maintained during the setback period by increasing the fan speed only as needed to keep the temperature within this setback range. The night setback feature of the present invention is a vast improvement over the setback systems which have been tried in connection with present systems. These setback systems operated by toggling the circulation fans on and off during the setback period. This constant on and off resulted in an increase in stress at the internal contacts and windings of the fan motors and in an increase in the wear and maintenance of these fans. This increased wear and maintenance is avoided in the present system because the fans used by the present system are never turned off and their speed is varied only gradually.

In addition, with the on/off setback systems previously employed the fan occasionally remained off for long periods of time resulting in hot and cold regions within the zone. In some applications, these hot and cold regions proved harmful to products, plants, or animal life stored within the zone. These hot and cold regions are eliminated by the setback system of the present invention because the fans controlled by the present system are always maintained at a certain predetermined minimum speed.

BRIEF DESCRIPTION OF THE FIGURES

Referring now to the drawings,

FIG.1 is a block logic diagram illustrating how the fan speed controller of the present invention could be employed to regulate heating, cooling and dehumidification.

FIG. 2 is a block logic diagram illustrating the control point satisfaction function of the present invention.

FIG. 3 is a block logic diagram of the demand period function of the present invention which is used to lower peak usage during a billing period.

FIG. 4 is a block logic diagram of the night setback function of the present invention.

FIG. 5 is a block logic diagram illustrating a fan control algorithm incorporating the regulation of heating, cooling and dehumidification, the control point satisfaction function, the night setback function and the demand period function.

DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

According to the preferred embodiment of the present invention, the control system and method may be implemented in a programmed general purpose microprocessor system such as a microcomputer employing an Intel iAPX microprocessor, together with peripheral support circuitry comprising random access memory, read-only memory, input/output circuits, timers, and the like. For example, a Compaq Model Deskpro 286/20 may be employed. Alternatively, special-purpose microprocessor systems, together with sensors and support circuitry may be employed. The method of the present invention may be implemented in a high-level programming language such as "C", or may be implemented in other languages such as assembly language. A further alternative embodiment may employ discrete circuitry such as operational amplifiers, timers, gates and the like.

FIG. 1 describes how the heating, cooling and dehumdification functions of the present invention could be employed in connection with a system where return air passed first through a cooling unit and next through a heating unit before being circulated back into the ambient environment as supply air. The present fan controller could also be employed in connection with a system where the heating and cooling units were reversed in order. Moreover, the present invention could be employed solely in connection with a cooling unit to perform only cooling, soley in connection with a heating unit to perform only heating, or in connection with a heating unit and cooling unit where both heating and cooling are controlled, but humidity is not. Finally, the present invention could be employed in connection with a heating unit and a cooling unit solely to control humidity.

In the system of FIG. 1, the air passing through the system is tested for temperature at various points. This testing may be accomplished by any conventional temperature sensor such as National Semiconductor's LM 34. The return air entering the system is tested by a sensor located prior to the cooling unit. In an alternative embodiment the temperature of the return air is sensed at a control point within the zone or simply at the thermostat. The temperature of this return air is hereinafter referred to as the return air temperature. The air exiting the cooling unit is tested by a sensor located between the cooling unit and the heating unit. The temperature of this cooled air is hereinafter referred to as the cooling air temperature. The air is tested a final time after it passes through the heating unit, the temperature of this air being hereinafter referred to as the heating air temperature.

Referring to block 1, the heating air temperature ("HAT") is compared against the cooling air temperature ("CAT") to determine whether the heating unit is being used. If HAT is greater than CAT then the heating unit is on and the algorithm moves to block 2. Here CAT is compared against the return air temperature ("RAT") to determine whether the cooling unit is on. If CAT is less than RAT then the cooling unit is on and the system is running in its dehumidification mode with both the heating and cooling units functioning. At this point the algorithm moves to block 3 where the temperature differential ("DT") across the cooling coil is calculated by subtracting CAT from RAT. In addition, the target delta temperature ("TDT"), which is the desired temperature differential across the cooling unit for dehumidification is set. This TDT value is set at the dehumidification delta temperature ("DDT") which is predetermined and a function of the particular cooling unit being used.

Referring again to block 2, if the result of the comparison was that CAT was not less than RAT, this would indicate that the cooling unit was not on and that the system was functioning in its heating mode. In block 4 the temperature differential across the heating unit is calculated by subtracting RAT from HAT. The target temperature differential across the heating unit is set at the heating delta temperature ("HDT"), which like DDT is predetermined and a function of the particular heating unit being used.

Referring back to block 1, if the result of this comparison was that the HAT was not greater than the CAT, the system next tests in block 5 to see if CAT is equal to RAT. If CAT and RAT are not equal this indicates that the system is in its cooling mode. In block 6 the temperature differential across the cooling unit is calculated for the cooling mode by subtracting CAT from RAT. The target temperature differential across the cooling unit for the cooling mode is set at the cooling delta temperature ("CDT"), which like the DDT is predetermined and a function of the particular cooling unit being used.

Once a determination is made that the system is either in a dehumidification, heating or cooling mode, the relevant temperature differential has been calculated and the target temperature differential set, the system moves to block 9 where the fan speed is adjusted. The current speed is adjusted up or down according to whether DT is greater or less than TDT. If DT is greater than DT the fan speed is increased in an amount equal to (DT-TDT)*SPDF, where SPDF is a predetermined constant. If DT is less than TDT, the result of the calculation of (DT-TDT)*SPDF will be negative and the fan speed will be slowed accordingly. In an alternative embodiment the amount of fan speed adjustment is determined in a derivative fashion according to rate DT changes with time. In yet another embodiment, the amount of fan speed adjustment is determined by inputting the value of (DT-TDT) into a proportional integrated and derivative ("PID") control function.

Returning again to block 5, if the result of this comparsion is that CAT is equal to RAT, this indicates that neither the heating nor the cooling units in the system are on and that the system is not heating, cooling or dehumidifying. In this situation the fan speed is slowed and maintained at a predetermined mimimum speed ("MIN-SPEED"). In the preferred embodiment, this minimum speed is determined in accordance with the relationship between KW and CFM for the particular fan being employed. In block 7 the fan speed is decremented by a predetermined "STEP". In block 8 the fan speed is then compared with the MIN-SPEED. If the fan speed is below the MIN-SPEED the fan speed is set at the MIN-SPEED at block 10.

In an alternative embodiment, if the system is not heating, cooling or dehumidifying, the fan speed is compared first to MIN-SPEED. If the fan speed is greater than MIN-SPEED, the fan speed is subsequently decremented by the predetermined STEP. If the fan speed is less than MIN-SPEED, the fan speed is set at MIN-SPEED. In yet another embodiment, if the system is not heating, cooling or dehumidifying the fan speed could simply be set at MIN-SPEED, as opposed to being brought down to that speed in a gradual or stepwise fashion.

In addition to that described above, an alternative embodiment of the present invention might employ a standard multi-stage thermostat or a multi-stage humidistat, instead of testing for RAT, CAT and HAT. In this embodiment, the fan speed is varied incrementally depending of the stage called for by the thermostat or humidistat. For example, if the multi-stage thermostat called for four stages of cooling, the fan speed controller of the present invention might adjust the fan speed as follows:

COOLING STAGE	FAN SPEED
First stage	Fan speed set at 25% of maxspeed
Second stage	Fan speed set at 50% of maxspeed
Third stage	Fan speed set at 75% of maxspeed
Fourth stage	Fan speed set at 100% of maxspeed

Similarly, if the multi-stage thermostat called for four stages of heating, the fan speed controller of the present invention might adjust the fan speed as follows:

HEATING STAGE	FAN SPEED
First stage	Fan speed set at 25% of maxspeed
Second stage	Fan speed set at 50% of maxspeed
Third stage	Fan speed set at 75% of maxspeed
Fourth stage	Fan speed set at 100% of maxspeed

Finally, if the multi-stage humidistat called for four stages of dehumidification, the fan speed controller might adjust the fan speed as follows:

DEHUMIDIFICATION STAGE	FAN SPEED
First stage	Fan speed set at 20% of maxspeed
Second stage	Fan speed set at 40% of maxspeed
Third stage	Fan speed set at 65% of maxspeed
Fourth stage	Fan speed set at 90% of maxspeed

As mentioned above, in the preferred embodiment a microprocessor based control means is employed in connection with a variable speed motor to control fan speeds. In an alternative embodiment pictured below, multiple motors with different horsepowers and different sized pulleys could be employed in connection with a blower to achieve the desired variation in fan speed or air velocity speed.

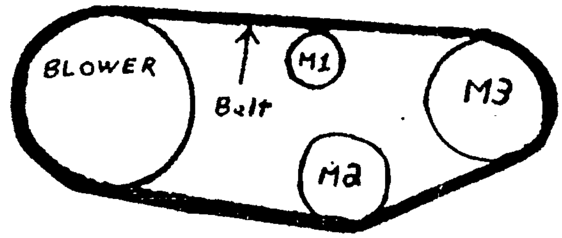

Illustration 2 — Multiple Motor Fan Drive System

The motors in the above diagram might have horsepowers and pulleys sized as follows:

MOTOR	HORSEPOWER	PULLEY SIZE DIAMETER (INCHES)
M1	5HP	2.5
M2	10HP	5.0
M3	20HP	10.0

In this embodiment, fan speed or air velocity is varied as desired by toggling the various motors on or off.

Finally, in yet another embodiment, a multiple speed motor, i.e, a two speed or three speed motor, could be employed to achieve the desired variation in fan speed or air velocity.

Turning to FIG. 2 which depicts the operation of the control point satisfaction function, in block 11 the store temperature ("ST") is compared against the minimum allowable temperature ("MNT"). If this condition is satisfied it is an indication that the warm heated air in the room has risen to the ceiling leaving the lower area of the room unacceptably cool. In order to correct this situation air pulsing is used to move this warm air off the ceiling. This air pulsing is accomplished by increasing the fan speed to its maximum ("MAX-SPEED") for a predetermined time interval at the end of each cycle period. This pulsing results in the hot air near the ceiling being recirculated throughout the lower portions of the room. In an alternative embodiment, this pulsing is accomplished by increasing the fan speed in a stepwise fashion up to MAX-SPEED during the predetermined interval of time at the end of each cycle. In yet another embodiment, this pulsing could be accomplished without regard to cyclical intervals simply by increasing the fan speed until the warm had recirculated.

In block 12 the amount of time which is remaining during the cycle period ("CDP") is tested to see if it is positive and a variable denoted MSP is tested to see if it equals 0. MSP represents the length of the cycle period ("CPP") minus the pulse period minus the amount of time which has elapsed during the cycle period. If the condition in block 12 is false, the system moves to block 13 to see if CDP is zero. If CDP is not zero then in block 15 the fan speed is increased to MAX-FAN. Otherwise the system moves to block 14 and CDP is reset to CPP and MSP is reset to CPFSP, which represents CPP minus the pulse period.

FIG. 3. illustrates the demand period function of the present invention. As mentioned above, the utility of this feature stems from the fact that an electric bill is a function of two variables, total usage and peak usage. An entity that can spread its demand for electricity more evenly over time will have a lower electric bill even if its total usage remains constant.

In order to take advantage of this situation, the present invention employs a control loop which monitors cycle periods equal in duration to the cycle window used by the electric company. During the last few minutes of each cycle period this control loops turns the fan speed down to a predetermined minimum fan speed. This operation reduces the peak usage of the system thereby cheapening the cost of operation. In alternative embodiments of the invention, the fan could simply be shut off during the last few minutes of the cycle period or it could be reduced in some stepwise manner either down to a predetermined minimum speed or down to zero.

In block 16 the amount of time which is remaining in the cycle period ("CDP") is tested to see if it is positive and MSP is tested to see if it equal 0. In this function, MSP represents the length of the time remaining in the cycle period minus the interval of time where the fan speed will be reduced to MIN-SPEED in order to lower peak usage (5 minutes in the illustrated example). If the result of block 16 is true, this indicates that it is time to lower the fan speed and in block 19 the fan speed is reduced to MIN-SPEED where it will stay for the remainder of the cycle period. If the result of block 16 is false, CDP is tested to see if it is zero in block 17. If CDP is zero, this indicates that a cycle period has ended and in block 18 CDP and MSP are reset. CDP is reset to a value representing the length of the cycle period used by the supplying electric utility to monitor peak usage (15 minutes in the illustrated example). MSP is reset to a value representing the length of the cycle period used by the supplying electric utility to monitor peak usage minus the interval of time where the fan speed will be reduced to MIN-SPEED in order to lower peak usage. Thus, in the illustrated example MSP is set at 10 minutes (15 minutes minus 5 minutes).

FIG. 4 illustrates the night setback function of the present invention. As mentioned above, this feature allows for the adjusting of temperature during the night when the site of the system may not be in use and less comfortable conditions may be tolerated. This feature is accomplished by slowing the fan to is minimum speed thereby letting the ambient temperature move to the edge of its allowable setback range. The setback temperature range is maintained during the setback period by increasing the fan speed only as needed to keep the temperature within the desired setback range.

In block 20 the store temperature ("ST") is compared against the minimum allowable store temperature ("MNT") and the maximum allowable store temperature ("MXT") to see whether it falls within their range. If ST is within this range, the fan speed is lower by a predetermined amount ("STEP") in block 21. In block 22 the fan speed is compared against the minimum fan speed (MIN-SPEED). If the fan speed is below MIN-SPEED then the fan speed is set at MIN-SPEED. If in block 20 ST is not within the range between MNT and MXT, the fan speed is increased by the predetermined STEP amount in block 24. In block 25 the fan speed is then compared against the maximum fan speed ("MAX-SPEED"). If the fan speed is greater than MAX-SPEED, then in block 26 the fan speed is set at MAX-SPEED.

In an alternative embodiment, if ST is within its desired range, the fan speed is compared first to MIN-SPEED. If the fan speed is greater than MIN-SPEED, the fan speed is subsequently decremented by the predetermined STEP. If the fan speed is less than MIN-SPEED, the fan speed is set at MIN-SPEED. In yet another embodiment, if ST is within its desired range, the fan speed could simply be set at MIN-SPEED, as opposed to being brought down to that speed in a gradual or stepwise fashion.

In a similar alternative embodiment, if ST is not within its desired range, the fan speed is compared first to MAX-SPEED. If the fan speed is less than MAX-SPEED, the fan speed is subsequently incremented by the predetermined STEP. If the fan speed is greater than MAX-SPEED, the fan speed is set at MAX-SPEED. In yet another embodiment, if ST is not within its desired range, the fan speed could simply be set at MAX-SPEED, as opposed to being brought up to that speed in a gradual or stepwise fashion.

FIG. 5 is a fan control algorithm incorporating the algorithms illustrated in FIGS. 1 through 4. In block 27, the time of day ("TOD") is compared against the evening setback time ("ESB") and the morning start-up time ("MSU"). If TOD is greater than ESB and less than MSU the night setback function of FIG. 4 is triggered.

In block 28, TOD is compared against the start of the demand period ("SDP") and the end of the demand period ("EDP"). If TOD is after SDP and before EDP, then the demand period function of FIG. 3 is triggered. Next, block 29 triggers the control point satisfaction function of FIG. 2 and block 30 triggers the heating, cooling and dehumidification function of FIG. 1. Finally, in block 31 the fan speed is set according to the updated fan speed value and CDP and MSP are decremented.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes of the invention. Accordingly, reference should be made to the appended claims, rather than to the foregoing specification, as indicating the scope of the invention.

STATEMENT OF INDUSTRIAL UTILITY

The present invention may be useful in the reduction of energy demand of a building environmental control system. Specifically, the system and method of the present invent ion may be used to reduce both energy consumption and cost in a conventional HVAC system, in dehumidification systems, and in combinations involving those systems.

Claims

1. A method for improving the energy efficiency of a building environmental control system comprising modulating fan speed in response to actual thermal load upon the system.

2. The method of Claim 1 wherein said fan speed is set according to the ratio of the actual thermal load on said system to the design capacity of said system.

3. The method of Claim 1 wherein said fan speed is modulated according to the temperature differential between the air entering said system and the air exiting said system.

4. The method of Claim 1 wherein said fan speed is modulated according to the temperature differential between the actual ambient air temperature and the desired ambient air temperature.

5. A method for controlling the fan speed of an air circulation and cooling system with reference to a predetermined desired ambient temperature, comprising the following steps:

(A) testing the ambient air to determine the return air temperature;

(B) substracting said predetermined desired ambient temperature from said return air temperature to obtain the temperature differential;

(C) setting said fan speed at a rotational speed corresponding to said temperature differential; and

(D) repeating steps A through C.

6. A method for controlling the fan speed of an air circulation and cooling system, comprising the following steps:

(A) testing the ambient air to determine the return air temperature;

(B) testing the air exiting the cooling unit to determine the cooling air temperature;

(C) subtracting said cooling air temperature from said return air temperature to obtain the temperature differential;

(D) setting said fan speed at a rotational speed corresponding to said temperature differential; and

(E) repeating steps A through D.

7. A method for controlling the fan speed of an air circulation and heating system with reference to a predetermined desired ambient temperature, comprising the following steps:

(A) testing the ambient air to determine the return air temperature;

(B) subtracting said predetermined desired ambient temperature from said return air temperature to obtain the temperature differential;

(C) setting said fan speed at a rotational speed corresponding to said temperature differential; and

(D) repeating steps A through C.

8. A method for controlling the fan speed of an air circulation and heating system, comprising the following steps:

(A) testing the ambient air to determine the return air temperature;

(B) testing the air exiting the heating unit to determine the heating air temperature;

(C) subtracting said return air temperature from said heating air temperature to obtain the temperature differential;

(D) setting said fan speed at a rotational speed corresponding to said temperature differential; and

(E) repeating steps A through D.

9. A method for controlling the fan speed of an air circulation and cooling system with reference to first and second predetermined control variables, comprising the following steps:

(A) testing the air entering the cooling unit to determine the return air temperature;

(B) testing the air exiting the cooling unit to determine the cooling air temperature;

(C) subtracting said cooling air temperature from said return air temperature to obtain the temperature differential;

(D) adjusting said fan speed by an amount equal to said first predetermined control variable multiplied by the difference between said temperature differential minus said second predetermined control variable; and

(E) repeating steps A through D.

10. A method for controlling the fan speed of an air circulation and heating system with reference to first and third predetermined control variables, comprising the following steps:

(A) testing the air entering the heating unit to determine the return air temperature;

(B) testing the air exiting the heating unit to determine the heating air temperature;

(C) subtracting said return air temperature from said heating air temperature to obtain the temperature differential;

(D) adjusting said fan speed by an amount equal to said first predetermined control variable multiplied by the difference between said temperature differential minus said third predetermined control variable; and

(E) repeating steps A through D.

11. A method for controlling the fan speed of an air circulation and dehumidification system with reference to first and fourth predetermined control variables, comprising the following steps:

(A) testing the air entering the cooling unit to determine the dehumidification air temperature;

(B) testing the air exiting the cooling unit to determine the cooling air temperature;

(C) subtracting said cooling air temperature from said dehumidification air temperature to; obtain the temperature differential;

(D) adjusting said fan speed by an amount equal to said first predetermined control variable multiplied by the difference between said temperature differential minus said fourth predetermined control variable; and

(E) repeating steps A through D.

12. A method for controlling the fan speed of an air circulation system wherein return air passes through a heating unit and a cooling unit, comprising the following steps:

(A) determining the operational mode of said system;

(B) if said system is operating in a heating mode then;
(1) determining the temperature differential across said heating unit;
(2) adjusting said fan speed by an amount according to the value of said temperature differential;
(C) if said system is operating in a cooling mode then;
(1) determining the temperature differential across said cooling unit;
(2) adjusting said fan speed by an amount according to the value of said temperature differential;
(D) if said system is operating in an off mode then;
(1) reducing said fan speed;
(E) repeating steps A through D.

13. A method for controlling the fan speed of an air circulation system with reference to first, second and third predetermined control variables wherein return air passes first through a cooling unit and second through a heating unit, comprising the following steps:
(A) testing the air exiting said heating unit to determine the heating air temperature;
(B) testing the air in exiting said cooling unit to determine the cooling air temperature;
(C) comparing said heating air temperature with said cooling air temperature, if said heating air temperature is greater than said cooling air temperature then;
(1) subtracting said cooling air temperature from said heating air temperature to obtain the temperature differential;
(2) adjusting said fan speed by an amount equal to said first predetermined control variable multiplied by the difference between said temperature differential minus said third predetermined control variable;
otherwise;
(1) testing the air entering said cooling unit to determine the return air temperature;
(2) comparing said cooling air temperature with said return air temperature, if said cooling air temperature is equal to said return air temperature, then;
(a) decrementing said fan speed by a predetermined value;
(b) comparing said fan speed with a predetermined minimum speed, if said fan speed is less than said predetermined minimum speed, then;
(i) setting set fan speed at said predetermined minimum speed;
otherwise;
(a) subtracting said return air temperature from said cooling air temperature to obtain said temperature differential;
(b) adjusting said fan speed by an amount equal to said first predetermined control variable multiplied by the difference between said temperature differential minus said second predetermined control variable;
(D) repeating steps A through C.

14. A method for controlling the fan speed of an air circulation system with reference to first, second and third predetermined control variables wherein return air passes first through a heating unit and second through a cooling unit, comprising the following steps:
(A) testing the air exiting said heating unit to determine the heating air temperature;
(B) testing the air entering said heating unit to determine the return air temperature;
(C) comparing said heating air temperature with said return air temperature, if said heating air temperature is greater than said return air temperature then;
(1) subtracting said return air temperature from said heating air temperature to obtain the temperature differential;
(2) adjusting said fan speed by an amount equal to said first predetermined control variable multiplied by the difference between said temperature differential minus said third predetermined control variable;
otherwise;
(1) testing the air exiting said cooling unit to determine the cooling air temperature;
(2) comparing said cooling air temperature with said heating air temperature, if said cooling air temperature is equal to said heating air temperature, then;
(a) decrementing said fan speed by a predetermined value;
(b) comparing said fan speed with a predetermined minimum speed, if said fan speed is less than said predetermined minimum speed, then;
(i) setting set fan speed at said predetermined minimum speed;
otherwise;
(a) subtracting said cooling air temperature from said heating air temperature to obtain said temperature differential;
(b) adjusting said fan speed by an amount equal to said first predetermined control variable multiplied by the difference between said temperature differential minus said second predetermined control variable;

(D) repeating steps A through C.

15. A method for controlling the fan speed of an air circulation system which may operate in either a heating mode, a cooling mode, a dehumidification mode or an off mode, wherein return air passes through a heating unit and a cooling unit, comprising the following steps:

(A) determining whether the said system is operating in said heating mode, said cooling mode, said dehumidification mode or said off mode;

(B) if said system is operating in said heating mode then:

(1) determining the temperature differential across said heating unit;

(2) adjusting said fan speed by an amount according to the value of said temperature differential;

(C) if said system is operating in said cooling mode then;

(1) determining the temperature differential across said cooling unit;

(2) adjusting said fan speed by an amount according to the value of said temperature differential;

(D) if said system is operating in said dehumidification mode then;

(1) determining the temperature differential across said cooling unit;

(2) adjusting said fan speed by an amount according to the value of said temperature differential;

(E) if said system is operating in said off mode then;

(1) reducing said fan speed;

(F) repeating steps A through E.

16. A method for controlling the fan speed of an air circulation system with reference to first, second, third, and fourth predetermined control variables wherein return air passes first through a cooling unit and second through a heating unit, comprising the following steps:

(A) testing the air exiting said heating unit to determine the heating air temperature;

(B) testing the air exiting said cooling unit to determine the cooling air temperature;

(C) comparing said heating air temperature with said cooling air temperature, if said heating air temperature is greater than said cooling air temperature then;

(1) testing said return air to determine the return air temperature;

(2) comparing said cooling air temperature with said return air temperature, if said cooling air temperature is greater than said return air temperature then;

(a) subtracting said cooling air temperature from said return air temperature to obtain the temperature differential;

(b) setting the target temperature differential to the value of said fourth predetermined control variable; otherwise;

(a) subtracting said return air temperature from said heating air temperature to obtain said temperature differential;

(b) setting the target temperature differential to the value of said third predetermined control variable;

(3) adjusting said fan speed by an amount equal to said first predetermined control variable multiplied by the difference between said temperature differential minus said target temperature differential; otherwise;

(1) comparing said cooling air temperature with said return air temperature, if said cooling air temperature is equal to said return air temperature, then;

(a) subtracting said cooling air temperature from said return air temperature to obtain said temperature differential;

(b) adjusting said fan speed by an amount egual to said first predetermined control variable multiplied by the difference between said temperature differential minus said second predetermined control variable; otherwise;

(a) decrementing said fan speed by a predetermined value;

(b) comparing said fan speed with a predetermined minimum fan speed, if said fan speed is less than said predetermined minimum fan speed, then;

(i) setting set fan speed at said predetermined minimum fan speed;

(D) repeating steps A through C.

17. A method for controlling a forced air ventilation system to efficiently redistribute heated air which has risen to the ceiling of a heating zone, comprising the following steps:

(A) determining whether said heated air has risen to said ceiling;

(B) if said heated air has risen to said ceiling; then

(1) redistributing said heated air by modulating the air velocity within the ventilation system;

(C) repeating steps A through B.

18. The method of Claim 17 wherein said determining of step (A) is made by testing the ambient air at an altitude below where said heated air collects and comparing said ambient air temperature to a predeter-

mined temperature.

19. A method for lowering the peak electric power consumed by a building environmental control system comprising reducing said fan speed during cyclical intervals.

20. The method of Claim 19 wherein said cyclical intervals are spaced in time according to the time window used by the supplying electric utility to determine peak usage rates.

21. The method of Claim 19 wherein said fan speed is reduced to a predetermined minimum fan speed.

22. A method for lowering the peak electric power consumed by the fan of a building environmental control system with reference to fifth and sixth predetermined control variables, comprising the following steps:

(A) comparing said fifth predetermined contrcl variable with zero;

(B) comparing said sixth predetermined control variable with zero;

(C) if said fifth predetermined control variable is greater than zero and said sixth predetermined control variable is equal to zerc, then;

(1) setting said fan speed at a predetermined minimum speed;

otherwise;

(2) if said fifth predetermined control variable is equal to zero, then;

(a) setting said fifth predetermined control variable at a value equal to the duration of the time window used by the supplying electric utility to determine peak usage rates;

(b) setting said sixth predetermined control variable at a value equal to the duration of the time window used by the supplying electric utility to determine peak usage rates minus a predetermined slow speed interval;

(D) repeating steps A through D.

23. A method for setting back the performance of a building environmental control system which may operate in a setback mode through the adjustment of fan speed comprising determining the operational mode of said system and modulating said fan speed in accordance with said operational mode.

24. The method of Claim 23 wherein said operational mode is determined in accordance with predetermined values corresponding to the time of day.

25. The method of Claim 23 wherein said fan speed is modulated in accordance with predetermined control variables corresponding to a predetermined minimum temperature and a predetermined maximum temperature.

26. The method of Claim 25 further comprising testing the ambient air temperature, comparing said ambient air temperature to said minimum temperature and to said maximum temperature, and decreasing said fan speed if said ambient air temperature is within the range of said minimum temperature and said maximum temperature.

27. The method of Claim 26 wherein said fan speed is decreased to a predetermined minimum fan speed.

28. The method of Claim 26 wherein said fan speed is increased if said ambient air temperature is not within the range of said minimum temperature and said maximum temperature.

29. The method of Claim 28 wherein said fan speed is increased to a predetermined maximum fan speed.

30. A system for improving the energy efficiency of a building environmental control system comprising means for modulating fan speed in response to actual thermal load upon the system.

31. A system for controlling the fan speed of an air circulation and cooling system with reference to a predetermined desired ambient temperature, comprising:

(A) means for testing the ambient air to determine the return air temperature;

(B) means for comparing said desired ambient temperature to said return air temperature; and

(C) means for setting said fan speed at a rotational speed in response to the result of said comparison.

32. A system for controlling the fan speed of an air circulation and cooling system, comprising:

(A) means for testing the ambient air to determine the return air temperature;

(B) means for testing the air exiting the cooling unit to determine the cooling air temperature;

(C) means for comparing said cooling air temperature to said return air temperature; and

(D) means for setting said fan speed at a rotational speed in response to the result of said comparison.

33. A system for controlling the fan speed of an air circulation and cooling system with reference to first and second predetermined control variables, comprising;

(A) means for testing the air entering the cooling unit to determine the return air temperature;

(B) means for testing the air exiting the cooling unit to determine the cooling air temperature;

(C) means for subtracting said cooling air temperature from said return air temperature to obtain the temperature differential;

(D) means for adjusting said fan speed by an amount equal to said first predetermined control variable multiplied by the difference between said temperature differential minus said second predetermined control variable.

34. A system for controlling the fan speed of an air circulation and heating system with reference to a predetermined desired ambient temperature, comprising:

(A) means for testing the ambient air to determine the return air temperature;

(B) means for comparing said desired ambient temperature to said return air temperature; and

(C) means for setting said fan speed at a rotational speed in response to the result of said comparison.

35. A system for controlling the fan speed of an air circulation and heating system, comprising:

(A) means for testing the ambient air to determine the return air temperature;

(B) means for testing the air exiting the heating unit to determine the heating air temperature;

(C) means for comparing said heating air temperature to said return air temperature; and

(D) means for setting said fan speed at a rotational speed in response to the result of said comparison.

36. A system for controlling the fan speed of an air circulation and heating system with reference to first and third predetermined control variables, comprising:

(A) means for testing the air entering the heating unit to determine the return air temperature;

(B) means for testing the air exiting the heating unit to determine the heating air temperature;

(C) means for subtracting said heating air temperature from said return air temperature to obtain the temperature differential;

(D) means for adjusting said fan speed by an amount equal to said first predetermined control variable multiplied by the difference between said temperature dif ferential minus said third predetermined control variable.

37. A system for controlling the fan speed of an air circulation and dehumidification system, comprising:

(A) means for testing the temperature of the air entering the cooling unit to determine the dehumidification air temperature;

(B) means for testing the temperature of the air exiting the cooling unit to determine the cooling air temperature;

(C) means for comparing said dehumidification air temperature to said cooling air temperature; and

(D) means for setting said fan speed at a rotational speed in response to the result of said comparison.

38. A system for controlling the fan speed of an air circulation and dehumidification system with reference to first and fourth predetermined control variables, comprising:

(A) means for testing the air entering the cooling unit to determine the dehumidification air temperature;

(B) means for testing the air exiting the cooling unit to determine the cooling air temperature;

(C) means for subtracting said cooling air temperature from said dehumidification air temperature to obtain the temperature differential; and

(D) means for adjusting said fan speed by an amount equal to said first predetermined control variable multiplied by the difference between said temperature differential minus said fourth predetermined control variable.

39. A system for controlling the fan speed of an air circulation system wherein return air passes through a heating unit and a cooling unit, comprising:

(A) means for determining the operational mode of said system;

(B) means for determining the temperature differential across the heating unit;

(C) means for determining the temperature differential across the cooling unit;

(D) means for adjusting said fan speed in response to said operational mode and said temperature differential.

40. The system of Claim 39 wherein said means for determining said operation mode further comprises means for sensing temperatures of air flows entering and exiting the heating unit and entering and exiting the cooling unit and means for comparing said air flow temperatures to determine the temperature differentials across the heating unit and the cooling unit.

41. A system for controlling a forced air ventilation system to efficiently redistribute heated air which has risen to the ceiling of a heating zone, comprising means for redistributing said heated air by modulating the air velocity within the ventilation system.

42. The system of Claim 41 further comprising means for determining whether said heated air has risen to said ceiling.

43. The system of Claim 42 wherein said determining means further comprises means for testing the ambient air at an altitude below where said heated air collects and means for comparing said ambient air temperature to a predetermined minimum tolerable temperature.

44. A system for lowering the peak electric power consumed by a building environmental control system comprising means for reducing said fan speed during cyclical intervals.

45. The system of Claim 44 wherein said cyclical intervals are determined with reference to a timing means.

46. The system of Claim 45 wherein said timing means is a real-time clock.

47. A system for setting back the performance of a building environmental control system which may operate in a setback mode through the adjustment of fan speed comprising means for determining the operational mode of said system and means for modulating said fan speed in accordance with said operational mode.
48. The system of Claim 47 wherein said operational mode is determined with reference to a timing means.
49. The system of Claim 48 wherein said timing means is a real-time clock.
50. The system of Claim 47 further comprising means for testing the ambient air temperature, means for comparing said ambient air temperature to a predetermined minimum temperature and to a predetermined maximum temperature, and means for decreasing said fan speed if said ambient air temperature is within the range of said minimum temperature and said maximum temperature.

HEAT — COOL — DEHUMID FUNCTION

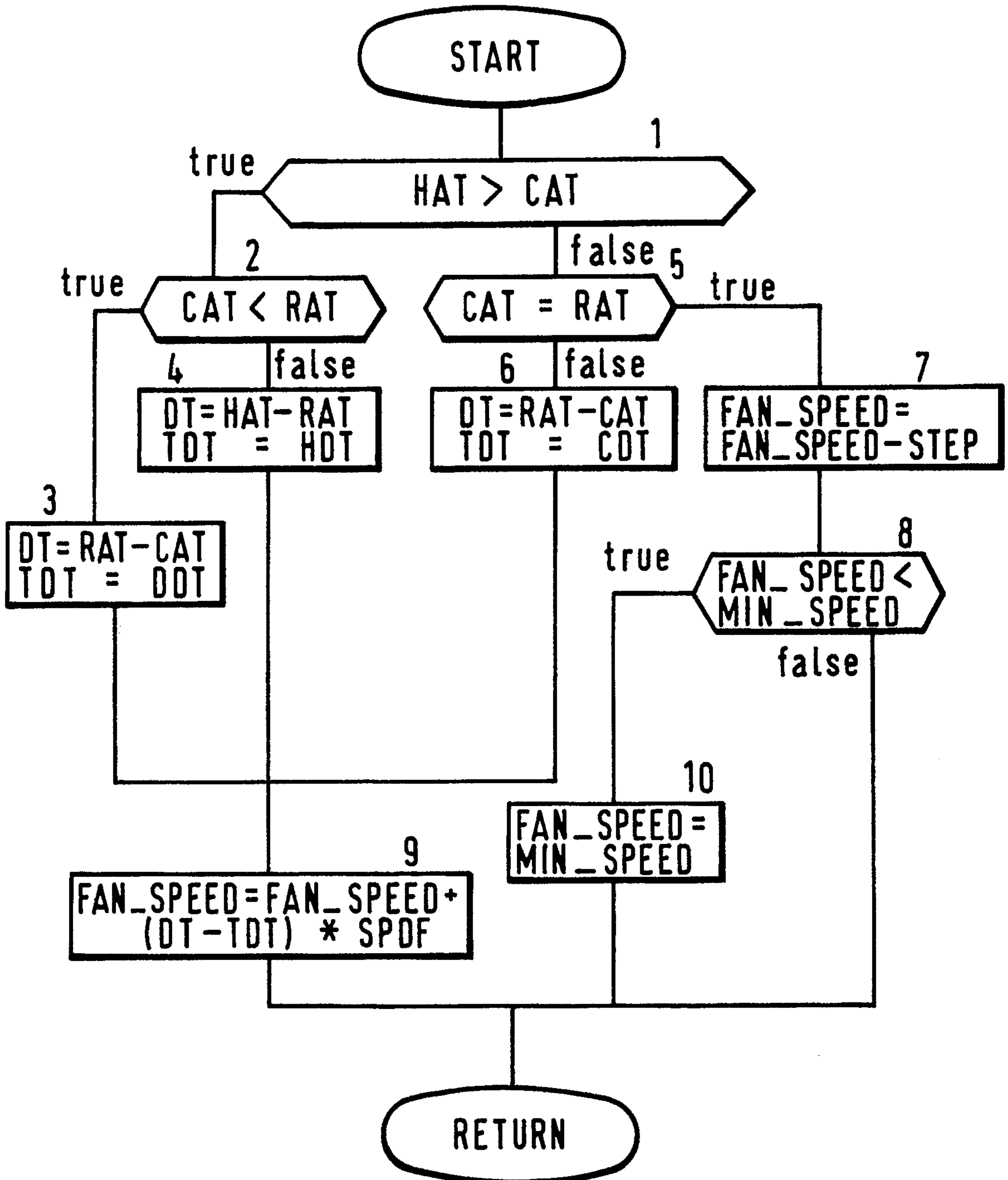

FIG. 1.

CONTROL POINT SATISFACTION FUNCTION

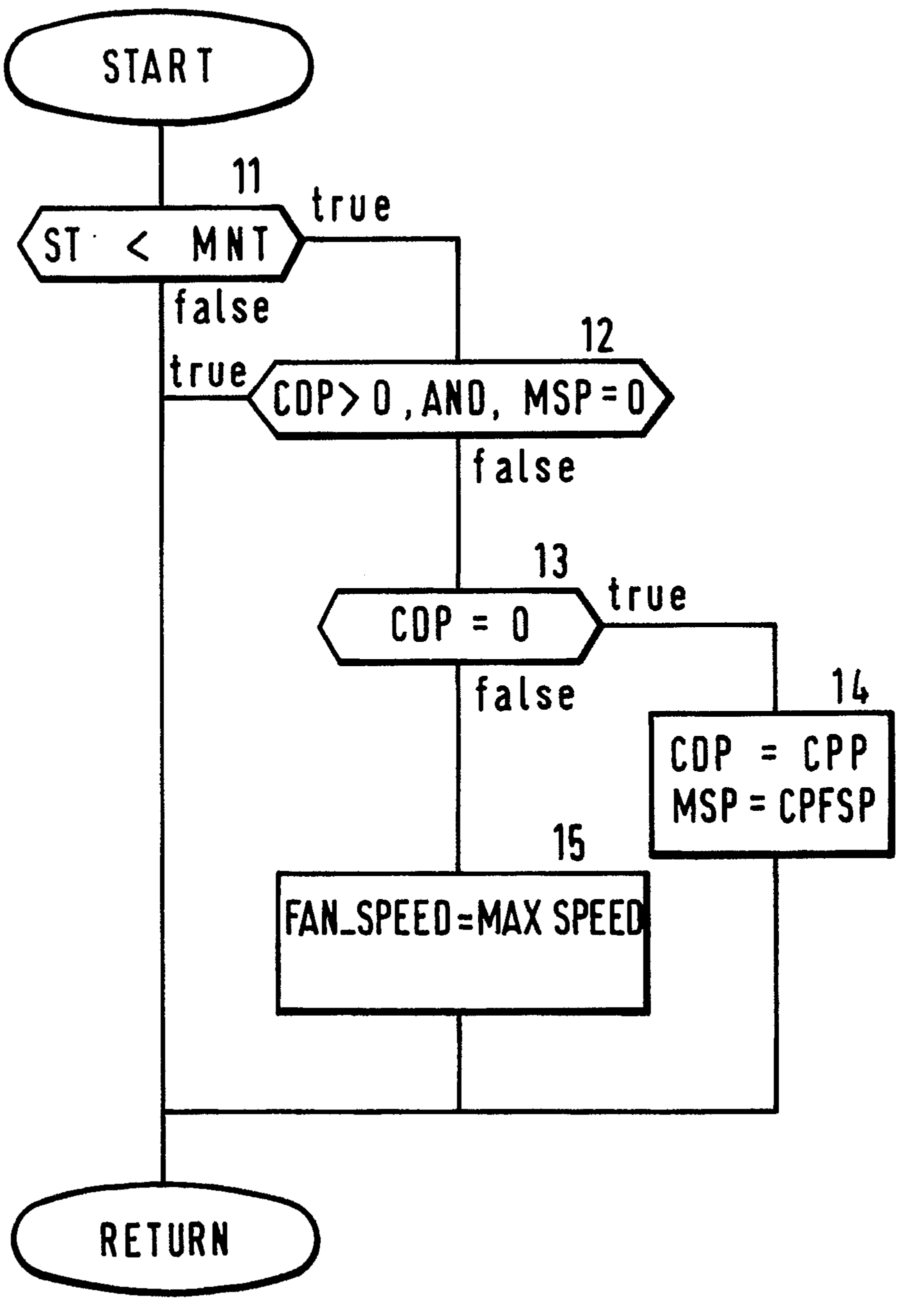

FIG. 2.

DEMAND-PERIOD FUNCTION

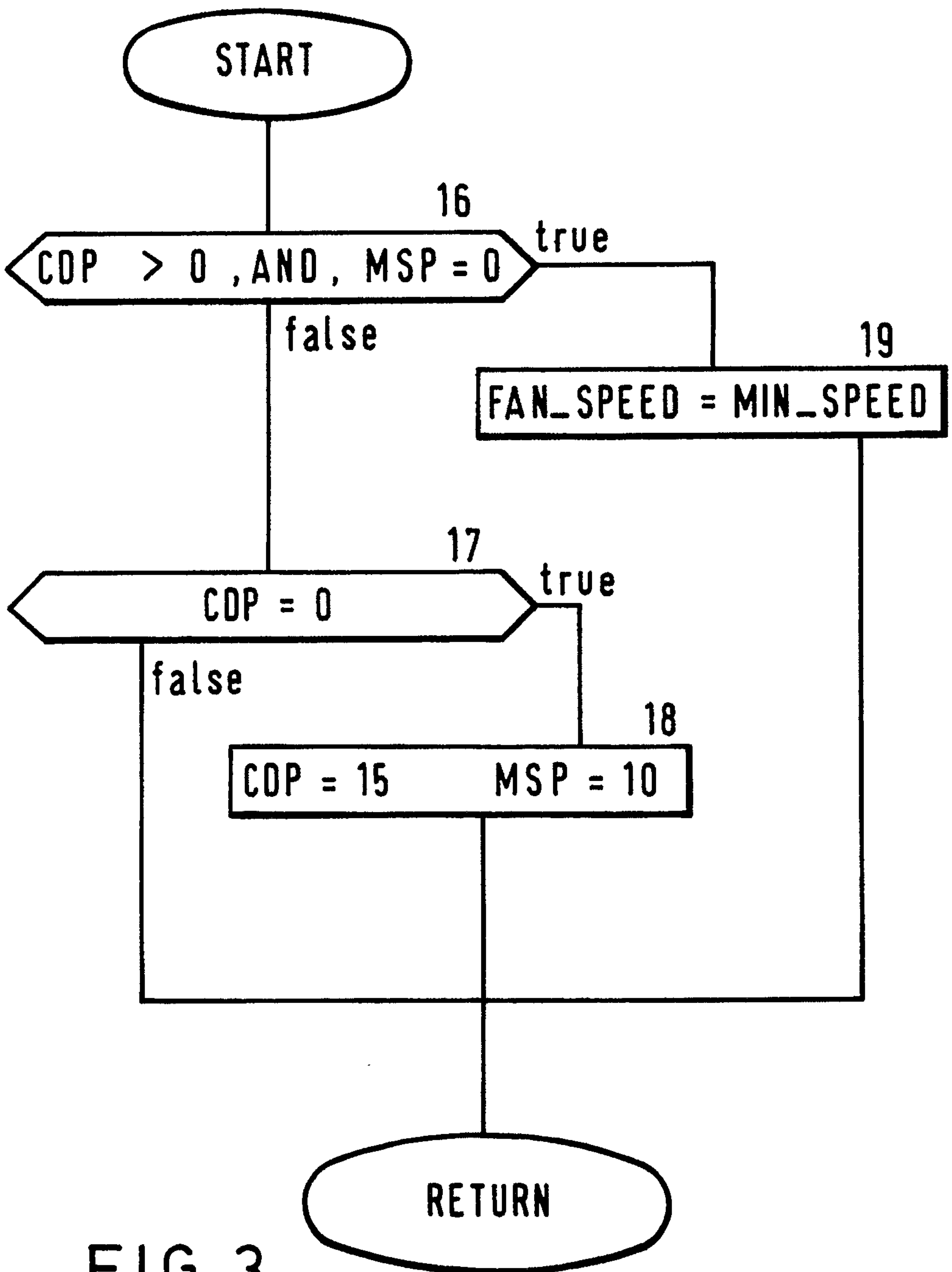

FIG. 3.

NIGHT SETBACK FUNCTION

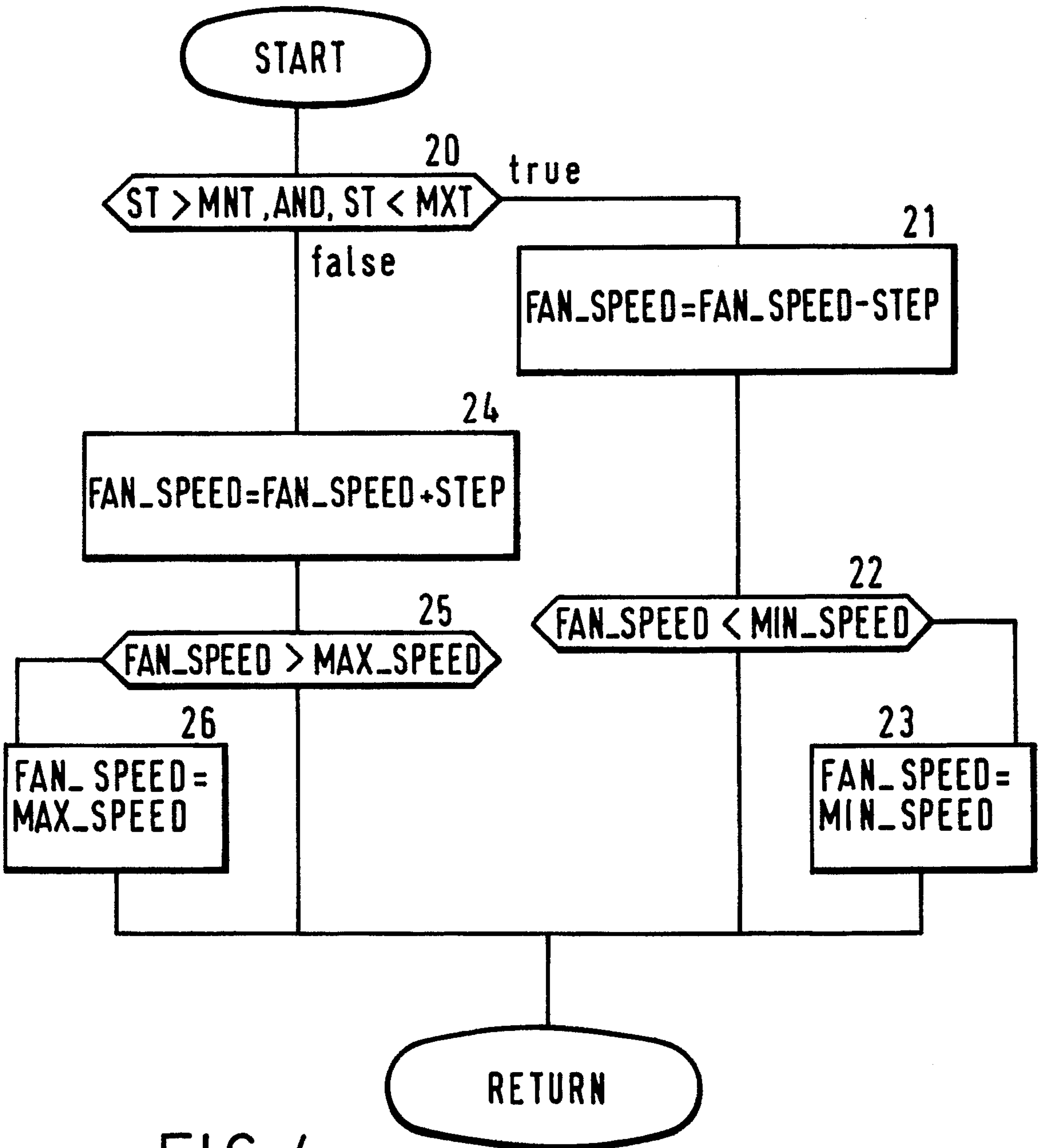

FIG. 4.

FAN CONTROL ALOGRITHM — MAIN LOOP

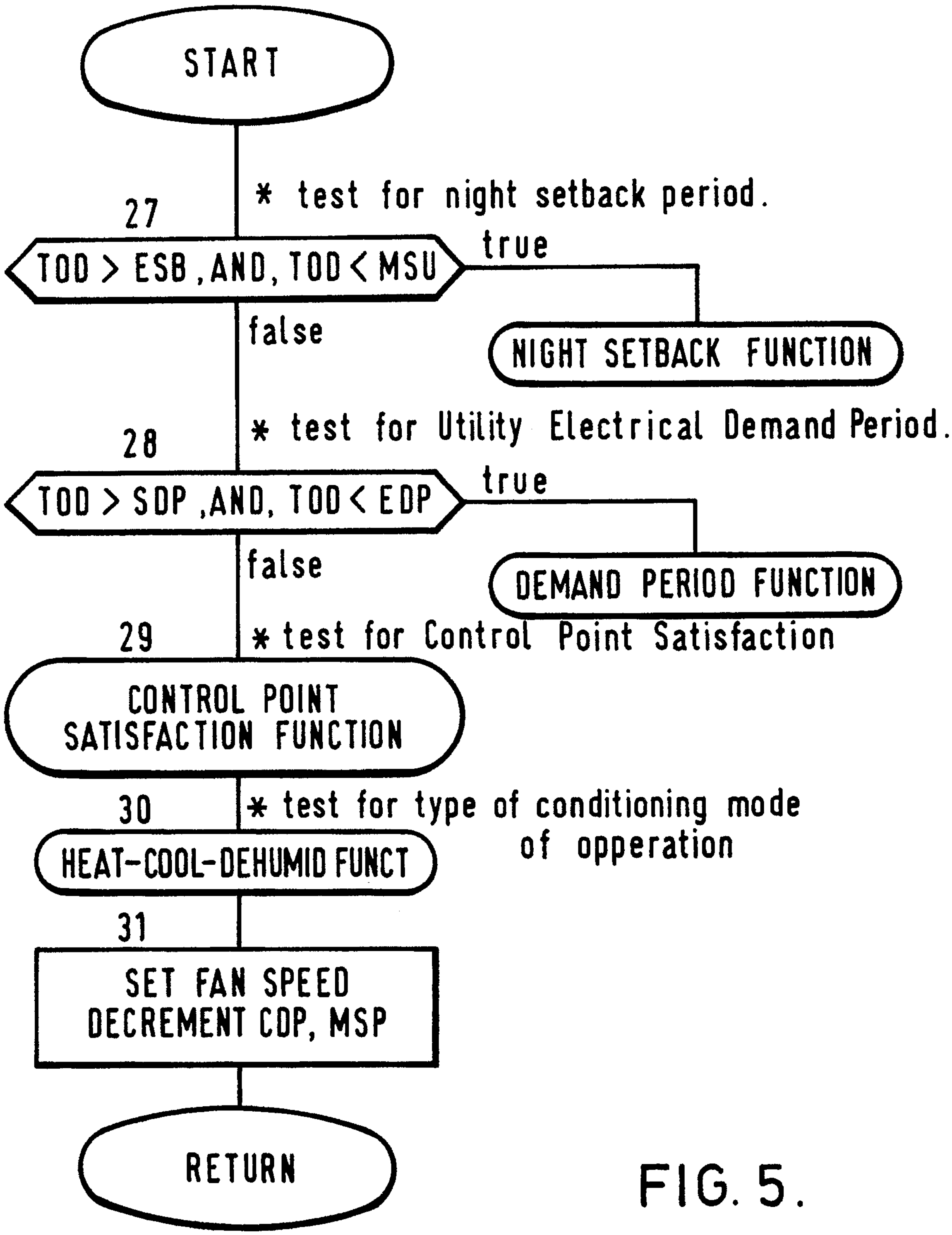

FIG. 5.