NISTIR 4604

Direct Digital Control Based Building Automation System Design Criteria

...ent of Commerce
...ute of Standards and Technology
...Fire Research Laboratory
... MD 20899

Prepared for:
General Services Administration
Public Buildings Service
Office of Real Property Development
Washington, DC 20405

NISTIR 4604

Direct Digital Control Based Building Automation System Design Criteria

James Y. Kao

June 1991

U.S. Department of Commerce
Robert A. Mosbacher, *Secretary*
National Institute of Standards and Technology
John W. Lyons, *Director*
Building and Fire Research Laboratory
Gaithersburg, MD 20899

Prepared for:
General Services Administration
Richard G. Austin, *Administrator*
Public Buildings Service
William C. Coleman, *Commissioner*
Office of Real Property Development
Washington, DC 20405

Abstract

This document serves to provide design guidance for Direct Digital Control (DDC) based Building Automation Systems (BAS). Explanations of general design philosophy, current unresolved problems confronting the application of DDC in BAS, and considerations for choosing alternative control strategies in specifying application programs are given. This guide is intended for use by GSA and contract designers as a means of identifying major aspects in DDC based BAS design where new construction or major renovations of control systems are included.

Key Words: automatic control, building automation system, building control, building design, design criteria, direct digital control

Table of Contents

Page

CHAPTER 5. CONTROL/MONITORING INFORMATION

CHAPTER 1. GENERAL

1.1 OVERVIEW

Conventional pneumatic control in commercial heating, ventilating, and air-conditioning (HVAC) systems basically uses analog devices. An error signal is obtained by comparing the magnitude of a pressure signal from the sensor with a preset pressure in the controller. An output pressure based on this error signal is sent continuously to the controlled device to offset the error. Direct digital control (DDC) feeds electronic signals (in volts or amperes) from a sensor to a microprocessor in the controller. After certain mathematical operations, a digital output from the microprocessor is converted to either a voltage or a pneumatic signal to the controlled device to maintain a preset controlled condition. Unlike the conventional control, the DDC operation is not continuous. However, if the sampling period of a DDC system is designed properly, the controller performance will have insignificant degradation. Since DDC system basically uses digital signals in transmission and processing, it offers the promise of more accurate monitoring and hence control than the conventional control system.

The cost of DDC based Building Automation Systems (BAS) have dropped substantially in the recent past, enabling them to be very competitive to conventional control systems in many applications. However, the real strength of DDC based BAS is their promise of improved reliability, versatility, and performance compared to conventional control systems. There are many control functions which are ideal for DDC applications, some of which would be cumbersome, if not impossible, to be performed by conventional systems. This fact is not due to design, but results from limitations of technology and system costs. With energy monitoring and control systems (EMCS) of the past two decades, managing plants and building energy has been much enhanced. Yet, the sophistication of control function and quality of control performance had not been really improved until DDC technology was used in building controls.

The basic components of a DDC based BAS include field panels, actuating devices, host computers, software to run microprocessors and computers of the BAS, and a communication network enabling interaction between the components of the system as well as to the outside. A diagram of a DDC based BAS with possible component combinations is given in CHAPTER 3. A DDC based BAS has "stand-alone" field panels which alone perform all functions of monitoring and control of certain pieces of mechanical or electrical equipment. These panels are also connected to one or more host computers for supervisory control and reporting. Field panels contain power supply packages, input and output cards (these cards may include multiplexer devices, analog-to-digital converters, signal conditioning devices, digital-to-analog converters, and memory devices), microprocessors, memory devices, and other auxiliary devices. These field panels will perform their monitoring and control functions even when other parts of the BAS fail. This quality together with the enduring nature of electronic components potentially makes BAS very reliable. Since microprocessors are used in these systems, accurate control can be accomplished by precise control actions. DDC based BAS may perform many sophisticated control strategies which would be very difficult to implement with conventional control systems. Thus, precise control and optimization of building energy usage can be realized.

1.2 SCOPE

These Guidelines cover microprocessor based, distributed-network control systems, including pneumatic actuating devices and their supporting systems, for HVAC, fire safety, and building security. It is intended for new construction and major renovations where new or replacement control systems are being considered.

1.3 DESIGN PHILOSOPHY

Since DDC based BAS are still rapidly developing, rigid design guidelines are not appropriate. The designer should describe the Government's requirements and encourage the contractor to provide control schemes and equipment to achieve the goals resulting in better system performance and optimum energy conservation. Since many control functions of DDC based BAS are implemented in software, project specifications must instruct the contractor in detail about the required control objectives, so that all intended control operation will be provided.

The specified BAS must have distributed intelligence. The controllers of BAS must be able to perform all required functions without the instruction or assistance from other components of the system. When other controllers and host computers fail, the control function of the controller in question should not be affected.

1.4 A REMAINING PROBLEM

One problem which impedes the use of DDC based BAS today is the proprietary schemes for network communication caused by non-standard protocols between different manufacturers. Data transmissions between BAS components or subsystems of different manufacturers are, in most cases, not possible. Although some manufacturers use "translators" to interconnect different protocols, they are designed only to communicate with the systems of certain specific manufacturers, not to other systems universally. Many organizations, including the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), are developing more basic communication protocol standards to be used in building control networks. It is estimated at this time that a draft ASHRAE standard will be completed in June, 1991 and the final standard will be completed in about a year. The ASHRAE recommendations will be implemented by control manufacturers thereafter. Since large projects take more than two years to formulate and design, the communication problem described here should not be a serious obstacle in planning the application of DDC based BAS to new projects. For projects with short lead times, the general principles described in CHAPTER 2 should also be followed, realizing that pre-standardized systems may be installed. Some vendors will provide a written guarantee today that they will provide a way to convert their current products to a future ASHRAE standard network.

CHAPTER 2. PROJECT QUALITY CONTROL

2.1 DDC BASED SYSTEM AS SPECIFICATION

All GSA projects involving new BAS should be designed and specified to allow contractors to bid DDC based BAS as an option to conventional pneumatic and pneumatic/electric systems. It is anticipated that in the near future (2 to 5 years), all new projects will require DDC based BAS. This interim determination is based on industry trends and the following facts:

Historical Perspective. Conventional control systems have been serving commercial buildings satisfactorily for many years. They are generally reliable and the majority of maintenance personnel are familiar with their operation and maintenance. However, many sophisticated control schemes are not available with conventional systems but can be implemented easily with DDC based systems.

System Operating Energy. Large scale field studies comparing energy consumption of conventional and DDC based control systems have been scarce. However, studies have shown that DDC based systems can minimize energy waste due to precise control of some components in air handling systems.

System Installation Cost. Although the installation cost of DDC based BAS has decreased rapidly, in certain instances DDC based systems can be more costly than conventional systems. However, recent trends indicate that many contractors chose DDC based systems in bid submissions when given a choice.

Problems Yet To Be Resolved. Incompatibility of DDC based systems produced by different manufacturers is still a problem (see CHAPTER 1). This fact may hinder future expansion or modification of control systems of buildings having DDC based control systems.

2.2 SELECTION OF BIDDERS

Since DDC based BAS is relatively new and is still evolving, as in many high-technology applications, there are contractors in the BAS field who may be unqualified and inexperienced. The necessity for good project quality control is evident. One approach which enhances quality control under these circumstances is to emphasize qualifications in specifications. For major construction work, the control manufacturer and the control system contractor shall be one and the same. For minor work having to interface with large DDC control systems, this requirement shall also be maintained. The control contractor shall manufacture at least 70% of their own products to be used in the project. The control contractors not only must have proven experience of at least 3 years in successful installation of DDC based BAS, they should also have experience in HVAC control in general of at least 5 years. It is also important to know if the components and systems to be used will be maintained and supported by the manufacturers for a period of not less than 10 years. Project specifications should spell out all these qualifications and should require certifications to be submitted. Certifications should also include lists of completed projects by the contractor of comparable size and complexity with the building owners' address provided.

Equally important are the qualifications and experiences of the control contractor's project foreman. The project foreman should be an employee of the BAS manufacturer and should be reviewed for his experience on DDC based BAS, including the pertinent information of recent projects which were supervised by the foreman during construction. A minimum of three previous successful projects of comparable size and complexity should assure the foreman's qualification. Certification by the contractor of the foreman's qualification should be specified. Any substitute foreman should meet the same requirements.

2.3 FUNCTIONAL INSPECTION AND TESTING

Since there are many field connections of wires and various software conditions, functional inspection and testing of the DDC based system prior to acceptance by the Government is especially important. Functional testing of BAS can be done manually and/or with control manufacturer's specially designed instruments. The process should be concentrated on three areas: verifying correct responses of all commands and the response time; verifying control actions of all application programs; and verifying control accuracies of the system by measuring variables of the controlled media. A well planned step-by-step logical check is necessary. GSA's HVAC Functional Inspection and Testing Guide, which details inspection and testing procedures for commissioning a BAS, may be consulted in developing of specification requirements.

2.4 TRAINING OF GOVERNMENT PERSONNEL

One reason for poor operation of DDC based systems is poor operating personnel training. This aspect cannot be stressed enough. Like any other high technology application, BAS operating personnel must be knowledgeable of both DDC technology and HVAC equipment operation. Since DDC application in Government buildings is new to most building operators, it is essential that construction documents (basically specifications) emphasize training of operators. Good training programs for Government personnel and/or operating personnel of the Government's operation and maintenance (O & M) contractors by the BAS contractors must be included in the construction contract. Training is preferably done in several stages: (a) during start-up, check-out, and functional testing; (b) formal classroom-style training prior to Government acceptance; and (c) formal training 6 months after acceptance. Typically, a DDC based system has a one year warranty period. On-the-job training to Government personnel by the control contractor should also be required during this period.

2.5 OPERATION MAINTENANCE (O and M) CONTRACTS

An overall building O and M contract is sometimes executed by GSA through a Commercial Facilities Management (CFM) contract to run a new facility. However, a good way of insuring BAS performance is to require operation and maintenance of controls by the construction contractor. Similar to elevator maintenance contracts, the period of performance should be for one base year with two option years. The service and maintenance of DDC based control systems during the first year should also reflect a one year warranty period to assure operating performance. The reasons are: (a) DDC based BAS are complex and relatively new as stated previously; (b) the contractor may provide updated hardware and software that may be developed after the system is installed to improve system performance; and (c) additional time is typically required and beneficial to further train Government or CFM personnel. It may be advantageous to require bid alternates from control contractors for the extended service and maintenance portion of the contract. This extended service and maintenance bid and the construction bid would then be evaluated together. It is important that the requirements of the service and maintenance contract do not overlap those for the CFM contract.

2.6 COMPLIANCE WITH DEPARTMENT OF ENERGY (DOE) REGULATIONS

Effective July 31, 1989, all new Federal buildings of three or more stories must be designed and operated to follow the interim rules of "Energy Conservation Voluntary Performance Standards for New Commercial and Multi-Family High Rise Residential Buildings; Mandatory for New Federal Buildings". These rules were made public in the Federal Register on January 30, 1989 (pp 4538 - 4720, Department of Energy Office of Conservation and Renewable Energy, 10 CFR Part 435). This Standard sets design principles and minimum requirements for HVAC systems. It contains prescriptive requirements for compliance. Details of requirements of energy management systems are also given. Some of these regulations delineate HVAC system designs which may also involve BAS requirements. The following items describe briefly these requirements. However, there are numerous exceptions, limitations, and alternative methods in the regulations for achieving compliance. It would be essential for designers to familiarize themselves with this DOE document during the design stage in developing contract documents.

- Separate HVAC systems shall be considered to serve areas expected to operate on widely differing operating schedules or design conditions.
- Areas with special temperature or humidity requirements shall be served by systems separate from those serving areas that require comfort heating and cooling only.
- The supply of zone cooling and heating shall be sequenced to prevent the simultaneous operation of heating and cooling systems for same space.
- Systems serving areas with significant internal heat gain shall be designed to take advantage of mild or cool weather conditions to reduce cooling energy if heat recovery systems are not used.
- Economizer controls shall be integrated with mechanical controls so that mechanical cooling is only operated when necessary. The systems and control shall be designed so that economizer operation does not increase heating energy use.
- Controls shall be provided to allow systems to operate in an occupied mode and an unoccupied mode.
- Provisions shall be made for the measurement of energy inputs and outputs to determine equipment energy consumption and/or installed performance capabilities and efficiencies of all heating, cooling, and HVAC delivery systems equipment.

- o All energy delivery systems shall have a local control loop for each system. The control equipment of the local control loop shall be arranged so that sensing, control action, and control setting variables can be read or tested at the device.

- o The energy management requirements shall accomplish the following: (a) read and retain daily totals for all energy measurement instruments; (b) total all energy values weekly, and record and retain values placed on a summary report; (c) record and plot hourly outdoor and indoor temperatures against real time, and summarize and report for each year in a format compatible with degree-days or bin temperature; (d) based on time schedules, turn on or off any HVAC or service water heating system or equipment; (e) based on time schedule, turn on or off major building lighting and occupancy power circuits; (f) reset local loop control system for HVAC equipment; (g) monitor and verify operation of heating, cooling and energy delivery systems; (h) monitor and verify operation of lighting and power outlets, auxiliary and service hot water systems; (i) provide readily accessible override controls so that time-based HVAC and lighting controls may be temporarily overridden during off hours; and (j) provide optimum start/stop for HVAC systems.

2.7 USE DRAWINGS TO SUPPLEMENT SPECIFICATIONS

Successful DDC design must include the same information as established for other control systems. Field panel and host computer locations (and host computer rooms, if required) should be shown on the drawings. Drawings should show flow diagrams to indicate the major components of the controlled/monitored equipment, and the locations of the sensors and actuators. The locations of static pressure sensors for fan pressure control in variable air volume (VAV) systems, temperature sensors for discriminator control, and air and water flow measuring stations should be indicated on floor plans. Point schedules indicating the essential elements of the required control and monitoring points may be included either on the drawings or in the specifications. A control valve schedule should be shown to detail flow capacities, flow medium, inlet pressure, and the selected pressure drop of the valves. When lighting on/off control is intended, indicate on the drawings lighting control areas.

2.8 COORDINATION BETWEEN CONTRACTORS

Good coordination between the BAS subcontractor and other subcontractors is very important. Liberal use of cross references in drawings and/or specifications must be done. Attention should be given to the following areas:

- With respect to the general contractor: Locate space sensing devices and associated equipment (wires and tubes). Coordinate entrance card units and intrusion alarm sensors.
- With respect to the mechanical and the sheet metal contractors: Locate sensing and actuating devices.
- With respect to the fire suppressing system contractor: Indicate sensing and actuating contact locations.
- With respect to the water treatment contractor: Although water treatment of condenser water and chilled water is usually supplied by a water treatment subcontractor, designers may elect to have the treatment pump controlled and monitored by the BAS.
- With respect to the electrical contractor: Indicate lighting circuits, electrical metering and control devices, emergency power connections, and power supply to BAS components.
- With respect to the telecommunication contractor: Identify the extent of BAS communication through building telecommunication networks.

CHAPTER 3.
BUILDING AUTOMATION SYSTEM

3.1 SYSTEM ARCHITECTURE

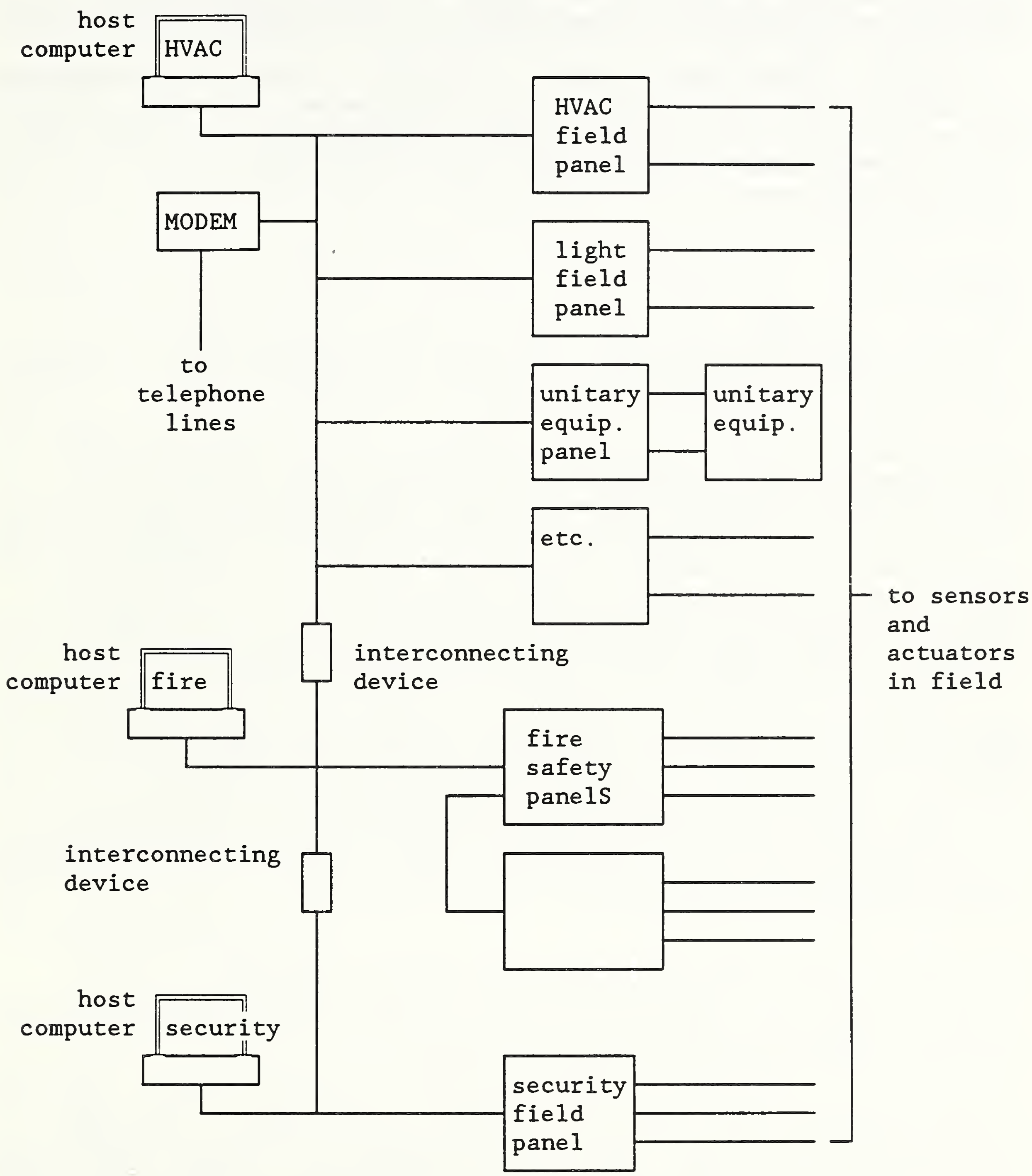
Performance oriented Design. Although the general architecture (configuration) of a BAS is to be distributed, there may be variations in system features from one manufacturer to another. As a general principle, the Government should not custom design BAS. Designers should rely on standard package products/systems that meet the following basic requirements:

System Performance. The system must provide all control functions as specified for the particular project in both local loop performance and control application strategies. The basic control functions for DDC based BAS are essentially performed by field panels. The trend of the industry has been to use these panels to perform control functions as much as possible (except for global controls such as electric load shedding). These panels function as stand-alone units to control their respective HVAC equipment and communicate with other panels. Any information available to any field panel should automatically be available to other field panels.

Host Computer System. By adding host computers and associated peripherals, the cost of which is quite low compared with the overall control system cost, global control functions and management of building systems and energy usage can be readily provided. All BAS should have host computer systems.

Fire Safety Redundancy. Fire safety, building security, and HVAC controls are functionally separate (one system's malfunction does not affect other systems). Hierarchy must be established in the order of fire safety, building security, and HVAC. During a fire emergency, certain control functions should be automatically transferred and initiated. Examples are: turning on or off air handling system and/or opening or closing dampers for smoke control; sending certain elevators to ground floor; and releasing of certain exits. The dedicated fire and the security host computer systems must have standby host computer systems which take over the normal functions automatically when malfunctioning of their own host computer system is detected. A preferred method is to interconnect the three (fire, security, and HVAC) networks, so that the HVAC host computer system may be used for fire or security control when malfunction occurs (Also see fire safety paragraph under DESIGN DETAILS section below). Interconnecting devices (see diagram on the next page) may be needed between the networks to accommodate message transfer between these networks. Depending on the communication system design, these interconnecting devices may not be required; they may be gateways ("translators") which are used for different protocols between the networks; or they may be other communication protocol devices.

The diagram shown on the next page illustrates a possible BAS configuration.


host computer
HVAC
HVAC field panel
MODEM
to telephone lines
light field panel
unitary equip. panel
unitary equip.
etc.
to sensors and actuators in field
host computer
fire
interconnecting device
fire safety panelS
interconnecting device
host computer
security
security field panel

3.2 DESIGN DETAILS

Compatibility of Components. Industry standard products should be used as much as possible, without degrading the system, to avoid being limited to a single supplier in the future. Field panels should be able to interface with almost any field devices such as sensors, transmitters, relays, and actuators. The panel should be able to accept any typical sensor input, such as 4 to 20 milliamps, resistance, 0 to 5 volts, or 0 to 10 volts, without hardware modification. Designers and specifiers must prepare construction documents to avoid using proprietary components. The GSA/PBS guide specification on BAS reflects this principle.

Battery Backup. All random access memory for storing software should have battery backup protection from power failure. A minimum of 72 hours is recommended. For fire safety system, battery backup should provide 24 hours of supervisory operation with the capacity of sounding general alarm for at least fifteen minute duration.

Using Pneumatic Actuating Devices. Although the total prices of DDC based BAS are closely competitive with conventional systems in many cases, pneumatic actuation of large valves and dampers is generally still cheaper than using electric operated actuators. It is best to let the contractor decide the kind of actuators to be used. Therefore, construction documents should provide for the possibility of pneumatic devices, including air compressors, filters, dryers, and storage equipment and systems, air piping and tubing, pneumatic actuators for valves and dampers, and other associated pneumatic devices.

Humidity Sensing. Keeping calibration of humidity sensors is more difficult than most other environmental sensing devices (e.g. temperature, pressure). Although good humidity instruments are available, they are relatively costly and generally require periodic maintenance to keep their calibration. Avoid their use if other control methods and devices will accomplish the desired result. (see ECONOMIZER CONTROL paragraph in CHAPTER 4.)

Selection of Indicating, Measuring and Control Components. Sensors, indicating devices, transmitters, and controllers should have their ranges or spans selected to cover only the anticipated operating ranges to improve measurement and control accuracy.

Field Panel Locations. Field panels should be located close to the equipment they are controlling. However, too many field panels may increase the project cost. In order to minimize the overall cost of the system, considerations should be given to the distances between the field panels and their associated sensors and actuators, the number of input and output points of the panels, and the number of field panels.

Field panels should generally be located so that the building operators may access them without the need of ladders. It is advisable to group VAV controllers and associated devices in common panels on the floor level. Diagnosing performance and adjusting control parameters of VAV terminal units should be through these panels or through space sensors.

Speed of Data Transmission. The speed of data transmission of BAS depends on the amount of data flow and the hardware/software of the communication systems. Designers should prescribe the required needs for the control action and let the contractors meet these needs. Control actions in response to an operator's command should not take longer than 5 seconds. Alarms caused by sensing change should occur within 8 seconds. Alarms caused by system failure should occur within 5 seconds.

Control Valve Selection. Control valves are often selected in a size too large for good operation. The valve flow coefficient Cv is generally used to compare valve capacities. Valves should be selected for their Cv's based on the available pressures, velocity, and noise to yield maximum pressure drops. The pressure drops of water valves should be at least equal to the pressure drops through the heat transfer elements and their associated fittings. Size steam valves at critical pressure drop which is 45% of the inlet absolute pressure. List Cv's and the maximum inlet pressure in the valve schedule.

Fire Safety. NFPA 90A (Standards for Installation of Air Conditioning and Ventilating Systems) requires that smoke detectors be installed to automatically stop fans for air handling systems over 944 L/s (2,000 cfm) capacity. This Standard does not require duct smoke detectors in air handling systems of less than 7,080 L/s (15,000 cfm) capacity, if the entire system is within the space served and such space is protected by an area smoke detection system. It should be noted that considerable smoke dilution can take place in multi-inlet returns to air handling equipment. In such areas, separate smoke detection sensors at each inlet may be more effective in controlling for fire safe operations. PBS Fire Protection Engineers should be consulted in deciding the scope of BAS fire protection.

Keep the System Simple. DDC based control systems are very versatile and can be very complex. However, within the scope of the functional requirements, efforts should be made to simplify the systems as much as possible. A good example is avoiding using transmitters in conjunction with sensors. The present DDC controllers can receive a variety of signals from different sensors. This is particularly true for temperature sensing. Eliminating temperature transmitters reduces chances of malfunction for one layer of components.

3.3 POINT SCHEDULES

Point schedules which include all monitoring and control points will convey the designers' intentions to the control contractors, and should be provided either on design drawings or in contract specifications to supplement control diagrams and control descriptions. The schedules should clearly identify all analog and digital input and output points such as temperature, differential temperature, pressure, differential pressure, flow rate, humidity, electrical energy consumption, equipment run time, equipment status such as on/off, open/close, flow/no flow, etc.; command requirements such as start/stop, open/close, reset, change-over, etc.; and control requirements, such as demand limit, control point adjustment, economizer cycle, etc. All alarm requirements should be included in the schedule by indicating trip points and required personnel action. Requirements of trend logs and displays of various points should also be shown. Certain instrumented data, although useful, should not be included in the BAS. Examples are pressure levels of water entering and leaving coils. The benefit of including these points must be evaluated against the cost of connecting them to the BAS and the project budget.

Points to be included depend on the system design. Listed below are typical points that should be considered for inclusion, when a point schedule is constructed.

For an air handling system:

- o Inputs to sense air temperatures at outdoor, outdoor air and return air mixing plenum, after heat transfer coils, at fan discharge, in return air main duct, and in thermally controlled zones. Also needed are heating/cooling media temperatures, e.g., water temperature in and out of heat transfer coils, and steam and condensate temperatures of heating coils. Any temperature sensor which provides input to a controller or may assist operators to diagnose system performance should be included.

- o Inputs to sense differential pressure of air ducts and building pressure for fan and building pressure controls in a VAV system.

- o Inputs of air flow rate, valve position, damper position, and motor current.

- o Binary inputs from equipment to indicate their status, e.g., fan, switch closure (open/close for dampers), flow switch (flow/no-flow), change-over position, etc.

- o Analog outputs from controllers, e.g., controller output to variable speed fan, cooling and heating coil valve positions, and outdoor air and return air damper positions.

- Binary outputs from controllers and interlocking devices, e.g., start/stop, open/close, reset, change-over, enable/disable.

- Control strategies, e.g., optimized start/stop, economizer control, temperature reset, ventilation control, VAV control.

- Alarm points, e.g., coil freeze protection, any high and low limits (fan discharge pressure of VAV system, high limit of humidified air, high or low temperature of critical rooms, etc.), smoke and fire sensors and devices.

- Maintenance alerts, e.g., run time and maintenance messages for bearings and air filters.

- Calculated values of set points of reset temperature (e.g., heating air temperature reset by outdoor air temperature), water and steam flow rates, energy consumption of heating and cooling coils, and electric consumption. Both instantaneous and accumulated energy values.

- Trend logs of groups of points the designer judged to be useful in diagnosing the system. In practice, the majority of monitored points should be included.

- Display of air handling system, including major components, all sensors, actuators (control valves and dampers), fire and smoke dampers, main and major branch ducts with associated floors.

For a refrigeration system:

- Analog inputs of chilled water and condenser water temperatures in and out of the chiller, main bearing temperature, and oil temperature. Differential temperatures of chilled and condenser water are also useful.

- Analog inputs of refrigerant pressure in evaporator and condenser, and oil pressure.

- Analog inputs of chilled water and condenser water flow rates.

- Run time and power input rate of compressor motor. Run time of chilled water and condenser water pumps.

- Binary inputs of the status of compressor, pumps, and cooling tower fan.

- Binary outputs to compressor, pumps, and cooling tower fan. Also outputs from controllers for interlocking pumps and resetting of chilled water temperature.

- o Temperature alarms of chilled water, condenser water, compressor bearing, and oil. Pressure alarms of evaporator, condenser, oil, and safety control of chiller.
- o Calculated values of chilled water energy rate and compressor electric consumption. Both instantaneous and accumulated values.
- o Trend logs of all analog inputs.
- o Display of chiller system, including chiller, chilled and condenser water pumps, cooling tower, control valves, and sensing devices.
- o Maintenance logs for evaporator and condenser tubes, compressor bearings, chilled and condenser water pumps and motors, cooling tower fan and motor.

For a heating plant:

- o Analog inputs of boiler pressure, leaving and entering water temperatures, feed water temperature, water or steam flow rate, fuel consumption rate, boiler run time, stack temperature, and carbon dioxide level of combustion product.
- o Binary inputs of boiler and water pump status.
- o Alarms for high and low boiler pressure.
- o Calculated values of boiler output, both instantaneous and accumulated values.
- o Trend logs of analog inputs.
- o Display of heating plant, including major components of heating plant equipment, control valves, and sensing devices.
- o Maintenance logs for boiler tube cleaning, draft fan service, and water pump service.

For major heat exchangers (e.g., steam or hot water heated domestic hot water heater):

- o Analog input of leaving domestic water temperature.
- o Binary input of circulating pump or flow switch status.

- o Analog output to control valve.
- o Binary output to circulation pump.
- o Maintenance log for heating surface cleaning.

For building electrical systems:

- o on/off status of lighting zones.
- o Alarms for battery charger malfunctioning.
- o Building electric consumption rate and accumulated energy amount.
- o Status of global energy control strategies involving electrical equipment, e.g., electrical load shedding.

For fire safety system:

- o Alarms for fire/smoke alarm, sprinkler valve status, and sprinkler system low water pressure.
- o Fire pump status.
- o Elevator locations during emergency.
- o Display of entire fire-fighting system and instructions to fire-fighters.
- o Maintenance and testing logs for fire pumps.

For building security system:

- o Building entrance and security alarm status.
- o Display of entire building scurity system and instructions to security personnel during emergency.
- o Maintenance and testing logs for building security system.

An illustrative point schedule for an air handling system with its points partially shown is depicted on the following page. The format of the point schedule may be changed to express the desires of the designer.

	ANALOG INPUT							BINARY OUTPUT					CONTROL				ALARMS				VALUES					
	TEMPERATURE	DIFF PRESSURE	PRESSURE	DAMPER POSITION	FLOW RATE	RUN TIME	MOTOR AMPERAGE	ON/OFF	OPEN/CLOSE	CHANGE OV/NORM	RESET		OPTI START/STOP	ECONOMY CONTROL	VENT CONTROL	TEMP RESET	COIL FREEZE °F	HIGH TEMP °F	HIGH PRESSURE in. w.c	HIGH HUMIDITY %RH	ELEC ENERGY RATE	ACCU ELEC ENERGY	ENERGY RATE	ACCU ENERGY	MAINTENANCE	DISPLAY
A H UNIT #1													X	X	X	X										X
O A DAMPER				X					X	X															X	
R A DAMPER				X					X	X															X	
HEATING COIL	X																								X	
COOLING COIL	X																38								X	
FAN DISCHARGE	X	X	X		X						X							62	3	70						
FAN & MOTOR						X	X	X													X	X			X	
MIX AIR PLENUM	X		X																							
CHILL WATER SUP	X				X																		X	X		
CHILL WATER RET	X																									
HOT WATER SUP	X				X																		X	X		
HOT WATER RET	X																									
AIR FILTER																									X	
OUTSIDE AIR	X																									

CHAPTER 4. APPLICATION SOFTWARE

This section covers the application software normally used in HVAC control strategies to enhance system performance and energy efficiency. Although most software provided by control contractors is proprietary, the following discussion gives general logic and practices of some important software programs. For specific control statements of operations, consult GSA/PBS guide specification on BUILDING AUTOMATION SYSTEMS.

4.1 OPTIMUM START/STOP

The optimum start/stop program determines the start/stop time of HVAC systems after night and weekend shut-downs. The objective of this program is to operate these systems only for the durations necessary. There are various ways to achieve optimum start/stop of air handling systems, heating plants, and cooling plants. These programs usually involve input from outdoor conditions, indoor conditions, thermal characteristics of the building and systems, system capacities, occupancy schedules, and other factors. Sampling of data takes place periodically. These programs may also use the recent history of the building responses as inputs to set the start/stop time. Regardless of the logic complexities and program algorithms, the designer should specify the desired end result. Certain safety conditions should also be incorporated so that the desired conditions may be maintained during off periods without damaging equipment, such as freeze up of coils. If scheduled start/stop programs are also included in BAS software, both the optimum and scheduled start/stop programs must be coordinated. For example, an optimum start/stop program for an air handling system requires the input of on/off schedule of lights which are controlled by a scheduled on/off program. Optimum start/stop should be specified for chillers, boilers, and air handling units involved in perimeter spaces. For air handling systems serving interior spaces where the load is relatively constant regardless of outside conditions, scheduled start/stop should be specified. No start/stop program should be needed for HVAC equipment serving 24-hour operation areas, such as computer rooms.

4.2 ELECTRIC LOAD SHEDDING

Electric utility companies charge commercial customers not only by the energy consumed but also by the maximum demand that occurs during a defined time interval within a billing period. The objective of electric load shedding software is to predict the demand and to down-load low priority electric consuming equipment so the demand charge may be minimized. There are various ways to record electric demand and to determine demand charges, depending on the utility company and customer rate category. Therefore, it is important to know the electric rate structure of the utility company where the building is located.

The specification of a load shedding program for a particular building should be influenced by the electric rate structure, the amount of electric consuming equipment, and its operating control importance. Instantaneous high electric loads, such as during equipment start-ups, may not necessarily cause high demand charge, since demand load is integrated over time. Generally, all GSA office buildings should be specified for load shedding because of their relatively large sizes and the diversity of electric-using equipment.

A list of equipment should be prepared by the HVAC system designer to indicate the kind of equipment which may be shed to reduce the demand. Equipment which is essential for safety of personnel and protection of other equipment should not be shed. Examples are emergency equipment, certain elevators, and essential lights. Nor should any equipment be included where shedding may cause adverse effects on equipment operation or cost, such as large computing equipment. Nonessential loads should be determined in consultation with building users and GSA Facilities Managers. Demand control is commonly associated with forced down-loading of chillers and air handling fans but can also include certain lights (garage, equipment room, non-egress corridor), pumps, electric hot water heaters, nonessential elevators, certain electric heating units, and electric boilers. Lights in exterior offices and the light intensity in offices in general may also be reduced. Different equipment may also be grouped to be shed at the same time to reduce down-load schedule complexity. A priority list should be prepared to shed equipment based on this list. The load of the lowest priority is shed first and restored last. Within the same priority (such as lights in different areas) shedding can be done on rotational base. Certain time limits are necessary to be included in the schedule and the software. Minimum off-times and minimum on-times is recommended to prevent equipment short cycling and possible damage. Maximum off-times are also needed to prevent unacceptable deterioration of operating conditions, such as space temperature, humidity, and air quality. A thorough analysis of the equipment to be included in the load shedding list should be made. When lighting circuits are part of the shedding schedule, coordinate with the electric design.

4.3 ECONOMIZER CONTROL

Air conditioning systems for office space, having a supply air capacity over 1,416 L/s (3,000 cfm), should have either dry bulb or enthalpy economizer control. Although in theory an enthalpy economizer control can save more energy than dry bulb economizer control, the anticipated saving must take control system maintenance into account. Efficient operation of an enthalpy economizer control depends very heavily on good measurement of dry bulb temperature and humidity level of both indoor and outside air. Since humidity sensors are prone to contamination and drift, the computed enthalpy is often not accurate. Erroneous enthalpy calculations can actually waste system energy. If enthalpy economizer control is specified, designers should make sure that the humidity measurement instrument will be installed and maintained to give accurate readings and that enthalpies will be calculated with correct engineering equations. When more than one application of outside enthalpy measurement is needed, it is usually cost effective to have only one set of measurement instrumentation and computation. Then, have the enthalpy data transmitted to involved control applications.

Dry bulb economizer control is much simpler to install and maintain than enthalpy economizer control. Energy calculations should be made during the design to compare the energy savings between these two types of controls. Evaluate the energy savings and possible maintenance problems of humidity sensing to determine the type of control to be used. For locations having dry climates, dry bulb economizer control is advantageous, since the extra energy saving of enthalpy control is limited. When a dry bulb economizer control is used, it is very important to select a correct change-over temperature to achieve optimum energy savings. No wider than 2.8 °C (5 °F) intervals of wet bulb temperature should be calculated and compared in determining the change-over temperature. Calculations should be done by using an hourly energy program or by BIN method. The change-over temperature should be specified in the construction documents.

Designers should select temperature and humidity sensors carefully and should show sensor locations on design drawings. Using a prefabricated weather station to house outdoor air sensors should be considered.

4.4 SUPPLY AIR TEMPERATURE RESETTING

For most air handling units, the supply air temperature is controlled by dry bulb temperature sensors located at the discharge side of cooling coils or at the supply air fan discharge. For most applications, this arrangement is simple and works satisfactorily. However, certain spaces may be overcooled, when space loads in these spaces are reduced. This condition can be remedied by reheating the air or by mixing hot and cold air streams. Consequently, the low supply air temperature would result in either too cold space temperature or wasting of energy. In order to correct this disadvantage, the supply air temperature may be raised or lowered, "reset", just to satisfy the space cooling requirement within certain limits. There are basically two arrangements for the supply air temperature reset. The simple one is to reset the supply air temperature by the outside air temperature based on the assumption that the space heating or cooling loads are a function of a dominant single variable, namely, the outside air temperature. In order to compensate for the other factors such as solar heat gain, infiltration, and latent heat loads, an equation is set up to account for all these factors in determining the relationship of supply air temperature and outside air temperature. This arrangement requires, obviously, an outside air temperature sensor. The second method of temperature reset uses "discriminator" control. In this arrangement multiple sensors are located in key representative spaces of the building served by the same air handling unit to detect the space conditions. A logic is predetermined to select the supply air temperature based on worst case room conditions. Because this second method involves multiple sensors and associated devices, it is usually more expensive than the first arrangement.

All air handling systems supplying air to multi-control spaces should have supply air temperature reset control. Both of these two arrangements involve some hardware installation (temperature or position sensors and wiring) and software instructions. The discriminator control also involves a feedback loop. However, the outside air reset is based on load predictions, and the discriminator control is based on actual space temperature feedback which can usually provide more accurate control and energy savings than given by predictions. Generally, unless cost overwhelmingly favors resetting by outside air temperature, all systems should have discriminator control. Zone sensor locations should be carefully selected to represent key thermal areas. Avoid areas where extreme load swings may occur. Show sensor locations on contract drawings.

In applying supply air temperature reset to VAV systems, special caution should be exercised. Since raising the supply air temperature in a VAV system requires higher air flow rate for the same building load, the reduced coil load is partially compensated by higher fan energy. From recent ASHRAE Technical Committee 4.6 (Building Operation Dynamics) research work, it appears to be favorable to reduce fan energy even if it requires increased chiller energy. A comparative energy analysis should be exercised during the design stage to determine whether and how the supply air temperature reset should be set up. Upper limits of temperature setting and humidity level should be specified.

4.5 VENTILATION AIR CONTROL ASSOCIATED WITH START/STOP PROGRAMS

For unoccupied periods in a start/stop program (scheduled or optimum, see OPTIMUM START/STOP paragraph), ventilation air is normally turned off by closing outside air dampers. However, outside air may be used prior to the starting of air handling system control in the morning to utilize the cool outside air to precool a building. Depending on the local weather, this ventilation purge is usually incorporated as part of a cooling strategy. The ideal application of this control is for a building with high thermal mass and in an area where the outdoor summer mean daily range of air temperature is large. The ventilation purge can allow the mass of the building to remain cool for a relatively long period of time after the system is returned to the day mode. Since the temperature differential between the outside air and the inside of the building is usually not very large, the effect of ventilation purge must be weighted against the energy needed for any additional periods of fan operation. Consider this control program in any area where the summer mean daily range of air temperature is over 17 °C (30 °F).

Ventilation control is also used in association with start/stop programs during heating seasons. Between the time the system is turned on in the morning and the start of occupancy, outside air dampers must be closed to save heating energy. However, it is advisable to open outside air dampers early before occupancy time to reduce stuffy feeling in the space. This is especially necessary after weekends. Energy may also be saved by closing outside air dampers before the end of scheduled occupancy. The time for early opening and closing outside air dampers should be no more than 30 minutes.

4.6 VAV AIR HANDLING SYSTEM CONTROL

The supply air fan is usually controlled by static pressure sensors about 2/3 to 3/4 of the distance from the fan in the longest supply duct. For larger installations and multi-branch duct arrangements, multiple sensors should be installed in a few key branches. This enables the BAS to select a worst case pressure to modulate the fan operation. The static pressure controller should be specified and tuned to maintain a constant pressure regardless of the building load.

In the case of maintaining building pressure, it is controversial at the present as to the equipment (supply, return, and relief fans) and control methods to be used. Part of the reason is, of course, due to the diversity of climate, building construction, and air system variety. Currently, various ways are being used: (1) return air fans tracking supply air fans using the same sensed variable or separate variables; (2) sensing building pressure to control return or relief fans; (3)

measuring the supply and the return air flow rates with fixed or pre-determined variable ratios of the supply and the return flow rates (the difference of supply and return air changes following system load); and (4) measuring the supply and the return air flow rates with fixed difference between these rates (the difference does not change regardless of the system load). It is usually a matter of the designer's choice and confidence. However, in all cases, detailed calculations must be made with anticipated load variation assumptions, and in accordance with the control strategies specified in the BAS control sequence to assure that building pressure, ventilation air quantity, fan performance, and system requirements are met. For a VAV system having more than one main branch duct or serving zones with large load variations (e.g., multi-exposures), system performance at the maximum and the minimum load conditions should be calculated (see PBS Variable Air Volume System Design Guide for details).

VAV terminal units should have heating and cooling operation separated by at least 2.8 °C (5°F). Units should be at minimum air-flow state during heating operation. For pressure independent terminal units, air flow rate measurement and subsequent modulation action should enable units to supply the required flow rates accurately down to the designed minimum flow rates. Manual override of air handling unit on/off control should be provided to operate a VAV system during unoccupied periods. This override should have a fixed time interval to revert the system back to BAS.

4.7 MAINTENANCE SOFTWARE

Each BAS should track the operation and maintenance of major pieces of equipment. Examples are chillers, air filters, fans, cooling towers, pumps, motors, and all heat exchangers and other equipment requiring periodic cleaning or service. Instrumentation needs for periodic calibration should also be included. Recommended service intervals, general service procedures and service precautions should be listed. Equipment running time should be entered and accumulated automatically. Service reminders should be issued automatically when service intervals are reached. Provisions should be provided so that the operating personnel can enter data on actual service intervals and service remarks.

4.8 LIGHTING CONTROL

The Quality Standards for Design and Construction Handbook (PBS P 3430.1A) requires consideration of using BAS for switching lights for energy conservation. However, using occupancy sensors will allow greater savings and lower first cost compared to BAS switching. For areas that can not be regulated by occupancy sensors, the following guidelines shall apply.

Lights in general offices should have scheduled on/off operation for unoccupied hours including legal holidays. Lights should be divided into lighting zones with less than 1500 watts of connected lighting power in each zone. Override by occupants should be provided for off-hour needs, and the override should be programmed to revert back to the lighting control after a fixed period.

4.9 ENERGY MONITORING

The energy monitoring software should be able to calculate, store, and display all energy usage from data obtained from field instruments. Energy monitoring should include electric lighting, miscellaneous power outlets, HVAC systems and equipment, service hot water, and process loads. As a minimum, BAS should enable operators to obtain instantaneous rate and periodically accumulated energy data. On major energy conversion equipment such as boilers and chillers, equipment efficiencies should be available. Other desirable data are temperature and humidity conditions of the outside air.

4.10 ELEVATOR CONTROL

Building elevators should have scheduled control and status monitoring under BAS. The schedule should be based on calendar, holiday schedule, and time of the day and should provide manual override from BAS for building operators. Controls of elevators should be coordinated with the fire safety program.

4.11 DOMESTIC HOT WATER

Service hot water system should have supply water temperature monitored. If dual temperature system is designed, coordinate with special equipment (e.g. kitchen equipment) requirements.

4.12 FIRE SAFETY

When any heat or smoke sensor, pull station, or sprinkler flow switch is activated, the following events should take place: the fire safety system video indicates alarm conditions and shows the floor plan where the alarm is occurring with the affected sensor locations; the system initiates calls to designated offices (fire, security, etc.); the system activates (e.g. stair pressurizing system, smoke dampers) and deactivates (e.g. supply air fans) certain air handling equipment; and the system sends elevators to ground floor. Instructions to fire-fighters, such as egress means, evacuation plans, stand pipe locations, etc., should be available on video display. As soon as a fire condition is detected, the fire safety system shall have higher functional priority than other systems of the BAS. Any command given by other systems which may interfere with the prosecution of the fire safety system shall be ignored. All alarms initiated by the fire safety system must be acknowledged manually before they can be restored to normal status. PBS Fire Protection Engineers must be consulted during building design in deciding the extent of fire safety software.

4.13 BUILDING SECURITY SYSTEM

The building security system should include scheduled locking and unlocking of entrance doors, monitoring and control of entrance card units, and intrusion alarms for first floor windows. The entire security system should be under the supervision of the security system host computer. The entrance door locking/unlocking control should be flexible with individual day/time schedules for each entrance door or each group of doors resettable from the host computer by persons with access authority. The entrance card system should allow different levels of entry (e.g. general workers entering during weekdays only, essential and special permitted workers entering non-working hours). The levels of entry and time schedule should also be resettable from the host computer. When given an appropriate command, the host computer should monitor and print all essential entry information, such as time of entry and the identification of the entering person (name, organization, etc.). The beginning and ending time and locations of alarms should always be stored in the memory and printed on the printer. The level of security requirements are different among Federal buildings. The BAS designers must following the design directives and, if necessary, consult with PBS personnel.

4.14 REQUIRED CONTROL FUNCTIONS MUST BE SPECIFIED IN DETAIL

The application programs described previously are not intended to be exhaustive. Life cycle energy savings are typically greater than the costs of implementing these programs. Therefore, they should be programmed for all projects, unless proven otherwise by analysis.

Since control variations are literally unlimited in DDC applications to HVAC equipment, control objectives and essential sequences must be specified in detail. The GSA Guide Specification on BAS (Section 15980, Building Automation Systems) gives typical requirements of application programs. However, each project is different and each system may have unique requirements. It is the responsibility of the designer to state all required control functions. Design representation is limited to specifying all required control functions, with the BAS contractor providing the programming and system components to achieve required functions.

CHAPTER 5. CONTROL/MONITORING INFORMATION

5.1 COORDINATION BETWEEN DESIGNERS

A BAS within a Federal buildings interacts with a multitude of areas which require close attention during project design. It is the responsibility of BAS designers to undertake this task. BAS designers should initiate and maintain good coordination with HVAC and electrical design professionals in gathering needed information for BAS design. BAS designers should also consult architects, special equipment (e.g. kitchen equipment, medical equipment, elevator, telecommunication equipment) consultants, and PBS fire protection engineers in developing design documents.

5.2 REQUIRED INFORMATION

The following information is typically required in a BAS design:

Chiller: chilled water and condenser water in and out temperature, flow rate, and differential temperature; evaporator and condenser pressure; compressor status, accumulated run time, and energy consuming rate; oil temperature and pressure; bearing temperature; safety control status; cooling production rate; and cooling COP.

Fuel-burning heating equipment: boiler pressure; steam pressure/temperature and flow rate; water output temperature and flow rate; water inlet temperature; fuel input rate; flue gas temperature; flue gas oxygen or carbon dioxide level; heating production rate; and heating efficiency.

Pump: on/off status; flow rate and motor run time.

Cooling tower: on/off status of fans; basin temperature; and auxiliary equipment (such as winterizing heating) status.

Air handling system: supply air, return air, and mixed air temperature; heating coil inlet and outlet temperatures; cooling coil inlet and outlet temperatures; damper status; fan status; and key space temperature and humidity. For VAV systems: supply air and return air flow rate; static pressure sensor for fan control and at fan discharge.

Heat transfer equipment: (e.g. hot water convertor) water in and out temperatures; water flow rate; steam pressure and flow rate.

Lighting: on/off status of all lighting zones; zones under manual override.

Elevator: in/out of service status; elevators under manual override.

Alarm requirements: list required alarm points of all equipment by category of normal operation, failure, and critical failure.

Log requirement: energy data for all energy consuming equipment.

Maintenance: list equipment and parts where maintenance is required and maintenance log.

Other requirements: specify all information that BAS interaction is required.

This information should be conveyed to the BAS contractor by control specifications, control drawings, and point schedules (see POINT SCHEDULES in CHAPTER 3).

NIST-114A
(REV. 3-89)

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NUMBER
NISTIR 4604

2. PERFORMING ORGANIZATION REPORT NUMBER

3. PUBLICATION DATE
JUNE 1991

4. TITLE AND SUBTITLE

Direct Digital Control Based Building Automation System Design Criteria

5. AUTHOR(S)

James Y. Kao

6. PERFORMING ORGANIZATION (IF JOINT OR OTHER THAN NIST, SEE INSTRUCTIONS)

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
GAITHERSBURG, MD 20899

7. CONTRACT/GRANT NUMBER

8. TYPE OF REPORT AND PERIOD COVERED

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP)

General Services Administration
Washington, DC

10. SUPPLEMENTARY NOTES

☐ DOCUMENT DESCRIBES A COMPUTER PROGRAM; SF-185, FIPS SOFTWARE SUMMARY, IS ATTACHED.

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.)

This document serves to provide design guidance for Direct Digital Control (DDC) based Building Automation Systems (BAS). It also provides instructions to design engineers for the BAS design. Explanations of general design philosophy, current unresolved problems confronting the application of DDC in BAS, and considerations for choosing alternative control strategies in specifying application programs are given. This guide is intended for use by GSA and contract designers as a means of identifying major aspects in DDC based BAS design where new construction or major renovations of control systems are included.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

automatic control, building automation system, building control, building design, design criteria, direct digital control

13. AVAILABILITY

- [x] UNLIMITED
- [ ] FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NATIONAL TECHNICAL INFORMATION SERVICE (NTIS).
- [ ] ORDER FROM SUPERINTENDENT OF DOCUMENTS, U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, DC 20402.
- [x] ORDER FROM NATIONAL TECHNICAL INFORMATION SERVICE (NTIS), SPRINGFIELD, VA 22161.

14. NUMBER OF PRINTED PAGES
39

15. PRICE
A03

ELECTRONIC FORM