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trol Algorithms for Building Management and Control Systems -- Hot Deck/Cold Deck/Supply Air Reset, Day/Night Setback, Ventilation Purging, and Hot and Chilled Water Reset

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Building Equipment Division
Washington, DC 20234

March 1984

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CONTROL ALGORITHMS FOR BUILDING MANAGEMENT AND CONTROL SYSTEMS -- HOT DECK/COLD DECK/SUPPLY AIR RESET, DAY/NIGHT SETBACK, VENTILATION PURGING, AND HOT AND CHILLED WATER RESET

William B. May, Jr.

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, ***Secretary***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

ABSTRACT

Software is an important component of building management and control systems (BMCS). This report describes concepts, algorithms, and software used in BMCS components developed in the NBS building systems and controls laboratory. The basic concepts, considerations and general algorithms for hot deck/cold deck supply air setpoint reset, day/night thermostat and ventilation setback, ventilation purging, and hot/chilled water supply setpoint reset are presented. Reset is the changing of a setpoint on a Heating, Ventilating and Air Conditioning (HVAC) system controlled by a feedback controller to match the system output to the system load. Setback is the changing of HVAC system operation to reduce energy use during unoccupied periods. Purging is the use of outdoor air during unoccupied periods to reduce mechanical conditioning requirements. Specific implementations of the algorithms in software on an actual BMCS are presented as examples.

KEY WORDS: air handling unit control; building (energy) management and control systems (EMCS,BMCS); chilled water reset; computer control; control algorithms; control software; day/night setback; energy management; hot water reset; heating, ventilating and air conditioning (HVAC); outside air reset; supply air setpoint reset; ventilation purging.

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1. INTRODUCTION

A computer-based building management and control system (BMCS) relies heavily on computer software to utilize efficiently the heating, ventilating, and air conditioning (HVAC) equipment in the building. HVAC control software is available in proprietary or system dependent packages, usually supplied with a BMCS system supplied by a particular vendor. However, if listings of the software source are not supplied, the BMCS owner or HVAC designer will not know if the BMCS system can meet the HVAC design specifications. Even if the control algorithms used are known, there is only a small amount of HVAC control algorithm software in the public domain to use for baseline comparison purposes. This report describes basic concepts and non-proprietary algorithms used in control software that was developed at the National Bureau of Standards (NBS) for use in the NBS building management and controls laboratory.

BMCS control strategies fall into at least two categories. Direct control (or Direct Digital Control, DDC) refers to strategies and algorithms that control the building equipment directly without the use of conventional pneumatic or electronic local analog control, implementing lower level functions such as closed loop control of valves, dampers, and actuators. Supervisory or management strategies control the building in a broader sense, managing equipment systems by methods such as selecting setpoints, and choosing optimum operating times as a function of variables including electrical demand, time, weather conditions, occupancy, and heating and cooling requirements.

The many functions of modern building management and control systems are usually distributed among a number of computer processors. Control algorithms are usually intended for operation at a particular level of the system. For a large BMCS, the tri-services specification [1] defines four levels in a hierarchy. These are the central level (CCU), the communication controller level (CCC), the distributed control level (FID), and the data gathering and conditioning level(MUX). The distributed control level is occupied by equipment given the name FID for field interface device, or RPU for remote processing unit. It is at this level that the software described in this report is intended to operate.

This report discusses several types of supervisory control strategies. These are day/night thermostat and ventilation setback, ventilation purging, hot or chilled water supply temperature setpoint reset, multizone/dual duct hot deck/cold deck setpoint reset, and reheat/VAV supply air reset. These are all strategies that may be applied to control of air handling units serving building core or perimeter spaces in commercial or industrial buildings. Algorithms for these strategies are discussed in several chapters of this report, and actual algorithms and software developed for the NBS controls laboratory BMCS system are presented in a separate chapter.

2. THE AIR HANDLING UNIT AND BUILDING ZONE SYSTEM

The strategies discussed in this report are primarily intended for control of HVAC systems that utilize central air handling units to supply ventilation and/or conditioned air to the spaces in a building. Although day/night setback is applicable in any type of building, and supply water reset is applicable to any building with central boilers or chillers, all control strategies are discussed in the context of a building with one or more central air handling units.

An air handling unit can be one of several different types. The types of units currently in use will be described to define the terminology used in this report. One type of unit, the dual duct system, is shown in Figure 1 with much of the detail of an actual air handler omitted. Two ducts allow air to enter the unit, one carrying return air from the building spaces, the other bringing in outside air for ventilation or "free" conditioning. Dampers control the relative amounts of each air source. The dual duct unit has two paths or "decks" containing heat exchangers, and two supply ducts leading from the air handler to one or more building zones. The heat exchangers in each deck are either for heating or cooling, and a preheat coil used to avoid freezing of the other coils is shown just after the return-outside air mixing area. The cooling coils might be chilled water coils, refrigerant or direct expansion (DX) coils, or air washers. The heating coils could be steam or hot water heat exchangers. Two coils may be used in each deck to allow optional humidity control by overcooling to produce condensation, and reheating. In actual installations there may be more, fewer, or none of these coils in a deck. The upper deck is called the "hot deck", and is intended to produce warm air for the building spaces. The lower deck is called the "cold deck" and is intended to provide cool air. In a dual duct system air from hot and cold decks is sent through separate ducts to building spaces and is mixed at the space to maintain a desired room temperature.

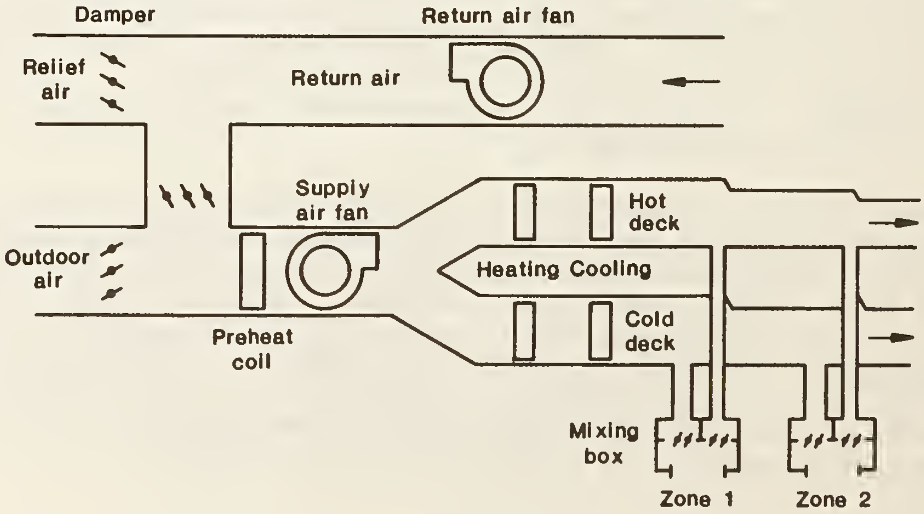

figure 1. dual duct air handling unit and multiple zone system

The dual duct air handler design can be converted to other types of air handlers by omitting one of the supply ducts or one of the decks. If the mixing for each zone is performed at the air handling unit and the mixed air is transported to each zone in a single duct, the system becomes a multizone system. If the cold deck is eliminated, so that only a single deck with a supply fan is used, this would represent a single or multiple zone constant volume system, or, if the fans and zone supply boxes could vary the volume of air delivered to the zones, this configuration would be a variable air volume system (VAV). If reheat coils were added to the individual zones, the system would be a reheat system, either VAV or constant volume. Complete descriptions of system types are available in the ASHRAE handbook [2].

In the central air handler and multiple building zone system, there are two important types of control or process variables which must be maintained at desired values. The first of these is the space temperature (and humidity) in the zones. The other variable is the temperature (and humidity) of the air stream or streams leaving the air handling unit. For a dual deck system, there is a cold deck setpoint temperature and a hot deck setpoint. For systems with a single deck such as reheat, single zone, or single deck VAV, there is a single supply air temperature.

The primary criterion for selection of the zone temperature setpoint is the comfort of the building occupants, or if the building is not occupied, the requirements of materials or machines located in the building. The zone setpoint is often not a single temperature/humidity but a range of temperatures and humidities, within which the comfort level is considered acceptable. This is the "zero energy band" concept which is useful for conserving energy when space loads swing from heating to cooling within a relatively short time span [3]. If the space condition is floating within the comfort band, no mechanical conditioning of the space is permitted.

The selection of supply air setpoint(s) is more complicated than the selection of a space setpoint. If a single zone is being supplied by an air handler, the supply air setpoint is the temperature (and humidity) of the supply air which will allow the space temperature (and humidity) for that zone to be maintained. This air condition is determined by the space heating or cooling requirement and the air volume flow rate entering the zone. If two or more zones are being supplied, it is to be expected that the proper entering air condition will vary among the zones. A building may be designed to have equal entering conditions for all zones, even though zone requirements differ, by adjusting the design air flow to each zone. The design air flow distribution is probably not ideal for all zone loading conditions, resulting in unequal entering air condition requirements at certain times. The supply air condition must then be chosen to allow the zone with the highest or lowest entering air temperature and humidity requirement (depending on the specific system) to be satisfied, because otherwise some zones will not be able to maintain a comfortable state.

The simplest control of supply air temperature is to use a constant hot deck, cold deck, or supply air temperature so that all zones are satisfied for all reasonable load conditions. For dual deck systems, mixing of hot and cold air streams, and for reheat systems, reheating of cool air at the zone, will allow any zone to be supplied with air at the proper temperature. However, when air is cooled and reheated, this uses more energy than if the air had simply been cooled or heated to the correct tempeature for a zone. Therefore it is important to select the proper supply air temperatures to minimize energy waste.

The least complex control system for a central air handler and zone system uses independent feedback control loops to maintain each zone temperature (by reheat coil control, or mixing damper control), and an independent system to maintain supply air temperatures. In this case the zone and supply air controls are loosely coupled, since neither control loop is connected to the other. An example of this is a system with "outside air reset" control of supply air temperature. The selection of supply air setpoints is based on the outside air temperature, not the actual space conditions. With tightly coupled controls, the system controlling supply air temperatures takes into account the actual conditions in the space zones. An example of this is the selection of supply air setpoints based on actual measurement of individual zone loads.

Two of the strategies discussed in this report control the setpoints for the zone and supply air temperatures. Day/Night thermostat setback changes the zone setpoints. Hot deck/cold deck/supply air reset changes the supply air setpoints. The other strategies discussed in the report are concerned with two other types of process or control variables. These are the ventilation air rate and the hot or chilled water supply temperatures for heat exchanger coils. Day/night ventilation setback changes the setpoint for minimum ventilation air rate. Hot water/chilled water reset changes the setpoint for the hot or chilled water supplied to the coils in the air handling unit. The remaining strategy, ventilation purging, makes a temporary change in the ventilation air setpoint to improve building operation economy.

3. SUPPLY AIR SETPOINT RESET CONTROL

Throughout this chapter, supply air setpoint will be assumed to be either a dry bulb temperature setpoint, or a combination of dry bulb and humidity (wet bulb) setpoints. If only the dry bulb temperature is controlled, under certain conditions the space humidity may approach an unacceptable state if the dry bulb setpoint is reset to a high value during cooling operation. If this is possible, it is desirable to have a humidity override included in a setpoint reset algorithm. A humidity override would use data from one or more humidity or wet bulb temperature sensors in the supply air stream or the building zones. If the humidity level became unacceptable, further reset of the supply air temperature would be prevented.

Depending on the specific system, an air handling unit may have one or two supply air conditions that must be maintained under closed loop control. In simple VAV or reheat systems there will be one supply air condition which is selected to match the space loading. For multizone or dual duct systems, there is a hot deck and a cold deck supply air setpoint. These must be selected both to match the space loading in the zones supplied, and to minimize the difference between the two supply conditions to avoid excessive reheating and recooling.

The use of fixed design setpoints for air supply temperatures is an easy approach, but can result in energy loss through reheating or recooling of air, either by mixing of hot and cold deck air streams which are widely separated in temperature, or by terminal reheat of excessively cold supply air. Since conditions change throughout the year and even during the day, the energy lost will vary with time.

"Reset" is defined as a method of changing the setpoint of a system to minimize system energy consumption by matching system output to the system load. Reset control methods may be categorized by the means used to select a setpoint temperature for different load conditions. Some control algorithms might use outdoor air temperature as a load indicator, while others might directly or indirectly measure actual space heating and cooling requirements.

3.1 Reset Algorithm for Single Path Systems Based on Outside Air Temperature

The least complicated method of supply air reset is outside air temperature reset. The basis of this method is the assumption that the heating or cooling requirements of a zone can be considered a function of a single variable, the outside air temperature. In reality, zone requirements are dependent on other factors such as solar gain, wind conditions which affect air infiltration rates, internal heat generation rates, and latent heat loads. However, the outside air reset method is not intended to exactly match supply air setpoints to system requirements. The reset schedule used is an estimate based on calculations for the best setpoint temperature at various design conditions where solar gain, infiltration, and internal loads are specified in addition to outside air temperature. If the design conditions selected are an accurate estimate of the conditions encountered in actual operation, then the outside air reset method will yield acceptable results, and savings over the use of a fixed setpoint.

If the infiltration, internal heat generation rates, and maximum solar gains are relatively constant in a given zone from day to day, the required dry bulb temperature for air entering the zone to maintain zone conditions can be assumed to be approximately a linear function of outside air temperature. The curves in figure 2 were generated using a simple model of a zone with an internal heat source, a gain or loss to the outside air, and a constant volume supply air source with a variable room entering dry bulb temperature. Latent loads were not included. A more complicated zone model could be used to generate more accurate curves.

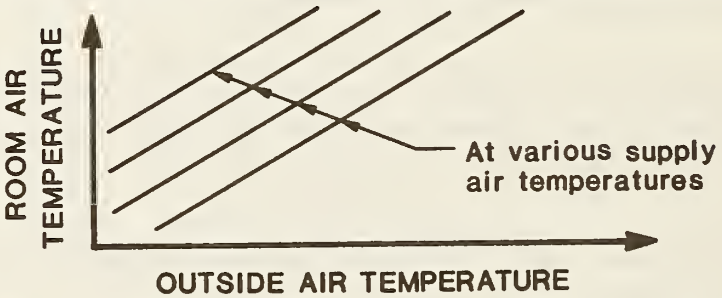

figure 2. Steady-state room temperature versus outside air temperature for various supply air temperatures.

Figure 2 shows that for a fixed supply air temperature, the steady state room temperature will vary with outside temperature, as would be expected. The curves for different supply temperatures can be considered to be parallel, indicating that figure 2 can be described by:

$$T_{room} = A * T_{oa} + B * T_{sa} + C, \tag{1}$$

where A,B, and C are constants, T_{oa} is outside air temperature, and T_{sa} is supply air temperature. The value of the constants will change with the characteristics of the zone. If the zone were highly insulated, the curves in figure 2 would be nearly horizontal. If the internal heat generation were increased, all of the curves in the figure would be translated upward. If equation (1) is solved for the supply air setpoint temperature:

$$T_{sa} = D * T_{room} + E * T_{oa} + F, \tag{2}$$

where D,E, and F are constants derived from A,B, and C. If a constant room temperature is desired, the supply air temperature is a linear function of outside temperature. If different room temperatures are required for cooling and heating seasons, the supply air temperature can be described by one equation for T_{sa} versus T_{oa} for outside temperatures above a balance outside air temperature (summer) and another equation for conditions below the balance (winter). An example of summer and winter curves is shown in figure 3. Obviously, if two room temperatures are used, at some point during the year there must be a switch from winter to summer, or summer to winter operation, since the two lines in figure 3 have no common point. The switch from winter to summer operation would ideally occur when the cost of providing air at the summer setpoint is less than the cost of supplying air at the winter setpoint.

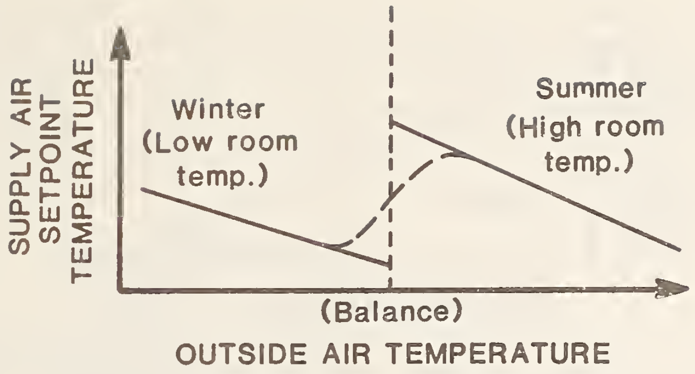

figure 3. Required supply air setpoint temperatures versus outside air temperature for winter and summer room temperatures.

If the building zones are under zero energy band control, then the space temperature will be allowed to vary from the "winter" setpoint to the "summer" setpoint throughout the year. When it is cold outside, the space temperature will move to the winter setpoint. When it is hot outside, the space temperature will then move to the summer setpoint. When outside conditions are moderate, the space temperature will be somewhere between the summer and winter setpoints. This might be represented by the dashed line on figure 3, between the two setpoint lines, which would prevent the abrupt change from the winter to the summer setpoint at the balance temperature.

It will be assumed that, for either the heating or cooling season, one unbroken curve will allow selection of the room entering air temperature for any outside air temperature. There are two additional factors which complicate the situation. The first factor is that due to air temperature rise through the supply fan, duct leakage, and thermal losses and gains, the temperature entering the air handling unit supply fan will not be the same as the air entering the zone. The sensor used to control supply air temperature is usually placed at the supply fan inlet, while the temperature of the air entering the zone is usually used in zone calculations. Therefore the actual supply air temperature used will be different than the desired zone inlet temperature. The change in air temperature can be estimated using standard methods [2].

A second factor complicating outside air reset is that unless the system is a single zone system, each zone will have a different equation for desired supply air temperature versus outside air temperature. The less well designed the system, the more diversity there will be between different zones served by the same air handler. Figure 4 an illustrates an extreme case of this situation. In this figure, two curves are shown, representing two zones out of several supplied by an air handler. One of the zones, 1, might be an interior zone, well insulated from the outside air. It requires a relatively constant supply air temperature. The other zone, 2, might be a perimeter zone, coupled to the outside air temperature. It requires a lower supply temperature in warmer weather than in cooler weather.

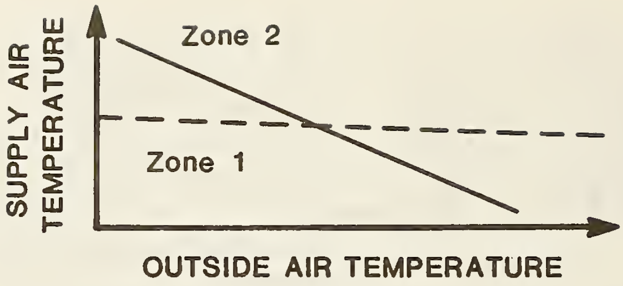

figure 4. Supply air temperature versus outside air temperature for two extreme zones served by an air handling unit.

Deciding on which curve from figure 4 to use for supply setpoint selection is somewhat dependent on the system type. For a single path (or deck) system, the system type is either terminal reheat or VAV. For a reheat system, the lowest supply air temperature should be selected, since air to the other zones can be reheated. This would indicate that curve 1 in figure 4 should be used at lower outside temperatures and curve 2 should be used for higher outside temperatures. For a VAV system without reheat, however, the situation is different. In the summer, the setpoint should be selected to satisfy the zone with the highest percentage of maximum zone cooling load, since the air to zones with lower percentages of maximum load can be throttled. In the winter, the setpoint should be selected to satisfy the zone with the highest percent of maximum heating load, since the air to zones with lesser loads can be throttled.

When reset is applied to supply air setpoints, the use of setpoints which are too high or too low should be avoided. In summer, a setpoint which is too low may cause condensation problems or cold drafts. A summer setpoint which is too high under humid conditions may not reduce humidity sufficiently to provide comfort. In such a case it might be desirable to have even the zone of greatest cooling load require some reheat or mixing of hot and cold air to reduce humidity. Alternatively, if comfort is not of primary importance, it may be desirable to use a supply temperature which will not satisfy the worst zone, thus causing some occupant discomfort in this zone, in order to minimize reheating in other zones.

For a VAV system without reheat, the use of supply air reset may not result in a net reduction of energy cost. Setpoint reset in VAV systems without reheat would only save some energy used by chillers and boilers in the plant, but not energy wasted by reheating or mixing of air streams, since these effects do not occur with a VAV system. However, in a VAV system with reset, more fan energy might be used to condition a space with a reset setpoint if the system is equipped with supply fan air volume reduction equipment, since with a reset supply temperature the fan must run at higher volume and consume more electrical power, given the same space load.

Based on the previous observations, it is assumed that a plot of supply air setpoint temperature versus outside air temperature can be drawn using four straight lines, as in figure 5. This can be done by plotting four curves for the zones with extreme loads, for winter and for summer, as in figures 3 and 4, and using rules for the system type, as described above, to draw a single curve which replaces the four curves. Alternatively, separate curves could be developed for winter and summer, and a manual change from the use of one curve to the other could be used.

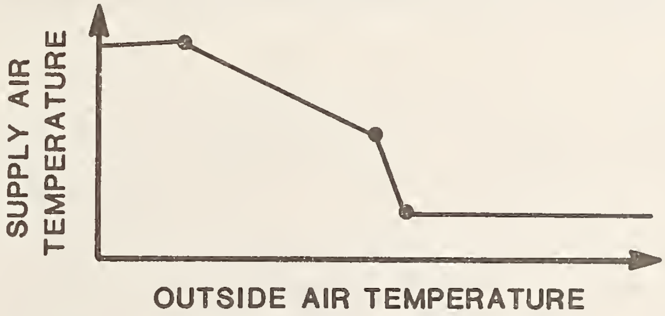

figure 5. Supply air temperature versus outside air temperature for an an air handling unit.

At high or low outside air temperatures, the setpoint would be constant to avoid extremes of temperature. The two middle regions of the curve might have different slopes, to allow use of the lowest curve like those in figure 4. The selection of the specific curves for any system must be performed by a person familiar with the building design. A program used at the central level could be used to assist a building operator in the selection of the proper values for a particular building. The points describing curves like those in figure 5 could then be used by the FID software during periodic execution of a supply air reset algorithm.

A general algorithm to perform outside air reset is shown in figure 6. This algorithm is intended to implement the reset schedule of figure 5. The outside air temperature is determined from an analog input point to the BMCS system. There may be several setpoints which are being reset by the same algorithm. Any or all of these setpoints may be designated as fixed if, for example, the building operator wants to hold the setpoint for a particular air handler constant, with no reset. If the setpoint is fixed, no reset is performed. If the reset is to be performed either a table or equation is used to determine the setpoint temperature. The equation or table is called the reset schedule. It is possible and may be desirable to have a different reset schedule for each setpoint to be reset. Once the new setpoint is determined from the schedule, it is substituted for the old setpoint. If there are more setpoints to reset, the same steps are repeated for the other setpoints. Otherwise an exit is made from the setpoint reset algorithm. The algorithm is intended to be periodically executed at some interval, which could be anywhere from once per day to once every minute.

The drawback to the use of an outside air supply air reset algorithm is that it is essentially open loop control, without feedback to the control system to allow the system to sense whether all zones are being adequately conditioned without waste. The success of outside air reset depends heavily on the correct determination of the reset schedule, which is in turn based on proper selection of design conditions and estimation of the response of the building zones at those conditions. It also necessary to change the reset schedule when there is a change in season. The advantage to outside air reset is that it is easy to implement in software, and requires only an outdoor air sensor.

An example of an actual outside air reset algorithm implemented in a real BMCS system for a constant volume reheat air handling system is described in section 7.2. Listing of the software is given in Appendix A.

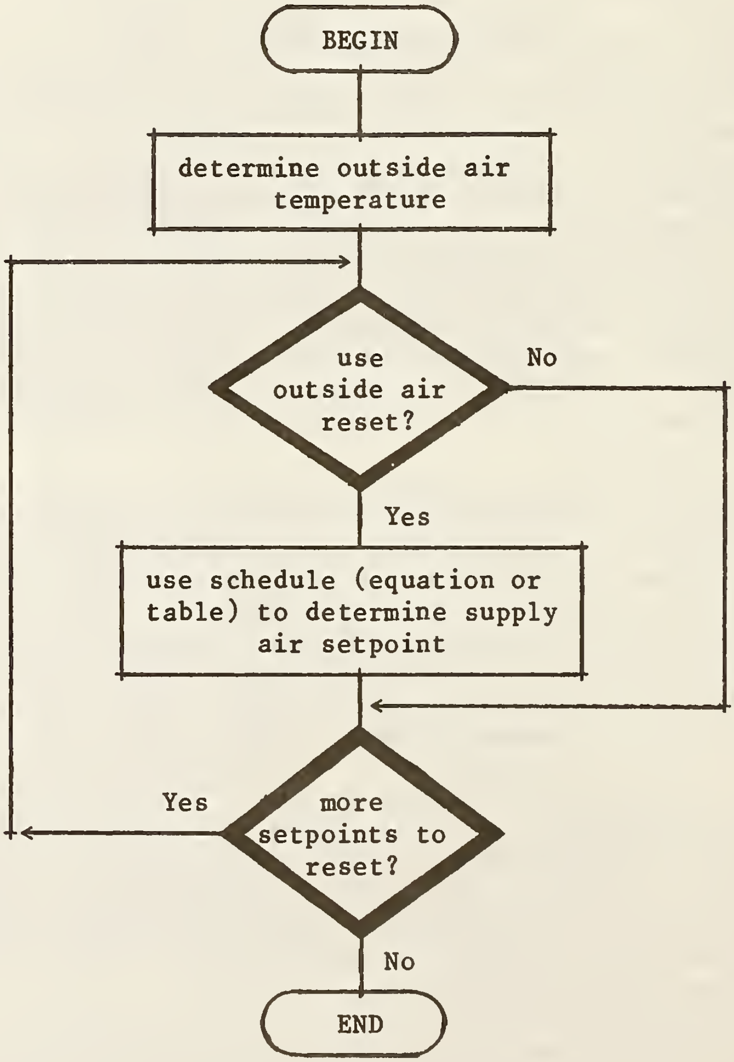

figure 6. Outside air reset algorithm for supply air temperature setpoint in single path(deck) air handling systems.

3.2 Reset Algorithm for Dual Path Systems Based on Outside Air Temperature

When an air handling system is of the dual path or dual deck type (multizone or dual duct), there are two supply air setpoints be concerned with. One air handler path supplies cool air with a setpoint lower than the other path, which supplies warm air. It is possible for each setpoint to be reset independently of the other, or one to be reset while the other is held fixed.

The reason for having two decks in a dual path system is to allow diversity of loads in the multiple zones served by a dual duct or multizone air handling unit. If all zones had identical loads, they could all be supplied with air at the same temperature and the same flow rate. In such a limiting case, both decks of the air handler would have the same setpoint. If a building is designed with zones of different heating and cooling requirements, the same supply air setpoints may be used for all zones by using different air flow rates for different zones. However, the heating and cooling requirements of the zones will diverge from the design values when internal, solar, transmission, and air infiltration loads become different from assumed design values. Under these circumstances the hot and cold deck setpoints must be different.

Ideally, at least one zone with a cooling load should be using 100 percent cold air from the cold deck and no warm air from the hot deck. Similarly, at least one zone with a heating load should be using 100 percent warm air and no cold air. In dual path systems without any supply air setpoint reset, however, the setpoints for the decks are usually fixed throughout the year or the season, resulting in conditions where all zones are using a mixture of warm and cold air. This situation results in energy waste due to reheating or recooling of air.

The basic strategy for dual path supply air reset is to set the hot deck temperature to cause a particular zone, the one which currently has the hot deck air making up the greatest percentage of the total air flow into the zone, to use only a small amount of cold deck air. Therefore the hot deck temperature will be the entering air temperature required to keep this zone at a comfortable temperature. Similarly, the cold deck temperature is set to cause a different zone, the one which currently has the cold deck air making up the greatest percentage of the total air flow into the zone, to use only a small amount of hot deck air. The cold deck temperature is then the proper entering air temperature for this zone.

The same assumptions apply to selection of a proper inlet temperature to a zone as were made in the case of single path systems in section 3.1. Basically zones are assumed to require a supply temperature which is a linear function of outside air temperature in order to maintain a desired room temperature without reheating or recooling supply air. Curves of supply temperature versus outside air temperature can be drawn as in figure 4. For a single path system, a single curve was chosen which fit the system requirements. For a dual path system, two curves must be chosen, one for the hot deck and one for the cold deck. The simplest solution is to select the hot deck curve to follow the highest points of the two curves in figure 4, and to select the cold deck curve to follow the lowest points of the curves in figure 4. This is illustrated in figure 7.

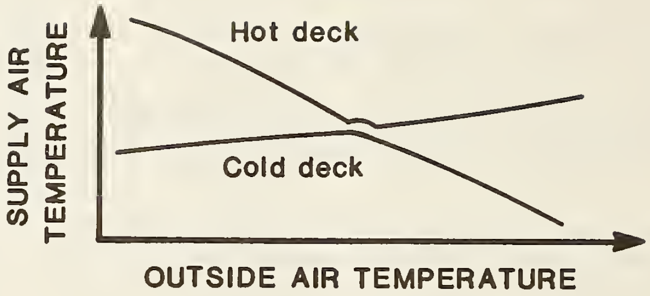

figure 7. Supply air temperature versus outside air temperature for two decks of a dual path system before application of limits.

As with single path systems, there are limits to deck setpoints when they are reset. The same restrictions apply as with single path systems with the additional problem that a hot deck setpoint may be set to a temperature colder than the equipment in the deck will allow, or a cold deck setpoint may be set to a temperature which is warmer than the equipment will allow. An example of this is a case where there is no heating apparatus in the cold deck and a setpoint above the air temperature entering the cold deck is specified.

As discussed in section 3.1, the outside air supply air reset method does not provide feedback to the control system as to the correctness of the setpoint choice. An example of this is that in dual path systems, if an incorrect schedule produces excessively low cold and hot deck setpoints, the building will become too cold and perhaps be using excessive mechanical cooling. If reheat coils exist, reheating will keep the building comfortable, but cause energy waste.

The schedule depicted in figure 7 must be modified to provide limits to the deck setpoints, in the same way that the schedule in figure 5 for single path systems was created by applying limits to the schedule derived from figure 4. The outside air supply air reset algorithm in figure 6 can be used for dual path systems, if the cold deck and hot deck setpoints are treated as separate setpoints with individual setpoint reset schedules. As with the single path systems, these schedules must be changed with the seasons, if a change in room temperature is required when a new season begins.

3.3 Setpoint Reset Algorithms based on Zone Requirements

Use of outside air temperaure to reset supply air setpoints has the inherent drawback that a simplified model of the HVAC system is used to represent the system and control actions are made based on the predicted response of the model rather than the actual response of the system. The control is open loop, without feedback. The alternative to the outside air reset method is to actually measure the requirements of the zones served by the air handling unit, and reset the setpoint until the zones with the worst loads are just satisfied. This results in closed loop control since there is a feedback loop from measurements at the local zone temperature control equipment to the controller determining the setback of supply air temperature. Figure 8 is a schematic block diagram showing a possible configuration of the complete system. An existing inner feedback loop controls the supply air based on a setpoint input. This setpoint input is based on the zone equipment output. This diagram implies that the system is continous in time, where in an actual system the setpoint would be changed only at discrete time intervals and held at the new value until changed again (a 'sample and hold').

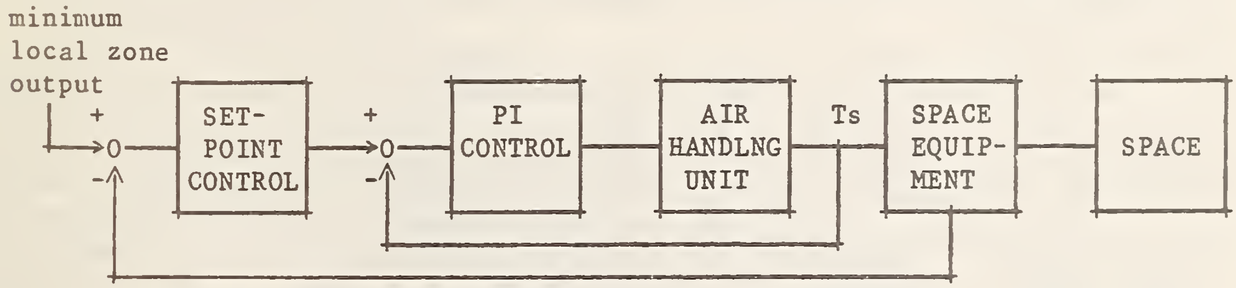

figure 8. Block diagram of feedback system for supply air reset based on zone requirements

There are two separate components to an algorithm for supply air reset on zone demand. First, the method of creating a feedback loop from the local zones to the setpoint controller must be decided upon, and the nature of the information to be determined from the feedback must be decided. Once the feedback loop has been arranged, a method must be decided upon for determining what the correct setpoint should be based on the feedback information.

There are three possible methods of determining the actual requirements of zones. All are based on instrumenting the building zones to some extent and this is a disadvantage of using a zone demand supply air reset algorithm. Outside air reset requires only the use of an outside temperature sensor. A complete implementation of load demand reset would involve at least one sensor in each zone. It should also be possible to select representative zones for instrumentation, taking into account the possible shifting of large loads between the zones of a building during the day or year. The sensor to be used in the zones depends on what type of local equipment and controls are used to control zone temperature. At this time, it is assumed that the local controls are not digitally controlled by the same controller that is controlling the air handler supply air temperature. The local controls will probably be some type of thermostat, either mechanical, electronic, or possibly digital. Eventually, most control systems may utilize some sort of microprocessor controlled thermostat with digital communication capabilities, or the local control may be taken over by the FID controller.

Local control mechanisms will either use on-off control, modulating control, or be non-existent. If local control is of the on-off type, a switch closure sensor can be installed in the zones to monitor the status of the on-off control. If this sensor is sampled by the controller, an approximate summation of the total on-time of the local conditioning equipment can be obtained. An example of this might be a thermal switch on a reheat coil or a contact on a wall thermostat.

If local control is of the modulating type, such as a VAV damper, modulating reheat valve, or dual duct mixing damper, the local sensor should be able to measure the position of the actuator. This sensor could be a potentiometer or similar device attached to the valve or damper, producing a change in electrical resistance with movement of the valve or damper. The measurement of damper position could be either averaged over a time period, sampled for a peak damper position, or used as a discrete measurement of instantaneous local equipment output.

If local control does not exist, or attachment of sensors to the local equipment is not feasible, an alternative is to directly measure the space temperature (and humidity) in each zone. In any zone there will be oscillations in temperature as conditioning equipment is modulated or turned on or off, and these oscillations can be monitored with temperature sensors. If the supply air temperature to the zone is exactly matched to the space requirements, the temperature oscillations will be minimal. If the the supply air temperature is incorrect, however, the local temperature will oscillate, if local conditioning equipment is active, or drift outside of allowable limits, if there is no local control of conditioning equipment. This information, then, can be used to alter, if necessary, the supply air setpoint.

When the feedback loop from the local zones has been implemented, information about heating and cooling in all instrumented local zones will be available. This information will be in the form of a value such as a total on-time of local conditioning equipment, or an instantaneous, average or peak value for local equipment output, or a value for space temperature oscillation frequency or rate of change. Some method must then be applied to use this information to determine the proper setpoint for the supply air.

The control of the supply air setpoint at a particular time is usually based on information from one of the zones served by the air handler. Which zone this is will probably vary seasonally or even from hour to hour due to changes in solar and internal gains, and will differ from system to system. Table 1 summarizes types of air handler systems, the zone used as a basis for reset, and a general method of selecting a setpoint. The basis for selecting the critical zone is not the absolute zone heating or cooling load, but is the ratio of the energy currently removed or delivered at a zone to the the total possible cooling or heating capacity available for a zone. This will be called the greatest percentage of maximum capacity. For a reheat system the zone with the largest percentage of maximum capacity will be the zone with the least use of local reheat. For dual path systems, the critical zone is the one with the greatest percentage of maximum heating capacity when setting hot deck supply temperature and the zone with the greatest percentage of cooling capacity when setting cold deck supply temperature.

For VAV systems, the situation is more complex. To minimize fan usage in a VAV system, the setpoint in the cooling season should be lowered, and based on the damper position in the zone of the smallest percentage of the maximum supply air flow. However, to minimize chiller energy in the cooling season, higher setpoints are required, and selection is based on the zone with the greatest percentage of maximum supply air flow. The reverse is true for the heating season. If local heating and cooling equipment is available, the selection of the zone is complicated by factors such as whether some zones are cooling and others are heating, and the cost of providing heating or cooling.

TABLE 1. Supply air reset criteria for various system types

system type	zone choice	method
1. Mix hot and cold air		
a. hot deck	Largest hot deck damper opening	Lower setpoint if hot deck damper not fully open. Raise if full open.
b. cold deck	Max. cold deck damper opening	Raise setpoint if cold deck damper not fully open. Lower if full open.
2. Reheat	Smallest amount of reheat(small % of max. cap.)	Raise setpoint to minimize reheat. Lower setpoint if reheat almost never on.
3. Packaged or unitary equip.and central air		
a. all zones heating	smallest % of max. local heat	Raise setpoint to minimize heating.
b. all zones cooling	smallest % of max. local cool.	Lower setpoint to minimize cooling.
c. Some zones cooling Some zones heating	Smallest % of max cooling if winter, smallest % of max. heat if summer. (or zone with most expensive local conditioning)	Raise setpoint to minimize heating if winter. Lower setpoint to minimize cooling if summer. Or adjust setpoint to minimize expensive local conditioning.
4. VAV (non-dumping)		
a. Minimum fan energy	lowest % of max supply air flow	lower setpoint to minimize air flow if cooling or raise setpoint to minimize air flow if heating.
b. Minimum supply air Conditioning	Largest % of max supply air flow	raise setpoint to maximize air flow if cooling or lower setpoint to maximize air flow if heating

Table 1 gives strategies for determining how to correct the current setpoint to minimize energy waste. For systems with local zone equipment which can only reheat the incoming air, the strategy is simply to minimize reheating of air which has been overcooled. In systems with the capability to both locally heat and cool air entering the zones, the strategies are complicated by factors such as whether the zone has a cooling or heating load, how expensive it is to lower or raise the setpoint of the supply air, and whether the zone temperature is allowed to float between limits (zero energy band). Two levels of strategies will be discussed. One level will assume that the information from a selected zone is sufficient to determine a new setpoint. This will be adequate for many systems with simple zone controls without zero energy band control. A second level is to include other factors and zero energy band zone control. A general algorithm for the lower level will be developed first.

The relationship between the supply air setpoint and the information from a zone currently being used to determine the supply air setpoint can usually be plotted in the form shown in figure 9. Figure 9 is an example for a zone with a reheat coil. The important point about this figure is that when the supply air setpoint is below the best value to maintain the zone condition, the zone equipment will have some measurable average output as an attempt is made to reheat the air to a better temperature. As the supply air setpoint approaches the best value for this room condition, the zone equipment output will approach zero. If the supply air setpoint is made too high, the zone equipment output will remain at zero. However, the zone will probably be uncomfortably warm. When the supply air setpoint is too low, the reheat coil will remain on. Continuous running of the reheat coil indicates that the room is too cold, but gives no indication of the error in the supply air setpoint.

For a simple system with local reheat and a constant space temperature, a practical approach to control of supply air setpoint is to assume that the best minimum value for zone equipment output is at some level slightly greater than zero, and to attempt control of the supply air setpoint to hold the zone equipment output at this level. If the setpoint is controlled to keep zone equipment output at zero, and the relationship of figure 9 is applicable, it is possible to determine that the setpoint is too low (local equipment on), but not if it is too high. By selecting the desired value of zone equipment output to be a small positive value, indicated as the control point in figure 9, then if the zone equipment output is zero, the supply air setpoint is known to be too high.

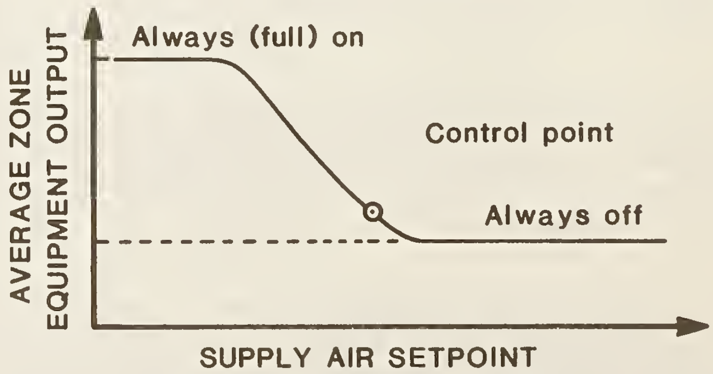

figure 9. Generalized zone heating equipment output versus supply air setpoint for a given room condition.

If the zone equipment is under modulating control and has both local heating and cooling capability, such as with heat pumps, an output versus supply air setpoint curve for this zone would have a similar shape compared to the curve in figure 9, but instead of remaining at zero output with increasing setpoint, There would be an increase in cooling output. The equipment would reach a maximum cooling output and stay there as supply air setpoint were increased. In this case, it is possible to determine if the setpoint is too high, and also the approximate error in the setpoint. A minimum value of zone equipment output must be specified for the heating and cooling output. The supply air setpoint must then be controlled to keep the output within the minimum values.

For a dual duct or multizone system, with two supply air setpoints, the local equipment is usually a modulating mixing box, providing a mix of warm and cool air. A plot of output versus supply air temperature for one deck would show the use of all warm air at low supply temperatures and all cool air at high supply temperatures. In this case the desired supply air setpoint is one which causes the mixing box to use air from only one duct (see table 1). Therefore the desired zone output is when warm or cool air flow is a maximum for the zone. The same principles apply, however, as in the case shown in figure 9, and therefore the control point should actually be when the warm or cool air flow is slightly below maximum.

Once a desired value for the local equipment output for the zone identified as the critical is selected, the actual zone equipment output can be measured, and compared to the desired value to determine how much the current output is in error. In the simplest case, a gain factor can be applied to the error to produce a correction to the current setpoint. For example, if a reheat coil is observed to operate 20 percent of the time, and the desired minimum is 5 percent, the error is 15 percent. If the gain is 0.033 degrees C/percent on-time, the correction to the setpoint is 0.5 degrees C. If the current setpoint is 15.0 degrees, the new setpoint would be 15.5 degrees. If the reheat coil in the zone is not operating at all, the error would be -5 percent. The setpoint correction would then be -0.165 degrees. Unfortunately, the setpoint might really be several degrees too high, but it is impossible to determine this. Thus, the response of the setpoint controller in this case might be slow when the setpoint is too high, although the setpoint would eventually arrive at the correct value.

More complicated algorithms could be developed to relate the supply air setpoint to the zone equipment output error, such as adding integration of past error to the algorithm (a PI controller). It is beyond the scope of this report to develop such algorithms, however.

Figure 10 depicts a general algorithm for supply air reset based on zone requirements. This algorithm is intended for periodic execution at some rate which must be selected based on how many measurements are required to obtain an accurate picture of what is occurring in the zones. Only after a sufficient number of samples have been obtained from the zones will the algorithm determine what the new setpoint should be. In figure 10, this is shown as an early exit from the algorithm if not enough samples have been collected. Each time a new set of samples is taken, the new set is either added to or averaged with the previous measurements and a count of the number of samples is incremented. If a measurement of modulating control output in the zones is being made, one sample may be sufficient to determine a setpoint, and the sample rate should be the rate at which the system is likely to require a new setpoint (a rate of once every fifteen minutes may be acceptable). If a measurement of on-off control output is being made, however, one measurement will not be sufficient. If, for example, twenty measurements are made on an on-off controller, this will allow the maximum resolution of on-time to be 5%. If the setpoint should be adjusted every fifteen minutes, a sample time of 45 seconds would be required.

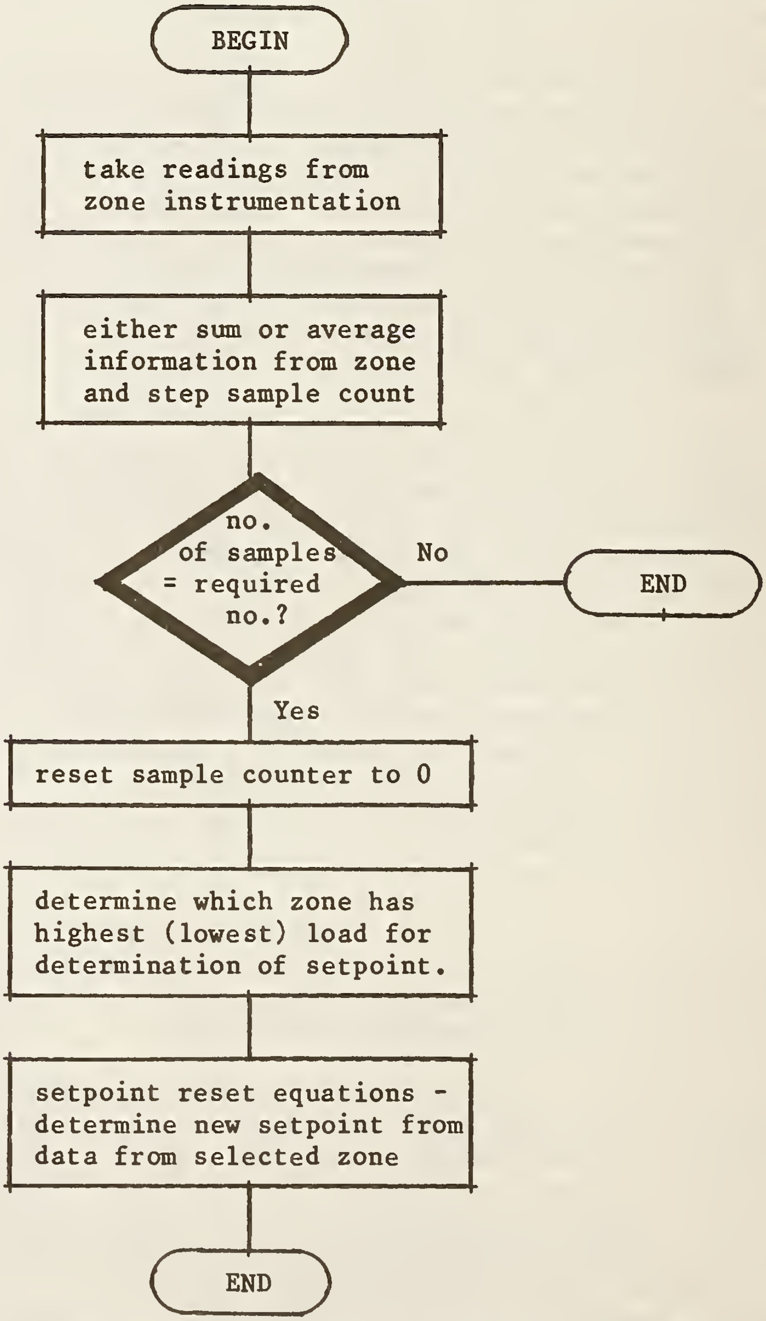

figure 10. Supply air temperature setpoint reset algorithm using feedback from measurement of local zone conditioning requirements.

After sufficient samples have been taken from the zones, the sample counter is reset, and the algorithm is ready to determine a new setpoint. A determination of which zone to use as a basis for the new setpoint is made, based on the type of the air handler system and the season. Rules for this were discussed previously. Once a single value for local zone activity has been determined, this can be used as input to equations to predict what a new setpoint should be and the setpoint can be altered. The equations used can be multiplication of an error in zone activity by a simple proportional or gain factor to produce a desired change or setpoint. More complex equations are certainly possible.

An example supply air setpoint reset algorithm based on the procedure in figure 10 is described in section 7.3. The system controlled in the example is a constant volume, terminal reheat system, with two zones. Actual software listings for the algorithm are included in appendix B. The basic algorithm is also applicable to dual duct systems, if the zone determination step is expanded to include a selection of separate zones for the hot deck and cold deck setpoints, and the setpoint equations are expanded for hot and cold deck setpoints.

If the zones in a building are under zero energy band control, more complicated algorithms than the one in figure 10 may be necessary to optimize building energy use. If, for example, the temperatures of the zones in a building were all floating between limits, but none were at the limits, and if mechanical equipment were being used to cool the supply air, energy would be wasted. If the supply air setpoint were adjusted to move the space temperature closer to the high limit, mechanical cooling would be reduced, and energy would be saved. More sophisticated instrumentation would be required for this application, such as sensors for measurement of space temperature or thermostats with analog or digitized analog output.

4. DAY/NIGHT SETBACK

Most commercial buildings are not occupied 24 hours a day, and do not require space conditions to be within a comfort zone when unoccupied. When the occupants leave a building, usually at night or on weekends, the space conditions can be allowed to drift outside of the usual setpoints for space temperature and humidity. If weather conditions are not severe, the HVAC equipment can be turned off completely. In many cases, however, weather conditions might result in space temperatures becoming so low or high as to either cause damage to the building (e.g. freezing, condensation, high humidity), or make it impossible to recover to a comfortable temperature before building occupation. In such cases the HVAC equipment must be activated to keep the space at a minimum or maximum temperature or humidity condition. The temperatures and humidity values at the minimum or maximum conditions replace the normal occupied period space setpoints. This strategy is commonly called "setback". Setback is usually associated with a lowering of space temperature setpoint. If the space temperature setpoint is raised, such as during the cooling season, this may be referred to as "setup." The modifier "day/night" is also added to the term "setback," to imply that the setback occurs at night. However, some buildings may have occupancy schedules not related to day and night, such as theatres and churches.

Space comfort condition specification also includes a minimum ventilation rate. This is commonly set at a minimum value for all conditions and is not under closed loop control. If the ventilation rate is placed under control, then the setpoint of minimum ventilation air can be setback, just as the temperature can be setback. Usually the ventilation level is setback to zero by closing the outside air dampers during unoccupied periods.

4.1 Local Space Equipment

Day/night setback is usually accomplished throught the control of local heating and cooling equipment located in the zones of a building, since this is the equipment which directly determines the space temperature. Although the basic concept of day/night setback is simple, the design of a general setback algorithm is complicated by the number of different system types and local equipment configurations. Day/Night setback is applicable to any building in which space conditions may be allowed to drift out of normal ranges at any part of the day. However this discussion will be limited to non-residential buildings which contain a central air handling system providing ventilation air and possibly conditioned air to the building spaces.

Table 1 in chapter 3 gave a listing of four generalized air system types which may serve a building zone. These types may be mixed in any particular building, with one type of system serving, for example, a perimeter zone and another type serving an interior zone. The actual control of local space conditions is usually accomplished by a separate controller device located in or adjacent to the zone. This device will be referred to as a thermostat, although more complex controllers such as those used in VAV systems might not usually be referred to by this term. Table 2 is a listing of the possible types of thermostats which might be used to control zone temperature.

TABLE 2. Space zone thermostat types

thermostat type	system type	comments
1. On-off heating or cooling only	reheat, package AC or HP, radiation	Setup and setback not possible at same time. Manual choice of heating or cooling equipment control.
2. On-off heating and cooling	package AC or HP	Setup and setback not possible at same time. Controls both heat and cool equipment at same time. Subject to cycling from heating to cooling.
3. On-off zero energy band heating and cooling.	package AC or HP	Setup and setback possible at same time. Gap between use of heating and cooling equipment.
4. Analog heating or cooling only	VAV, modulating reheat, hot/cold air mixing	Setup and setback not possible at same time. Manual choice of heating or cooling equipment control. Produces variable output.
5. Analog heating and cooling	hot/cold air mixing system, 4 pipe fan coils and radiation	Setup and setback not possible at same time. Produces variable output on one or two output lines.
6. Analog zero energy band heating and cooling	4 pipe fan coils	Setup and setback possible at same time. Gap between heating and cooling signals.

In table 2, the thermostats are one of two basic types, either on-off or analog. On-off thermostats produce either no output signal or an output signal of a fixed level. The output can be used to turn on or off equipment which is to be either fully on or off. Analog output thermostats can be used to modulate the output of zone local equipment. The output of such a thermostat varies with the difference between the setpoint and the measured space condition. In addition, thermostats can be classified as either zero energy band or conventional. A conventional thermostat is used to maintain a space at a fixed setpoint. A zero energy band thermostat is intended to allow the space condition to float between limits which may be as much as 5-10 degrees C apart.

Table 2 implies that zero energy band control is not possible with certain system types. Strictly speaking, this is true, since zero energy band control at the zone level requires that the zone controls be able to both locally heat and cool the zone. In a system such as a terminal reheat system, the cooling of the zone is provided by the temperature of the air from the air handler, which the reheat thermostat has no direct control over. However, it is possible to provide effective zero energy band control for the zones if the local thermostat can provide a signal to the air handler controller whenever the local zone is outside of zero energy band limits. For example, with a terminal reheat system, the local thermostat could provide a signal if the space temperature were above the upper space temperature limit. In this case the supply air temperature could be adjusted upward until either mechanical cooling at the plant could be turned off or until the zone temperature was at the upper limit. If the zone temperature were below the limit, the local reheat coil would keep the zone at the limit.

Local zone thermostats can be implemented in many types of devices. A thermostat can be mechanical, with a bellows or bimetallic strip moving a mercury switch, or pneumatic, with a fluid filled temperature sensor producing a fluid pressure which is converted to an air pressure, or electronic, using a sensor producing an electrical output signal. Many new thermostats are being designed with microprocessors and digital interfaces. Most thermostats have traditionally been set, calibrated, or programmed at the thermostat location. Thermostats to provide day/night setback have been built with internal clocks to switch between day/night setpoints. In order for day/night setback to become a function controlled by a BMCS (EMCS), the local thermostats must have the abiltity to either switch between locally programmed setpoints on the reception of a signal from a remote controller, or to have the setpoint directly programmed by the remote controller. Another concept is to have the remote controller take over the function of the local thermostats.

To reduce manual reprogramming requirements for setback of local thermostats at the transitions between cooling and heating seasons, it may be possible with some thermostats to implement cooling setup and heating setback at the same time. For a zero energy band thermostat, this requires that the zero energy band be increased in size on both ends of the band.

Control of the ventilation air provided to a space is usually not implemented locally. The criterion for acceptable space conditions is usually a minimum quantity of outdoor air per occupant of a zone. Some systems measure either occupant count or carbon dioxide concentration to control the amount of ventilation air. If a zone has no occupants, no ventilation air is required. The outdoor air quantity is varied by changing the opening of the air handler system outside air dampers. In this report, only change of ventilation air quantities from occupied conditions to unoccupied conditions will be considered.

4.2 Space Temperature and Ventilation Setback

When temperature and ventilation setback are to be considered for use in a particular building zone, the characteristics of the zone will determine to what degree setback may be used. If a zone is occupied continously, then no setback will be possible. Examples would be security guard offices or buildings with multiple shifts of workers.

If the zone is unoccupied for part of the day, but sensitive equipment or materials are located in the zone, or temperature sensitive equipment runs continously, then a limited setback may be possible. If the equipment or materials do not require ventilation, but do require a certain temperature range, it may be possible to shut off ventilation air to the zone. Examples of this type of zone would be computer rooms, laboratories, or rooms for storage of temperature sensitive chemicals.

If a zone is unoccupied for part of the day and contains no sensitive equipment or materials, a setback of the zone temperature is possible. The local controller can be setback to a temperature which is above any temperatures where damage to the zone might occur, or setup to a temperature which is below a temperature where heat damage might occur. Often the cooling ability of the space is disabled since heat damage requires very high outdoor temperatures or solar gain rates. Unless the local climate is mild, heating equipment is not disabled since cold damage such as condensation or freezing may occur at temperatures not that far below room temperature. A building zone whose setpoint has been setback can maintain the minimum space temperature by one of two methods. Many systems have a local perimeter heating system which does not require the central air system to be operating. Examples are terminal reheat systems with coils in the zone space (induction), or perimeter hot water radiation coils. In such systems the air handler fans may be completely shut off during the setback period. If a local perimeter heating system does not exist, the air handling system must be used to provide warm air to the space. Examples would be VAV, dual duct, or multizone systems without local zone heating equipment. In this case the air handler fans must either be left operating or cycled on and off to maintain the minimum space temperature.

A consideration in setback or setup of thermostats is that when the thermostat setting is returned to normal before the start of the occupied period, local heating or cooling equipment may turn on at full output. In some systems this might be undesirable and it might be necessary to delay the return to the normal thermostat setting until after the air handling unit has started.

4.3 Day/night Setback Actions

The use of day/night setback involves two separate procedures. These are the transition of the building to the setback condition, which will be referred to as "shutdown," and the transition of the building from the setback to the normal condition, which will be referred to as "startup."

For shutdown the actions that may be taken are as follows:

1. thermostat setback and/or setup - this action causes the local zone control equipment to use a minimum and/or maximum space condition as the zone thermostat setpoint.
2. stop air handling unit - this action is used when the zone can maintain the minimum or maximum condition without assistance from the air handler.
3. change operation of air handling unit controller - this action is required so that the air handler controller will not attempt to control

the unit in the same way as it would under normal conditions. This includes the operation of automatic supply air setpoint reset controllers (see chapter 3).

For action 1, the control unit (FID) which manages the shutdown must either send a signal to the local zone thermostats which will cause them to use a setback and/or setup setpoint for the zone, or somehow reprogram the zone thermostats to use an alternate thermostat setting. The choice of whether to force a setback or setup thermostat setting may have to be made as a function of the season. If the local zone equipment is not capable of maintaining the space condition without the air handling unit, then either the FID must monitor the zone conditions and restart the air handler if the space approaches minimum or maximum condtions, or the local zone thermostat must provide a signal which the FID can interpret as indicating that the zone requires that the air handler be activated.

Action 2, stopping the air handling unit, will usually consist of a number of separate actions including stopping the supply fan, and if present, a return fan, shutting valves to heating and chilled water coils, shutting all outside air dampers (including minimum outside air dampers), and stopping any auxiliary pumps or fans. If the zones require that the air handling unit provide conditioned air during setback, action 2 would consist only of shutting outside air dampers, and some of the non-essential air handler support equipment.

Changing the operation of the air handling unit controller, action 3, is required to prevent the controller from trying to maintain a supply air temperature when there is no airflow through the unit. If the FID is also running an algorithm to reset supply air temperature setpoint, it may be necessary to disable this algorithm, unless the supply air setpoint is initialized at the startup of the air handler.

For startup, the following actions may be required:

1. removal of thermostat setback and/or setup

2. start air handling unit

3. return operation of air handling unit controller to normal

For startup action 1, the control unit (FID) which manages the startup must either send a signal to the local zone thermostats which will cause them to use the normal setpoint for the zone, or reprogram the zone thermostats to use the normal thermostat setting. Startup action 2, starting the air handling unit, will usually be the opposite of stopping the unit. The start operations will include starting the supply fan, and if present, the return fan, opening outside air dampers for minimum ventilation, and starting any auxiliary pumps or fans. A delay between successive starts of separate pieces of electrical equipment should be used to avoid high utility demand charges. Returning the operation of the air handler controller to normal will cause the outside air dampers and heating and cooling coils to open as needed. If the FID is also running an algorithm to reset supply air temperature setpoint, it may be necessary to initialize the supply air setpoint at the startup of the air handler. Action 1 may be performed after 2 and 3 in certain situations where local equipment might turn on unnecessarily when the space setpoint is returned to normal.

4.4 Basic Setback Algorithm

The shutdown and startup sequences described in section 4.3 will be used before and after an unoccupied period. These sequences can be initiated in one of three ways. The simplest method is by a manual command to the FID from a building operator to either startup or shutdown. The disadvantage of this is that the operator must always be present before the sequence is to occur. Also the timing of the shutdown and startup determines the energy savings which will result from the use of setback. A manual setback will yield erratic savings if the operator forgets or is late in starting a sequence.

A second method is to use "time of day" control to initiate a setback sequence[4]. This method uses an algorithm in the FID which allows a "task" to be scheduled to occur at a specific time of day on a specific day of the week. A setback shutdown could then be scheduled to occur at, for example, 5PM, Monday through Friday, and a startup could be scheduled to occur at 6AM Monday through Friday. The startup time would have to be scheduled to allow enough time for the HVAC equipment to bring the building from the setback condition back to the normal state before the building were occupied. This time will vary depending on the severity of the weather. During the spring, the startup might require one half-hour, while during severe winter conditions the startup might require as long as 8 hours. To some extent the schedule can be changed to reflect the weather, but maximum savings occur if the end of startup recovery always coincides with building occupancy. With shutdown, the sequence may be scheduled to start when the building occupants leave. However, the shutdown can often be started prior to the unoccupied period and space conditions will not deterioriate out of the comfort region until after the building is unoccupied. To achieve the maximum savings with setback, the setback startup and shutdown should be controlled by an "optimum start/stop" control algorithm, which makes calculations based on outside conditions and the past behavior of the building to select the best time to begin startup and shutdown[5].

Figure 11 represents a basic algorithm that would be used for day/night setback shutdown and figure 12 presents the basic algorithm for startup. These algorithms would be executed under control of one of the three methods mentioned in the preceding paragraph. The setback actions were described in detail on previous pages.

An example of setback algorithms based on the procedure in figures 11 and 12 is described in section 7.4. The system controlled in the example is a constant volume, terminal reheat system, with two zones. Actual software listings for the algorithms are included in appendix C.

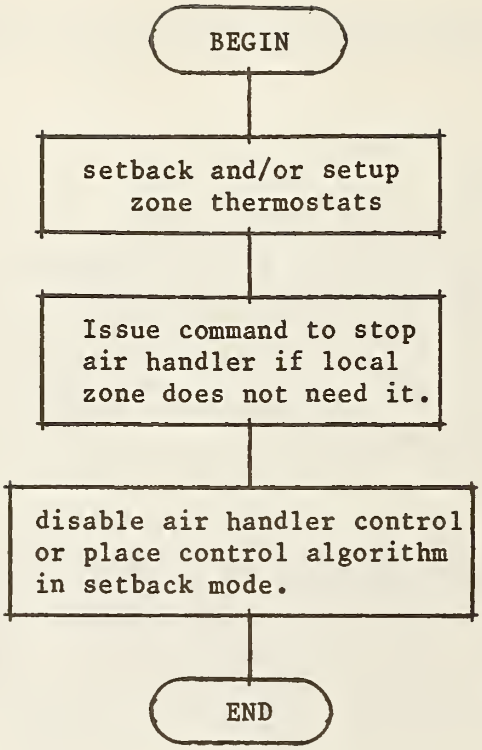

figure 11. algorithm for day/night setback from normal to setback state

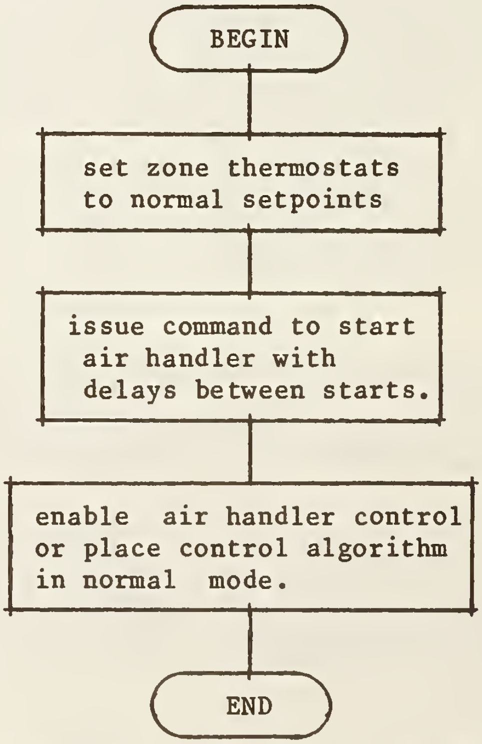

figure 12. day/night setback algorithm for return to normal state from setback

5. VENTILATION PURGING

Ventilation purging is a control strategy which uses outside (ventilation) air to reduce energy requirements and improve occupant comfort. This strategy is intended to operate in a building which has unoccupied periods when it is possible to allow space conditions to range outside of an envelope of acceptable dry bulb temperatures, humidity, and fresh air requirements. Ventilation purging is not useful in a building which must maintain comfort conditions at all times. Purging is defined as the use of outside air to either heat or cool a building during unoccupied hours (depending on the anticipated loads) if the outside air is at the correct conditions relative to the inside air. Ventilation purging is usually used as a cooling strategy. During the cooling season, cool outside air in the early morning (e.g. 4AM) can be used to precool a building if the outside air is cooler than the air currently in the building. This precooling can reduce the cooling capacity required for occupied period startup.

5.1 Basic Concepts

The ventilation purging concepts discussed here are assumed to apply to the use of purging as a cooling strategy. The usefulness of ventilation purging to provide inexpensive cooling during an unoccupied period depends on the characteristics of the particular building in which the strategy is to be used. Two characteristics are of primary influence. These are the building thermal mass and the unoccupied period internal gains. The ideal application for ventilation purging is a building with high thermal mass and low unoccupied internal gains, located in an area where the outdoor temperatures during the unoccupied period are lower than the temperatures during the occupied period. If outside air is used to purge such a building at night, then because the internal gains are low and entering air is relatively cool, the building mass will approach the outside air temperatures much more quickly than if no purging were used. This results in interior temperatures near the lower end of the comfort range by the time the building is to become occupied again. The high mass keeps building temperatures down for a relatively long period with subsequent reduced mechanical cooling equipment loads compared to days where purging is not used.

If a building has high internal gains during the unoccupied period, ventilation purging is still beneficial, but if the purging period is not timed correctly, savings can be negated. Timing considerations will be discussed in section 5.3.

Ventilation purging will not be desirable if the outside air temperature does not drop appreciably during the night, or if the building has very low thermal mass and low unoccupied internal gains. If the outside air temperature is not lower than the internal temperature, purging the building with outside air will actually increase cooling loads. If the building has low thermal mass and low internal gains during the unoccupied period, the interior temperatures will normally follow the outside temperature changes closely and ventilation purging will have no useful effect.

In order to make use of ventilation purging, the building air handlers must be capable of a "purge cycle." A purge cycle usually begins with an air handling unit in an off state with all heat exchanger water and steam valves fully off and outside air dampers closed. This state would have been entered when the building became unoccupied. To begin the purge, the air handling unit controller must start the air handling unit supply fan, and possibly the return fan (if one exists), and fully open the outside air dampers. Outside air will then flow into the building space, and air in the building spaces will be exhausted to the outside. In some systems such as VAV systems, the zone supply air boxes may have to be forced to a fully open condition. To end the purge, the air handling unit fans will be stopped and the outside air dampers closed. Throughout the purge, any heating or cooling coils will not be allowed to operate.

An example of the temperature response of a building during a purge cycle is useful to illustrate concepts. Figure 13 is a graph of the average interior temperature, the outside air temperature, and the air handler supply air temperature for a simulated building during the course of an unoccupied period. The simulation is for a single constant volume air handler serving two zones with terminal reheat. The figure can be divided into six time periods when the air handling unit is in different states. At the start of the figure, the air handler is in the "normal" state and the building is occupied. The space temperature is at approximately 24 C. The fan is on and the supply air temperature is below 15 C due to mechanical cooling. During the next period, the fan is off, but the space is still occupied. Due to internal gains, the space temperature rises. The supply air temperature is shown as approaching the space temperature, but this is not significant since there is no air flow through the air handler. The building is unoccupied during the next time period (III in figure 13) and this causes internal gains to be lower and the space temperature to fall. During this period the outside air temperature drops to a lower value. In period IV, the ventilation purge takes place. The fan is activated and the supply air temperature quickly reaches the outside air temperature. The room temperature drops due to the purging. In region V the purging has stopped and due to internal gains the space temperature rises slightly. Finally, in period VI, the air handling unit is started and placed in a normal mode in preparation for the next occupied period.

Two important quantities should be observed in figure 13. One is the smallest difference between room temperature and outside temperature that the purging can achieve (marked as Δ_{min} in figure 13). The magnitude of this differential depends on the amount of unoccupied internal gain and the heating of the air due to fan temperature rise and duct gain as it passes through the air handling unit. As this minimum is approached, the room temperature will not decrease unless the outside temperature drops. The purging has no effect at this point. The other important item is the time required for the system to arrive at the minimum differential between room and outside air temperatures. This is the purging time, and it depends on factors such as the indoor and outdoor temperatures, the building thermal mass, the supply air flow rate, and the internal gain.

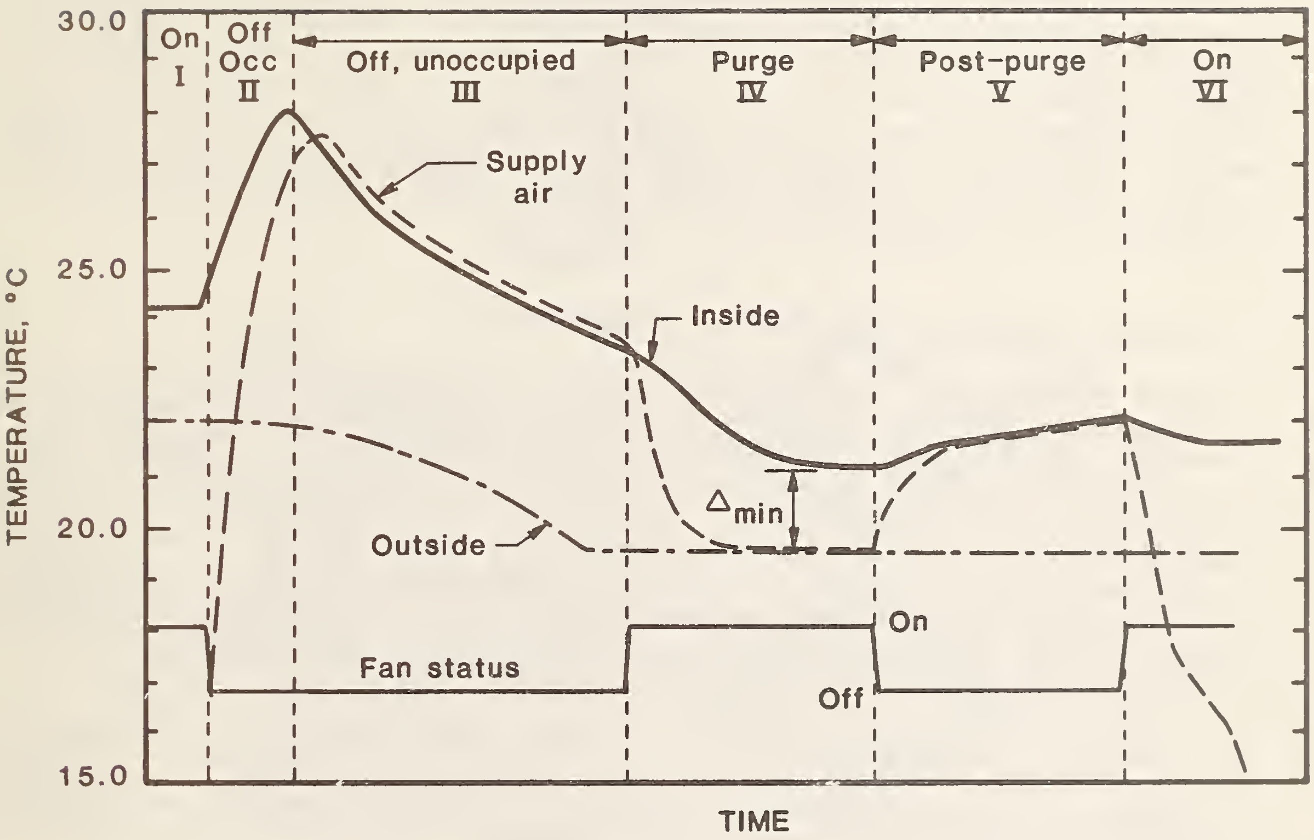

figure 13. Space, supply and outside air temperatures during an unoccupied period with ventilation purging

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Three types of measured data are required to implement a ventilation purging algorithm in a BMCS. The current state of the air handler used for purging must be known. In addition, measurements of outdoor air temperature (and humidity) and indoor air temperature (and humidity) must be made. The measurement of outdoor temperature is straightforward, but the determination of indoor temperature can be difficult. In a single zone small building, the indoor temperature can be easily determined from a single measurement. However, if the building is large, with multiple zones, and diverse internal and solar gains, each zone may be at a different temperature, particularly when the air handling units are off during the unoccupied period. Two alternatives to indoor temperature determination in this case are computing an average indoor temperature from a number of individual readings, or using selected temperature readings from zones with the highest and lowest temperatures. For determining when a purge is required, the highest temperature reading might be used. For determining when a purge should be stopped, the lowest reading might be used.

The use of ventilation purging can actually be considered an extension of the optimum start/stop control strategy [5]. With optimum start, the optimum time to begin the start up of air handlers and mechanical cooling equipment prior to the occupied period of a building is determined. The desired start time is just early enough to allow the building space to be brought to a comfortable state a short time before the building is occupied. If used in conjuction with optimum start time control, ventilation purging might be performed before the building start-up, or as a first stage in building start-up. In this report, the concerns involved in coordinating optimum start and ventilation purging strategies will not be discussed. Ventilation purging will be assumed to be an independent control technique.

5.2 Basic Algorithm for Ventilation Purge Control

A basic algorithm for ventilation purging must determine whether ventilation purging should be started if the building is unoccupied, or if purging is currently taking place, whether ventilation purging should be stopped. Figure 14 shows the structure of such an algorithm. It is assumed that a mechanism exists in the FID to periodically execute this algorithm at a selected time interval, such as every thirty seconds. The algorithm has three possible output actions each time it is executed. These are do nothing, start purging, or stop purging. The actual actions required to start and stop purging are assumed to be performed by another algorithm which is controlling the air handling unit, such as the controller described in section 7.2.

The algorithm of figure 14 has two major paths, one used if purging is currently taking place, and the other used if purging is not currently occurring. The determination of whether or not the air handler is purging is assumed to be made by checking a status variable which has been set by the air handling unit controller.

Each major path of the algorithm asks two questions to determine what action should be taken. Both paths ask the same two questions, but the answer will depend on which path the question was asked by. The two questions are "Does the building space require cooling?" and "can outside air provide a cooling effect on the building space?." The answers to these questions are determined by using measurements of the space and outside air temperatures, along with several parameters. Specific methods to answer the questions are discussed in the next section.

The algorithm in figure 14 may be stated in words as follows: If the air handling unit is off, the space requires cooling, and the outside air can provide cooling, a purge is begun. Otherwise no purge is started. If a purge is currently taking place, and either the space no longer needs cooling, or the outside air cannot provide cooling, the purge is stopped. Otherwise the purging is allowed to continue.

5.3 Ventilation Purging Algorithm Components

The two main component questions of the ventilation purging algorithm of figure 14 are presented in greater detail in figures 15 and 16. Detailed methods for answering the questions are presented in the following sections.

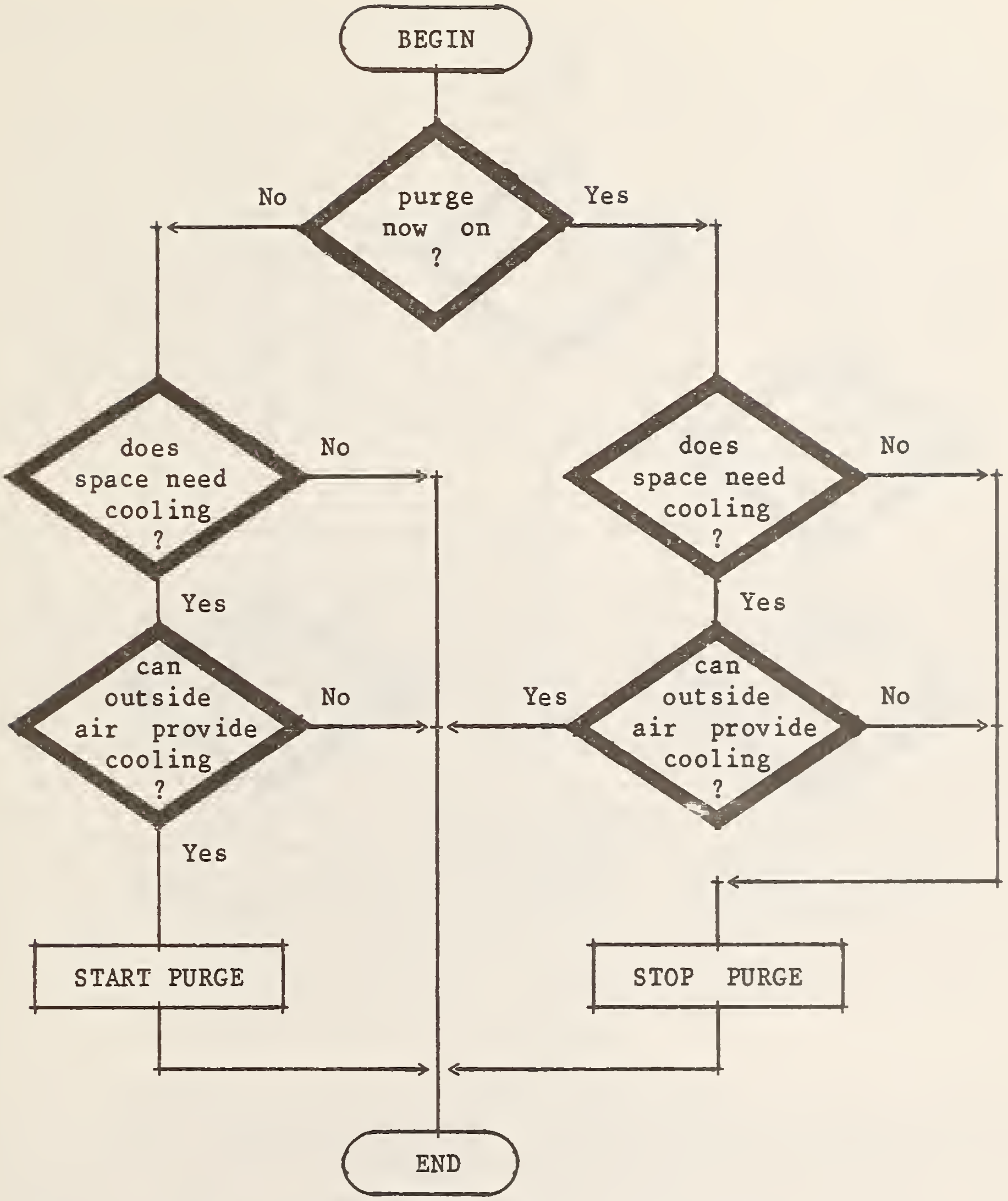

figure 14. Basic ventilation purging algorithm

5.3.1 Does the space need cooling? / not currently purging

This component of the ventilation purging algorithm determines whether the building space would benefit from ventilation purging during the unoccupied period. A simple test is to compare the current space conditions to space conditions defined as boundaries of a comfort zone. If the space conditions are warm or humid compared to the comfort zone conditions, then cooling is needed. If the space conditions are cooler or dryer than the comfort zone conditions, cooling is not needed. A threshold condition within the comfort zone must be defined, above which cooling is needed. This method will work if the space conditions have reached a steady state condition.

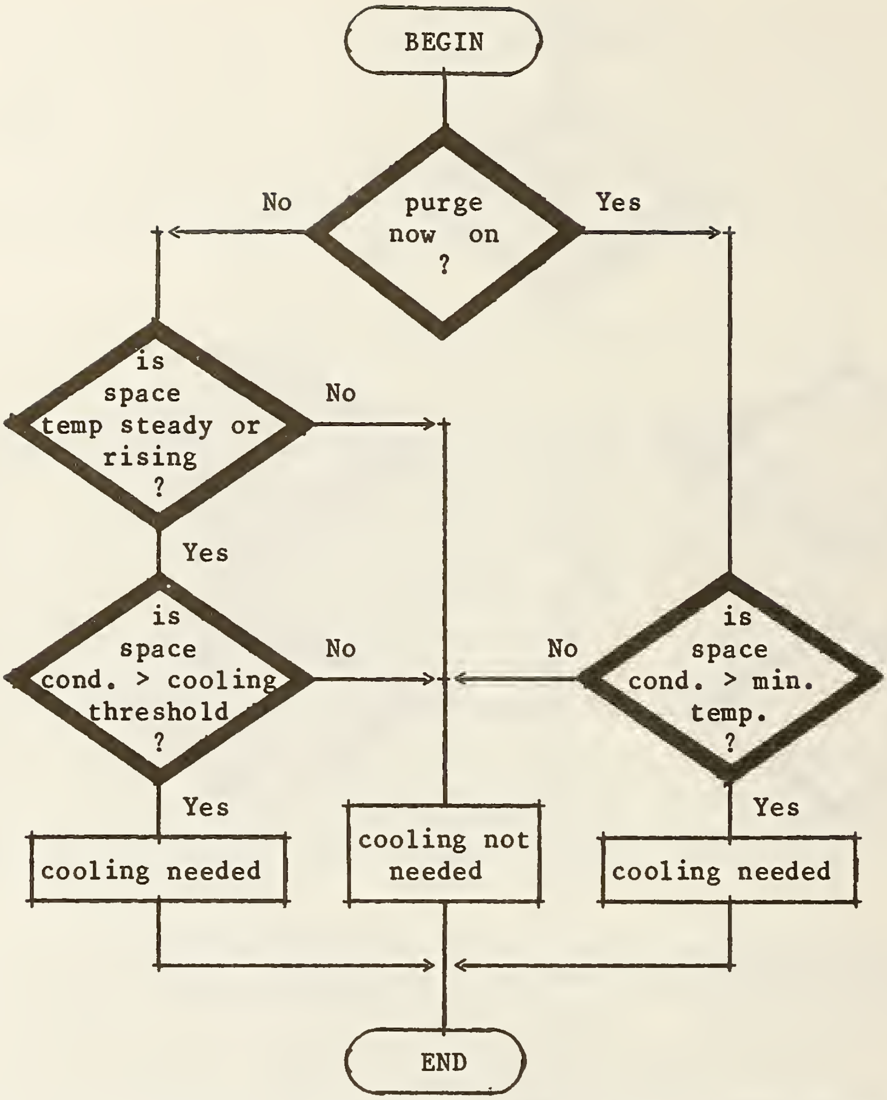

figure 15. Algorithm to determine if the building space requires cooling for the ventilation purging algorithm.

When the space becomes unoccupied, the space temperature may drop rapidly due to causes such as low outside temperatures or the removal of a large internal gain. Purging may not be desirable even though the space temperature is above the cooling threshold because the space temperature may reach comfortable temperatures without the use of purging. A second test, which determines if the space temperature is currently rising or holding steady, should be used in conjunction with the threshold test. An example method for determining the space temperature trend is given in section 7.5. These two tests to determine if the space requires cooling are shown in the left side of figure 15. If the result of both tests is positive, then cooling is needed. If the result of either test is negative, then cooling is not needed.

5.3.2 Does the space need cooling? / now purging

Once ventilation purging is in progress, the building space temperature should fall, if the decisions made by the purge-starting path of the algorithm have been correct. Eventually the space temperature will either level off at a value within or above the comfort zone, or, under certain conditions, at a point below the comfort zone. If the space temperature falls below the comfort zone, then heating energy will be required to bring the temperature back up, negating the benefits of the purge. Therefore it is important to stop the purging if the space temperature falls too low. This is accomplished by comparing the space condition with a lower limit. If the space condition falls below the limit, then cooling is not needed. As long as the condition stays above the low limit, then cooling is still needed. This test is part of the algorithm in figure 15, and is shown on the right side of the figure.

5.3.3 Is cooling available? / not currently purging

This test is intended to determine if starting the use of ventilation purging will provide practical cooling of the building space at the current time. As was shown in figure 13, if ventilation purging is started under the proper conditions, the space temperature will fall and level off at a value above the outside air temperature. To start purging when the differential between the space and outdoor temperatures is below the minimum differential would result in no useful cooling effect. Unfortunately the minimum differential is not a constant for all buildings, since it depends on building internal gains, thermal mass, and heat transfer coefficients. This differential could, however, be considered to be a constant for a particular building. The test for availability of cooling would then be to compare the current difference between indoor and outdoor temperatures with a minimum differential parameter which could be set by the building operator. Improper choice of a minimum differential parameter would result in either waste of fan energy or missed opportunities for useful ventilation purging.

To prevent damage to the air handling system when outdoor temperatures are low, a test should be made to determine if the outside temperature is low enough to cause freezing of heat exchange coils. The two tests for determining if cooling is available are shown on the left side of figure 16. If the outside temperature is above a safe minimum, and also the differential between indoor and outdoor air temperatures is above a minimum, then cooling from ventilation purging is considered available. If either of the two tests is not passed, ventilation purging is considered unavailable.

In areas where relative humidity is high during the cooling season, it is also important to include a comparison between indoor and outdoor relative humidity. If outdoor air is cooler than indoor air, but the relative humidity is high (such as during a rainstorm), ventilation purging should not be started, since the latent cooling load will actually be increased.

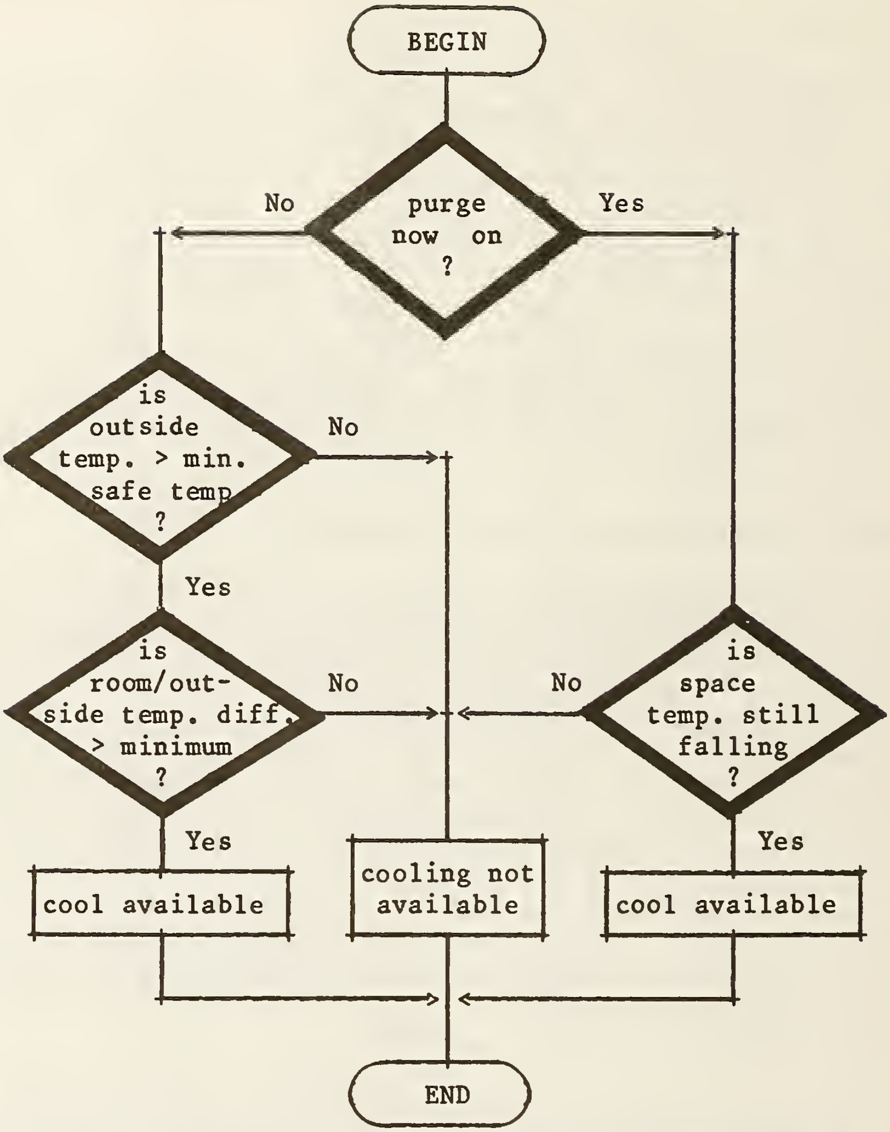

figure 16. Algorithm to determine if outside air can provide cooling used for the ventilation purging algorithm.

5.3.4 Is cooling available? / now purging

The purpose of this test is to determine if ventilation purging is continuing to have a cooling effect on the building space. In general, the space temperature will fall rapidly at the start of purging and approach a steady value. By monitoring the trend of the space temperature, a decision to stop purging can be made when the rate of decrease in space temperature has become so slow that further purging will not provide additional cooling. An example of a method for determining whether the space temperature is falling is given in section 7.5 (the same method is used to determine if the temperature is rising or steady). The test for continuing cooling availability is shown in the right side of figure 16.

If high relative humidity is a consideration, it may also be necessary to stop purging if the outdoor relative humidity rises above the indoor relative humidity. The indoor humidity will approach the humidity of the outdoor air in the same fashion as the temperature.

5.4 Ventilation Purge Algorithm Timing

The optimum starting time for ventilation purging when all of the tests described in section 5.3 have been passed depends to some extent on the characteristics of the building where the algorithm is applied. At first it will be assumed that the ventilation purge algorithm is executed periodically for the entire unoccupied period. If ventilation purging is started as soon as the tests of section 5.3 are passed, and the purging is stopped some time later by the algorithm of figure 14, the space temperature could conceivably rise and cause ventilation purging to be initiated again. Under certain conditions, the purge cycle might take place two or more times. Unless an attempt is being made to maintain the space at some condition with purging, the most important result of the purging is that when the building is occupied the space conditions are in the lower part of the comfort zone. If the purge cycle takes place more than once, the cycles before the last one will waste fan energy.

Excess cycling of ventilation purging is more likely to occur in a building with high unoccupied internal gains. In a building with low internal gains, once the space has been cooled to a minimum temperature, it will probably remain there once purging is stopped. Thus the time-of-day that the purging takes place is less critical. In such a case, the most important timing consideration is that the purging take place at a time when outdoor air enthalpy is at its lowest. This can be accomplished by time-of-day control or by monitoring the trend of outside temperature.

To prevent excess cycling of a ventilation purge, the simplest approach is to only begin periodic execution of the purge algorithm a relatively short time before the startup of equipment for the occupied period. The approximate time required to purge the building can be used as a guideline for how early the purge algorithm should start. A time-of-day control algorithm can be used to schedule the starting of the ventilation purge algorithm [4].

A more complicated method of causing the purge to occur just before the startup for the occupied period requires that records of purge times, and outside and indoor temperatures at the start of previous purges be kept. This information can be used to predict the time that will be required to purge the building. This method is actually a form of optimum start algorithm, and if an actual optimum start algorithm is being used for the startup of the air handler system, the control algorithms must be carefully designed to prevent conflicts.

An example algorithm used in the actual NBS FID and based on the algorithm of figures 14, 15, and 16 is presented in section 7.5. The system controlled in the example is a constant volume, terminal reheat system, with two zones, low thermal mass, and high internal gains. Actual listings of software for the example are included in appendix D.

6. HOT WATER AND CHILLED WATER SUPPLY TEMPERATURE RESET

HVAC equipment is usually sized to meet conditions at a design peak load. Coil water temperature setpoints are also chosen to meet the design load. During most of the equipment operating hours, the equipment will be operating at part-load conditions. Use of design setpoints on water loops at part-load results in unnecessary piping loss (or gain for chilled water) and possibly equipment inefficiencies. Setpoint reset control reduces energy consumption by performing a reset of hot water or chilled water supply setpoints to match the actual equipment load. Usually the supply water setpoint is constant for an entire HVAC system, since the water will typically be supplied from boilers or chillers in a central plant.

6.1 Outside Air Temperature Supply Water Reset

The goal of water supply temperature reset is to supply the various heat exchange coils that use either hot or chilled water with water at a temperature which is just sufficient to supply the load at the coil with the greatest demand. For example, if all chilled water coils in a system of air handling units have their valves open somewhere between 5 and 40 percent, this indicates that the coils are not at full load, and that the chilled water temperature could be raised to improve chiller economy and lessen piping heat gain. After the chilled water temperature is raised, the chilled water valves might be open from 70 to 85 percent, which is close to the full load of the coils. The coil with the greatest opening determines the limit for the reset. When any of the valves in the system reaches 100 percent open, then the chilled water temperature should be lowered, because the fully open valve indicates that this particular coil is at or above full load, and might not be able to provide sufficent cooling capacity for the air handling unit.

An approximate method of implementing supply water reset is to assume that the space load is a function of the outside air temperature. As the outside air temperature rises, chilled water temperature is adjusted downward and hot water temperature is adjusted downward. The algorithm for outside air supply water reset is functionally the same as the outside air supply air reset algorithm, as discussed in section 3.1 and presented in figure 6. Because of the similarity to outside air supply air reset, outside air supply water reset will not be discussed further in this chapter.

6.2 Demand Supply Water Temperature Reset

A more accurate method of supply water reset than outside air temperature reset is based on readings from instrumentation of actual heat exchanger coils, either the valves or the coils themselves. This will be referred to as demand supply water reset. Demand supply water temperature reset control is different from the other strategies discussed in chapters 3-5 because a demand supply water reset algorithm cannot be placed in a single FID associated with an air handling unit. The plant equipment for production of hot and chilled water is likely to be controlled by a FID unit or controller which is physically separated from the FIDs or controllers which oversee the air handling units in a building. There may be a controller, located in a plant FID, which maintains the hot or chilled water system at a setpoint. The algorithm to determine what the water system setpoint should be might reside in the plant FID, or at the central control level of the system. If the demand water reset algorithm is to monitor the coil loads at the individual air handlers, there must also be algorithms in the air handler FIDs, in communication with the main demand supply water reset algorithm, to provide information on valve positions or coil conditions. There are several possible configurations.

The simplest configuration of algorithm location for demand supply water reset is to have the main algorithm at the central control level. Information on the air handling units is obtained by the central control unit (CCU) and used by the reset algorithm. The selected supply water temperature is then transmitted to the control unit which is maintaining the supply water temperatures. This configuration has the disadvantage that the central unit is required in the system at all times. An alternative architecture might configure the CCU as only an operator interface device, which would not execute many control algorithms. The demand supply water reset algorithm might then reside at the FID level in a plant FID, and obtain information from routines in the air handling unit FIDs through the BMCS communication system. The air handler information might be transmitted through the CCU or directly to the plant FID, depending on what sort of communication network existed for the system.

The demand supply water reset algorithm is therefore divided into two physically separate parts, the actual setpoint determination and control part, and the air handler load determination part. The air handler load determination part is distributed among the FIDs which control air handling equipment. The information which must be supplied by the load determination part to the setpoint determination part depends on the sophistication of the algorithms in the air handling unit FIDs. The highest level of information would be a suggested supply water setpoint based on the local air handling unit load. The setpoint determination part would then consist of selecting the highest hot water or lowest chilled water setpoint suggested by all of the air handler FIDs. Table 3 contains a list of several possible levels of information that could be determined by the load determination algorithms.

The information in table 3 is organized in order of load determination algorithm complexity with more complex algorithms required by the first item. Conversely, as the load determination algorithm becomes more complex, the setpoint determination part becomes simpler. The advantage of greater load determination algorithm complexity is that the amount of information about air handling units that must be known by the setpoint determination part of the algorithm is minimized, making the total algorithm more flexible.

Table 3. Possible information transmitted between parts of a supply water reset algorithm.

1. suggested water setpoint
2. suggested change in water setpoint (+ or -)
3. suggested direction of change in water setpoint (up, down, or no change)
4. average valve position or average valve position error
5. averaged binary valve position (eg: above 80% / below 80%)
6. average coil inlet and outlet temperatures

6.3 Possible Demand Supply Water Reset Load Determination Algorithm

A possible demand water setpoint reset load determination algorithm might use a hot water or chilled water valve instrumented with a potentiometer to measure absolute valve position and produce as an output a suggested increase or decrease in supply water setpoint. The algorithm output would be used by a supply water reset setpoint selection algorithm. Figure 17 presents how such an algorithm might be structured.

The algorithm of figure 17 is intended for periodic execution at an interval which must be selected for the system being controlled. The first part of the algorithm is used to create an average value of valve position. If a sufficient number of samples for an average have not been taken, then the algorithm is exited.

Once an average valve position has been determined, this valve position is compared to a desired valve position which has been selected as a point with good control characteristics. The desired valve position is actually a range of possible valve positions, with lower and upper target values. If the average valve position is determined to exceed the upper target value, this indicates that supply water temperature should be decreased for a chilled water valve or increased for a hot water valve. If the average valve position is determined to be less than the lower target value, the supply water temperature should be increased for a chilled water valve and decreased for a hot water valve. If the valve position is between the upper and lower target values, then no change in setpoint is suggested. If a change is needed, an optional calculation can be made to estimate the magnitude of the change to be suggested. This value, in degrees of temperature, is combined with the direction of change determined previously to produce a suggested supply water setpoint for the setpoint determination part of the supply water reset algorithm.

The calculation to determine the size of the suggested change in supply water setpoint is performed using the error between the appropriate target value for valve position and the average measured valve position. This error is multiplied by a proportional factor with units such as degrees C/percent valve position. This factor is dependent on the characteristics of the valve and heat exchanger using the supply water, and would probably be determined experimentally by observing a valve's position for one water setpoint, changing the setpoint, and noting the change in valve position.

The algorithm in figure 17 can be expanded to include more than one valve if the FID controls more than one air handling unit, or the air handling unit has more than one chilled water or hot water coil. The algorithm would be duplicated if both hot and chilled water temperatures are to be reset, and the two algorithms might run independently. Additional tests could be added to the algorithm for a chilled water coil to ensure that the supply air humidity was not excessively high. If the humidity was approaching a limit value, the algorithm could suggest no change, or a lowering of setpoint, even if the valve were almost closed. Higher chilled water temperatures would lead to a loss of any humidity control.

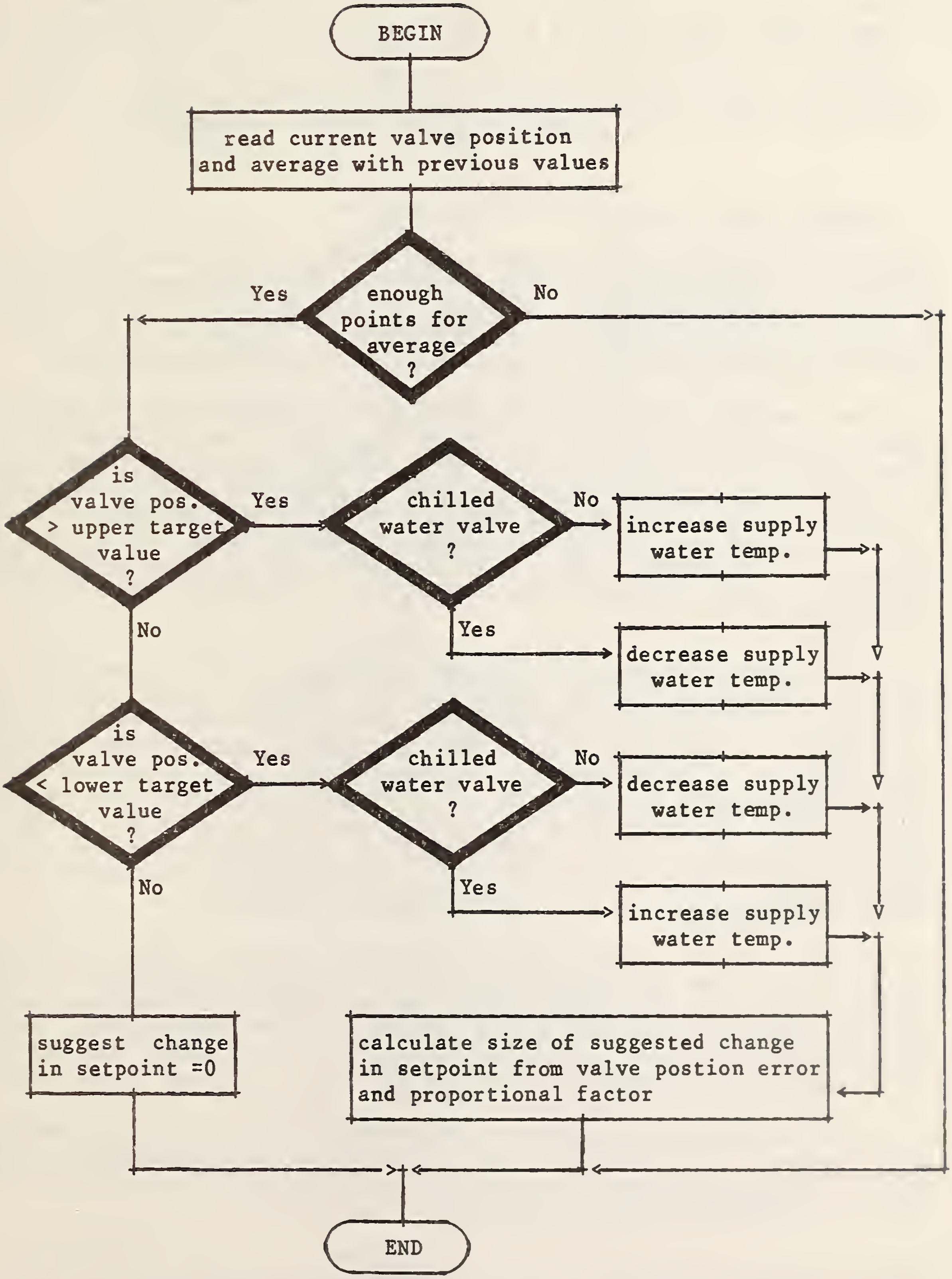

figure 17. Algorithm to determine current load of air handling unit coil for supply water reset.

An additional feature that might be included in a load determination algorithm for supply water reset would be to reserve a special value of suggested change in supply water setpoint to indicate a suggestion that the plant equipment be turned off. If the average valve position indicated that a valve were completely closed, this would imply that no chilled or hot water is required. If all valves were closed the plant equipment could be stopped.

6.4 Hot Water Reset Setpoint Selection Algorithm

The setpoint selection algorithm corresponding to the load determination algorithm of figure 17 would take the setpoint changes suggested by several distributed load determination algorithms and use them to select a setpoint to be used by the actual plant equipment controller. Figure 18 presents such an algorithm used to select the setpoint for a hot water heating system.

The algorithm of figure 18 would be executed at a regular interval which would depend on the requirements of the system on which it was implemented. This interval would not necessarily have to be the same as the execution interval for the load determination algorithms running in the air handler control FIDs, as long as it were not executing with a shorter interval. The algorithm would have to somehow obtain the suggested setpoint change from each load determination algorithm. This could be done by running the algorithm on the CCU and using the CCU data base, or by direct communication with the air handler FIDs.

Each FID air handler setpoint change suggestion would be compared to the others to determine which of the suggestions had the largest numeric value. The suggestions might include negative values (decrease temperature), zeros (no change), and positive values. If a positive suggestion were taken, this would result in a higher setpoint, and the heating loads at all air handlers and other coils would be satisfied. If a negative suggestion were taken, the setpoint would be lowered and any FIDs requesting an increase in setpoint would have coils which would be fully open, but not meeting the load. Thus if any positive suggestions are made, the setpoint must be increased. If only negative suggestions are made, the setpoint can be decreased.

In order to provide a check of the instrumentation, a comparison is made between current and previous load determination algorithm suggestions. If a setpoint change was made previously, and the current and previous suggested setpoint changes are not zero, then a change should occur in the suggestion value. If no change occurs this indicates an error in the valve instrumentation or the FID operation and the system operator is notified.

If all of the load determination suggestions indicate that all valves are shut, and were previously shut, the algorithm can either command or suggest that the plant water heating equipment be stopped. The controller for the plant will make the final decision about plant shutdown.

If no shutdown is indicated, the new setpoint can be calculated as the old setpoint plus the largest setpoint change suggestion from the load determination algorithms. This new setpoint must be checked to ensure that it does not exceed high and low limit values.

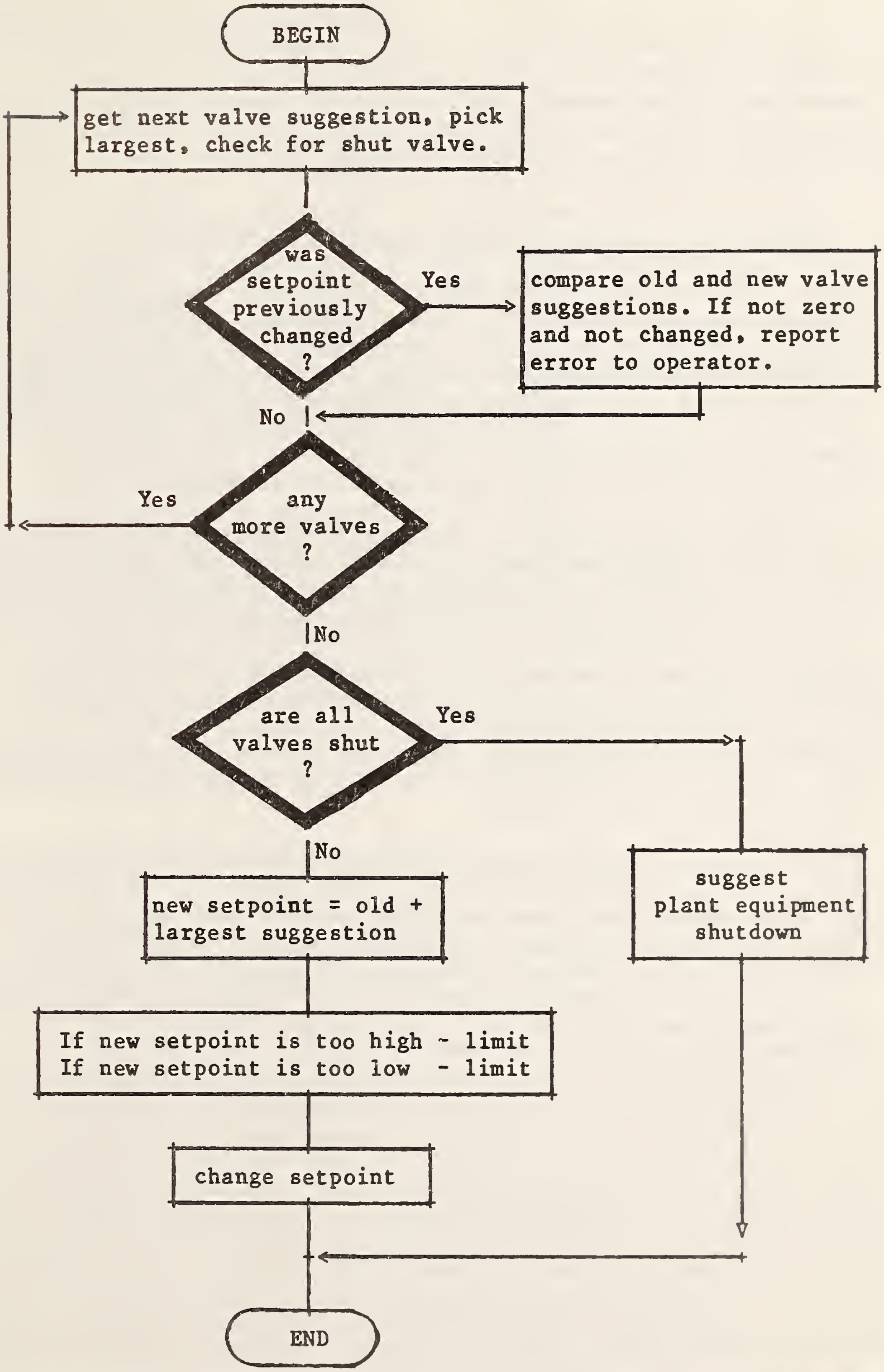

figure 18. Algorithm to select supply water setpoint temperature for supply water reset.

If the setpoint temperature is too high, this can cause dangerous system pressures and temperatures. If the setpoint is too low, this might cause problems with combustion heating equipment. If the setpoint is outside the specified limits, it will be set to the closest limit. Once the setpoint selection has been made and verified, it can be passed to the plant controller which may be in a separate FID or in the same FID.

6.5 Chilled Water Reset Setpoint Selection Algorithm

The setpoint selection algorithm for a chilled water system corresponding to the load determination algorithm of figure 17 would be very similar to the algorithm of figure 18, with minor changes. The method of execution would be the same, the same or similar timing of the algorithm execution would be used, and the method of obtaining load determination algorithm suggested setpoint changes would be the same. The major difference is that instead of using the numerically largest setpoint change suggestion required for heating, a chilled water algorithm would use the smallest numerical suggestion.

For a chilled water system, if a negative suggestion were taken, this would result in a lower setpoint, and the cooling loads at all air handlers and other coils would be satisfied. If a positive suggestion were taken, the setpoint would be raised and any FIDs requesting an decrease in setpoint would have coils which would be fully open, but not meeting the load. Thus if any negative suggestions are made, the setpoint must be decreased. If only positive suggestions are made, the setpoint can be increased.

The limits for setpoints must also be checked for the chilled water system. High setpoints or low setpoints can damage refrigeration equipment, or cause other problems in the system.

The algorithms for hot and chilled water reset, although studied, were not actually implemented in the NBS FID software at the time this report was written. This is because the NBS FIDs have been initially developed as air handling unit control FIDs rather than plant control FIDs, and therefore complete testing of the algorithms would not have been possible. The response of a simulated air handling system in a building to changes in chilled water supply water were studied with the building system emulator used to test the other algorithms in this report.

7. EXAMPLES OF ACTUAL CONTROL ALGORITHMS

As part of the research program in building HVAC control at NBS, a prototype BMCS has been constructed using "off-the-shelf" components and microcomputer boards. The system is organized into a hierarchy of three levels, central (CCU), distributed (FID), and data gathering (MUX). Custom software has been developed for the system. The software includes routines for supervisory control as well as direct control (DDC). The information in this report is a product of the development effort. The supervisory control software has been tested using a "building system emulator" (BSE) rather than an actual building system. The emulator is an independent pair of microcomputers. One computer uses a variant of a MUX to send analog and digital values representing the state of an HVAC system to the actual BMCS MUX. The second microcomputer supervises the first and runs a real time simulation of the HVAC system to represent the response of the system to control actions. Eventually, the control software will be tested in an actual building.

Since it is sometimes difficult to construct actual working programs from general algorithms, a description of working software from the NBS FID is included in this chapter. It should be understood that the software described is one possible implementation of the control strategies, and is not necessarily the best implementation. Other system architectures are certainly possible and would require different software for the control algorithms.

The algorithms presented as examples are intended for operation in the FID level of the BMCS. As background information, section 7.1 describes the basic architecture of the FID. Section 7.2 describes a DDC controller for an air handling unit which is used by the FID. The sections 7.3 through 7.5 describe the example software in detail.

7.1 Example Field Interface Device Software Architecture

The software to operate the FID is a complex computer program which is mostly written in the high-level computer language, FORTRAN. A number of utility routines are written in microprocessor assembly language, specifically for the microprocessor used in the FID.

The activities of the FID can be divided into two major categories: communication with the CCU, and execution of tasks. A task is defined as a software procedure that has a specific purpose such as turning on a fan or controlling a valve position and begins at a certain starting point in the FID computer memory. In the NBS FID, a task is in the form of a FORTRAN "subroutine" without arguments. Information is passed between tasks through common data areas. When there is no communication from the central level, tasks are executed with a "multi-tasking" scheme in which a number of software tasks are each executed in a periodic fashion in conjunction with the other tasks so that it appears that tasks are operating simultaneously. The two most essential types of tasks of the FID are collection and processing of data and execution of control software (DDC, duty cycling, etc.) through the MUXs.

An example of a task is the supply air temperature reset software which controls setpoints used by other control tasks. The day/night setback control software is a task which is scheduled to execute when the building becomes occupied or unoccupied at a specific absolute time-of-day.

Any "multi-tasking" software system must have some sort of "task manager software" to control when tasks will execute and resolve timing conflicts between tasks. The task manager used for the NBS FID is coded in assembly language and makes use of a hardware real-time clock issuing interrupts to divide time into 0.1 second intervals. The manager uses this division of time to coordinate all tasks in the FID. The FID task manager has three basic characteristics which are desirable for task control. First, the task manager allows the periodic execution of multiple tasks and has a priority scheme for use if two tasks are set to execute at the same time. The period of any task may be changed during execution of the FID software. Second, any periodic task may be stopped on demand. Third, any periodic task which is stopped may be started after a variable delay which is independent of the period of the task, or tasks may be set to execute only once after a variable delay (such a task may be called a "one-shot" task).

To control tasks, the task manager for the NBS FID uses a table of task starting points and associated time intervals at which these tasks are to be executed. This table will be referred to as the task table. Table 4 is a facsimile of the basic task table in the FID. There is a row in the task table for each task in the FID. There are two groups of columns (four columns per group) used for timing purposes. One group of four columns is designated the counter, and the other group is called the interval. The four columns in a group hold values for hours, minutes, seconds, and tenth-seconds. Every one tenth second, the manager software executes. The counter for each task is decremented each time the task manager is executed. If any counter becomes all zeros, this indicates that the associated task is to be executed. After the task is executed, the counter columns are reset using values from the interval columns, and the countdown resumes. The interval is not changed by normal operation of the task manager.

table 4. NBS FID task table

		COUNTER				INTERVAL				
task no.	status code	hr	min	sec	ts	hr	min	sec	ts	TASK NAME
01	1	00	00	60	00	00	00	60	00	CONTROL
02	1	00	00	01	07	00	00	02	00	DATA
03	0	00	05	25	09	00	10	00	00	INACTIVE
04	-1	00	01	30	00	00	00	00	00	ONESHOT
05	1	00	59	59	09	01	00	00	00	PERIODIC
06	1	00	00	00	00	00	00	20	00	ACTIVE
07	1	00	00	14	02	00	15	00	00	DUTCYC
08	1	00	48	08	00	01	00	00	00	SCHEDULR

The first column in the task table contains the task number. This number is also a priority (a lower number represents a higher priority). All tasks are given priorities and lower priority tasks will wait if it is time for a higher priority task to execute. The second column of the task table contains a code to indicate whether the task is stopped (0), set to execute once (-1), or set to execute in a continuous, periodic mode(+1). The last column contains a symbolic name which represents the starting address of the task.

A utility routine, separate from the task manager routine, is used to change the entries in the task table used by the task manager. This task table editor routine can be called as a subroutine from a FORTRAN program. There are three arguments which must be passed to the routine. The first argument is the number of the task in the table whose table entries are to be edited. The second argument is the value of the code to be loaded into the second column for that row of the table. The third argument is equal to 1 if the task intervals <u>and</u> the task counters for this row in the table are to be set to the same new values. The third argument is set to 2 if only the task counters are to be set to new values. The values to be loaded into the counters and intervals are passed to the subroutine using data in a common data area.

Another utility routine is used to determine the current values of the entries in the task table. The routine can be called as a subroutine from a FORTRAN program. There are two arguments. The first argument is the number of the task in the table whose table entries are to be checked; the second entry will contain the value of the code in the second column of the table. The values of the interval columns in the table will be stored in a common data area (same area used by the task table editor) as four consecutive values representing the hours, minutes, seconds, and tenths of seconds. The routine is very similar to the editor routine, but data are "read" from the table rather than being "written" to the table.

7.2 Basic Air Handling Unit Control Task

The NBS FID software contains a task which is designed to maintain the supply air temperature from an air handling unit. The air handler control software is oriented towards a constant volume reheat air handler, since this is the type of air handler in the majority of lab buildings at NBS. The air handler control task gets the supply air setpoint from a table in the FID and modulates valves to maintain the air being discharged from the air handler at the setpoint. The supply air setpoint table can be reset by other tasks or changed from the central level. Supply air reset software determines the proper setpoint and changes the value in the table periodically.

In the NBS configuration, the air handler control task has control over three actuators in the air handling unit. These are a chilled water valve actuator to control flow through a chilled water coil, a steam valve actuator to control steam flow through a preheat coil, and a damper actuator to control the quantity of outside air. The task must actuate the proper controlled element to the position which most economically produces discharge air at the setpoint. If only one valve were available, the task would use a simple velocity form proportional-integral (PI) control algorithm to position the valve [6]. With three controlled elements, there is a need for sequencing of the actuators so that no two valves are open at the same time, to avoid reheating or recooling of air (unless humidity control is required).

Sequencing is performed in the digital control system by having feedback from the actuators as to whether or not they are at the ends of their strokes. The three controlled elements are sequenced to produce increasingly warm air as each element is opened in turn. For this configuration, four end-of-travel sensors are required. These are chilled water valve closed, preheat valve open, outside air damper open, and outside air damper closed. The air handler controller only controls one element at a time. If modulation of one element will maintain the supply temperature, no other element needs to be controlled. If, for example, the chilled water valve were under control,and the supply air was too cold, the control algorithm would call for a reduction in the opening of the chilled water valve. If, however, the control action closed the chilled water valve, then the controller would leave the chilled water valve and attempt to modulate the outside air damper to achieve the setpoint.

There is a sequencing problem to be avoided at the transition between controlled elements. The solution used in the NBS FID is to accumulate control actions after the current element is either fully open or closed as indicated by the limit switches. The accumulated control actions must build to a certain level before transition from one element to another takes place. If control actions in the opposite direction occur before the switchover, the accumulated control actions are then reduced. This way, if there is slight oscillation about a control setting, there will be no continous switching between the two controlled elements.

The air handler control task uses a table of values to allow general control of any types of control elements in any sequence. Since PI velocity algorithm control is used, each of the controlled elements requires different control parameters, since their gains are different. These parameters are entered in the table. Other parameters are actuator travel time, maximum control action, size of "dead band" for sequencing between elements, and whether the device is for heating or cooling.

The outside air damper is treated as a cooling device. A simple dry bulb economizer algorithm is used to lock the damper shut if the outside air is too warm or too cold [7]. When locked out, the outside air damper is passed over in the sequencing.

7.3 Example Outside Air Supply Air Reset Algorithm

A supply air reset control algorithm using outside air temperature, based on the algorithm in figure 6, was developed to run in the NBS FID. The algorithm was implemented in FORTRAN as a software task (section 7.1). Appendix A contains the FORTRAN listing of the outside air reset task software.

In this example of outside air reset, the setpoints to be reset are contained in a data area ("common block") common to several tasks, in particular the outside air reset task and the air handling unit control task. Therefore when the outside air reset task changes the setpoint in the common data area, the next time that the air handler control task executes, it will use the changed setpoint.

The outside air reset task uses a reset schedule which has the shape of the curve in figure 5. For every value of outside air temperature there is a scheduled value of setpoint temperature. To implement the schedule, the outside air reset task uses an equation with variable parameters. The parameters may be changed from the central level of the system and may be different for each setpoint to be reset. The parameters are stored in a table where there is a row for each setpoint and columns for the parameters associated with that setpoint. In the example software there is one air handler control task with a maximum of five controlled elements, and each element can be used to maintain a different setpoint. Therefore, the reset table has five rows. Table 5 is a representation of a possible outside air reset table.

Table 5. NBS FID outside air supply air reset parameter table

setpoint index no.	T_{oa-max}	T_{oa-mid}	T_{oa-min}	T_{r-max}	T_{r-mid}	T_{r-min}	arstat
1	35.0	22.0	0.0	16.5	15.0	12.2	1
2	37.0	20.0	-5.0	16.0	14.5	13.0	1
3	37.0	20.0	-5.0	16.0	14.5	13.0	1
4	37.0	20.0	-5.0	16.0	14.5	13.0	0
5	37.0	20.0	-5.0	16.0	14.5	13.0	0

Note: All temperatures are in degrees C.

The first column of Table 5 designates the setpoint index number. In the NBS FID this points to a particular device used to maintain the setpoint of the supply air temperature and indicates the place that a controlled element takes in the sequencing of control. Values in the last column, marked arstat, are used to indicate what setpoint reset algorithm is to be used. The 1 indicates outside air reset. The 0 for setpoints 4 and 5 indicates no reset. These are under manual control only. The other columns are used to define the relationship between setpoint and outside air temperature. This is done by specifying three points on a plot of setpoint versus outside temperature. Figure 19 shows three points on such a plot.

When the outside air temperature is below T_{oa-min}, the setpoint is fixed at T_{r-max}. If the outside air temperature is above T_{oa-max}, the setpoint is fixed as T_{r-min}. Between outside air temperatures of T_{oa-min} and T_{oa-mid}, the setpoint varies linearly with outside air temperature between T_{r-max} and T_{r-mid}. Between T_{oa-mid} and T_{oa-max}, the setpoint varies linearly with outside air temperature between T_{r-mid} and T_{r-min}.

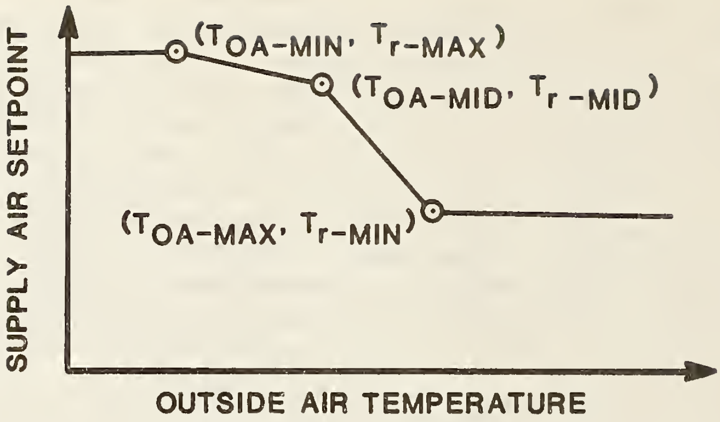

figure 19. Example of outside air supply air reset schedule specified by three points.

The operation of the outside air reset task follows figure 6 closely. After the current outside air temperature is determined by examining the correct analog input, a software loop is used to reset all five setpoints. Before the setpoint is reset the arstat variable for the setpoint is checked. If not equal to one, the setpoint is not reset. To determine the reset value for the setpoint, the region of figure 19 bounding the outside air temperature is determined. If the outside temperature is bounded by one of the regions where the setpoint is changing with outside temperature, the following equations are used:

$$\text{slope} = \frac{T_{r-lo} - T_{r-hi}}{T_{oa-hi} - T_{oa-lo}} \tag{3}$$

$$\text{setpoint} = \text{slope} * (T_{oa} - T_{oa-hi}) + T_{r-min} \tag{4}$$

where the subscript r indicates setpoint, oa is outside air temperature, lo is the lower of the two values which bound the outside temperature or setpoint in the correct region of figure 19 and hi refers to the higher of the two values.

7.4 Example Zone Demand Supply Air Reset Algorithm

An algorithm to perform supply air reset based on measurement of zone demand was developed to run in the NBS FID. The algorithm is a specific implementation of the algorithm in figure 10, written in FORTRAN as a software task (see section 7.1). A FORTRAN listing of the the actual software may be found in appendix B.

In this example of a zone demand reset algorithm, the setpoints to be changed are assumed to be located in a data area common to several tasks. The most significant task which can access the setpoints is the air handler control task which uses the setpoints to control the temperature of the supply air from an air handling unit.

The implementation of the supply air reset algorithm of figure 10 is dependent on what type of HVAC system is being controlled, unlike the implementation of the outside air reset algorithm of figure 5. The zone demand reset algorithm was designed to work with a specific HVAC system emulated on the Building System Emulator (see introduction to chapter 7.). The HVAC system for this example is a constant volume, terminal reheat system, supplying conditioned air to two zones. The zones each have a reheat coil controlled by a local thermostat which senses room temperature. The reheat coil is a hot water coil and has a control valve which is either open or closed in response to an on/off signal from the thermostat. It is assumed that there is a switch type sensor attached to the reheat coils in each zone which changes state when the reheat coil is turned on or off. This sensor is connected to the BMCS system as a digital input and the state of the sensor can be determined by the supply air reset algorithm.

There are two time interval values that must be assigned before the algorithm can be run. One of these is the setpoint reset sampling interval, given the variable name DRSAMP. This is the time between adjustments of the setpoint. As an example, this might be five minutes. The other important time value is the task execution interval, given the name DRTSKI. This is how often the setpoint reset task runs, and an example of this value might be 15 seconds. Each time the task executes, it samples the digital inputs connected to the reheat coil sensors. The value of the input will be 1 if the coil is on and 0 if it is off. For each zone, the integer equivalent of this digital input is added to a summation of previous digital input values. When a time equal to DRSAMP has passed, the sums are used to calculate a correction for the supply air setpoints. The number of samples in the sum is given by DRSAMP/DRTSKI. For the example given, the number of samples would be (5*60)/15 or 20 samples. The values of DRSAMP and DRTSKI must be adjusted for each system being controlled to yield the best results. DRSAMP is stored in FID memory and can be changed from the central control level. DRTSKI is equal to the task interval found in the main task table (see table 1). In the setpoint reset software a special routine is used to read this value from the task table.

With each execution of the task, a counter variable is used to hold the current number of samples taken of the reheat coil sensors. If this counter is not equal to DRSAMP/DRTSKI, the task is exited. If the counter is equal to the maximum number of samples, the setpoint reset section of the task is executed and the sample counter is reset to zero.

In the setpoint reset section of the algorithm, the zone with minimum use of the reheat coil is determined by examining the summation of digital inputs from all the zone reheat coils. The minimum value is converted to a fraction of time that the reheat was on by dividing the summation with the total number of samples taken (DRSAMP/DRTSKI).

Once a value for the minimum reheat on-time fraction is obtained, a software loop is entered. Each transition of the loop is used to set one of several possible supply air setpoints that the algorithm is capable of modifying. To determine the setpoints, a simple method is used. Six parameters must be specified and stored in a software table. Sample data for such a table is given in table 6. The parameter ARSTAT, in the last column, indicates what task should be used for supply air reset. A 2 indicates zone demand supply air reset, and a 0 is for no reset (manual adjustment). This value is checked for each setpoint and if the value is not 2, the rest of the loop is skipped. If the current value of the setpoint is above the value T_{r-max} or below the value T_{r-min}, the setpoint is not changed.

If the setpoint is within bounds, the parameters in the first two columns of the supply air reset parameter table are used to determine what action to take. If the minimum reheat on-time fraction is greater than R_{max}, this indicates that there is too much reheat being used and that the setpoint is too low. If the setpoint is too low, an error value is calculated as the minimum reheat on-time fraction in percent minus R_{max}. This error value is multiplied by the parameter R_{step}, which is really a proportional gain, to produce a correction to the setpoint. The setpoint is increased by this correction, checked to ensure that the setpoint is not greater than the maximum specified, and the task is exited.

If the minimum reheat on-time fraction is less than than R_{min} or equal to zero, this indicates that the setpoint is too high and that the zone with minimum reheat is probably too warm. If the zone is too warm it cannot be cooled unless the supply air setpoint is lowered. If an error were calculated between the minimum reheat on-time fraction and R_{min}, it would be very close to R_{min}, since the minimum reheat on-time fraction is probably zero. Therefore in this case, the setpoint correction is determined by multiplying R_{step} by R_{min}. The setpoint is decreased by this correction, checked to ensure that the setpoint is not less than the minimum specified, and the task is exited.

If the minimum reheat on-time fraction is between R_{min} and R_{max}, no correction to the setpoint is made. Under normal conditions, this condition would be expected to occur most of the time, unless the sample interval is very large.

In tests of the FID connected to the building system emulator, the supply air setpoint successfully adapted to changes in conditions such as outside air temperature and building occupancy. Eventually the algorithm will be tested on an actual building.

Table 6. NBS FID zone demand supply air reset parameter table

setpoint index no.	R_{max}	R_{min}	R_{step}	T_{r-min}	T_{r-max}	arstat
1	10.0	5.0	0.033	12.2	16.5	2
2	8.0	2.0	0.025	13.0	16.0	2
3	9.0	6.0	0.050	13.0	16.0	2
4	6.0	4.0	0.050	13.0	16.0	0
5	10.0	1.0	0.050	13.0	16.0	0

Note: R_{max} and R_{min} are in %, R_{step} is in degrees C/%, and T_{r-min} and T_{r-max} are in degrees C.

7.5 Example of Day/Night setback algorithms

An implementation of a day/night setback algorithm was installed in the NBS FID software. The algorithm follows closely the algorithms presented in figures 11 and 12 for shutdown and startup of a zoned air handling system. The startup and shutdown algorithms were written in FORTRAN and organized as two separate software tasks (see section 7.1). A FORTRAN listing of the the actual software may be found in appendix C. The startup and shutdown tasks were executed under control of a time-of-day control task, allowing them to be scheduled for any time of day on any day of the week. A description of the FID time-of-day control software may be found in reference [4].

For this example of day/night setback algorithms, there is a special air handling unit control task which maintains the supply air temperature from the unit at a setpoint by manipulating outside air dampers and heating and cooling coils. The air handler control task is described in section 7.2. The air handler control task was designed to always operate in one of five modes: normal, stop, off, vent, and purge. The air handler controller is in normal mode when the building is occupied and space thermostats are not in a setback condition. If the air handler controller is placed in the stop mode, fans are stopped, outside air dampers and all cooling and heating valves are shut, and the controller then enters the off mode. In the off mode, the air handling unit is inactive, and provides no space conditioning. The vent and purge modes are used for ventilation purge, as described in section 7.6.

The detailed implementation of the setback shutdown and startup algorithms of figures 11 and 12 is dependent on what type of HVAC system is being controlled. The setback algorithm was designed to work with a specific HVAC system emulated on the Building System Emulator (see introduction to chapter 7.). The HVAC system for this example is a constant volume, terminal reheat system, supplying conditioned air to two zones. The zones each have a reheat coil which is controlled by a local on-off thermostat. The thermostats, which must have a normal and setback setpoint manually programmed at the thermostat location, have a digital input which causes the thermostat to use the normal setpoint when the input is in a logical low state, and to use the setback thermostat when the input is in a high state. The FID controls the input to the thermostat by using one of the FID hardware digital outputs. All thermostats in the zones serviced by the air handler are assumed to be connected to a single output.

The shutdown task is a short routine. When the task is executed, it begins by shutting off four motors driving pumps and fans which are considered to be unnecessary when the building is unoccupied or setback. These devices are controlled using a routine, DIGOUT, which is designed to turn off a specified digital output. As a next step, the shutdown task places the air handling control task in the stop mode. This is done by changing a mode variable, AHSTAT, stored in a memory area common to the setback tasks and the air handler control task. The next time that the air handler control task executes, it will go through the actions to stop the air handler, which consist of stopping the supply air fan, and closing, in sequence, all controlled devices such as dampers and coils. The space thermostats are commanded to use the setback setpoint by using the digital output control routine, DIGOUT, to turn on an output which is connected to all of the space thermostat setback/normal control inputs.

The startup task is slightly more complicated than the shutdown task. Basically, all actions in the startup task are the opposite of the shutdown actions. The four miscellaneous motors which were turned off by the shutdown task are turned back on, but to avoid a large electrical demand peak, they must not be turned on at the same time. Therefore a special routine, DELAYD, is used to turn on the outputs. This routine is called in the same manner as DIGOUT, used to turn off the outputs, but DELAYD allows the specification of a delay time before the output is turned on. The use of staggered delays prevents the demand peaks. Since there is no "start" mode for the air handler controller, the air handler fan is turned on directly from the startup task, using the DELAYD routine. Also the air handler mode variable is set to the "normal" state. After the air handler has been started, the space thermostats are ordered to cease using the setback space setpoint by turning off the digital output connected to the zone thermostats. Since a task to reset the supply air setpoint is active in the FID (section 7.4) and the task may have based its current setpoint value on data taken from an inactive air handler, it is desirable to pick an initial value for the supply air setpoint. This is accomplished by calling an outside air supply air setpoint reset task (section 7.3) to select a setpoint based on the current outside air temperature.

In tests with the FID connected to the building system emulator, the building was successfully setback and returned to normal operation on a programmable schedule. No difficulties were encountered in the tests. Eventually the algorithms will be tested on an actual building.

7.6 Example Ventilation Purging Algorithm

An implementation of a ventilation purging algorithm was installed in the NBS FID software. The algorithm follows closely the algorithms presented in figures 14, 15, and 16. The ventilation purge algorithm was written in FORTRAN and organized as an independent software task (see section 7.1). A FORTRAN listing of the the actual software may be found in appendix D. The purge algorithm was intended to be executed under control of a time-of-day control task, allowing it to be scheduled for a time of day a short time prior to the scheduling of the startup task described in section 7.5. A description of the FID time-of-day control software may be found in reference [4].

For this example of a ventilation purging algorithm, there is a special air handling unit control task to maintain the supply air temperature from the unit at a setpoint by manipulating outside air dampers and heating and cooling coils. The air handler control task is described in section 7.2. The air handler control task was designed to always operate in one of five modes: normal, stop, off, vent, and purge. The normal and stop modes were described in section 7.5. In the off mode, the air handling unit is inactive, and provides no space conditioning. To start a purge, the purge algorithm causes the air handling unit controller to enter the vent mode. In the vent mode, the air handler fan is turned on, and the outside air damper is moved to the fully open position. The controller then automatically enters the purge mode, where the fan is operating and the damper is open. To stop purging the algorithm causes the controller to enter the stop mode which shuts down the fan and closes the dampers.

The ventilation purging task is organized as a main subroutine and three subordinate function subroutines. The main routine is a direct implementation of figure 14. The decision points in the figure are implemented as two subroutines, one for determining if the building space requires cooling and one for determining if cooling by outside air is available.

The main ventilation purging task begins by determining the current values of the outdoor air temperature and the space temperature. Humidity considerations were not included in this example, so outdoor air and space dry bulb temperature were used. The outdoor air temperature is contained in one element of an array of analog input variables, whose index is stored in a table of parameters used in conjunction with the outdoor air economizer algorithm for the air handler (see section 7.2).

The space temperature is approximated by using a value for the return air temperature pointed to in the same manner as the outdoor temperature. When the fan is running, this is a valid method of obtaining an average space temperature. In an actual building, when the fan is stopped, the return air temperature no longer represents the space temperature. In this example, however the FID is connected to the building system emulator device (see chapter 7 introduction). In the emulator the return air temperature can be defined to be equal to the space temperature when the fan is off. This step was taken to reduce the number of sensors and the algorithm development and testing time. In a normal building the space temperature would be taken from sensors actually located in the space.

Once the room and space temperatures are known, the remainder of the main routine is implemented using logical "if-then" structures. The cooling-available and space-needs-cooling decisions are implemented as FORTRAN in-line functions. These two functions make use of a number of parameters which must be selected by the building engineer or operator to customize the algorithm to a particular building air handling unit. Table 7 lists the parameters, brief descriptions and values used in the NBS FID software.

The space-needs-cooling function closely follows figure 15. The tests for whether the current room temperature is within certain bounds are implemented by comparing the room temperature to the values for ROOMAX and ROOMIN as defined in table 7.

A more difficult problem is determining the trend of the room temperature. This test requires more than a simple comparison with a constant. A separate routine is used to perform this test (RTDROP). The output of the routine is a logical value for whether or not the room temperature is steadily falling. Each time the routine is used, the current room temperature is subtracted from the former room temperature. This change is compared to a constant, PDTMIN, defined in table 7. If the change is smaller than PDTMIN (including negative values), the change is then identified as an upward or steady movement. If the change is larger than PDTMIN, the change is identified as a downward movement. A counter keeps track of how many times an increase has occurred and how many times a decrease has occurred. Basically as long as the up trend counter is less than the value NPURSA, defined in table 7, the room temperature is considered to be falling steadily. If the down trend counter exceeds NPURSA, the up trend counter is reset to one. If the movement is upward the down counter is reset to one. This means that a steadily falling temperature will keep the logical output at true, but an oscillating or rising output will cause the logical output to be false, after a delay which is determined by the value of NPURSA. If the room temperature is determined to be falling steadily using the room temperature trend test from the cooling-needed routine, then this means that cooling is considered unnecessary.

The cooling-available routine is constructed very much like the cooling-needed routine, except that the logic is based on figure 16. If a purge is not occurring, then ventilation purging is considered to be capable of providing cooling if the outside temperature is above OATMIN, defined in table 7, and the difference between the outside and indoor temperatures is greater than STPDEL, also defined in table 7. If purging is currently occurring, then the room temperature trend test routine is used to determine if the room temperature is falling steadily. If it is, then cooling is still considered to be available. If room temperature is not falling steadily, this means that it has not been falling steadily for a reasonably long time, and then cooling is considered to be unavailable.

Table 7. Parameters used by the ventilation purging algorithm

name		definition	e.g. value
ROOMAX	-	maximum room temperature, above which the building space is considered to require cooling by ventilation purging, when no purging is currently occurring.	22 C
ROOMIN	-	minimum room temperature, below which building space is considered to not require further cooling, when purging is currently taking place.	19 C
PDTMIN	-	the smallest decrease in the value of the space temperature that can occur between successive executions of the purge algorithm and be recognized as indicating a definite downward trend.	0.01 C
NPURSA	-	maximum value of a counter used to determine whether the building space temperature has a downward, upward, or constant trend. The count is of the number of samples of room temperature taken at algorithm executions which exibit a definite upward or downward trend, based on PDTMIN.	20
STPDEL	-	minimum differential between outside air temperature and indoor temperature which the current differential must exceed to start purging.	3 C
OATMIN	-	minimum outside temperature, below which there is a danger of freezing heat exchange coils if ventilation purging is performed.	5 C

In tests of the ventilation purge algorithm in the FID connected to the building system emulator, the building was setback using the routines described in section 7.5. When conditions were correct the ventilation purge correctly started the purge. The purge was terminated when the room temperature ceased to decrease. Figure 13 represents data from an actual test using the BSE. Eventually the algorithms will be tested on an actual building.

8. CONCLUSIONS

This report has described algorithms developed for use in the NBS Building Management and Controls Laboratory for several supervisory building control strategies. The strategies implemented were supply air setpoint reset, day/night setback, ventilation purging, and supply water reset. The algorithms were tested using an actual microprocessor-based FID running software incorporating the algorithms. The algorithms developed performed successfully on a test system using a microprocessor driven building system emulator (BSE) rather than an actual building system. Further research will be required to determine how the algorithms perform when connected to a real HVAC system and to measure the performance of the algorithms in terms of energy savings, accuracy of control, and reliability.

9. REFERENCES

[1] U.S. Army Corps of Engineers. Energy Monitoring and Control Systems. Technical Manual TM5-815-2/AFM 88-36/NAVFAC DM-4.9. Dept. of the Army, Air Force, and Navy, Washington, D.C. 1981 September.

[2] American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. ASHRAE Handbook and Product Directory, 1980 Systems. Chapter 3. 1980.

[3] Paoluccio, J.P. Dead Band Controls Guide. ASHRAE Transactions. Vol 86, part 1, 1980.

[4] May, W. B. Time of Day Control and Duty Cycling Algorithms for Building Management and Control Systems. Nat. Bur. Stand. (U.S.) NBSIR 83-2713; 1983 June, 60 p.

[5] Park, C. An Optimum Start/Stop Control Algorithm for Heating and Cooling Systems in Buildings. Nat. Bur. Stand. (U.S.) NBSIR 83-2720; 1983 May, 69 p.

[6] May, W.B.; Borresen, B.A.; Hurley, C.W. Direct Digital Control of a Pneumatically Actuated Air Handling Unit. ASHRAE Transactions. Vol 88, part 2, 1982.

[7] Park, C. Economizer Algorithms for Energy Management and Control Systems. Nat. Bur. Stand. (U.S.) NBSIR 84-2832, 1984 February, 81 p.

APPENDIX A - Outside Air Supply Air Reset Control Routines

This appendix contains the FORTRAN IV source code for the outside air supply air reset control routines used in the NBS FID. The routines are taken out of the complete FID program that they are designed to work with, but still provide an example of actual source code for outside air supply air reset.

```
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      SUBROUTINE ARESET
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C This routine is used to reset the supply air setpoint of an air
C handling unit. This version uses the outside air reset method, where
C the setpoint is a linear function of outside air temperature within
C a range of outside air temperatures.
C
C VARIABLE DEFINITIONS:
C
C  COMMON BLOCK SETPOINT:
C TREF   - array of setpoints used by the air handler task, each resettable.
C
C  COMMON BLOCK AIRSET:
C TOAMAX - array of outside air temperatures where the setpoints reach TRMAX.
C TOAMIN - array of outside air temperatures where the setpoints reach TRMIN.
C TRMIN  - array of minimum possible values for setpoints in TREF.
C TRMAX  - array of maximum possible values for setpoints in TREF.
C TOAMID - array of outside air temperatures where setpoints reach TRMID.
C TRMID  - array of values for setpoint in TREF between two linear regions.
C ARSTAT - array of values to indicate what type of reset strategy to use.
C          0 = no reset; 1 = outside air reset; 2 - zone demand reset
C
C  COMMON BLOCK ANALOG:
C ANAI   - array of analog input values obtained by data input task.
C
C  COMMON BLOCK OADAMP: from economizer task; TRETPT, TCODIF, TOAMN not used.
C TOAPT  - two part integer pointing to the value in ANAI for outside temp.
C          1st 8 bits = MUX number; 2nd 8 bits = point number
C
C FULL   - copy of TOAPT used to split TOAPT into two parts: HALF (1),HALF(2)
C MUX    - mux ID number where outside air temperature is taken.
C IPNT   - point ID number within MUX for outside air temperature sensor.
C TOA    - current outside air temperature.
C TRLO   - low setpoint limit for linear interpolation.
C TRHI   - high setpoint limit for linear interpolation.
C TOAHI  - high outside air temperature for linear interpolation.
C TOALO  - low outside air temperature for linear interpolation.
C SLOPE  - slope of line joining (TOALO,TRLO) and (TOAHI,TRHI).
C
      INTEGER FULL,TRETPT,TOAPT
      REAL TCODIF,TOAMN
      INTEGER*1 HALF(2)
      REAL*8 ANAI
      REAL TREF
```

```
      REAL TOAMAX,TOAMIN,TRMIN,TRMAX,TOAMID,TRMID
      INTEGER ARSTAT
C
      COMMON/AIRSET/TOAMAX(5),TOAMIN(5),TRMIN(5),TRMAX(5)
     &,TOAMID(5),TRMID(5),ARSTAT(5)
      COMMON/SETPNT/TREF(5)
      COMMON/ANALOG/ANAI(1,32)
      COMMON/OADAMP/TRETPT,TOAPT,TCODIF,TOAMN
      EQUIVALENCE (FULL,HALF(1))
C
C--------determine outside air temperature------------------------------
      FULL=TOAPT
      MUX=HALF(2)
      IPNT=HALF(1)
      TOA=ANAI(MUX,IPNT)
C--------change setpoint value as a function of outside air temp.-------
      DO 3000 I=1,5
      IF(ARSTAT(I).NE.1)GO TO 3000
      IF(TOA.LT.TOAMIN(I))GO TO 1000
      IF(TOA.GT.TOAMAX(I))GO TO 2000
      IF(TOA.GT.TOAMID(I))GO TO 500
C--------outside air temperature between TOAMIN and TOAMID--------------
      TRLO=TRMID(I)
      TRHI=TRMAX(I)
      TOAHI=TOAMID(I)
      TOALO=TOAMIN(I)
      GO TO 600
C--------outside air temperature between TOAMID and TOAMAX--------------
  500 TRLO=TRMIN(I)
      TRHI=TRMID(I)
      TOAHI=TOAMAX(I)
      TOALO=TOAMID(I)
C--------calculate new setpoint by linear interpolation-----------------
  600 SLOPE=(TRLO-TRHI)/(TOAHI-TOALO)
      TREF(I)=SLOPE*(TOA-TOAHI)+TRLO
      GO TO 3000
C--------if air temperature is outside of limits, fix setpoint----------
 1000 TREF(I)=TRMAX(I)
      GO TO 3000
 2000 TREF(I)=TRMIN(I)
 3000 CONTINUE
      RETURN
      END
```

APPENDIX B - Zone Demand Supply Air Reset Control Routines for Constant Volume Reheat System

This appendix contains the FORTRAN IV source code for the zone demand supply air reset control routines used in the NBS FID. The routines are taken out of the complete FID program that they are designed to work with, but still provide an example of actual source code for zone demand supply air reset.

```
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      SUBROUTINE DRESET
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C This routine is used to reset the supply air setpoint of an air
C handling unit. This version uses the demand determination method, where
C the demand is determined from the measured usage of reheat coils in the
C zones served by the air handler. The setpoint is moved up or down by a
C step change when the reheat usage is outside of specified limits.
C
C VARIABLE DEFINITIONS:
C
C  COMMON BLOCK TSKINT:
C H,M,S,TS - task execution interval times from task table (hrs, mins, etc.).
C
C  COMMON BLOCK DIGITA: from digital data base. DOPRI, DIGO not used here.
C DIGIN  - array of current digital input values.
C
C  COMMON BLOCK RHDEMA:
C RHMAX  - array of maximum desirable values for % of maximum reheat used.
C RHMIN  - array of minimum desirable values for % of maximum reheat used.
C RHSTEP - proportional constants to correct setpoint. applied to ERROR.
C DRSAMP - sampling period (s) for adjusting setpoint and summing reheat.
C
C  COMMON BLOCK AIRSET:
C TOAMAX - array of outside air temperatures where the setpoints reach TRMAX.
C TOAMIN - array of outside air temperatures where the setpoints reach TRMIN.
C TRMIN  - array of minimum possible values for setpoints in TREF.
C TRMAX  - array of maximum possible values for setpoints in TREF.
C TOAMID - array of outside air temperatures where setpoints reach TRMID.
C TRMID  - array of values for setpoint in TREF between two linear regions.
C ARSTAT - array of values to indicate what type of reset strategy to use.
C
C  COMMON BLOCK SETPNT:
C TREF   - array of setpoints used by the air handler task, each resettable.
C
C DRTSKI - task interval(s) at which DRESET executes. From FID task table.
C ERROR  - difference between measured and maximum % of maximum reheat.
C MAXCNT - number of samples required before reset calculation can be made.
C MCOUNT - counter holding current number of samples that have been taken.
C MINRHV - current minimum value of reheat used for one zone.
C NRHZON - number of zones with reheat status sensors.
C RHPCT  - minimum measured percentage of maximum reheat usage.
C RHZONE - array of counters for summing times reheat is on when sampled.
      INTEGER ARSTAT
```

```
      INTEGER RHZONE(2)
      BYTE DIGO,DOPRI,DIGIN
      REAL TREF
      BYTE H,M,S,TS
      COMMON/TSKINT/H,M,S,TS
      COMMON/DIGITA/DIGO(1,24),DOPRI(1,24),DIGIN(1,16)
      COMMON/RHDEMA/RHMAX(5),RHMIN(5),RHSTEP(5),DRSAMP
      COMMON/AIRSET/TOAMAX(5),TOAMIN(5),TRMIN(5),TRMAX(5)
     &,TOAMID(5),TRMID(5),ARSTAT(5)
      COMMON/SETPNT/TREF(5)
      DATA RHZONE/2*0/,MCOUNT/0/,NRHZON/2/
C------------determine execution interval ----------------------------
      CALL TSKCHK(7,IEDOS)
      DRTSKI=M*60+S
      MAXCNT=DRSAMP/DRTSKI
C--------determine reheat coil usage-----------------------------------
      DO 100 I=1,NRHZON
      J=I+6
      RHZONE(I)=RHZONE(I)+DIGIN(1,J)
  100 CONTINUE
      MCOUNT=MCOUNT+1
      IF(MCOUNT.LT.MAXCNT)GO TO 9000
      MCOUNT=0
C------Determine minimum reheat usage for all zones--------------------
      MINRHV=MAXCNT
      DO 200 I=1,NRHZON
      IF(RHZONE(I).GT.MINRHV)GO TO 190
      MINRHV=RHZONE(I)
  190 RHZONE(I)=0
  200 CONTINUE
      RHPCT=FLOAT(MINRHV)/FLOAT(MAXCNT)*100.
C--------change setpoint value as a function of reheat usage-----------
      DO 5000 I=1,5
      IF(ARSTAT(I).NE.2)GO TO 5000
C--------if air temperature is outside of limits, fix setpoint---------
      IF(TREF(I).GT.TRMAX(I))TREF(I)=TRMAX(I)
      IF(TREF(I).LT.TRMIN(I))TREF(I)=TRMIN(I)
      IF(RHPCT.GT.RHMAX(I))GO TO 3000
      IF(RHPCT.LE.RHMIN(I))GO TO 4000
C--------no change in setpoint desired---------------------------------
      GO TO 5000
C--------too much reheat - raise setpoint------------------------------
 3000 ERROR=RHPCT-RHMAX(I)
      TREF(I)=TREF(I)+RHSTEP(I)*ERROR
      IF(TREF(I).GT.TRMAX(I))TREF(I)=TRMAX(I)
      GO TO 5000
C--------not enough reheat - lower setpoint ---------------------------
 4000 TREF(I)=TREF(I)-RHSTEP(I)*RHMIN(I)
      IF(TREF(I).LT.TRMIN(I))TREF(I)=TRMIN(I)
 5000 CONTINUE
 9000 CONTINUE
      RETURN
      END
```

APPENDIX C - Day/Night Setback Control Routines

This appendix contains the FORTRAN IV source code for the day/night setback routines used in the NBS FID. The routines are taken out of the complete FID program that they are designed to work with, but still provide an example of actual source code for day/night setback.

```
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      SUBROUTINE STARUP
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C This routine is used as a task for morning startup of a building
C including space thermostat setup, air handling unit controller
C activation and starting of fans and pumps which have been off.
C
C VARIABLE DEFINITIONS:
C
C  COMMON BLOCK AIRSET: from supply air reset task. only one variable used:
C ARSTAT - array of values to indicate what type of reset strategy to use.
C
C  COMMON BLOCK ACTUA: from air handler control task. only one variable used:
C AHSTAT - variable indicating current status of air handling unit.
C          "N" = normal
C
C THREE,FOUR,FIVE,SIX,FAN,SETBAK - pointers to digital outputs for various
C                                  devices. Two parts: MUX and Point no.
      BYTE ON,AHSTAT,NORMAL
      INTEGER SIX,THREE,FOUR,FIVE,T,FAN,SETBAK
      INTEGER OPEN1,HEAT,DAMPER,DCLOSE,DOPEN,BAND,ARSTAT
      REAL TACT,TOAMAX,TOAMIN,TRMIN,TRMAX,TOAMID,TRMID
C
      COMMON/AIRSET/TOAMAX(5),TOAMIN(5),TRMIN(5),TRMAX(5)
     &,TOAMID(5),TRMID(5),ARSTAT(5)
      COMMON/ACTUA/OPEN1(5),HEAT(5),DAMPER(5),TACT(5),DCLOSE(5),DOPEN(5)
     &,BAND(5),AHSTAT
C
      DATA SIX/X'0106'/,THREE/X'0103'/,FOUR/X'0104'/,FIVE/X'0105'/
      DATA FAN/X'0118'/,SETBAK/X'0117'/,ON/1/,NORMAL/'N'/
C----------------activate miscellaneous devices-------------------------
      CALL DIGOUT(THREE,1,127)
      CALL DELAYD(2,FOUR,127,ON,0,1)
      CALL DELAYD(2,FIVE,127,ON,0,2)
      CALL DELAYD(2,SIX,127,ON,0,3)
C---------activate main air handler fan---------------------------------
      CALL DELAYD(2,FAN,127,ON,0,5)
      AHSTAT=NORMAL
C---------send signal to space thermostats to set up--------------------
      CALL DIGOUT(SETBAK,0,1)
C---------initialize supply air temperature reset value-----------------
      DO 100 I=1,5
      ARSTAT(I)=1
  100 CONTINUE
      CALL ARESET
      DO 200 I=1,5
```

```
      ARSTAT(I)=2
  200 CONTINUE
      RETURN
      END
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      SUBROUTINE SHUTDN
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C This task is used to shut down the air handling unit, pumps and fans,
C and set back space thermostats for an unoccupied period.
C
      INTEGER SIX,THREE,FOUR,FIVE,SETBAK
      INTEGER OPEN1,HEAT,DAMPER,DCLOSE,DOPEN,BAND
      BYTE AHSTAT,STOP
C
      COMMON/ACTUA/OPEN1(5),HEAT(5),DAMPER(5),TACT(5),DCLOSE(5),DOPEN(5)
     &,BAND(5),AHSTAT
C
      DATA SIX/X'0106'/,THREE/X'0103'/,FOUR/X'0104'/,FIVE/X'0105'/
      DATA SETBAK/X'0117'/,STOP/'S'/
C--------------shut off miscellaneous devices---------------------------
      CALL DIGOUT(SIX,0,1)
      CALL DIGOUT(THREE,0,1)
      CALL DIGOUT(FOUR,0,1)
      CALL DIGOUT(FIVE,0,1)
C--------------set air handler to stop----------------------------------
      AHSTAT=STOP
C--------------set back space thermostats-------------------------------
      CALL DIGOUT(SETBAK,1,1)
      RETURN
      END
C=======================================================================
      SUBROUTINE DELAYD(MOTSK,OUT,PRIOR,ONOFF,MIN,SEC)
C=======================================================================
C this routine is called to turn a load off or on, after a specified time
C interval. An available on-off task is found, where DOTSK is the number
C of the highest on-off task which can be used to control the load. OUT is
C the digital output to control, PRIOR is the priority to control the load
C under, ONOFF is 1 to turn on a load, 0 to turn it off, and MIN and SEC
C are the time interval that should elapse before the output is controlled.
C COMMON BLOCK ONOFF contains a table of on-off task parameters that are
C set before the task can be used.
C
      INTEGER PRIOR,OUT,MOTSK
      BYTE H,M,S,TS,TSK,ONOFF
      BYTE DONOFF,INUSE
      INTEGER MIN,SEC,IPR,DNUM
      BYTE CNTRL,SCAN0,SCMAST,SCSLAV,ONOFFT,TSKMAX,DCMAST
      COMMON/TSKINT/H,M,S,TS
      COMMON/ONOFF/DNUM(16),DONOFF(16),INUSE(16),IPR(16)
      COMMON/TSKLNK/CNTRL(2),SCAN0,SCMAST,SCSLAV(16),
     &ONOFFT(16),TSKMAX,DCMAST
      DATA NOOTSK/16/
      CALL LOCK
```

```
C----------find unused on/off task pair-----------------------------------
      ITSK=0
         DO 1000 I=MOTSK,NOOTSK
         IF(INUSE(I).NE.0)GO TO 1000
         ITSK=I
         GO TO 2000
 1000    CONTINUE
      ITSK=16
 2000 INUSE(ITSK)=1
C----------set parameters in on-off task table---------------------------
      INUSE(ITSK)=1
      IPR(ITSK)=PRIOR
      DNUM(ITSK)=OUT
      DONOFF(ITSK)=ONOFF
C----------cause on-off task to execute after a delay time-------------
      TS=0
      H=0
      M=MIN
      S=SEC
      CALL TSKEDT(ONOFFT(ITSK),-1,1)
      CALL UNLOCK
      RETURN
      END
```

APPENDIX D - Ventilation Purging Control Routines

This appendix contains the FORTRAN IV source code for the ventilation purging routines used in the NBS FID. The routines are taken out of the complete FID program that they are designed to work with, but still provide an example of actual source code for ventilation purging.

```
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      SUBROUTINE VEPURG
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C This task is used to determine if ventilation purging would be useful
C and if so to start the purging. If purging is currently occurring, the
C task determines if it is useful to continue. If not, purging is stopped.
C
C VARIABLE DEFINITIONS:
C
C  COMMON BLOCK ACTUA: from air handler control task. only one variable used:
C AHSTAT - variable indicating current status of air handling unit.
C
C  COMMON BLOCK ANALOG:
C ANAI   - array of analog input values obtained by data input task.
C
C  COMMON BLOCK OADAMP: from economizer task; TRETPT, TCODIF, TOAMN not used.
C TOAPT  - two part integer pointing to the value in ANAI for outside temp.
C          1st 8 bits = MUX number; 2nd 8 bits = point number
C
C FULL   - copy of TOAPT used to split TOAPT into two parts: HALF (1),HALF(2)
C OFF,PURGE,VENT,STOP - possible air handler states
C MUX    - mux ID number where a desired sensor is located.
C IPNT   - point ID number within MUX for desired sensor.
C ROOMT  - current space temperature.
C OUTSIT - current outside air temperature.
C
      LOGICAL NEEDCL,CLAVAL
      INTEGER OPEN1,HEAT,DAMPER,DCLOSE,DOPEN,BAND,FULL,TRETPT,TOAPT
      BYTE AHSTAT,PURGE,VENT,OFF,STOP,HALF(2)
      REAL TACT,TCODIF,TOAMN
      REAL*8 ANAI
C
      COMMON/ACTUA/OPEN1(5),HEAT(5),DAMPER(5),TACT(5),DCLOSE(5),DOPEN(5)
     &,BAND(5),AHSTAT
      COMMON/ANALOG/ANAI(1,32)
      COMMON/OADAMP/TRETPT,TOAPT,TCODIF,TOAMN
C
      EQUIVALENCE (FULL,HALF(1))
      DATA PURGE/'P'/,VENT/'V'/,OFF/'O'/,STOP/'S'/
C--------determine outside air temperature------------------------------
      FULL=TOAPT
      MUX=HALF(2)
      IPNT=HALF(1)
      OUTSIT=ANAI(MUX,IPNT)
```

```
C--------determine space air temperature-------------------------------
C in this case, use return air temperature since in emulator return air
C temperature equals space temperature also when fan is off.
C---------------------------------------------------------------------
      FULL=TRETPT
      MUX=HALF(2)
      IPNT=HALF(1)
      ROOMT=ANAI(MUX,IPNT)
      IF(AHSTAT.EQ.PURGE)GO TO 2000
C--------------air handler currently off-------------------------------
      IF(AHSTAT.NE.OFF)GO TO 9000
      IF(NEEDCL(AHSTAT,ROOMT).EQ..FALSE.)GO TO 9000
      IF(CLAVAL(AHSTAT,OUTSIT,ROOMT).EQ..FALSE.)GO TO 9000
      AHSTAT=VENT
      GO TO 9000
C--------------air handler currently in purge mode----------------------
 2000 IF(NEEDCL(AHSTAT,ROOMT).EQ..FALSE.)GO TO 3000
      IF(CLAVAL(AHSTAT,OUTSIT,ROOMT).EQ..FALSE.)GO TO 3000
      GO TO 9000
 3000 AHSTAT=STOP
 9000 RETURN
      END
C=====================================================================
      FUNCTION NEEDCL(AHSTAT,ROOMT)
C=====================================================================
C This function determines whether the space currently needs cooling.
C
      LOGICAL NEEDCL,RTDROP,CLEAR
      BYTE AHSTAT,PURGE,OFF
      COMMON/PURGPA/ROOMIN,PDTMIN,NPURSA,STPDEL,OATMIN,ROOMAX
      DATA PURGE,OFF/'P','O'/
      IF(AHSTAT.EQ.PURGE)GO TO 500
C---------not currently purging-----------------------------------------
      NEEDCL=.FALSE.
C---------is space temperature changing by itself, rising or falling?---
      NEEDCL=(.NOT.RTDROP(NPURSA,ROOMT,PDTMIN))
      IF(.NOT.NEEDCL)GO TO 900
C---------does space currently need cooling?----------------------------
      NEEDCL=(ROOMT.GT.ROOMAX)
      IF(.NOT.NEEDCL)CLEAR=RTDROP(0,ROOMT,PDTMIN)
      GO TO 900
C---------currently purging-is space becoming too cold?-----------------
  500 NEEDCL=.FALSE.
      IF(ROOMT.GT.ROOMIN)NEEDCL=.TRUE.
      IF(.NOT.NEEDCL)CLEAR=RTDROP(0,ROOMT,PDTMIN)
  900 CONTINUE
      RETURN
      END
```

```
C=======================================================================
      FUNCTION CLAVAL(AHSTAT,OUTSIT,ROOMT)
C=======================================================================
C This function is used to determine if cooling is available by the use
C of ventilation purging.
C
      LOGICAL CLAVAL,RTDROP
      BYTE AHSTAT,PURGE,OFF
      COMMON/PURGPA/ROOMIN,PDTMIN,NPURSA,STPDEL,OATMIN,ROOMAX
      DATA PURGE,OFF/'P','O'/
C
      CLAVAL=.FALSE.
      IF(AHSTAT.EQ.PURGE)GO TO 500
C---------is outside air too cold for purging (coil freeze)-------------
      IF(OUTSIT.LT.OATMIN)GO TO 900
C---------can outside air provide useful cooling?-----------------------
      IF((ROOMT-OUTSIT).LT.STPDEL)GO TO 900
      CLAVAL=.TRUE.
      GO TO 900
C---------is outside air too cold for purging (coil freeze)-------------
  500 IF(OUTSIT.LT.OATMIN)GO TO 900
C---------currently purging-is outside air still cooling ?--------------
      CLAVAL=RTDROP(NPURSA,ROOMT,PDTMIN)
  900 CONTINUE
      RETURN
      END
C=======================================================================
      FUNCTION RTDROP(NPURSA,ROOMT,PDTMIN)
C=======================================================================
C This function is used to determine if there is a relative drop in
C room temperature since past samples were taken. If so, returns true.
      LOGICAL TUP,TCDOWN,RTDROP
      REAL OROOMT,OPDT,PDT
      INTEGER ICDOWN,ICNTUP
      DATA ICDOWN/1/,ICNTUP/1/,OROOMT/100./,OPDT/0./
      RTDROP=.FALSE.
C----------determine change in room temperature (PDT)-------------------
      PDT=OROOMT-ROOMT
C----------determine if up (TUP = T) or down (TDOWN = T)----------------
      TUP=(PDT.LT.PDTMIN)
      TCDOWN=(.NOT.TUP.AND.OPDT.GT.PDTMIN)
C----------increment counters for up or down ---------------------------
      IF(TUP)ICNTUP=ICNTUP+1
      IF(TCDOWN)ICDOWN=ICDOWN+1
      IF(.NOT.TCDOWN)ICDOWN=1
C----------decide on trend----------------------------------------------
      IF(ICDOWN.GT.NPURSA)ICNTUP=1
      IF(ICNTUP.LT.NPURSA)RTDROP=.TRUE.
      IF(.NOT.RTDROP)ICNTUP=1
      OROOMT=ROOMT
      OPDT=PDT
      RETURN
      END
```

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11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

Software is an important component of building management and control systems (BMCS). This report describes concepts, algorithms, and software used in BMCS components developed in the NBS building systems and controls laboratory. The basic concepts, considerations and general algorithms for hot deck/cold deck supply air setpoint reset, day/night thermostat and ventilation setback, ventilation purging, and hot/chilled water supply setpoint reset are presented. Reset is the changing of a setpoint on a Heating, Ventilating and Air Conditioning (HVAC) system controlled by a feedback controller to match the system output to the system load. Setback is the changing of HVAC system operation to reduce energy use during unoccupied periods. Purging is the use of outdoor air during unoccupied periods to reduce mechanical conditioning requirements. Specific implementations of the algorithms in software on an actual BMCS are presented as examples.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

air handling unit control; building management and control systems (EMCS,BMCS); chilled water reset; computer control; control algorithms; control software; day/night setback; energy management; hot water reset; heating, ventilating and air conditioning (HVAC); outside air reset; supply air setpoint reset; ventilation purging.

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