HVAC CONTROLS: Operation and Maintenance

THIRD EDITION

BY GUY W. GUPTON, JR.

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Operation & Maintenance

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Foreword

This book is one in a series addressing building systems design, operation, and maintenance.

The material presented in this book can be used for office reference, for formal in-house training programs, and for informal self study. The material is not intended to be used as a replacement for manufacturers' instructions for specific equipment.

This book is written to provide a complete and concise reference volume for persons engaged in the operation and maintenance of automatic control systems serving building heating, ventilating, and air conditioning systems, including refrigerating machines, and interface to building automation systems (BAS) systems. Energy management and control system (EMCS) are of such diverse types and arrangements that it is not possible to cover them in this book.

This book assumes a basic familiarity with HVAC equipment and systems and the related control systems. In order to allow use of the book as a study guide, the first chapters review HVAC system processes and equipment, control system types and equipment, and equipment-to-control interactions. The succeeding chapters cover specific control system functions including electrical interlock and motor starting, electrical and electronic control system diagrams, pneumatic control system diagrams, maintenance of electric and electronic control systems, maintenance of pneumatic control systems, testing direct digital control (DDC) systems, and training operating and maintenance personnel.

The Appendix includes a comprehensive glossary of terms used in HVAC systems and in control system operation and maintenance.

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Preface to the Third Edition

In the four years since the publication of the second edition of this book, there have been continuing changes in the automatic temperature control industry due to the widespread use of direct digital control (DDC) systems.

This book is intended to provide guidance in the operation and maintenance of all types of ATC systems. At the time of writing the first edition, the majority of systems in use were of the electric/electronic and pneumatic types. With the rapid increase in installations of DDC systems, it became necessary to include material in the second edition that will provide basic coverage of DDC systems.

This book includes basic procedures in the operation and maintenance of DDC systems, particularly in the initial checkout and operator training on newly installed systems. Those procedures are also applicable to the recommissioning of existing DDC systems and in recurrent training of DDC system operators and maintenance technicians.

The complexity of DDC system programming and the major differences in program language between system manufacturers, limits the discussion in this book of the actual programming of DDC systems. That type of information is application specific and must be obtained from the system manufacturer's literature and training seminars.

Chapter 1

Basic Functions of HVAC Systems and Control Systems

The purpose of a Heating, Ventilating, and Air Conditioning (HVAC) system is to provide and maintain a comfortable environment within a building for the occupants or a suitable environment for the process being conducted.

This book covers basic HVAC systems of the all-air type, where all functions of heating, ventilating, and air conditioning are performed by an air handling system. Some functions for central hydronic cooling and heating distribution are included which also apply to air-water and all-water types of systems.

The principal functions of HVAC systems and control systems are:

- To maintain comfortable conditions in the space by providing the desired cooling and heating outputs, while factors which affect the cooling and heating outputs vary.
- To maintain comfortable conditions while using the least amount of energy.
- To operate the HVAC system so as to provide a healthy environment for occupants and safe conditions for equipment.

The ability of a system operator to diagnose and correct automatic temperature control (ATC) system operating problems requires a working knowledge of HVAC system types, the components of HVAC systems, the intended function of those components in the HVAC system, and the HVAC equipment-to-control interactions. Many problems which are considered to be HVAC system design problems are found to be ATC system operating problems.

In order to determine whether the ATC system is functioning properly, it is necessary to determine how each control sequence is intended to function.

Although HVAC systems must be designed to satisfy the maximum cooling and heating loads at design conditions, HVAC systems do not operate at full capacity very often. Systems seem to operate for most hours of the year at near half capacity, with variations due to changes in outside conditions for time-of-day and time-of-year and to changes in internal heat releases. The ATC system must be designed, set up, and operated to recognize changes and to maintain the space temperature at partial load.

HVAC SYSTEM CONTROL FUNCTIONS

Controlled Parameters

An HVAC system functions to provide a controlled environment in which these parameters are maintained within desired ranges:

- Temperature
- Humidity
- Air Distribution
- Indoor Air Quality

In order to accomplish this task, the ATC control system must be designed so as to directly control the first three parameters. The fourth parameter, indoor air quality, is influenced by the first three but may require separate control methods which are beyond the scope of this book.

Approaches to Temperature Control

Temperature control in an air conditioning system that uses air as a delivery medium may use one of the following approaches:

- Vary the temperature of air supplied to the space while keeping the airflow rate constant. This is the basic constant volume, variable temperature approach.

- Vary the airflow rate while keeping the temperature constant for air supplied to the space. This is the variable volume, constant temperature approach.

- Vary the airflow rate and change the temperature for air supplied to the space. This is the variable volume and temperature approach.

- Vary both the supply air temperature and flow rate where the airflow rate is varied down to a minimum value, then energy input to reheat the coil is controlled to vary the supply air temperature. This is the variable volume reheat approach.

Approaches to Humidity Control

Humidity control in a conditioned space is done by controlling the amount of water vapor present in the air in the space. When relative humidity at the desired temperature setpoint is too high, dehumidification is required to reduce the amount of water vapor in the air for humidity control. Similarly, when relative humidity at the desired temperature setpoint is too low, humidification is required to increase the amount of water vapor in the air for humidity control.

Because *relative* humidity varies significantly with dry bulb temperature, it is important to state dry bulb temperature and relative humidity together, such as 70°F and 50% RH. For example, at a room air condition of 70°F dry bulb and 50% RH, the moisture content, or *specific* humidity, is 54.5 grains of water per pound of dry air. Air with the same *specific* humidity at 60°F will have about 71% RH and when read at 80°F will have about 36% RH.

Commonly used dehumidification methods include:

- Surface dehumidification on cooling coils simultaneous with sensible cooling.
- Sprayed coil dehumidifier with indirect cooling coils.
- Direct dehumidification with desiccant-based dehumidifiers.

Humidification is not always required in an HVAC system but, when required, it is provided by a humidifier.

Commonly used humidification methods include:

- Water spray humidifier.
- Steam grid humidifier.
- Steam pan humidifier.

Methods of Temperature Control

Temperature control in a space is done by a temperature controller, commonly called a thermostat, which is set to the desired temperature value or setpoint. A temperature deviation, or offset, from the setpoint causes a control signal to be sent to the controlled device at the HVAC system component which is being controlled. In this book, the term "temperature controller" means thermostats and temperature sensor/controller devices, as well as remote bulb type temperature controllers.

When the temperature in a conditioned space is to be controlled by heat exchange to supply air from a heating or cooling coil, the temperature control signal will cause a change in the flow of the cooling or heating medium through the coil. With a chilled water or heated water coil, the temperature controller may position a water valve to vary the flow rate of heated or chilled medium through the coil or may position face and bypass dampers at the coil to vary the proportion of air passing through the air side of the coil to that which bypasses the coil and is not conditioned.

Automatic control valves used to control water flow through a water coil may be either two-way or three-way pattern and may be positioned in either two-position or modulating sequence. Valves used to control steam flow through a coil are two-way type and may be positioned in either two-position or modulating sequence.

Methods of Humidity Control

Dehumidification is usually done at the same time as the sensible cooling by a surface dehumidification process on the system cooling coils, either indirect cooling using chilled water or other heat transfer medium or direct expansion refrigerant evaporator coils. Dehumidification in low dew point process systems may be done in a separate dehumidification unit.

Air leaving the cooling coil during surface dehumidification is often near a saturated condition. When cooling in a process area is controlled from the relative humidity in order to remove water vapor, the supply air will often be cooled more than is required for sensible or dry cooling of the space and may require reheating to prevent overcooling of the space. When the supply air is reheated to the temperature required to maintain the space temperature at the desired level, and the required air volume is supplied to the space, that air volume will also maintain humidity at the desired level.

Humidity relationships in HVAC systems are expressed in percent relative humidity and noted as % RH.

The system humidity controller, commonly called a humidistat, is located in the conditioned area, preferably adjacent to the thermostat, to ensure that the ambient temperature is that which the humidity is to be based upon. The space humidity controller is set at the desired relative humidity setpoint. A change in relative humidity from that setpoint causes a control signal to be sent to the controlled component.

For example, to control a duct-mounted, steam grid humidifier, when the space relative humidity drops below the humidity controller setpoint, a control signal is generated to open the steam valve at the inlet to the duct-mounted humidifier unit. When the steam valve is positioned open, steam flows through the humidifier in the supply air stream to the space, which raises the space relative humidity. A second humidity controller located in ductwork downstream from the humidifier acts as a high-limit safety controller. When the relative humidity of the airstream approaches the saturation point, the high-limit controller overcalls the space humidity controller to reposition the steam valve and decrease the steam flow. This will prevent condensation and water carryover downstream from the humidifier. The control of an electrically heated steam humidifier is similar to valve-controlled, with electric contactors being the controlled devices.

Methods of Air Volume Control

When variations of supply air volume are used to control the space temperature, the temperature controller may cycle the fan motor in on-off sequence, may modulate the fan motor speed, or damper the airflow, such as through volume control dampers in air terminal units.

For example, in a fan-coil unit system, the space temperature can be regulated by regulating the airflow rather than the water flow through the coil. When the space temperature rises or drops from the desired level, the temperature controller will either vary the fan speed through a solid state speed controller or cycle the fan "on" and operate the fan until the space temperature changes in response to load generated and capacity applied, then cycle the fan "off."

In a Variable Air Volume (VAV) system, the supply air volume delivered to the space will vary as the temperature controllers on individual terminal units position each of the modulating dampers on individual terminal units. The central station air handling unit fan will operate continuously and the fan performance must be varied to maintain duct static pressure within acceptable limits.

Methods used for fan performance control include:

- Riding the fan curve.
- Inlet or discharge damper control.
- Inlet guide vane control.
- Fan speed control by mechanical means.
- Fan speed control by electronic means.

Air System Pressure Control

Pressure control in variable volume air distribution systems utilizes a pressure controller set for the desired setpoint pressure. A pressure deviation from the setpoint value causes a control signal to be sent to the controlled device at the controlled component.

When space cooling load decreases, dampers in air terminal units are positioned to reduce the supply air volume at terminal units to meet the reduced load. The restriction to airflow imposed by the closing of dampers causes an increase in duct pressure and causes the fan to operate on its characteristic curve to reduce airflow volume.

For systems with limited VAV devices, the reduction in airflow volume does not cause an objectionable increase in duct static pressure and a resulting change in air volume to non-controlled terminals. That operation is "riding the fan curve."

For systems with all terminals under VAV control, a large increase in static pressure would not be acceptable and static pressure control must be provided.

For example, for duct pressure control in a VAV system, a static pressure controller receives a duct static pressure signal from a pressure sensing station located in the supply ductwork. The duct static pressure change is interpreted by the pressure controller which generates a pressure change signal in accordance with the parameters programmed into the controller during system setup and positions the controlled devices to reduce the fan output and thus bring the system pressure back toward the setpoint value.

The controlled device positioned by the pressure controller to modify the fan performance may be an inlet or discharge damper actuator, an inlet guide vane actuator, a mechanical speed control device, or a variable frequency drive.

Pressure controllers generally employ floating control so that controlled devices are positioned toward reduced pressure until pressure drops to setpoint, then are stopped, and then are positioned to increase pressure until pressure rises above setpoint and the cycle repeats itself.

Air Distribution Control

Airflow control is done by several different methods or combinations of methods, such as on-off fan control, variable volume control, terminal reheat, terminal bypass, and terminal induction.

Air-quality Control Methods

Control of air quality is done by several different methods or combinations of methods depending on the degree of contamination, such as odor dilution with outside ventilating air, filtration of particulate matter with air filters, filtration of gaseous contaminants with odor-adsorbent or odor-oxidant filters, and local control of gaseous and particulate contaminant emission by use of local exhaust with exhaust hoods over processes.

HVAC SYSTEM CLASSIFICATIONS

HVAC systems are given broad classifications based on the medium which is used to transfer heat within the system. There are many variations and combinations of these types. It is helpful to understand the basic system classification scheme.

The basic system types are:

- All-Air
- Air-Water
- All-Water
- Packaged Terminal.

All-Air systems—All-Air systems perform all the conditioning processes with air. The processes are cooling and dehumidification, heating and humidification, along with air cleaning and air distribution. Conditioning of air is usually done in central station equipment located remotely from the space. An all-air system supplies only conditioned air to the space. No other cooling or heating medium crosses the boundary into the conditioned space.

Air-Water systems—Air-Water systems use both air and water for cooling and heating. Conditioning of air and water is performed in a remote central plant, then distributed to terminal units in the conditioned space where they are used to satisfy the space cooling and heating loads and the ventilation requirement. The chilled and heated water may be delivered to the building from the central plant in 2-pipe changeover type or 3-pipe or 4-pipe simultaneous type piping systems.

Fan-coil units with central ventilating air, terminal reheat units, induction reheat terminals, under-window induction terminals, and fan-powered induction terminals are examples of air-water systems.

All-Water systems—All-Water systems use heated or chilled water circulated through a terminal unit situated within the conditioned space, and the terminal unit provides cooling and dehumidification or heating according to the zone load requirements. No conditioned air is brought to the room from a central air handling system. Outside air for ventilation is introduced either by normal infiltration through window and door cracks or through wall intakes located behind each unit. The terminal units may be fan-coil units or unit ventilators. Heating-only systems serving heated water terminals, such as reheat coils and convectors, are often referred to as "hydronic" systems.

Packaged systems—Packaged systems are similar to All-Air systems in that they perform the conditioning processes of cooling and dehumidification, heating, and ventilating with air but the apparatus is located in the conditioned space. Air distribution may be ducted or from integral grilles. Conditioning of heating water for hydronic coils and of loop water for water-source heat pumps is usually done in central station equipment located remotely from the space. No other cooling or heating medium crosses the boundary into the conditioned space.

Basic Control Functions

The basic control functions to be performed include:

- Starting air handling fan motors with controls system energization and interlock of other motors.

- Emergency system shutdown from high or low temperature safety temperature controller, smoke detectors, or fire alarm system.

- Opening outside air damper to minimum position.

- Positioning mixed air section dampers for economizer cycle cooling with outside air.

- Providing seasonal changeover control for mixed air section by dry bulb, compensated dry bulb, or enthalpy-based control input to enable cooling and heating functions.

- Providing space temperature control on cooling cycle by controlling of face and bypass dampers or water valve at chilled water cooling coils, controlling refrigerant flow in direct expansion cooling coils, or controlling airflow to air terminal units.

- Providing space temperature control on heating cycle by control of heating medium, such as heated water or steam valve at heating coils or energization of electric heating coils.

ALL-AIR SYSTEMS

Commonly used All-Air system types include:

- Single-path, single-zone systems
- Single-path, multi-terminal systems
- Parallel-path systems
- Air-water terminal systems
- All-water terminal systems

Single-path, single-zone, draw-through systems. The basic controller is the space temperature controller or temperature sensor and controller. When the supply fan is started, the control system is energized and the outside air damper opens to minimum position. Changeover of temperature controls between cooling and heating modes may be done either automatically or manually, or the controls may be designed for sequenced operation to operate without changeover by use of different spring ranges or voltage ranges for the cooling and heating actuators.

The temperature controls may be either two-position or modulating. Two-position controls may cycle a refrigeration compressor or position a refrigerant liquid line solenoid valve. Modulating controls may modulate a chilled water valve or face and bypass dampers on the cooling coil or valve on the heating coil. On two-pipe changeover systems and other systems where both chilled water and heated water are not available all year long, the heating system is often integrated with an economizer cycle to provide "free" cooling when mechanical cooling is not available.

Fire and smoke safety control devices used in all-air systems include code mandated devices such as smoke detectors, smoke dampers, manual fan shutdown switches, and firemen's control panels, with various accessories. Changes in some mechanical codes and fire codes in recent years have removed the requirements for fire safety thermostats or firestats, but many buildings will still have firestats in systems.

An all-air system may have either firestats or smoke detectors installed in supply air ductwork leaving air handling units larger than 2,000 cfm capacity; systems with over 15,000 cfm capacity may have firestats or smoke detectors in both supply air and return air ductwork to de-energize the supply fan and other interlocked fans when air temperatures reaches the setpoint temperature, often 125°F for return air and 165°F for supply air with electric or heated water heat source or 300°F for systems with steam coils controlled by normally open valves. Duct smoke detectors may not be sensitive due to the dilution effects of the air being handled. Area smoke detectors installed in the space provide a more reliable means of smoke safety shutdown. Where multi-floor return inlets are used, a separate smoke detector is required at each inlet. Smoke dampers may be installed in code-mandated locations. Dampers isolating air handling units will usually be interlocked to close when the fan motor stops. Smoke dampers in required smoke barriers separating areas of a building may be left open when fan motor stops when dampers are controlled by local area smoke detectors.

Remote annunciation of alarm and trouble conditions is required for smoke detectors. Manual reset of fire and smoke control devices is required to assure that someone acknowledges that excessive temperature or smoke has been detected.

Manual fan shutdown switches, usually furnished as break-glass stations similar to fire alarm boxes, are required to be installed in exit pathways to ensure that fans are shut down when the building is evacuated. Many jurisdictions will allow fans to be shut down from the fire alarm system when manual fire alarm pull stations are located near each exitway.

Fire Service Personnel control panels are provided as part of engineered smoke removal systems and allow fire service personnel to restart fan motors stopped by firestats or smoke detectors and to position dampers as required to evacuate smoke from the building.

Single-path, multi-terminal systems. Single-path, multi-terminal system types include: variable air volume (VAV) single duct; ceiling induction reheat, constant volume reheat (CVR); and fan-powered terminal or powered induction unit (PIU) types.

The central air handling unit for single-path, multi-terminal systems is similar to the single-zone, single-duct system except that the supply-air temperature is controlled by a discharge air temperature controller and the airflow volume is varied in response to demand. The discharge air temperature may be reset by inputs from space temperature controllers to give the highest primary air temperature that will satisfy the zone with the greatest load. Space temperature is controlled by individual terminal units.

Variable air volume (VAV), single duct systems. In single duct VAV systems the supply air temperature is held constant and the supply air volume is changed to satisfy the space cooling load. When this system serves both exterior spaces which require heat and interior spaces which do not require heat, no heating source is provided in the central air handling unit, but heating coils are provided in the terminal units serving the exterior zones.

Terminal unit heating coils may be either hydronic or electric resistance type. On a drop in temperature, the exterior zone controls first reduce the amount of supply air down to a minimum value, about 50%, then on further drop in temperature, the controls regulate the heating source to maintain space temperature.

The interior zone units are variable air volume (VAV) terminals and the exterior zone units are variable volume reheat (VVR) terminals. VVR terminal units are often provided with dual minimum airflow limit settings so that, during the cooling season, the VVR unit may function as a VAV unit to reduce airflow on a drop in space temperature down to a summer minimum of zero flow. During heating season, a control signal sent to VVR units imposes the winter minimum airflow rate, which is determined by the amount of heat that must be delivered by the air and is often in the range of 50% of maximum cooling flow.

Terminal unit air valves may be pressure independent so that the amount of air delivered does not vary with changes in duct pressure due to other positioning of other valves. A reset differential controller may be provided to measure the flow of primary air and compensate for changes in system pressure and position the air valve to keep the flow constant for a given space load.

As the volume of the supply air to the zones through the terminal units increases or decreases, the air volume delivered by the fan must also be adjusted. One volume control method employs motor-actuated variable inlet vanes on the fan positioned by a static pressure controller sensing supply duct pressure. The static pressure controller compares the static pressure in the duct with the pressure setpoint, determines the offset, and positions the variable inlet vanes to bring duct static pressure to its setpoint.

Another volume control method uses fan speed regulation. According to the "fan laws," the air volume delivered by a centrifugal blower is directly proportional to its speed in rpm, while the pressure developed by the fan varies with the square of the fan speed, and the power required varies with the cube of the fan speed. By changing the fan speed in response to duct pressure changes, a variable air volume will result with good pressure control and optimum energy use. Fan speed can be regulated by several methods including mechanical speed change, frequency control, and voltage control.

Induction reheat (IR) system. IR systems may be mounted in ceiling plenums or under windows. In IR systems the supply air temperature and pressure are held constant and the supply air volume to each terminal is changed to satisfy the space cooling load. The terminal unit is designed so that the supply airflows through an orifice that creates a low pressure inside the terminal unit casing which induces a flow of room air from the return air plenum or from the space to maintain the airflow rate to the conditioned space. At full design airflow, an induction unit may induce a return airflow equal to the primary airflow. On reduction of primary airflow, the induced airflow reduces in proportion. In some systems, no heat source is provided in the central air handling unit, but heating coils are provided in the terminal units.

A space temperature controller positions air valves in the terminal unit in response to cooling load. On drop in space temperature, the primary damper is positioned toward closed as the induced air damper is positioned toward open, until the terminal has reduced primary air to the minimum flow rate. On further drop in space temperature, the heating coil will be controlled to maintain space temperature. The heating coil may be electric resistance or hydronic type.

Constant volume reheat (CVR) systems. In CVR systems air is supplied to terminal units at constant volume and constant temperature. A reheat coil in each unit is controlled from a space temperature controller. The air temperature supplied from the unit must be cold enough to satisfy the zone with highest cooling load. Using a discriminator control sequence to compare all the zone reheat loads and to reset the supply air temperature to the value which will satisfy the zone having the greatest cooling load without requiring any reheat will significantly reduce the amount of reheat energy required.

Powered induction units (PIU) systems. In PIU systems, the terminal units are fan-powered mixing boxes comprised of a supply air fan, a primary air variable volume valve (VVV), and a heating coil. PIUs may be arranged for parallel flow with PIU fan in parallel with VVV or series flow with PIU fan in series with VVV. In both arrangements, the heating coil, either electric or hydronic, is the final controlled element in the supply air stream through the unit.

The parallel flow PIU is a variable volume/constant temperature unit at high cooling loads and a constant volume/variable temperature unit at low cooling loads and on heating. On high cooling loads, the VVV in the constant temperature primary air supply is positioned by the room temperature controller to vary primary air volume in response to cooling load, down to a preset minimum value with the PIU supply fan de-energized. On further decrease in cooling load below the preset minimum airflow, the PIU fan is energized to maintain a constant volume supply, while the supply air temperature is varied by further primary air decrease down to a preset minimum ventilation airflow followed by addition of heat through the heating coil. On an increase in cooling load, the sequence is reversed, reducing heat input, increasing primary air supply, stopping the PIU fan, and increasing the primary airflow up to the maximum.

The series flow PIU is a constant volume/variable temperature unit. The PIU fan runs whenever the unit is energized to provide essentially constant volume room supply air. The room temperature controller varies primary air volume in response to cooling load, down to a preset minimum value for ventilation. On further decrease in cooling load below the preset minimum airflow, the room temperature controller varies the heating coil output. On an increase in cooling load, the sequence is reversed, first reducing heat input to zero then increasing the primary airflow up to the maximum.

During unoccupied cycle low temperature limit operation, only the PIU fan and the heating coil are energized.

Parallel-Path Systems

Multizone, blow-through systems. The basic controls are the zone temperature controllers, either zone temperature controllers or zone temperature sensors and controllers. The zone controllers position zone mixing dampers from cold and hot decks so that the total supply air volume remains about constant. A cold-deck temperature controller, if used, positions an automatic control valve on the cooling coil on cooling cycle and positions the mixed air section controls in an "economizer cycle" when mechanical cooling is not available. A discriminator relay with inputs from each zone temperature controller resets the cold deck controller to supply the highest cold deck temperature that will satisfy the zone having the greatest cooling load.

In systems with hydronic hot-deck coils, a hot-deck temperature controller positions a control on the heating coil, with the setpoint usually reset in reverse sequence from an outside temperature sensor to increase hot deck air temperature as outside air temperature decreases. Careful tuning of reset schedules for hot deck controllers is necessary to minimize energy wastage due to unavoidable mixing of cold deck and hot deck airflows. Some systems may have an electric hot-deck coil but that arrangement is subject to nuisance tripouts from high temperature cutouts when airflow is reduced during periods of light heating demand.

A more satisfactory electric heating solution is to install individual electric resistance type duct heaters in zone ductwork downstream from the mixing dampers. In this system, the hot deck is provided with a pressure baffle with pressure loss roughly equal to a hydronic coil and the hot deck acts as a bypass around the cold deck coil. The zone temperature controls are arranged to energize the individual zone electric resistance heaters in sequence with the cooling cycle, so that the cold-deck damper must be fully closed before the zone heating coil is energized.

The cold-deck controller is not used in all systems. When waterside economizer systems are used, and chilled water is available during intermediate seasons, the chilled water flow through the cold deck coil may be uncontrolled.

In air-side economizer systems, on a rise in supply temperature above the cold deck controller setpoint, the outside air and relief/exhaust air dampers are gradually opened and the return air damper is gradually opened to admit up to 100% outside air to maintain supply air temperature at temperature low enough to provide cooling.

On a drop in temperature, a mixed air low-limit temperature controller in the fan discharge will overcall primary control to limit the opening of outside air dampers as required to maintain the low temperature limit value. A firestat and a smoke detector may be located in the return duct. An additional temperature controller may provide low temperature safety control sequence to prevent coil freeze-up by de-energizing supply air fan and interlocked fans and closing outside air dampers.

Dual-duct, constant volume systems. On dual-duct, constant volume (DD/CV) systems, the central station unit arrangement is similar to the multi-zone blow-through unit except mixing dampers are not provided at the unit. Cold deck and hot deck ducts extend from the unit to the conditioned areas. Terminal units located at each area to be served have duct connections from cold deck and hot deck ducts. Mixing of cold deck air and hot deck air takes place inside the terminal unit. The space temperature sensor or controller in each zone controls the zone terminal unit by positioning the cold duct damper to vary the cold air volume delivered to the box while a constant volume regulator in the box controls the total air delivered by the box. The control of total air volume supplied indirectly limits the amount of hot deck air mixed with cold deck air.

Discriminator control can be used to reset the cold deck and hot deck supply temperatures to minimize energy wastage caused by mixing of cold and hot air. Because a dual duct system usually serves many zones, only a few zones need to be connected to the discriminator control. These selected zones are selected to be representative of other zones with similar load characteristics.

Some dual-duct systems have been converted to variable air volume operation by modifying the constant volume regulator to allow a turndown to about 50% minimum cold deck airflow before allowing any hot deck air to be mixed. That sequence is required to meet energy code requirements in some areas.

Dual-duct, variable volume systems. The main difference between variable and constant volume, dual duct systems is that a pressure independent variable volume regulator is used on the hot duct inlet instead of a constant volume regulator, or the hot deck inlet is closed altogether, to allow the pressure dependent cold air damper to be the variable volume device. The latter scheme may encounter control instability during start-up and during light loads when some cold deck valves open and upset the pressure balance in the system. Other functions are the same as the dual-duct, constant volume system.

AIR-WATER TERMINAL SYSTEMS

Commonly used Air-Water system types include:

- Fan-coil units with central ventilating air and 2-pipe system.
- Fan-coil units with central ventilating air and 3-pipe system.
- Fan-coil units with central ventilating air and 4-pipe system.

Fan-coil units, central ventilating air, 2-pipe systems. Temperature controllers, either wall-mounted or unit-mounted, control flow of air or water in one of these sequences:

a. Controller modulates water valve with constant fan operation at occupant-selected fan-speed setting.

b. Controller cycles fan or modulates fan speed with constant water flow through coil.

Fan-coil units, central ventilating air, 3-pipe systems. Airflow is manually selected as high, medium, or low. Temperature controllers, either wall-mounted or unit-mounted, control water flow through a 3-pipe valve at the combination cooling-heating coil. When the space temperature drops below the setpoint, the valve positions to modulate flow through the hot water port while the chilled water port is closed. In the dead band between cooling and heating temperature setpoints, there is no water flow through the coil. When the space temperature rises above the setpoint, the valve positions to modulate flow through the chilled water port while the hot water port is closed. There is no mixing of chilled and hot water.

The combination cooling-heating coil capacity is designed for high water temperature rise on cooling and high temperature drop on heating so that the water temperature leaving the coil is about the same whether the coil is on cooling or heating. Water from all coils in the system flows into a common return pipe. This is a proprietary system. Many 3-pipe systems have been converted to 2-pipe changeover operation or to 4-pipe systems.

Fan-coil units, central ventilating air, 4-pipe systems. Airflow is manually selected as high, medium, or low. Temperature controllers, either wall-mounted or unit-mounted, control water flow through the cooling or heating coil or common cooling/heating coil. When the space temperature drops below the setpoint, the valve positions to modulate flow through heated water supply port the heating coil while the chilled water port is closed. In the dead band between desired cooling and heating temperatures, there is no water flow through the coil. When the space temperature rises above the setpoint, the valve positions to modulate flow through the chilled water port while the hot water port is closed.

The common cooling and heating coils are designed for normal water temperature rise on cooling and drop on heating so that the heating water temperature may be low, such as is available from solar heat or reclaimed heat systems. The separate cooling and heating coils are designed for normal water temperature rise on cooling and high water temperature drop on boiler heated water so that the heating coil may be one-row deep. The separate cooling and heating coils may be built with separate tube bundles contained in the same fin bank. There is no mixing of chilled and hot water.

ALL-WATER TERMINAL SYSTEMS

Commonly used All-Water system types include:

- Fan-coil units with direct outside air intake, 2-pipe, 3-pipe, and 4-pipe systems.

- Unit ventilators.

Fan-coil units, direct outside air intake. Fan-coil units with outside air intake are similar to fan-coil units with central ventilating air and all types of water distribution systems described above except that ventilating air is provided through the outside wall directly to an opening in the unit rather than through a duct system. During subfreezing weather, constant water flow through coils should be maintained to minimize chance of coil freezeup.

Unit ventilators. Unit ventilators are essentially fan-coil units with integral air-side economizer cycles. The control components used in unit ventilators are: cooling/heating changeover switch or relay, room temperature controller, low-limit temperature controller, two-way valve, and motorized outside air/return air damper. Unit ventilators are often served by 2-pipe changeover systems.

When the unit ventilator is on heating mode, the damper is open to minimum outside air and fully open to return air and the normally open water valve is open. On a rise in space temperature, the outside air damper opens beyond minimum position, the return damper begins to close, and the low-limit temperature controller overcalls the primary control to prevent the discharge air to the room dropping below the setpoint temperature, often about 50°F. When the space temperature rises above the setpoint, the outside air damper opens fully and the two-way valve closes fully.

When the unit ventilator is on cooling mode, as the space temperature changes from the setpoint the outside air damper stays at minimum position and the chilled water control valve is positioned to vary the flow of chilled water to the coil.

PACKAGED TERMINAL SYSTEMS

Commonly used Packaged Terminal system types include:

- Ductless split systems.

- Through the wall units with electric or hydronic heat.

- Unit ventilators with direct expansion cooling and electric or hydronic heat.

- Water source heat pump systems.

Ductless split systems. Ductless split systems have an indoor unit connected to an outdoor unit with refrigerant tubing. An integral selector switch is used to select cooling or heating functions and a temperature controller cycles cooling and heating functions. Heat may be from a reverse cycle heat pump or from an electric resistance heater.

Through the wall units with electric or hydronic heat. Through the wall packaged terminal air conditioners, called PTACs, are set in wall sleeves with plug-in electric connections for cooling and heating and piped hydronic connections for hydronic systems. An integral selector switch is used to select cooling or heating functions and a temperature controller cycles cooling and heating functions. A refrigerating section operates subject to integral safety controls. With hydronic heat, controller positions solenoid valve at hydronic coil.

Unit Ventilators with direct expansion cooling and electric or hydronic heat. Unit Ventilators may be set in wall sleeves similar to PTACs or as a split system having an indoor unit set on a through-the-wall damper box and remote condensing unit set at grade, both system types with hard-wired electric connections. An integral selector switch is used to select cooling or heating functions and a temperature controller cycles cooling and heating functions. A refrigerating section operates subject to integral safety controls. With hydronic heat, controller positions solenoid valve at hydronic coil.

Water source heat pump systems. Water source heat pumps utilize packaged units, either console type or concealed horizontal or vertical type with ductwork. Cooling or heating functions are controlled either by manual changeover switch or by a temperature controller which cycles refrigerant compressor and positions a reversing valve to allow reverse cycle heat pump operation.

On cooling cycle, space heat is absorbed on room-side air evaporator coil and space heat plus compressor heat is rejected to loop water cooled condenser coil. On heating cycle, heat is absorbed from loop water by water cooled evaporator coil and absorbed heat plus compressor heat is rejected to space through room-side air condenser coil.

Loop water temperature is allowed to vary from as low as about 60°F to as high as 95°F. When loop water temperature drops below minimum value, heat must be added to the system using a boiler water heated heat exchanger or a swimming pool heater. When loop water temperature rises below maximum value, heat must be rejected from the system by a closed circuit liquid cooler, cooling tower cooled heat exchanger, or directly by cooling tower.

Because loop water is circulated during winter, provisions must be made and extreme care must be taken to prevent freezeup of loop water in the heat rejection side, either closed circuit cooler or cooling tower.

System Pressure Control in Hydronic Systems

Hydronic systems with centrifugal pumps must be controlled in a similar manner to air distribution systems with centrifugal fans. As the demand for heating decreases, modulating valves at heating elements are positioned to reduce fluid flow and the piping pressure increases as the pump backs off on its characteristic curve. This too is an example of a centrifugal device "riding the curve." To prevent system damage due to pressure buildup, and to effect energy savings in operation, the pump speed is varied to maintain the piping system pressure within acceptable limits.

Pressure control methods used for centrifugal pumps include:

- Riding the pump curve.
- Discharge valve control.
- Pressure bypass.
- Pump speed control by electronic means.

Hydronic Piping System Pressure Control

Pressure control in hydronic piping systems may employ physical principles or mechanical controls. A piping system serving a large number of modulating control valves, such as a fan-coil unit system, may use all 3-way valves and operate as constant flow pumping system, may use 2-way valves and operate as either a constant flow or as a variable flow system, or may use a mixture of 2-way and 3-way valves and operate as a limited variable flow system.

A constant flow system is desirable on a basic chilled water piping system because, for some system types, the chiller water flow must be held relatively constant for the control strategy to function. All chillers have a minimum water flow to prevent freezing of reduced water flows through the evaporator tubes. Some boilers have a similar minimum flow requirement to prevent hot spots on tubes and to minimize thermal shock from cold return water resulting from low flow through the system.

The basic 3-way valve, constant flow system uses balancing cocks in lines to bypass ports to ensure that flow through the bypass is not greater than the flow through the coil at full load.

A 2-way valve, constant flow system may use any of several pressure control methods, including: bypass valve; discharge valve; or variable speed drive. A modulating 2-way throttling valve at pump discharge can artificially load the pump and cause the pump to "ride the curve," with a minimum flow programmed into the controls to prevent overheating. A modulating 2-way bypass valve can be used to bypass water from supply main to return main as required to maintain piping system pressure within desired limits. A variable speed drive controller on the pump motor can be used to vary pump speed to produce a system pressure within the desired range. Either a variable speed drive controller or a bypass valve is controlled from a pressure regulator sensing pressure in the most hydraulically remote segment of the piping system to maintain the system pressure in the desired range. A 2-way variable flow system allows the pump to "ride the curve" with a minimum system flow ensured by providing one or more valved bypasses at ends of piping loops. The minimum flow must be adequate to prevent excessive increase of fluid temperature in the system due to pump heat produced by the pump motor operating near shut-off head.

Systems may use a mixture of 2-way and 3-way valves and operate as a limited variable flow system. One or more 3-way valves, selected to give a flow rate equal to the minimum flow rate, are used at the ends of piping loops with 2-way valves used for closer-in loads. The 3-way valves ensure a minimum system flow as the 2-way valves modulate and increase the system pressure. This performance of this system type is difficult to predict because the flow through the 3-way valves increases when the piping system pressure increases as the pump "rides the curve."

Chapter 2

HVAC Equipment-to-Control Interactions

A complete knowledge and understanding of the interaction of HVAC equipment with the control systems which are applied to that equipment is necessary for a thorough understanding of this book.

SYSTEMS AND SUBSYSTEMS

Systems Covered

This chapter is organized to match the usual arrangement of HVAC automatic control systems on a subsystem basis. The subsystems covered are:

- Air moving system control.
- Air filter section control.
- Preheat coil control.
- Mixed air section control.
- Cooling and heating coil control.
- Humidifier control.
- Air distribution control.
- Fan capacity modulation and static pressure control.
- Terminal devices control.
- Pumping systems control.
- Boiler and chiller plant control.

AIR MOVING SYSTEM CONTROL

The basic control functions for air moving systems include daily start-stop, emergency fan shutdown, smoke damper operation, smoke removal, and outside air control. These control functions are documented on electrical wiring diagrams.

Daily Start-Stop

The on-off or start-stop sequence of central air handling unit fan or fans may be controlled manually from a starting switch or hand-wound interval timer, automatically through a program timing device, or automatically from a relay energized from a direct digital control (DDC) system, an energy management system (EMS), or an energy management and control system (EMCS). The manual starting switch method is generally used only on systems which run 24 hours per day. The manual switch may be a manual "start-stop" switch, a "hand-off-automatic" selector switch or push-button station located on or adjacent to the magnetic starter serving the supply fan motor.

The manual interval timer method may be used as the primary start-stop control for occasionally used systems or may serve to overcall the unoccupied cycle for after hours occupancy, cleanup, or other non-programmed operating times.

For systems serving spaces with daily or weekly usage programs, an automated start-stop sequence is required.

Related air moving devices, such as return air and exhaust fans, may be interlocked to follow the same start-stop sequence as the supply fan. Power to other fans and to automatic control systems may be energized through auxiliary contacts on the supply fan starter, relays on the load side wiring of the supply fan motor starter, or by an airflow switch in the supply duct.

Emergency Fan Shutdown

Provisions for emergency fan shutdown are required to comply with the requirements of fire codes for life safety and for safety of the contents and the structure from injury and loss due to fire and smoke. The fire code most often used in the United States is NFPA 90A, Installation of Air Conditioning and Ventilating Systems.

NFPA 90A requires:

- Manual emergency stop means for each air distribution system to stop operation of supply, return, and exhaust fans in event of an emergency.
- Smoke detectors located downstream of air filters and upstream of any supply air takeoffs in all systems larger than 2,000 cfm capacity.
- Smoke detectors in systems larger than 15,000 cfm capacity serving more than one floor at each story prior to connection to a common return and prior to any recirculation or outside air connection.

The manual emergency fan shutdown is intended to be used to stop the fan to prevent spreading fire and smoke through the duct system before the automatic smoke or temperature-based shutdown devices function. An emergency stop switch must be in a location approved by the authority having jurisdiction, usually the local fire marshal.

For small systems the electrical disconnect switch may be used for the emergency stop switch. For larger systems a separate "break-glass" station or a tie-in with a fire alarm system will provide the means for emergency stop.

Older buildings will often have manual reset fixed temperature automatic devices, called fire safety thermostats (FST) or simply firestats, in systems from 2,000 to 15,000 cfm, installed to comply with fire codes which were current at time of construction and which required automatic shutdown from temperature. Firestats open when temperature is sensed above the setting. Firestats are wired to interrupt the holding coil circuit on the magnetic starter which serves the primary fan to shut down the primary unit. Firestats must be of the manual reset type to ensure that a system shutdown from a high temperature condition is investigated.

Firestats mounted in return air streams are generally set from 125°F to 135°F. Firestats in supply ducts are often selected with setpoints similar to fire dampers. Setpoints will be based on the normal temperature to be transmitted in the duct on heating cycle and are to be set no more than 50°F higher than that temperature.

Large systems in older buildings and systems larger than 2,000 cfm capacity in newer buildings may have smoke detectors installed in lieu of firestats.

The most commonly used smoke detector for duct systems is the self-contained ionization-type smoke detector, as shown in Figure 2-1.

When smoke detectors are installed in a building having an approved protective signaling system, the smoke detectors must be connected so that the activation of any smoke detector in the air distribution system will cause a supervisory signal to be indicated in a constantly attended location or will initiate an alarm signal.

When smoke detectors are installed in a building that does not have an approved protective signaling system, the activation of any smoke detector must cause an audible and visual signal to be indicated in a constantly attended location. Trouble conditions in the smoke detector must be indicated either audibly or visually in a normally occupied location and identified as duct detector trouble condition.

Other fire and smoke detection devices may be wired into an emergency fan shutdown loop, including "alarm" contacts in a manual fire alarm system and the "sprinkler flow" contacts in an automatic fire protection sprinkler system.

Systems using water coils may have a freeze safety thermostat (FZT), commonly called a freezestat, as shown in Figure 2-2. A freezestat is wired into fan holding coil circuits to stop fan and prevent further motion of air at near-freezing temperatures to protect the cooling coil from freezing.

All interlocked motors and controlled circuits units will be stopped by action of either firestats or smoke detectors through the electrical interlock through an auxiliary starter contact or through an airflow switch wired to interrupt control power. High pressure fan systems may have a high pressure limit switch which will stop the fan when duct pressure

Figure 2-1. Duct Mounted Ionization Smoke Detector (*Courtesy Pyrotronics*)

Figure 2-2. Low Limit Thermostat or Freezestat (*Courtesy Barber-Colman*)

rises above a point at which duct damage may result from further pressure increase.

Start-stop control of ventilating and exhaust fans may be directly controlled from BAS, interlocked with the supply fan, or controlled from a temperature controller, thermostat, other ambient condition sensing device, or hand-wound interval timer. For example, a mechanical room exhaust fan which uses a 2-speed fan motor with fan speed selected manually from a selector switch, low speed during heating season and high speed during cooling season, and with fan operation cycled by a space thermostat. Exhaust and ventilating fans must have heat or smoke detectors according to the capacity, similar to other air distribution systems.

Smoke Dampers

Smoke dampers are multiblade dampers specifically designed and UL classified under UL 555S for use as smoke dampers.

Smoke dampers are required in systems over 15,000 cfm capacity to isolate the air handling equipment, including filters, from the rest of the system to prevent circulation of smoke in event of a fire. Smoke dampers are not required in a system that serves only one floor and is located on the same floor or where the system is located on the roof and serves the floor immediately below it.

Smoke dampers are required to be closed on signal from a smoke detector and whenever the supply fan is shut off. Smoke dampers may be positioned from a remote location, such as a fireman's control panel, when necessary for smoke removal but must be designed to reclose automatically when the damper reaches the maximum degradation test temperature determined under UL 555S.

Smoke Control Systems

The duct systems used in HVAC systems will not usually be engineered to perform smoke control functions. An effective engineered smoke control system will require an extensive set of controls, often with a microprocessor-based logic panel with software tailored to the building. Each building represents a separate engineering problem of considerable complexity.

Older buildings may have a "fireman's control panel" arranged to allow selection of fan operation and damper positions to perform smoke and heat containment or smoke removal functions under control of the fire service personnel.

Some earlier fire codes required that the temperature and smoke controls, upon detection of fire or smoke, stop all fans and close all smoke dampers in order to prevent the spread of heat and smoke through the duct system. In smoke control systems, the same basic components are used but all components are generally subject to individual control from a central fire control panel. That is, each fan is arranged to be restarted from the fire control panel and dampers are arranged to exhaust smoke from a fire compartment or to supply smoke-free air into an adjacent compartment to prevent entry of smoke and heat.

Wiring Diagrams

Control wiring diagrams may be elemental ladder type for motor starting and interlock functions or point-to-point type showing all control functions. A ladder diagram is easier to follow in determining system operating sequences.

A typical ladder wiring diagram is shown in Figure 2-3, with a supply air fan motor shown as the primary controlled element.

An interlocked return air fan and an electric-pneumatic (E-P) relay for pneumatic controls system energization are activated by an airflow switch, which would be located in the main supply duct to prove airflow. When the supply fan motor starter starting sequence is initiated by depressing the "start" button, the starter holding coil 1M will be energized, subject to normally closed firestat (SD) and three normally closed overload heater relays (OL) being satisfied.

At the same time, a "sealing contact" 1M-1 will close to maintain the holding coil circuit and an air solenoid valve relay E-P will position to close the exhaust port and to open the supply port and apply main control air pressure to the control system.

As airflow increases in the ductwork, the airflow switch (AFS) closes to prove airflow and a green "running" pilot indicator light (PIL) is lighted.

With the return air fan starter selector switch in "automatic" posi-

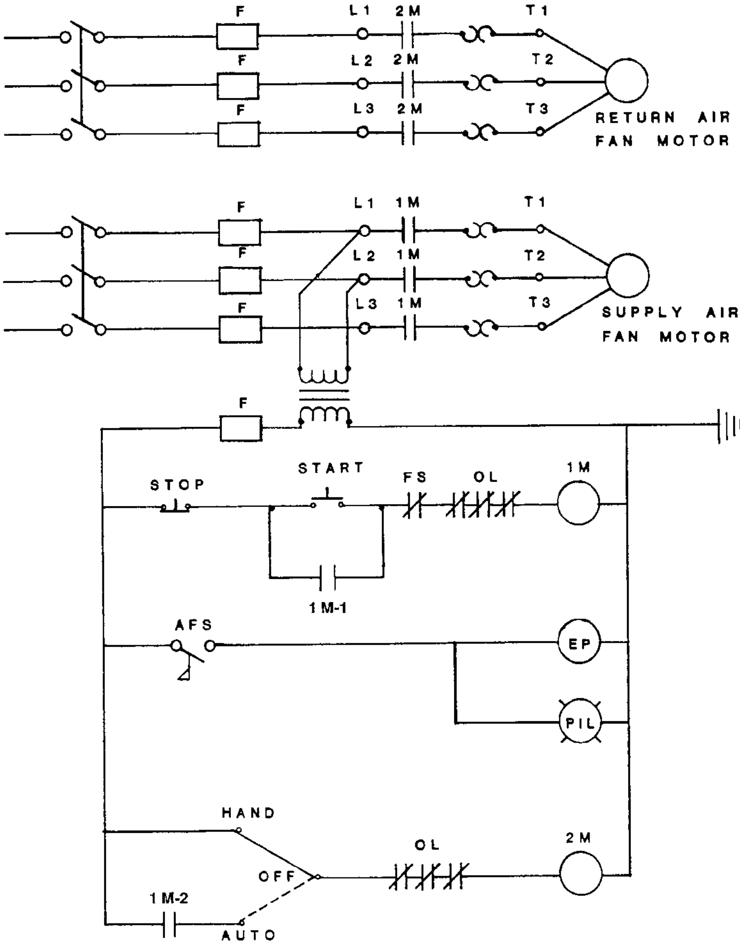

Figure 2-3. Schematic Ladder Diagram for Air Handling Unit

tion, when starter 1M is energized, the auxiliary contact 1M-2 in the starter selector switch circuit closes to energize the return air fan starter holding coil 2M, subject to overload heater relays (OL) being satisfied.

AIR FILTER SECTION CONTROL

Filter Types

Filters may be of the automatic or manually changed type.

Automatic filter installations that may be found include electrostatic, roll-fed, and combined electrostatic and roll-fed.

Manually changed filter installations that may be found include disposable cell or throwaway cells, disposable sheet media, washable type, and manual roll-fed types.

Filter Control

Automatic filter controls used on roll-fed media filters may be based on either pressure drop or time-in-service. Pressure drop controls are usually closed loop type that use a differential pressure switch to energize a timer on the filter drive motor to advance just enough media to maintain air pressure drop within given limits. A typical pressure switch used to monitor the pressure drop across a filter bank and energize a "filter change" signal light is shown in Figure 2-4. Time-in-service controls are open loop type that use one timer to set the interval between media advances and a second timer to operate the media take-up drive motor to advance the desired length of media on each run.

Both filter types may have media run-out alarms to signal when a media roll has run out and a paper blank-off has rolled across the filter and reduces or stops airflow.

Manual filter controls are usually limited to simple alarm devices with local signal or signal to BAS indicating high air pressure drop across the filters. The signal indicates a required filter replacement either by changing media or by rolling manual roll-fed filters.

It is important that filter controls be inspected at each filter change to verify that they are functioning properly.

PREHEAT COIL CONTROL

Preheat coils are used to heat incoming outside air from subfreezing temperatures before it enters the apparatus to avoid freeze-up of water coils and overcooling of the space.

Control of Preheat Coils

Preheat coils can use either heated water or steam. The temperature of air leaving the coil can be controlled by one of the following methods:

Figure 2-4. Change Filter Indicator (*Courtesy Honeywell Inc.*)

Outside air control. A straight-tube steam coil with 2-position valve is generally used with this sequence as shown in Figure 2-5. The steam valve is opened by a temperature controller with sensor in outside air so that when the outside air temperature falls below a certain level, the valve opens and steam is admitted to the coil. The 2-position valve is used to keep full steam pressure on the coil when exposed to subfreezing air and thus minimize the chance of coil freezeup.

Discharge temperature. Either hot-water or steam coils of distributing tube type are used with this sequence. A temperature controller with sensor on the discharge side of the preheat coil modulates the heated water or steam valve to maintain space temperature at the setpoint. The heat output of a steam coil remains relatively high with changes in pressure above atmospheric. The pressure drop that occurs from modulating a steam valve does little to regulate the coil surface temperature. However, the resulting mass flow change may cause temperature stratification across the length of a coil, with the surface hot near the header and cold at the tube ends.

A steam coil, when throttled down, is subject to hang-up of condensate in the tubes. The hang-up of condensate may cause a freezeup when the steam valve is open. A steam valve, when throttled down to near closed, is subject to seat damage, called wire-drawing.

A water coil, when using a modulating 3-way mixing valve, may use a secondary pump in the common line from the coil, as shown in Figure 2-6, to provide a constant water movement through the coil. A variation on this sequence may be used which will employ a dual-input controller with setpoint reset from outside temperature, as shown in Figure 2-7.

Face and bypass damper control. Steam preheat coil sections may be provided in an enclosure with a system of internal face and bypass dampers which allows the steam coil to be controlled with a 2-position valve for daily "on-off" control, while the actual temperature control is done by bypassing jets of unheated air between finned tube sections of the steam coil. The multiple air jets promote good mixing of the heated

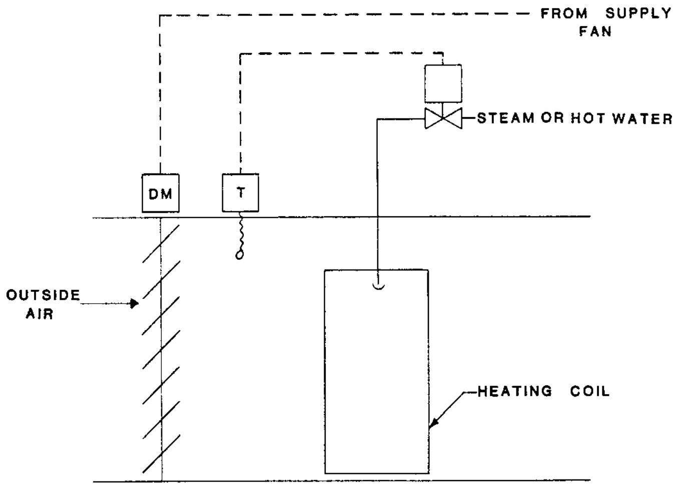

Figure 2-5. Control of Preheat Coil, Open Loop. ***"Copyright 1987 by the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., from*** **1987 HVAC Systems and Applications Handbook.** ***Used by permission."***

and bypassed airstreams, to avoid stratification of cold and hot air. The coil valve is interlocked with the fan system and the dampers are controlled from a temperature controller.

Psychrometrics

Psychrometrics is the science of moist air, such as is conditioned in an HVAC system. A brief discussion of psychrometrics is included in Chapter 17, "A Short Course in Psychrometrics."

The psychrometrics of preheat coils operation involves the heating only process and the air mixing process.

The heating only process is drawn on a psychrometric chart as a straight line of constant dew point temperature and humidity ratio moving to the right with increasing dry bulb temperature.

The mixing of two airstreams is drawn as a straight line connecting the conditions of the two airstreams, with the resulting mixture condition lying on the line and located at a point in inverse ratio to the condition plotted.

The temperature rise through a preheat coil is determined by dividing the coil total heating load by the product of the coil air flow in

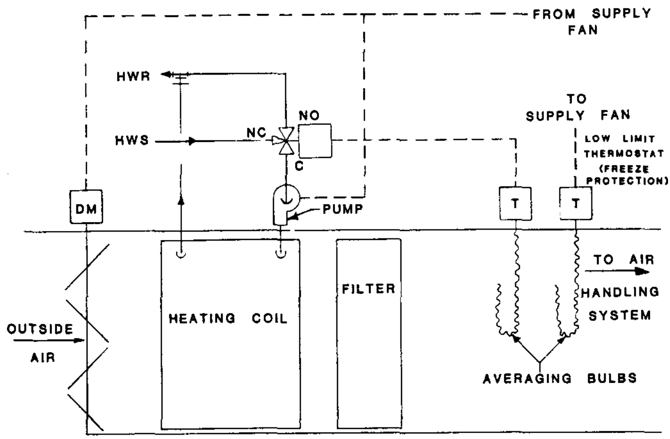

Figure 2-6. Control of Hot Water Preheat Coil, Closed Loop. *"Copyright 1987 by the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., from* **1987 HVAC Systems and Applications Handbook.** *Used by permission."*

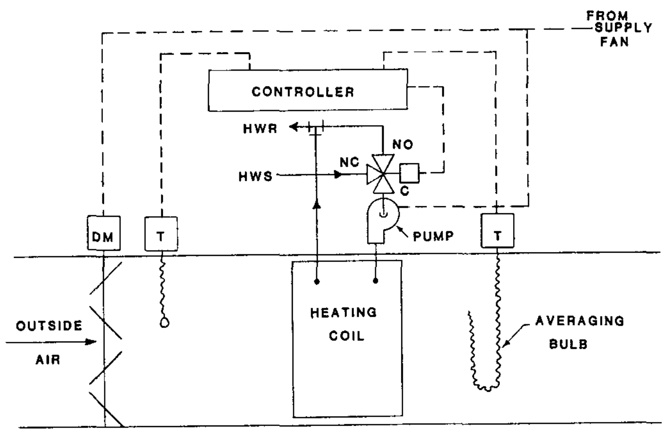

Figure 2-7. Discharge Temperature Reset of Preheat Coil from Outside Air. *"Copyright 1987 by the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., from* **1987 HVAC Systems and Applications Handbook.** *Used by permission."*

cfm and the constant 1.1 Btu/hour-cfm-°F. The final temperature of air leaving the coil is determined by adding the temperature rise to the coil entering air condition. The designed entering air temperature may be determined from the coil schedule or it may have to be calculated from the given indoor and outdoor temperatures using the air mixing formula.

Set-Up and Checkout Techniques

Preheat coil control is important for freeze-protection and comfort reasons. Set-up of some temperature controller setpoints must be done from system capacity information abstracted from the design documents. Other settings must be made using judgment as to the temperature differences which will be required to prevent freezing.

One of the items to be set up is the freezestat. The freezestat should be installed in a spot in the coil discharge air where the lowest temperature can be sensed. Some heating coils allow stratification of air passing through the coil so that air near the header end will be hot and air near the opposite air will be measurably colder, on the order of 10°F to 20°F. The thermostat bulb location should be established during installation by use of a digital thermometer to find the coldest air.

MIXED AIR SECTION

The mixed air section is where ventilating air from outdoors and return air from the space are mixed before entering the conditioning apparatus. During air-side economizer operation, the mixed air section becomes the principal controlled device.

Control Functions and Hardware

During mechanical cooling cycle and heating cycle operation, the mixed air section provides mixing of a fixed proportion of outside air and return air. The outside air and return air dampers each open to a fixed position when the system is running and close when the system stops. A minimum positioning relay on the mixed air temperature controller can position the outside air damper to an adjustable minimum position when the system is in operation.

During economizer cycle operation, a mixed air section is controlled from a temperature controller located to sense an accurate mixed air temperature. The controller, often set at about 55°F, simultaneously positions outside air damper, return air damper, and relief air damper to admit up to 100% outside air for "free" cooling.

In normal operation, the controller may function as a low-limit controller, positioning dampers to reduce outside air volume as required to prevent the mixed air temperature from falling to the freezing level.

Mechanical Cooling and Economizer Cycle Cooling Changeover

The use of up to 100% outside air for "free" cooling when the outdoor temperature is below the required air conditioning system supply air temperature is called "economizer cycle." When operating on economizer cycle, the mixed air section is controlled by a mixed air temperature controller to maintain the required temperature for supply air to the system.

The economizer cycle has been used for many years but recent advances in control system development have made it possible to optimize the use of the economizer cycle in an overall energy conservation approach to facilities management. Many sophisticated economizer cycle changeover sequences have been disconnected because the control technicians did not understand the logic in the system based on psychrometrics.

The methods of changeover from mechanical cooling to economizer cycle which are in common use include: dry bulb changeover, compensated dry bulb changeover, and enthalpy cycle changeover. The functions of these methods are:

Dry bulb economizer changeover. The dry bulb economizer changeover switches the control system from mechanical cooling to economizer cycle cooling whenever the outdoor temperature is below the changeover setpoint (usually the required supply air temperature) and often taken as 55°F. When the outdoor temperature is above the setpoint, the control system is switched to mechanical cooling cycle. On economizer cycle, the mixed air temperature controller positions the mixed air section dampers to admit up to 100% outside air, often subject to overcall from a mixed air low limit thermostat.

Compensated dry bulb economizer changeover. Compensated dry bulb changeover is applied often on unitary products, such as rooftop units. The device is so named because the outdoor air dry bulb changeover temperature setpoint is compensated for relative humidity by action of a hygroscopic element which shifts a bimetal strip in the temperature sensing element to vary changeover temperatures with changes in relative humidity.

Each combination of conditions gives a higher changeover temperature with lower relative humidity coincident to lower changeover temperatures with higher relative humidity. A typical compensated dry bulb changeover device is shown in Figure 2-8. The basic control device can be adjusted to four different calibration curves, marked A, B, C, and D.

The temperature and humidity ranges for those four settings are plotted on a psychrometric chart in Figure 2-9. The setting for a specific instrument is selected according to the requirements of the application.

Whenever the outdoor condition lies on or below the selected curve, the outside air damper opens fully. When the mixed air temperature drops below the setpoint, the mixed air temperature controller overrides the economizer control and closes the outside air damper to minimum position. This sequence yields 2-position control of the mixed air section dampers. The mixed air temperature controller may continue to control mechanical cooling during the economizer cycle when the outdoor air is warm and dry.

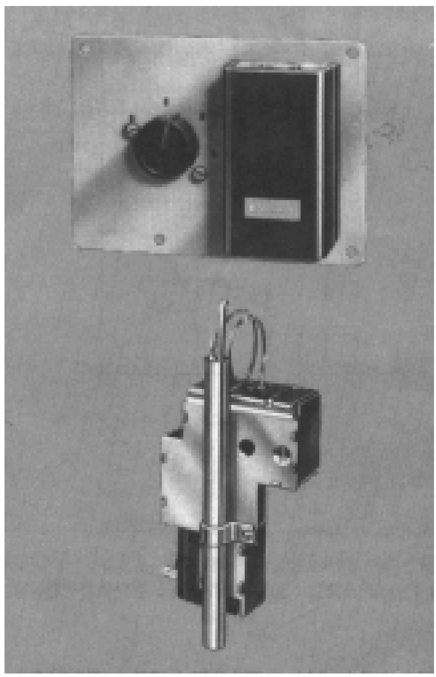

Figure 2-8. Typical Compensated Dry Bulb Changeover Device. (*Courtesy Honeywell, Inc.*)

Enthalpy cycle changeover. Enthalpy cycle changeover is usually applied on large central station systems with chilled water cooling. The method is so named because it constantly compares the enthalpy, or total heat content, of the outside air and of the return air. When the outside air enthalpy drops below the return air enthalpy, the control energizes the economizer control functions to use up to 100% outside air through the chilled water cooling coil, even though the dry bulb temperature of outside air is higher than that of return air.

Performance under varying load conditions. As the outdoor air temperature drops below the desired mixed air temperature, the mixed air controller simultaneously positions the dampers to reduce the percentage of outside air and increase the percentage of return air in the mixture. The mixed air temperature tends to offset above the setpoint with decreased outside air percentage until the minimum outside air percent-

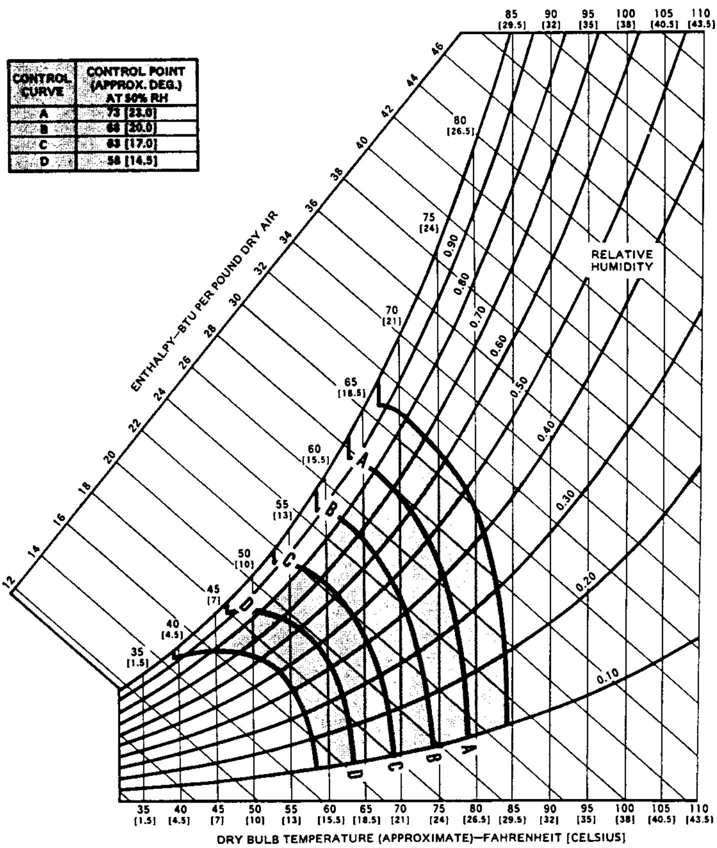

Figure 2-9. Partial Psychrometric Chart with Compensated Dry Bulb Changeover Device Performance Curves Superimposed. Shaded Area Represents Control Range. (*Courtesy Honeywell, Inc.*)

age is reached. With the increased return air volume at colder outside temperatures, the humidity control problem is lessened.

As the outdoor temperature drops below the point at which the minimum outside air percentage, as set by the minimum positioning relay, will produce mixed air temperature below the desired amount, the airstream must be heated. That can result in excessive energy consumption if the minimum positioning relay is set for too high a minimum outside air percentage.

Psychrometrics

When the return air and outside air are mixed, the resulting mixture can be represented by a point on a psychrometric chart.

A psychrometric chart showing the HVAC processes of air mixing is shown in Figure 2-10 and is calculated as follows:

$$T_{MA} = \{\% \text{ RA } (T_{RA})\} + \{\% \text{ OA } (T_{OA})\} \tag{2-1}$$

Where:

T_{MA} = Temperature mixed air, °F.
% RA = Percent return air = (cfm return air/cfm total air) × 100
T_{RA} = Temperature return air, °F.
% OA = Percent outside air = (cfm return air/cfm total air) × 100
T_{OA} = Temperature outside air, °F.

To determine the mixed air temperature, first, the return air condition is plotted on the psychrometric chart in Figure 2-10 and called point "A." Next the outside air condition is plotted and called point "B." Next, a straight line is drawn between points "A" and "B" and called A-B. The condition of the resulting return air/outside air mixture lies on this line.

Using Formula 2-1, the resulting mixture temperature is calculated and the point is plotted on the chart, as point C. The location of point C on line A-B depends on the proportion of return air to outside air. The larger the percentage of outside air, the closer the mixed air temperature will be to the outside air temperature.

Below the changeover point to "economizer cycle," where the temperature controller is calling for a supply air temperature near the outside air temperature, the mixed air section must handle as close to 100% outside air as damper leakage will permit. With damper leakage commonly in the 10% range, it becomes difficult to maintain the desired

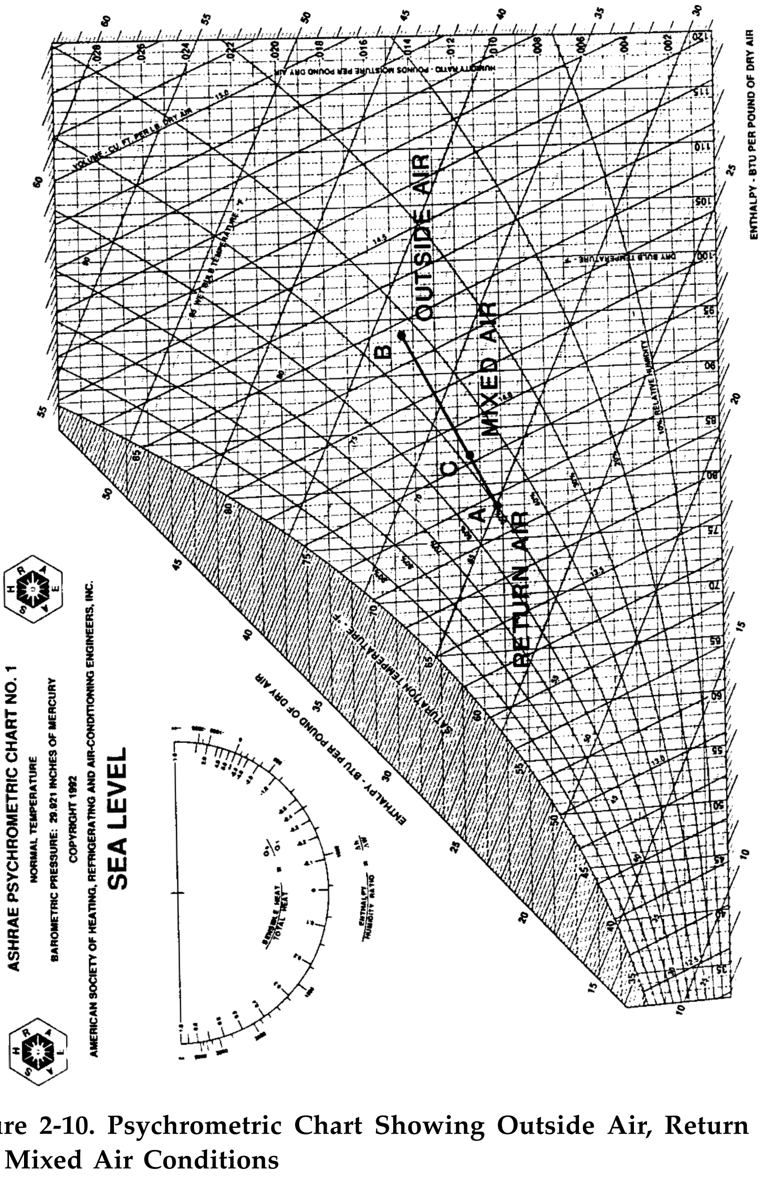

Figure 2-10. Psychrometric Chart Showing Outside Air, Return Air, and Mixed Air Conditions

supply air temperature with the same outside air temperature so an offset must be programmed into the controller to delay changeover to a few degrees below the setting of the supply air controller.

For enthalpy changeover systems, in the range of enthalpy between the return air condition and the supply air condition, the system will introduce 100% outside air while the cooling cycle is energized. The concept of mechanically cooling 100% outside air in the enthalpy economizer cycle is hard to accept until it is plotted and analyzed on a psychrometric chart, as is shown in Figure 2-11.

In that figure, the "enthalpy economizer" area is that area between the enthalpy line corresponding to 63.5°F wet bulb for room air and the enthalpy line corresponding to 56°F wet bulb for supply air. This figure shows that, when the outside air has an enthalpy, or total heat value, lower than the room air, the load on the cooling coil will be lower when using outside air than when using return air.

Refer to Chapter 17 for an illustration of the psychrometric calculations for "enthalpy economizer."

Set-Up and Checkout Techniques

The control of the mixed air section is another basic temperature control process. The set-up of the temperature controller setpoints must be done from system capacity information abstracted from the design documents or calculated as described under 2-4 above for cooling and heating systems. Some other settings must be done by using judgment as to the temperature which will be required to provide the required supply air temperatures. The changeover controller setpoints must be set up in a similar manner.

COOLING AND HEATING COIL CONTROL

In this section, three types of cooling and heating coils are discussed: direct expansion evaporator cooling coils; water coils for cooling or heating; and electric resistance heating coils.

In order to understand the effects of control sequences on coil performance, it is necessary to analyze the changes in temperature and moisture content or humidity. The tool we use to analyze these processes is called the psychrometric chart.

Psychrometrics

A brief discussion of psychrometrics is included in Chapter 17, "A Short Course in Psychrometrics." A diagram of all the psychrometric processes that can be plotted on a psychrometric chart is shown in Fig-

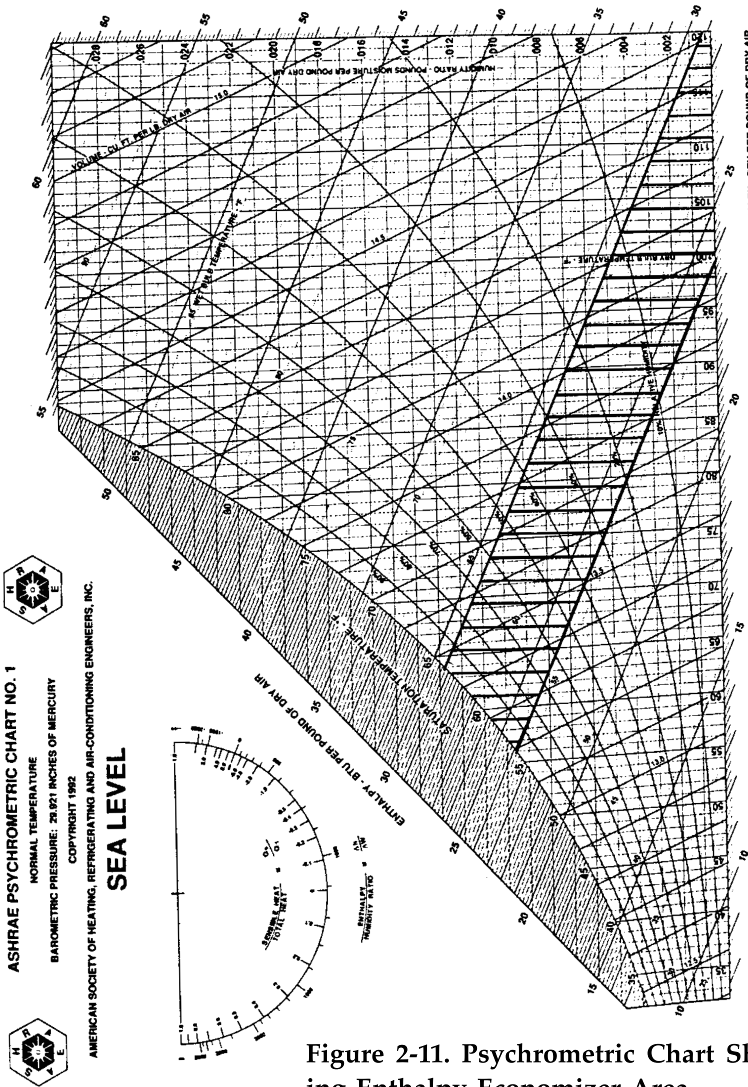

Figure 2-11. Psychrometric Chart Showing Enthalpy Economizer Area

ure 17-1b. The control of cooling and heating coils may involve these four psychrometric processes: heating only, simultaneous cooling and dehumidification, sensible cooling, and air mixing.

Direct Expansion Evaporator Cooling Coil

Refrigerant flow to a direct expansion evaporator coil in small systems, usually less than 7.5 tons, may be controlled by cycling the compressor. In larger systems, refrigerant flow is controlled by positioning liquid line solenoid valves or energizing cylinder unloaders. In either case, the flow of refrigerant to the expansion device determines when cooling is available and the output of the expansion device determines the degree of cooling provided.

Airflow through a refrigerant must be maintained at a level high enough to prevent frost or icing on finned surfaces.

The compressor contactor or a liquid line solenoid valve are controlled electrically by a signal from the space temperature controller or from limit switches on the face and bypass damper linkage to cause refrigerant flow on call for cooling from the space. The liquid line solenoid valve is a normally closed valve that controls refrigerant flow and prevents migration of liquid refrigerant into the compressor during "off" cycle.

Packaged equipment above medium size may have dual compressors, each serving separate "intertwined" refrigerant circuits in the evaporator coil. When only one compressor is operating, refrigerant is fed to every other tube so that half the tubes are refrigerated and the cooling effect is spread over the entire evaporator face by the fins.

Larger systems may have evaporator coils arranged for "face split" to make several refrigerant circuits across the face of the coil, each with a liquid line solenoid valve to allow capacity reduction. When the required degree of control is more precise than can be provided by cycling either the compressor or the liquid line solenoid valves, a hot gas bypass valve may be provided to inject hot refrigerant gas into the liquid line between the expansion device and the evaporator to artificially load the evaporator and keep the compressor from turning "off" from low refrigerant pressure. However, the hot gas injected into the system may raise the coil surface temperature above the air dew point, which will stop the dehumidification process that constant compressor operation was intended to maintain.

Water Coil Control with 2-Position Valve

Two-position valve control gives either full flow or no flow. Coil cooling or heating output goes to maximum after the valve opens and drops to zero as the valve closes.

On cooling systems, this sequence causes a basic problem because no dehumidification occurs when no chilled water is flowing through the coil and because condensate remaining on the coil fins when chilled water flow stops is re-evaporated into the supply air, causing a latent heat or moisture load increase to the conditioned area.

On heating systems with heated water temperature reverse reset, this system is very effective. Temperature controllers must employ heat anticipation on both cooling and heating cycles to avoid overshooting the space temperature setpoint.

With this sequence, valve bodies may be 2-way throttling type, shown in Figure 2-12a, or 3-way mixing type, shown in Figure 2-12b.

Water Coil Control with Modulating Valve

With this sequence, valve bodies may be 2-way throttling type or 3-way mixing type.

Flow control plugs in modulating valves are positioned between open and closed positions in direct proportion to the signal received from the temperature controller but the flow is not in direct proportion to the valve plug position. Flow characteristics of a valve depend on the type of valve plug used. Types of valve plugs are *linear,* where the percent of total flow at constant pressure drop is directly proportional to percent valve plug lift or opening, *quick opening,* where maximum flow is reached shortly after the valve begins to open, and *equal percentage,* where each equal increment in valve opening increases flow by an equal

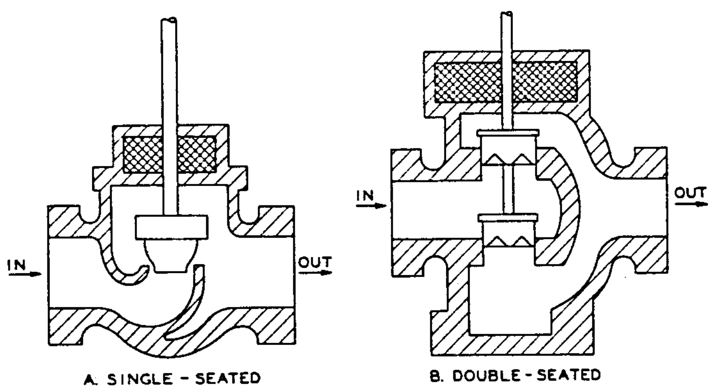

Figure 2-12a and 2-12b. Typical Two-way Throttling or Three-way Mixing Valve ***"Copyright 1987 by the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., from*** **1987 HVAC Systems and Applications Handbook.** ***Used by permission."***

percentage over the previous value.

Typical flow characteristics for the three plug types are shown in Figure 2-13.

With modulating sequence on chilled water coils, assuming constant supply water temperature, temperature rise across coil will usually increase with reduced water flow rate. After the valve closes to a certain position, coil surface temperature on the air entering side of the coil will rise above the entering air dew point. At that time, dehumidification will stop and humidity control will be lost.

Coil Face and Bypass Damper Control

Face and bypass damper control of cooling coils and steam coils requires a face damper over the coil "face" and a bypass damper located to allow air to flow around or "bypass" the coil, as shown in Figure 2-

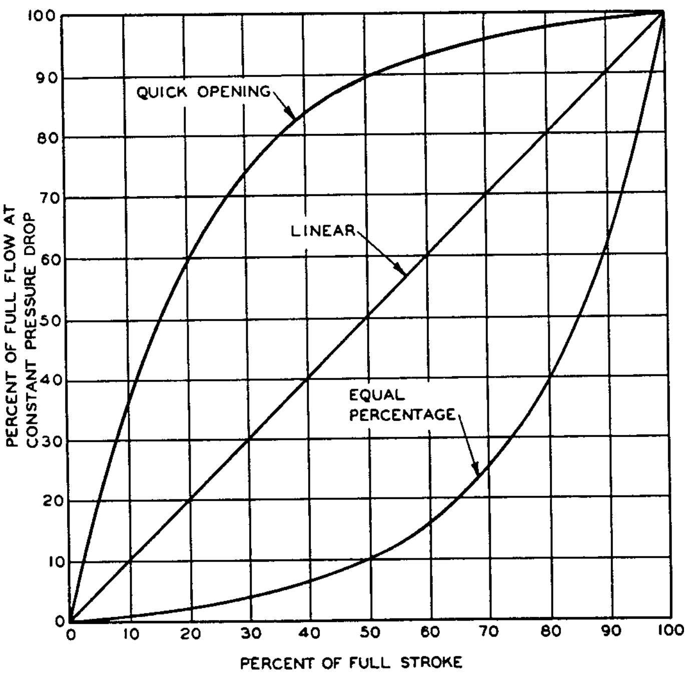

Figure 2-13. Typical Valve Flow Characteristics ***"Copyright 1987 by the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., from*** **1987 HVAC Systems and Applications Handbook.** ***Used by permission."***

14. The face damper is sized to match the "face" of the coil and the bypass damper is sized about 1/3 to 1/4 of the coil size. The temperature controller positions a damper actuator in accordance with temperature changes in the controlled medium, either discharge air or conditioned space.

The required cooling or heating must be done on that portion of the air that flows through the coil. The portion of air which bypasses the coil is mixed with the conditioned air leaving the coil and the resulting air mixture becomes the supply air condition.

On cooling coils, when possible, the bypassed air is taken from return air so that all the outside air entering the system must flow through the coil and be conditioned.

With this sequence, full chilled water volume flow is maintained through the coil and the water temperature rise decreases with a decrease in cooling load so that coil surface temperature becomes colder and remains below the air dew point.

For the latter reason, face and bypass damper control on cooling coils provides better humidity control than valve control, because with reduced airflow through the coil with a constant water flow, the coil latent heat removal per volume of air is actually increased. The reduced airflow is made drier so that the space latent heat loads can be absorbed while the reduced sensible heat loads are controlled in response to dry-bulb temperature changes.

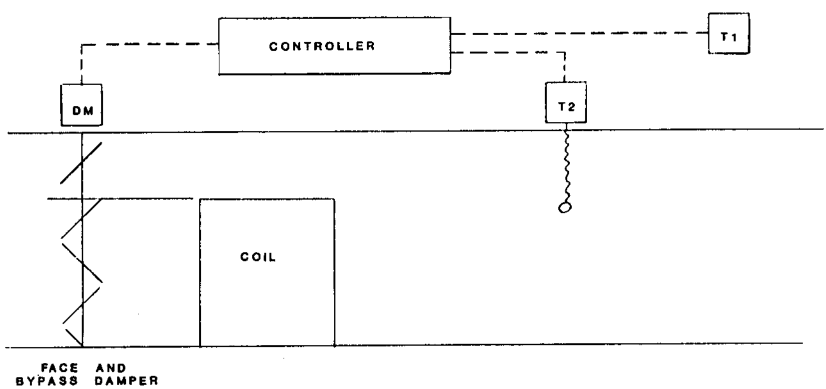

Figure 2-14. Temperature Control with Face and Bypass Damper

Electric Resistance Heating Coils

Output of electric resistance heating coils is generally controlled in steps of capacity through magnetic contactors in response to temperature control signals. The minimum number of capacity steps is determined by the maximum electrical load allowed per circuit by the National Electrical Code. A designer will often select the number of capacity steps to give a certain temperature rise on the air passing through the heater or on a percent of total capacity basis depending on the service and the size of the heater.

Electric resistance heaters will burn out when operated without adequate airflow. Airflow safety controls are usually included in the control sequence, either as vane-type air switches or as diaphragm type pressure switches, to de-energize the heater control circuit when airflow drops below the minimum value.

Many heater control circuits will have two integral high-limit temperature cutouts, one an automatic reset type set at a nominal high temperature, and the other a manually reset type set at a maximum high temperature. The manually reset type cutout may be a set of fusible links in the power conductors to the heater which must be replaced when they fuse.

Variable heater output control from 0 to 100% capacity is possible by use of silicon controlled rectifiers (SCR). SCRs must be designed for switching at zero voltage to avoid radio frequency interference (RFI).

Cold-Deck and Hot-Deck Temperature Control

In parallel path systems, where one air handling unit is serving several zones, a separate temperature controller for each deck maintains the desired deck supply air temperature. The setpoint may be set or reset by cold-deck discriminator or by hot-deck outside air reset. Temperatures from chilled water coil supplied cold-decks on systems which do not operate 24 hours per day may be uncontrolled with unregulated coil water flow.

Multi-zone mixing dampers use two damper blades mounted on a common axle with the position of the cold-deck damper at 90° to the hot-deck damper. When one section is 25% open the other will be 75% open.

The flow rate through each mixing damper segment is greater than its percentage opening, that is, at 25% open the airflow may be 90% of fully open flow. For this reason, the total flow through a damper will be greater than the percentage opening for the two damper segments. This condition causes some variation of airflow among zones as the damper positions are changed and the fan shifts its operating point on the fan curve, but the resulting variation in airflow does not cause a problem.

Heating Coil Discharge Temperature Control

The air temperature leaving a heating coil can be controlled by use of either open loop or closed loop control strategies.

Discharge Air Limit Control. This is an open loop strategy for a fixed discharge temperature value. The discharge temperature controller varies the flow of heating media, steam or heated water, through the coils so that discharge air is conditioned to the desired temperature. This strategy causes problems with overheating because, as the space heating load decreases, the fixed supply temperature will cause an increase in the space temperature without feedback to the open control loop.

Discharge Air Outdoor Air Reset Control. This is a modified open loop control strategy by which the discharge temperature is reset from the outside temperature. As the outside temperature varies, the supply air discharge temperature is reset in reverse ratio. That is, as the outdoor temperature drops, the supply air temperature is increased to satisfy the space heating load. The potential for problems with overheating or underheating is less than with a fixed discharge air temperature because the supply air temperature is changed in response to the prime factor for varying heating load.

Discharge Air Space Temperature Reset Control. This is a closed loop control strategy by which the discharge temperature is reset from the space temperature. As the space temperature varies, the supply air discharge temperature is reset in reverse ratio. That is, as the space temperature drops, the supply air temperature is increased to satisfy the space heating load. The closed loop control minimizes the potential for problems, with overheating or underheating except for the problems that are inherent in the control loop itself.

Hot Deck Temperature Control. This is an indirect closed loop control strategy to control the hot deck temperature in dual duct or multizone systems, with a discriminator relay comparing signals from each of the zone or terminal unit temperature controllers to determine the one with the greatest heat requirement. The discriminator relay generates a signal that is used to reset the discharge temperature of the hot deck by damper or valve control. Signals from a maximum of about 7 zone controllers may be input to one discriminator. When more zones need input, a second discriminator is used. The discharge temperature is thus reset to satisfy the zone having the lowest space temperature, which will require full heating output from that zone while the zone controllers with lesser heating demand will throttle the airstream from the hot deck to match the heating load.

Cold Deck Temperature Control. The multizone or dual duct unit cold deck discharge temperature is not usually controlled by positioning a chilled water valve because reducing the flow rate of chilled water through the coil results in raising the average coil surface temperature which, in turn, reduces the latent heat removal. A frequent practice is to let the chilled water flow remain constant (sometimes called "wild flow"). When the cold deck airflow is reduced by throttling dampers on the cold deck or on terminal units, the coil face velocity is reduced, which causes the reduced airflow to be dehumidified more than at design conditions. That drier supply air tends to keep the humidity under control.

To avoid overcooling during overnight light load periods on systems that are used 24 hours per day, it is desirable to provide a 2-position chilled water valve positioned by a cold deck discriminator relay comparing signals from each zone or terminal unit temperature controller. When the discriminator relay finds a cooling load, even on only one zone, the chilled water valve is opened and kept open until there is no longer a cooling load present.

Coil Freeze Protection

In systems using water coils, either chilled or heated water, and having the capability to introduce large percentages of outside air, a low limit temperature controller or freezestat may be provided as part of the fan shutdown loop.

A low limit controller may be a modulating-type temperature controller with averaging bulb element installed in air leaving the cooling coil to sense potential freezing temperatures and to overcall other mixing controls on return air and outside air dampers and reduce the outside air quantity as required to raise the mixed air temperature above the freezing point.

A freezestat is usually an electric temperature controller with plain averaging bulb element installed in mixed airstream to sense air temperatures nearing the freezing point and to open the fan shutdown loop circuit to stop the supply fan.

Many freezestats can sense a temperature along any one foot of the sensing element and are often factory set at 40°F. It is important to verify the sensing element location as being in the coldest part of mixed air. This must be done by actual temperature measurements during subfreezing weather.

When face and bypass damper control is used on a preheat coil, stratification may result if the hot and cold airstreams do not mix downstream. A subfreezing cold airstream can cause nuisance tripouts of the freezestat. To avoid this problem, a mixing baffle may be added in air leaving the coil face and bypass dampers to mix the two airstreams to a temperature above the freezestat setpoint and prevent the problem.

Space Temperature Limit Control

In heating season, a night low-limit thermostat may be used to overcall time-of-day controls and start an air handling system to keep the temperature of space above the freezing level.

Similarly, in cooling season a high-limit thermostat may be used to overcall the unoccupied cycle controls to start an air handling system to keep the space temperature below the setpoint. An electric 2-position thermostat may be used to overcall the time controls and energize the fan system. When the limit thermostat overcalls the time controls, the outside air dampers remain closed, the interlocked exhaust fans remain off, and the unit cooling and heating coil controls function as on occupied cycle until the limit thermostat setpoint is satisfied, which generally requires a change of from 3°F to 5°F.

Most programmable electronic thermostats include space temperature limit control features.

Set-Up and Checkout Techniques

The control of cooling and heating coils is the basic temperature control process. The set-up of the temperature controller setpoints must be done from system capacity information abstracted from the design documents.

For example, when the cooling coil discharge temperature is not scheduled, the temperature controller setpoint can be calculated by translating the scheduled coil capacity into a dry bulb temperature drop and subtracting that temperature drop from the coil entering air temperature to determine the designed coil leaving air temperature.

When the cooling coil capacity is scheduled with "total sensible heat" and "grand total heat," the "total sensible heat" is the amount of heat removed from the air in cooling the given air flow rate from the entering dry bulb temperature to the leaving temperature, which is the desired setpoint temperature.

The temperature drop in °F is determined by dividing the "total sensible heat" in Btu/hour by the product of the coil airflow rate in cfm and the constant 1.1 Btu/hour-°F-cfm. The entering air temperature may be determined from the coil schedule on the drawings or it may have to be calculated from the given indoor and outside temperatures by using the air mixing formula using the percentage of outside air to total air. The required coil leaving air temperature is determined by subtracting the required temperature drop from the coil entering air temperature.

The set-up of reset control sequences follows the procedure described in Chapter 4, "Performance Prediction in HVAC Control Systems," using reset schedule data abstracted from the system documentation.

The set-up of outside temperature control points for changeover or for operation of circulators is done by logical selection processes to allow temperature differences adequate to prevent freezing.

TERMINAL DEVICES

Types of Terminal Devices

Terminal devices are those devices used to provide the final control element for the conditioned space.

Types of terminal devices are:

- Zoning dampers.
- Constant volume boxes.
- Variable volume boxes.
- Powered induction units or powered mixing boxes.

Functions of terminal units are:

Zoning dampers. Zone mixing dampers for multizone systems were described under cold-deck and hot-deck temperature control above. Sub-zoning dampers may be found where the end of a duct run is under control of a separate zone damper. An example is where a small eastern exposure zone is served on the end of a southern exposure zone and the zoning damper reduces the air flow to the eastern zone as the sun load reduces. The control of zoning dampers is basically direct from controller to damper actuator. Output from zone temperature controllers may be used as input to discriminator circuits for reset of cold-deck and hot-deck temperatures.

The term "hot-deck" may be misleading as the action of the cold-deck and hot-deck temperature controls is intended to fade-out the hot-deck as the outdoor temperature rises so that the "hot-deck" is really a "bypass" deck during cooling season.

Constant volume reheat terminal boxes. Constant volume reheat (CVR) terminal boxes are single-inlet boxes with either heated water or electric resistance reheat coil. Constant volume regulators are mechanical devices built into the box with manual setpoint adjustments to be made during system commissioning, as a part of the testing and balancing work. The only automatic control function is the temperature control of the reheat coil. The coil is controlled in the same manner as described above for cooling and heating coil control.

Constant volume, dual-duct boxes. Constant volume, dual-duct (CVDD) terminal boxes are served from cold-air and hot-air ducts which have temperature controlled as described above under cold-deck and hot-deck temperature control. Constant volume regulators are mechanical devices built into the box.

Temperature control functions vary between terminal box manufacturers. The simplest method is to control cold-air volume from space temperature with variable volume valve at box inlet and to control hot-air volume by action of the constant volume regulator. When the cold-air volume required to meet the cooling loads is less than the constant volume setting, the difference between the required cold-air volume and the constant volume setting will be made up by hot air. Similarly, when the required cold-air flow to meet the space cooling load is equal to the constant volume setting, no hot air will enter the box.

The constant volume regulator may be pressure-dependent or pressure-independent. Some boxes may utilize air flow sensors instead of pressure sensors, which make the box pressure-independent. A pressure-dependent regulator will allow delivered air volume to change in response to input pressure changes. A pressure-independent regulator will hold delivered air volume to the selected value over a large range of input pressures.

Variable volume boxes. Variable air volume (VAV) boxes or valves and variable volume reheat (VVR) boxes are single duct inlet type. VVR boxes are basically VAV boxes or valves with the addition of a reheat coil, either heated water or electric resistance. Some VAV boxes or valves are pressure-dependent and serve only cfm limiting functions. Others are pressure-independent and act as variable constant volume devices, with the setting of the constant volume regulator controlled from space temperature.

VAV boxes may have minimum air flow cfm settings at a level to prevent air flow decrease below an acceptable level of space air motion in the space or the air flow may be allowed to close off completely to prevent overcooling of the space. VVR boxes may have dual minimum air flow cfm settings to give about 40% to 60% minimum to provide adequate air flow over the reheat coil or to give 100% shut off during cooling cycle to minimize overcooling. Dual minimum settings are indexed by the central control system similar to summer-winter changeover.

Control of VAV boxes is from space temperature controller controlling the volume regulating device over the full throttling range of the controller. Control of VVR boxes is from space temperature controller controlling the volume regulating device down to minimum position in the upper half of throttling range, then positioning the reheat coil control in the lower half of the throttling range. For 100% shut off boxes, the control for the zero minimum allows the controller to position the volume regulator the same as for a VAV box during cooling cycle. The coil is controlled in the same manner as described above for cooling and heating coil control.

Controllable diffusers. Several types of controllable diffusers may be found which will provide variable volume performance. The most widely used type of controllable diffuser is a self-actuating type, with a beeswax-filled cylinder located in the induced airstream at the center of the diffuser. This cylinder responds to space temperature changes by expanding or contracting and actuating a linkage to move damper blades in the diffuser body, to vary the volume of air delivered. The controllable diffuser may have a bimetal strip changeover element located in supply air to shift the action of the damper blades for cooling when cold air is being supplied and for heating when heated air is being supplied.

Balancing

Balancing of terminal units for airflow is done as required by the specific type of terminal device installed. Zoning dampers and multi-outlet terminal units are tested by the "sum-of-the-outlets" method, where all the outlets served by a specific terminal device are measured for airflow and proportionally balanced; then the total airflow is balanced by positioning the zone balancing damper or by adjusting the air volume regulator setpoint.

Terminal devices serving a single outlet are balanced directly by testing the outlet flow, then positioning the zone balancing damper, or by adjusting the air volume regulator setpoint. The balancing of outlets should be done by adjusting the branch damper. The damper at the outlet should only be used for changing the air pattern, so that the increased noise generated in increasing the pressure loss for balancing will be attenuated before reaching the conditioned space.

Set-Up and Checkout Techniques

Set-up of terminal devices requires that all airflow data be obtained from building design drawings to provide a basis for cfm settings on air volume regulators.

Some trial-and-error testing may be required in establishing minimum cfm settings for heating, particularly when electric resistance heaters are used. Be careful to make sure that enough airflow is maintained at all times across electric resistance heaters to prevent nuisance tripouts and possible element burnouts caused by overheating with reduced airflow rates.

Checkout of the dual minimum changeover circuit is required to make sure that good minimum values are being selected for each terminal device.

CAPACITY MODULATION AND STATIC PRESSURE CONTROL

In a variable volume system, where the supply air volume delivered varies with the building load, it is necessary to provide means for fan capacity modulation and static pressure control in the duct system. Static pressure control prevents excessive noise generation and energy wastage as variable air volume systems reduce the volume of air delivered through the terminal units.

The principal methods used for fan capacity modulation and static pressure control in HVAC systems include:

- Riding the fan curve.
- Return air dumping.
- Discharge damper control.
- Variable inlet vane control.
- Fan speed control.

Of these methods, the first relies on inherent fan performance, the second controls air direction without reduction of volume, and the other three modify fan performance.

Riding the Fan Curve

Fans in HVAC systems are usually centrifugal blowers, and may have forward-curved, backward-curved, or airfoil-bladed wheels. Each wheel type has different pressure-volume-horsepower relationships but the performance of all types can be predicted using the "fan affinity laws" which relate the air volume handled, the static pressure developed, and the horsepower required to the fan speed.

Basically, the fan affinity laws state that *the air volume delivered by a centrifugal blower fan varies directly with changes in fan speed, while the pressure varies with the square of changes in fan speed, and the horsepower required varies with the cube of changes in fan speed.*

The forward-curved wheel has a characteristic curve which shows that horsepower increases and decreases in direct relation to the volume of air delivered when operated at a constant speed.

The backward-curved and airfoil-bladed wheels have a limiting value at a given speed beyond which no further pressure will be developed or horsepower will be required, but the power requirements do not reduce in proportion to volume reductions as closely as forward-curved bladed wheels.

The characteristics of the forward-curved bladed wheel allow fan modulation by "riding the fan curve." This means that no action is taken to modulate the fan speed. The fan is allowed to shift its operating point on its fan characteristic curve as the pressure and volume change. When the fan is operating at a constant speed, as a variable volume air damper acts to decrease the air volume delivered, the pressure developed by the fan will increase to a new operating point on the constant rpm curve and the power required will usually decrease.

"Riding the fan curve" with a forward curved wheel is the lowest first cost control method.

Although "riding the fan curve" will occur with other types of fans, the reduction in power required will not be as much as with a forward-curved bladed wheel. For this reason, other fan modulation systems are more economically attractive. When "riding the fan curve," the air volume delivered is varied by action of the terminal unit dampers alone with no control at the fan. Some terminal units do not have the ability to control air volume at high inlet pressures that result from "riding the fan curve." When supplying that type of terminal, some other static pressure control method must be used to prevent overpowering the terminal boxes and disturbing the temperature control functions of variable air volume systems.

Return Air Dumping

When system duct pressure is controlled by return air dumping, as the pressure sensed by the duct static pressure controller increases above the setpoint of the controller, a signal is generated to position an actuator to open a bypass damper installed between the supply and the return air duct and to allow airflow from the supply duct to the return air duct. This method is illustrated in Figure 2-15. This is the second lowest first cost control method.

Discharge Damper Control

When a centrifugal blower fan is operating at a given speed, each point on a given fan speed curve represents a different combination of air volume delivered and pressure developed, so that when the volume of air delivered is reduced, the pressure developed increases.

When the air volume delivered by a fan is to be reduced, the static

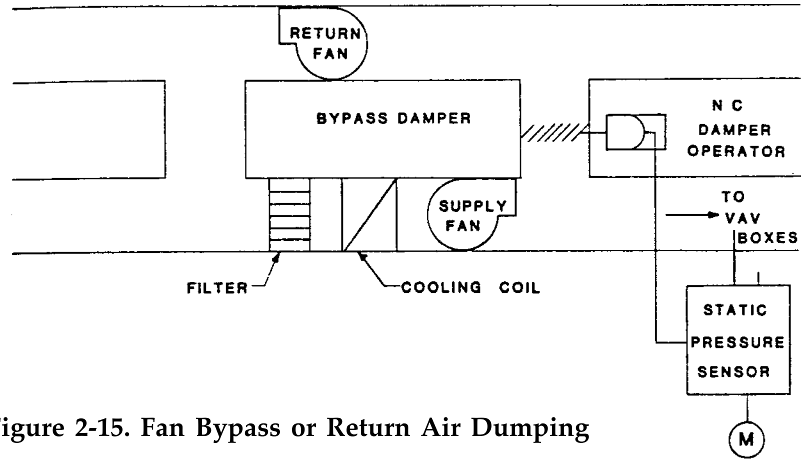

Figure 2-15. Fan Bypass or Return Air Dumping

pressure can be increased by dampering or "closing-down" the air supply from the fan discharge. An automatic static pressure control damper in that location is called a "discharge damper." A discharge damper is usually a standard opposed-blade volume control damper controlled from either a static pressure controller or a controller with a remote static pressure sensor.

As the static pressure at the duct static pressure monitoring point increases, the controller generates a signal to position the damper toward closed. As the damper is positioned toward closed, the pressure loss through the partially closed damper increases, the air volume delivered decreases, the static pressure at the fan discharge increases, and the duct static pressure decreases until an equilibrium point is reached.

The variable volume terminal box dampers are continually repositioning, which causes continual changes in duct static pressure and resulting continual repositioning of discharge dampers. Discharge dampers may be the least expensive choice of control methods for application in retrofit projects. Fan power requirements for discharge dampers are higher than for some other methods. With forward-curved bladed fan wheels, discharge dampers give about the same power consumption as variable inlet vanes.

Variable Inlet Vane Control

The characteristic curve for each centrifugal blower wheel varies with type of wheel and wheel diameter. The performance characteristics of any fan can be altered by changing the speed, as described below, or by changing the airflow direction at the inlet to the wheel.

When a radial-blade damper is placed at the inlet to the fan, with a control actuator connected to change the angle at which the radial blades cut the air entering the wheel, the blades are called "variable inlet vanes." The use of variable inlet vanes allows modulation for all types of centrifugal fans. The lowest power requirements are obtained with airfoil-bladed and backward curved fans.

As the static pressure controller senses an increase in duct static pressure, the controller generates a signal to position the variable inlet vanes to close partially, which causes the air entering the round fan wheel inlet to start a spiral movement. The spiral movement directs the incoming air in a direction against the direction of rotation of the fan wheel and causes the fan to perform on a different characteristic curve from the full-open damper position. That results in lower air volume delivered, lower static pressure developed, and lower power required. This regulation of fan volume and static pressure is achieved at the expense of an added system pressure loss for the dampers, which amounts to about 3% to 5% base load horsepower penalty. Although the first cost for variable inlet vanes when factory installed is lower than for a variable speed motor, inlet vanes are not suitable for retrofit applications.

Fan Speed Control

Fan speed control is the most effective method for controlling fan performance, but it is also the most expensive. Each centrifugal blower wheel has a characteristic curve for each discrete fan speed. The performance "curve" for a fan running at different speeds is plotted as a family of curves, with a curve for each increment of fan speeds.

A change in fan speed will result in a corresponding change in the air volume delivered, static pressure developed, and power required. Methods available for controlling fan speed include: *mechanical speed changing mechanism* which uses mechanical methods to vary the motor output shaft speed from a constant speed motor, and *electric current inverters* which modify the electric current characteristics to cause standard constant-speed motors to operate at variable speed. The latter method is more popular in HVAC systems.

Mechanical speed control. This system consists of a variable-speed belt drive plus a speed controller. A sheave with a spring-loaded variable pitch diameter mechanism is mounted on the fan motor drive shaft and is connected with a specific duty v-belt drive to a fixed pitch sheave on a countershaft which connects to the fan shaft with standard v-belts and sheaves.

Upon receiving a signal from the controller, the variable drive base moves closer to or further from the fixed drive base. This allows the faces of the variable pitch diameter sheave to move against their compensating springs; they move closer together to increase diameter of the variable pitch diameter sheave when the drive bases are close together, and force the sheave faces further apart and decrease the pitch diameter as the drives move further apart. As the pitch diameter of the motor sheave increases, the speed of the fan sheave increases: as the pitch diameter decreases, the fan sheave speed decreases.

Electric current inversion. This system uses an inverter, which is a solid-state device used to control motor speed. The incoming electric current is processed through an inverter to change the electrical current characteristics so that a standard constant-speed induction motor will operate at any speed down to about 25% of the nominal motor RPM.

Inverters use one of three basic technologies—variable voltage input (VVI), current source input (CSI), or pulse width modulation (PWM). Each inverter system uses three common components: 1) a rectifier to convert alternating current to direct current, 2) a regulator to receive the automatic control system speed input signal and establish the appropriate dc voltage, and 3) an inverter which processes the dc signal to generate a proportioned voltage-to-frequency waveform. Each of the three inverters uses different techniques to modify the electrical current for frequency and voltage.

Variable Voltage Input Inverter

This inverter, shown by schematic in Figure 2-16, has 3-phase line power as the primary input into the phase controlled rectifier which controls the phase angle. The rectifier receives a motor speed reference signal from the regulator, which causes the rectifier to vary its output by controlling the firing angle of the silicon controlled rectifier (SCR) or thyristor banks.

The pulsing dc is filtered and then inverted to an ac waveform by six power switching devices within the inverter. The frequency of the wave is generated on the basis of the speed referenced signal received from the regulator section. The resulting voltage and current waveforms are as shown in Figure 2-17. The resulting voltage and current waveforms are proportioned in volts and frequency to produce the required speed-to-torque relationship to suit the driven motor and load.

When it is desirable to produce minimum line noise and a power factor near unity, the phase controlled rectifier diagrammed in Figure 2-16 can be replaced with a diode rectifier/chopper module where voltage is controlled in a transistorized chopper section by converting the dc current to a truncated waveform of controlled amplitude or voltage, as diagrammed in Figure 2-18. The diode/chopper module may also be used on CSI and PWM type inverters.

Current Source Input Inverter

The current source input inverter (CSI), or adjustable current inverter, controls current, not voltage. The adjustable current waveform is shown in Figure 2-19. The current waveform is similar to the 6-step waveform shown in Figure 2-17 with the voltage waveform being generated by the back emf (electro-motive force) of the motor.

Pulse Width Modulation Inverter

The pulse width modulation (PWM) inverter uses an inverter section which simulates the ac sine wave by rapidly pulsing the dc voltage, positive and negative, as shown in Figure 2-20. The PWM inverter can use either transistors or fast turn-off SCRs for this service.

The proper voltage required to achieve the voltage-to-frequency ratio is controlled by the width of the pulse. Because the PWM inverter

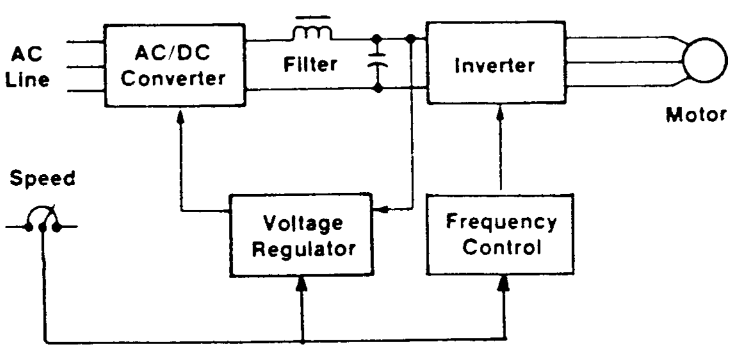

Figure 2.16. Mechanical Speed Control (*Courtesy Dynamatic*)

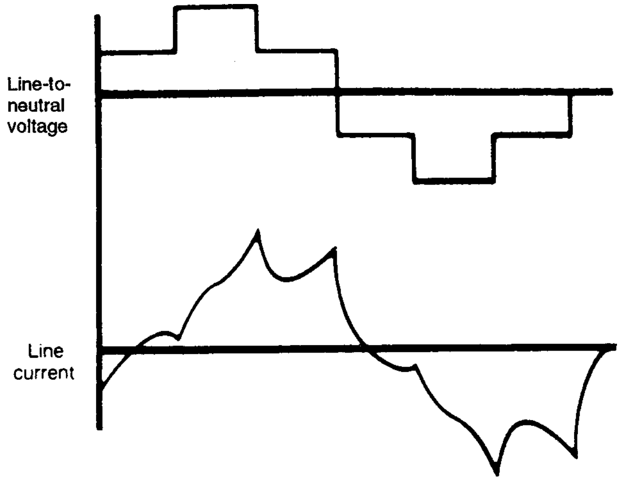

Figure 2-17. Block Diagram for a Typical VVI Drive (*Courtesy Dynamatic*)

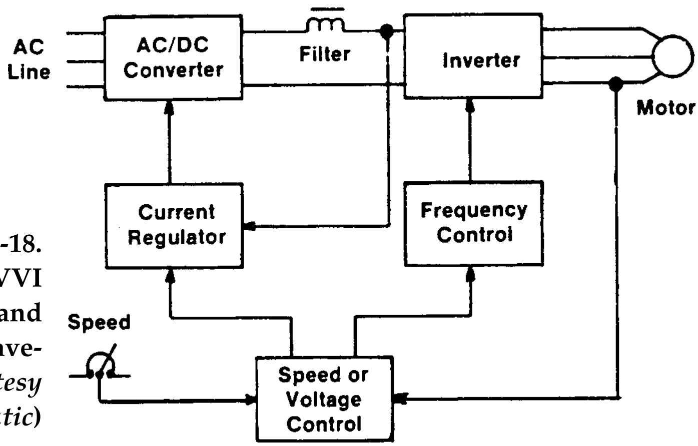

Figure 2-18. Typical VVI Voltage and Current Wave-forms (*Courtesy Dynamatic*)

must use microprocessor logic to control the switching sequence, the PWM inverter is considerably more complex than the 6-step inverters used in VVI and CSI systems. CSI or VSI is more efficient because pulses in the PWM sine wave are transformed into heat, which reduces both the efficiency and the service life of motors. Typical PWM voltage and current waveforms are shown in Figure 2-21.

Open Loop Fan Tracking

When a supply air fan is being controlled for volume and static pressure, it is necessary to control the interlocked return air fans in order to maintain building pressure balance. When the return air fan is con-

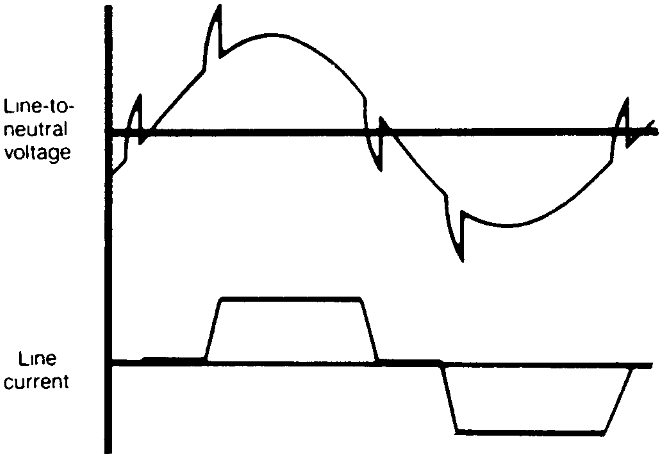

Figure 2-19. Diagram for a **Typical CSI Drive (*Courtesy Dynamatic*)**

trolled in the identical manner as the supply air fan, without any feedback from the building, the sequence is called open loop fan tracking. The open loop will often result in variations in building pressure due to effects on the return air fan of positioning of the volume control system.

Closed Loop Fan Tracking

When a supply air and return air fan system is controlled in a closed loop sequence, the return air fan control will be compensated for the building pressure balance or for a related system pressure. The supply fan capacity control device will be the primary controlled device, and will be controlled from a static pressure controller connected to a static pressure monitoring station sensing supply duct static pressure in a representative point in the ductwork.

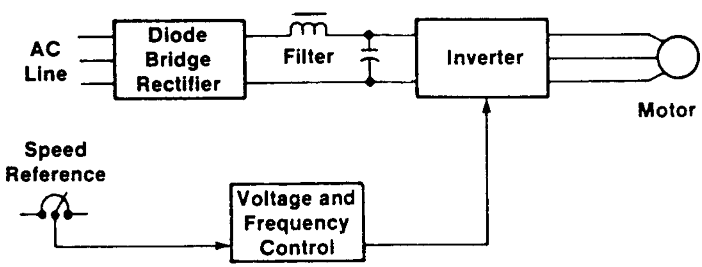

Figure 2-20. Typical CSI Voltage and Current Waveforms (*Courtesy Dynamatic*)

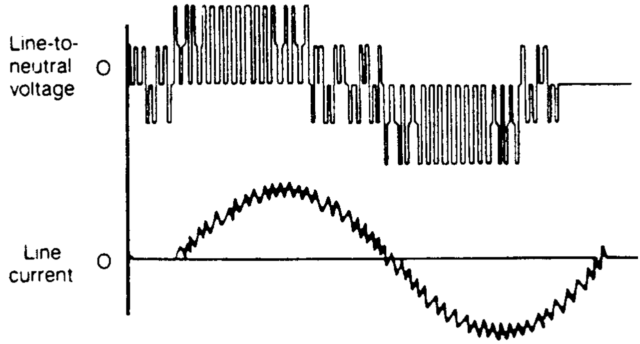

Figure 2-21. Block Diagram for a Typical PWM Drive (*Courtesy Dynamatic*)

The return air fan capacity control device will be the secondary controlled device and will be controlled by a parallel signal from the supply fan controller which will be compensated to maintain the desired building indoor to outdoor pressure difference or to maintain a specific pressure at the return air inlet to the mixed air section.

Many techniques are available in closed loop fan tracking, including the use of airflow measuring stations in each duct system to monitor actual volume flow and to process the airflow signals through adapters called "square root extractors" to obtain a signal which can be input into a conventional dual-inlet controller for static pressure control of the particular fan modulation method employed in the system. Hunting, or constant positioning, of dampers or other controlled devices is a frequently encountered problem. That problem can often be solved during the control system set-up by proper setting of the controller throttling range. Refer to Chapter 11, "Fine Tuning Program for Pneumatic Control Systems," for more information.

Testing and Balancing Techniques

The testing of fan performance is the first step in system balancing and becomes a very important procedure to the overall testing and balancing program. The testing of each fan must include air delivered, pressure produced, and power required. Those values must be compared to the fan characteristic curve to verify that the fan is operating on the curve. If it is not possible to find good resolution of the measured parameters with the parameters on the curve, it is necessary to determine why the discrepancy exists.

Causes of Discrepancies

The most common cause of discrepancies between performance and the fan curve is *system effect*. System effect has many causative factors but two frequently found causes are poor inlet conditions and poor outlet conditions.

Poor air inlet conditions make the air behave as if the air were flowing through partly closed variable inlet vanes. The inlet ductwork should have a straight section of at least 1.5 times the wheel diameter or the same clearance to an enclosing surface over the fan inlet.

Poor outlet conditions include elbows located too close to the fan outlet. The fan discharge duct should have a straight length equal to 2.5 times the wheel diameter before the first turn. Fans discharging into a plenum without an evase or expanding duct section of length at least 2.5 times the wheel diameter will cause fan operation off the curve with more than design rpm and fan power required to obtain only about 50% to 60% of design airflow.

Another common cause of discrepancies in fan performance is found to be a fan motor running backward. A centrifugal blower will deliver a significant portion of its design output even when running backward, but the pressure will be lower than the corresponding cfm-pressure point for normal operation.

Any causes of discrepancy must be corrected before a fan can be placed under automatic control for air delivery and static pressure.

Testing Procedures

Recognized authorities, including the Air Movement & Conditioning Association, Associated Air Balance Council, National Environmental Balancing Bureau, and Sheet Metal and Air-Conditioning Contractors National Association, each publish standardized testing procedures for fans and other components. Those procedures should be consulted to ensure the accuracy of the testing work.

The basic testing work determines the air volume delivered by each fan by measuring the air velocity across a point in the air handling system. The cross-sectional area is measured at that point. The air flow volume is calculated by multiplying the air velocity in feet-per-minute by the area in square feet.

In cases where it is not practicable to read the velocity close to the fan discharge, it will be necessary to measure the air volume after the duct splits into two or more branches. This is a "sum-of-the-branches" measurements of the total air volume delivered by the fan.

Measurement of fan static pressure must be done very carefully. Pressure measuring devices are very sensitive to the effects of air velocity and can vary significantly with changes in alignment of the measuring probe in the airstream. Several readings around the inlet and discharge of the fan are often required to obtain an accurate pressure measurement. The fan inlet pressure will be a negative value and the discharge pressure will be a positive pressure. Many authorities advise that total pressure measurements should be used in lieu of static pressure. Measurements of total pressure, i.e., static pressure plus velocity pressure, can be made with Pitot tubes.

The fan static pressure is determined by subtracting the negative inlet pressure from the positive discharge pressure. Subtraction of the negative pressure makes a positive value. The fan static pressure is the arithmetic sum of the two pressures.

Fan power requirements are difficult to obtain without use of a kW meter. Fan motor running amperes are often used as an indication of power required but the amperage readings must be interpreted on a motor performance chart which relates kW power drawn from the power lines to hp developed on the shaft.

Some motors will draw over 40% of full load amperes when running without any load, due to internal losses. The various testing and balancing manuals have detailed instructions for determining the approximate power output from amperage readings.

HUMIDIFIERS

Three types of humidifiers are discussed here:

- Steam grid.
- Steam pan.
- Water spray.

Steam grid. The steam grid humidifier, Figure 2-22a, supplies steam directly from a steam generator to the airstream through orifices along the length of a grid installed in a plenum or duct. A humidity controller with a sensor in the conditioned space or return airstream positions the inlet steam valve.

For duct-mounted humidifiers, a downstream high limit humidity controller is sometimes used to prevent condensation of moisture in the ductwork which can leak on ceilings. Some steam grid humidifiers are

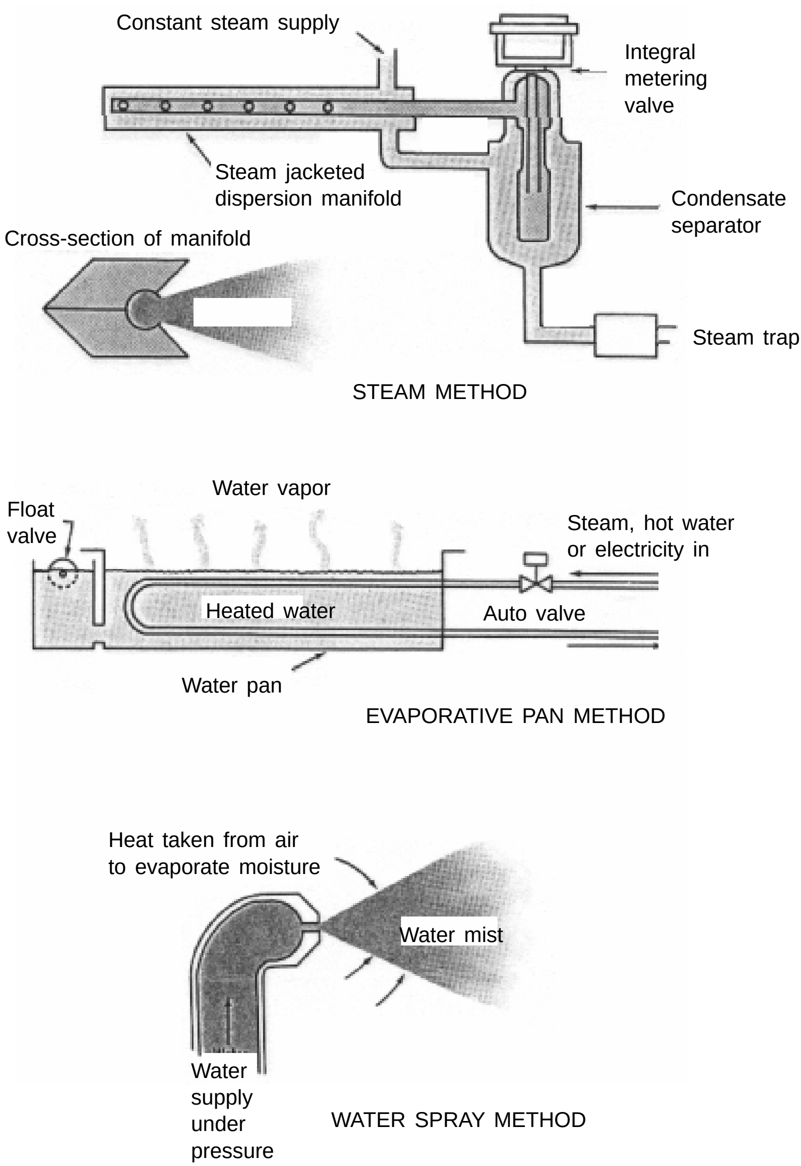

Figure 2-22. Humidification Methods (*Courtesy Armstrong International*)

steam-jacketed and trapped to provide dry steam to the grid.

The steam generator may be an electric heated grid in a disposable container or it may be the space heating boiler. When the steam is supplied direct from the boiler, problems may occur because of chemical treatment in the boiler which can cause offensive odors or indoor air contamination from treatment chemicals introduced into the conditioned space.

Steam pan. The steam pan humidifier, Figure 2-22b, consists of a water pan located in the airstream and heated by either steam coils or electric resistance heaters immersed in the water. Makeup water supply is from potable water lines. The potable water is heated until it flashes into steam and is absorbed by the airstream. A humidity controller in the conditioned space or return airstream positions the inlet steam valve or energizes the electric heater coils.

Because the water is potable, no problems are expected from odor and contamination as experienced with steam grid humidifiers, but the water pan must be provided with constant bleed piping to prevent concentration of solids. The pan must also be cleaned and sterilized regularly to prevent the growth of microorganisms which can cause health related problems.

Water spray. The water spray humidifier, in Figure 2-22c, has spray nozzles which spray and atomize cold water into a heated airstream. The heat for vaporization comes from the air itself, so the preferred location of water spray humidifiers is downstream of the heating coil.

An automatic valve in the water line is opened or closed by a humidity controller with its element in the conditioned space or return air. Some installations use heated water for the sprays but this method wastes energy because only a small percentage of the water sprayed is absorbed and the remainder of the water flows to drain.

Set-Up and Checkout

In checking out the humidifier control system, it is important to make sure that the system will fail "safe," that is, with the steam valves or water valves closed and the electric heaters de-energized.

Humidity controls must be checked and recalibrated in cold weather to assure that excessive condensation of windows does not occur.

AIR DISTRIBUTION

This part of the book covers all-air type systems where air distribution is the principal method for conveying cooling and heating between the air handling or air-conditioning unit and the conditioned space. Direct control of air distribution, other than as described under fan systems control and terminal devices control, is not covered here.

Set-Up and Checkout

In checking out the air distribution system, testing and balancing techniques are used. The required air flow rates in each branch duct and trunk ducts are obtained from the building design drawings and from other calculations. The air flow in each duct is measured by traversing the duct with a Pitot tube connected to an air flow meter or manometer and measuring the average air velocity in the duct.

The air flow volume in cfm is determined by multiplying the duct area in square feet by the average duct velocity in fpm. Air flow measurement at individual inlets or outlets may be performed with a rotating vane anemometer, a hot wire anemometer, or a velocity pressure measuring grid in a pyramidal test "cone."

HYDRONIC PUMPING SYSTEMS

Start-Stop Control

Methods for start-stop control for pumping systems are:

- Control interlock circuits.
- Temperature controls.
- Time-actuated controls.
- A combination of these methods.

Control interlock circuits. Pumps are interlocked to run when a particular equipment item is running, such as a condenser water pump interlock with a refrigerating system.

Temperature controls. Temperature controllers start and stop heating pumps or run pumps constantly when outdoor temperature is below 32°F to prevent freeze-ups in hydronic piping systems.

Time-actuated controls. Pumps are started and stopped from DDC or BAS time-of-day programs or from program timers.

Combination of methods. Pumps which are started and stopped from time-actuated controls or from control interlock circuits may be overcalled from temperature controls.

Multiple Pump Staging

Multiple pumps can be piped in parallel for individual operation to give 100% standby with each pump sized to deliver full capacity when operated singly. Dual pumps can each be sized for 50% flow to deliver 100% capacity with both pumps operating or about 65% flow when operated singly.

When only one pump of a parallel pair sized for 50% capacity is running on the full piping system, the resulting flow will not be 50% but will be closer to 65%. This is because of the lower friction losses that result from reduced flow. The pump will "ride the curve," in a manner similar to that described for centrifugal blowers. This gives reasonable standby capacity for the average pumping system.

When equal sized pumps for 100% standby are installed, an alternating device may be provided in the control circuit to alternate operation between pump A and pump B so as to equalize wear. A logic loop may be installed with flow switches connected to start the "off" pump if the "on" pump does not establish flow.

Pumps may also be piped in series with each pump selected for full flow rate at one-half of total head.

Pumping System Pressure Control

In a system where a constant water flow rate is required through the chiller and a variable flow is required through building loop, such as when using two-way throttling valves, a pressure bypass valve is installed from the supply water line to the return water line and a pressure controller is used to control the valve, as in Figure 2-23.

The pressure controller may be a differential pressure controller sensing pressure drop across either a flow measuring element or the water chiller tube bundle, or it may be a dual-input controller with two pressure sensors, one in the supply line and the other in the return line. Upon sensing a decrease in water flow or an increase in water pressure differential, the pressure controller generates a signal to position the

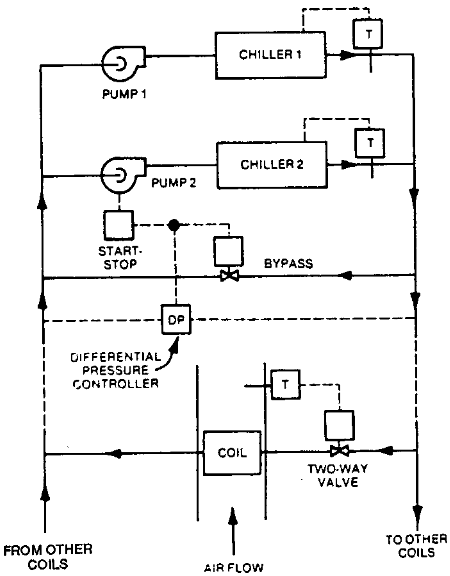

Figure 2-23. Pressure Control with Bypass Valve

bypass valve and allow water to bypass the building loop and flow directly to the return line at the flow rate required to maintain the loop flow rate or differential pressure.

BOILER AND CHILLER CONTROL

The boilers and chillers covered in this book are assumed to be packaged units, complete with operating and safety controls, and requiring only a control signal to energize the integral control system.

Boilers

Boilers may be energized by:

- Temperature controller sensing outside air temperature.
- Heating demand from contact closing on valve opening.
- BAS, DDC, or EMCS signal.
- Manual switching.

Integral boiler controls will include safety cutoffs of fuel source in case of overheat or overpressure in the boiler system. Boiler controls may include flow switch to prove fluid flow through the boiler before energizing the energy source. The operating temperature or pressure control will be set at a lower value than the safety cutoff controls.

Some heated water boilers can safely employ variable water flow allowing control of heated water supply by bypassing the boiler with a 3-way valve. Other heated water boilers and steam boilers must employ "convertors" which are steam-to-water or water-to-water heat exchangers. In this book, where reference is made to convertor control, the valve control of heated water temperature is included.

Chillers

Chillers may be energized by:

- Program timer.
- Control signal from mixed air or cooling coil section.
- Control signal from flow switch.
- Signal from BAS or DDC.
- Manual switching.

Integral chiller controls will include compressor safety cutouts in event of low or high refrigerant temperatures or loss of lubricating oil pressure.

Controls should include a chilled water flow switch or pressure differential switch to prove fluid flow through the evaporator before energizing the compressor. In that case, the chilled water pump is started from the control signal, then the chiller is energized after flow is proven. Interlocking circuits from the integral controls call for operation of fans and pumps on the heat rejection equipment, such as air cooled condensers, evaporative condensers, and cooling towers.

Heat rejection equipment will usually have controls to vary equipment capacity. Capacity control methods include: fan cycling; varying water flow rate over heat rejection surface, with either modulating or 2-position valve; and air bypass around heat rejection surface.

Cooling-Heating Changeover in Water Distribution Systems

Water distribution systems are classified by the number of pipes used, such as 2-pipe, 3-pipe, and 4-pipe.

Each system type requires different control procedures for changeover between cooling and heating and for temperature regulation.

Two-pipe systems are changeover type systems that require controls to prevent problems when changing between cooling and heating mediums. If changeover from heating to cooling occurs when heated water temperature is high, heated water flow through the chiller may raise the refrigerant temperature and pressure to the point where the relief valve opens and "blows" the refrigerant charge.

Three-pipe systems are blending type systems that require controls to maintain a maximum temperature rise on the chilled water loop and maximum temperature drop on the heated water loop to minimize energy losses from mixing return water flows from cooling and heating. Some of these systems are designed with coils selected for temperature rises as much as 20°F and temperature drops of 40° to 50°F.

Four-pipe systems are simultaneous flow systems that may use one coil or separate coils for cooling and heating. Changeovers between cooling and heating will involve no mixing in separate coil units or will involve mixing only the fluid in the coil itself when one coil is used for both cooling and heating. Flow in the heated water piping may be stopped during heating season and flow in the chilled water piping may be stopped in very cold weather, depending on the building and whether an air-side economizer is being used.

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Chapter 3

Operating and Maintaining HVAC Control Systems

The building staff is responsible for operating and maintaining the building systems, including HVAC systems and their associated automatic temperature control (ATC) systems. Although ATC systems operating and maintenance activities are closely related, they must be differentiated in order to facilitate building management, including budgeting and staffing of the maintenance group.

THE DIFFERENCE BETWEEN OPERATING AND MAINTAINING SYSTEMS

Operating Systems

Operating automatic temperature control systems for building HVAC systems includes performing the tasks required to set up the ATC systems to function as intended to produce the specific service intended, such as cooling or heating. Operations include calculating original ATC system setup parameters, observing HVAC systems for proper operation, rejustifying and changing ATC system setup parameters as required to cause proper operation of the HVAC systems, and checking ATC system for proper operation.

Maintaining Systems

Maintaining ATC systems and building systems includes the performance of those tasks which are required to keep the ATC and building systems' equipment and installations in proper condition to assure that an optimum service life is obtained from the equipment, that the systems will be available for use when needed, and that energy usage will be as planned by the building owners through techniques such as energy analyses and life cycle costing.

WHY OPERATION AND MAINTENANCE OF CONTROL SYSTEMS IS REQUIRED

Studies have indicated that more energy is wasted in building operations due to improperly functioning HVAC system controls than to any other single cause.

Automatic temperature control systems of all types are made up of components with highly complex mechanisms and circuits. Maintenance is required to maintain the control devices in a condition of accuracy which will allow the system to provide comfort and safety to occupants, with optimum energy usage in accordance with the design intent.

Operation of ATC systems is required to assure that the ATC system and the building HVAC system are initially commissioned, programmed, and adjusted to work together to provide the occupant comfort and provide control of process environments without causing energy wastage due to the control system design.

Continuing maintenance is required to maintain the control devices at a condition of accuracy which will provide system operation as designed and to make the system reliable in operation.

Maintenance of ATC systems serving building HVAC systems must be carefully planned and executed. Procedures for periodic maintenance and preventive maintenance must be scheduled and executed in accordance with the schedule. Adequate supervision is required to assure that the procedures are completed as planned and that modifications to the maintenance plan are made when necessary to recognize changing conditions as a system requires more or changed maintenance procedures.

CLASSIFICATIONS OF OPERATIONAL PROCEDURES

Operational procedures for ATC systems may be classified by the criteria for performing the procedures to include:

- Initial set-up of control components in the system.
- Operational checkout of control system.
- Functional checkout of control system.
- Periodic checkout of control devices.

Initial set-up of control components in the system is the process of programming the control components with the setup parameters as obtained from the control system documentation or as obtained in a rejustification of setup parameters after changes are made in the system or after complaints are received for comfort conditions or for excessive operating cost. The process of determining setup parameters is explained in Chapter 4, "The Mathematics of Control Systems: Controller Equations."

An operational checkout of a control system is the process of verifying that the ATC system is installed in accordance with the control diagrams and is performing in accordance with the sequences of operation in the control system documentation.

Functional checkout of a control system is the process of verifying that the ATC system is functioning in accordance with the sequences of operation in the control system documentation. The checkout process is discussed in detail in Chapter 10, "HVAC Control System Checkout Procedures."

Periodic checkout of actuator motors and controlled circuits of control devices is the process of checking calibration and recalibrating controllers when required. The calibration process is discussed in Chapter 12, "Trouble-shooting ATC Control Systems."

CLASSIFICATIONS OF MAINTENANCE PROCEDURES

Maintenance procedures for control systems are classified according system shutdown the criteria used for scheduling the maintenance work, including:

- Periodic or routine maintenance.
- Preventive maintenance.
- Breakdown maintenance.

Periodic or Routine Maintenance

Periodic or routine maintenance is that which is done on a maintenance program on a periodic basis, such as on operating hours, monthly, seasonally, or annually, and includes those operations which will be performed on the basis of calendar time, running hours, or cycles of operation, that is, the number of start-ups and shut-downs.

Preventive Maintenance

Preventive maintenance includes those operations which detect impending failure, restore deterioration, or prevent deterioration during shutdown periods. Preventive maintenance includes specific tasks done for a cause, such as painting a coil drain pan to stop corrosion, replacing packing on a valve stem to stop drips, or refastening gaskets on damper blades to stop air bypass.

Breakdown Maintenance

Breakdown maintenance includes those operations which will be performed to place the system back in operation after a system or component failure, such as a compressor failure. Breakdown maintenance is that which is performed only after a failure in control system operation has been detected. Breakdown maintenance may involve a single component which has failed due to a localized cause, such as vibration, or may involve an entire system, such as when the piping for an entire pneumatic control system becomes oil-logged due to oil carryover from a defective air compressor.

PLANNING MAINTENANCE

A good first step to take in planning a control system maintenance program is to make a physical inventory of automatic control devices in each system to be maintained. That inventory should provide data on manufacturer, model number, action, range, date manufactured and function in the system.

Other information will be available for some devices including documentation data for the setup of individual devices, such as throttling range, authority, reset ratio, and proportional band. From the inventory, a review of control device types and applications will provide information as to which devices will need routine maintenance.

The best initial source of data for the inventory is from the control system documentation, including the manufacturer's original control diagrams and sequences of operation. These may be available in the individual mechanical equipment rooms (MER). Those documents may not show the actual installed devices because of changes made during the construction phase, changes made during BAS addition, or changes made by maintenance personnel.

The inventory can start with the "bill of materials" on the control diagram, which will identify each control device and list the full model number. Some diagrams will include full documentation data, either in the "bill of materials" or on the drawing itself. After all available data have been obtained from the documents or if no documents exist, an actual on-site physical inspection is necessary to verify that the installed system is the same as the designed system and to determine what differences exist between the systems "as-designed" and "as-built."

This is a difficult job to do properly. It will often take two people working together using two-way radios for communication in order to relate the documented data to the actual installation and to compare the designed conditions with actual conditions.

PERIODIC OR ROUTINE MAINTENANCE

Control device calibration tests and recalibration are required after each control system related complaint and at the change of seasons. If calibration is found to drift over several months' time, it will be necessary to establish more frequent calibration intervals. At each calibration test recheck calibration and perform a repair/replace analysis. A *calibration test* is verification that the controller is operating properly and emitting the proper midpoint pressure, resistance, or voltage or is switching on or off when set at the desired calibration setpoint. Calibration tests may be performed on controllers of all types and on certain auxiliary devices, including sensors, bridges, and relays.

Recalibration

Recalibration is the work necessary to restore the device to calibration so that, when value of media sensed by the device is at setpoint, control output to system from a proportional device is at midpoint value, or the switching points occur at the setpoint and at the differential value. Recalibration must be performed in accordance with the component manufacturer's specific instructions using tools, fixtures, and instruments as detailed in the instructions.

Some devices cannot be field-calibrated but must be removed and returned to the factory or to the shop or replaced. Some components may be field-calibrated but require several variable inputs for recalibration, making a bench test necessary.

Functional Testing

System functions which are checked under periodic maintenance include: setting, accuracy, and function for safety controls; present setting, justification of setting, and operating function for operating controls. After making modification or repairs to the system or after changeover between cooling and heating seasons, functional testing is required for freedom of movement, actuator direction of travel, and actuator extent of travel for the controlled device.

Testing Safety Controls

Testing safety controls for setting and accuracy requires some ingenuity to simulate the setpoint, which must be hot for firestats or cold for freezestats. Accuracy is measured by use of a test thermometer measuring the same ambient medium as the safety control sequence, such as measuring temperature at a firestat element when simulating an emergency fan shutdown sequence with an electric heat gun blowing on the element.

Air Tank and Piping System Drainage

The normal periodic tank draining functions are handled by automatic tank drainers. When compressor running time increases, it may be due to system air leaks or to a waterlogged tank.

Periodic manual draining of the air tank from a manual drain valve and examination of the effluent material is recommended to determine whether any oil is condensing or separating in the tank. Addition of a number of oil sampling tube points on air mains and branches is recommended as part of the cleanup procedures following an oil contamination episode.

PREVENTIVE MAINTENANCE

Testing for contamination in pneumatic control systems is required when contamination of the system is due to observed changes in instrument operation and calibration stability, or when evidence of oil or water is found on instrument filters, at bleed ports, or in system dirt legs.

Testing for Oil and Water Contamination

In a pneumatic system, the first line of defense against oil and water contamination is a dual unit oil and water separator followed by a particulate filter, rated at 3 microns, which is generally installed between the high pressure storage tank and the dehydrator. Close inspection of the glass bowl of the separator will reveal the presence of oil or water. By blowing down the separator and collecting any contaminants in a clean cloth, the contaminants can be inspected with a magnifier for identification, or sent to a lab for exam.

After oil contamination is detected, it may be necessary to install oil test tubes at several points in the system. This is discussed in more detail in Chapter 8, "Maintaining Pneumatic Control Systems."

Testing for Particulate Contamination

In a pneumatic system a check for particulate contamination can be made when testing the oil and water separator for liquid contaminants. The particulate contaminants may include wear particles from bearings and seals, debris from piping installation, and dirt.

Testing for General Contamination

The filter elements installed in many makes of receiver-controllers are used to test for general contamination. When excessive pressure drop is suspected across a line filter, the filter should be replaced and the old filter cut open for inspection. Many filters have instruction sheets for the inspection of used filters and the interpretation of findings.

Interpretations of Test Findings

After the testing has been done, the test findings must be interpreted. Where contamination is abnormal, a program must be implemented to determine what steps must be taken to correct the contamination problem and place the system back in proper operation.

Elimination of Source of Oil

The usual measures which are employed to stop oil contamination include eliminating the source of the oil. Because oil generally originates in oil-lubricated compressors, replacement of oil-lubricated compressors with oil-free compressors is a positive measure to eliminate that source of contamination. Oil left in piping must be removed. Methods for cleaning piping systems are described in Chapter 8.

Elimination of Source of Water

Water generally originates as vapor in atmospheric air and is condensed out of air during the compression cycle.

One way to minimize the amount of water in the system is to limit the amount of water vapor introduced into the system. This can be done by piping conditioned supply air from a dehumidified air duct into the controls air compressor intake.

The volume of air pumped by the compressor is so small as to be no factor in the HVAC system load.

Testing for overall control system functions is required annually, and after each addition to the HVAC system building usage.

Testing Operating Controls

Testing operating controls for setting requires a point-by-point review of system documentation to determine the desired values and verification of each of those settings, which may include main setpoint, reset setpoint, throttling ranges, proportional band, and ratio or authority.

After the control setpoints and settings are verified, they must be justified, which may require simulation of inputs, such as with gradual switch or manual transmitter from main air for pneumatic devices or by use of decade box to input resistance values to simulate electronic sensors or by use of potentiometer to simulate controller inputs on slide wire type bridge circuits in electric controls. The process of justification is that of proving the control outputs to be appropriate to the control inputs.

After the controls have been justified, they must be tested for function. Function is tested by observing for appropriate action, whether the direct acting reset of a direct-acting controller is giving reverse reset of the controller, or whether the chilled water valve is opening on a rise in space temperature.

Testing Controlled Devices

Controlled devices to be tested may include dampers, valves, or relays, either electric or pneumatic.

Dampers and valves must be tested for freedom of motion. Damper motion may be restricted because of the friction caused by seals and blade linkages, particularly on low-leakage damper designs. Valve motion may be restricted when stem packing is over tightened in stopping leaks, or after a stem has become galled due to leakage of the controlled fluid causing the stem to seize in the packing. In pumping systems without pressure control, dynamic forces in the piping system can overcome the actuator power and prevent movement of the valve in response to the control signal.

Actuators must be tested and observed for *direction* of travel in order to justify proper control response.

Actuators must also be tested and observed for *extent* of actuator travel in order to verify that damper and valve linkages are properly adjusted to provide full positioning of controlled device when full actuator travel is applied.

Testing of minimum positioning relays and other multi-positioning devices is a necessary part of this work.

Servicing Air Filters

Air filters in a pneumatic system include air intake filters on compressor, particulate filters in the main air supply dual element unit, and "finger" filters at individual control components.

The required frequency of change should be based on exposure to contaminants and pressure drop. The possibility of media blowout due to excess pressure drop is very good reason for changing filters. The required frequency can range from a few months to several years and is determined by experience.

No part of a pneumatic system should be left unfiltered except under emergency conditions and then only for the shortest possible time.

Verifying Tight Connections

Electric, electronic, and pneumatic systems all require periodic attention to tightness of connections between control components and their interconnecting piping and wiring systems.

Electric and electronic control system connections may be checked for tightness by using a volt-ohm-ampere multimeter to measure the resistance across the joint. A measurable resistance across a joint is considered excessive and must be corrected.

Pneumatic control system connections may be given a rough check for tightness by listening for the hiss of an air leak. Suspected leaking joints may be checked using the soap bubble test. Where major air leaks are suspected in pneumatic controls system air mains due to loss of air pressure, a sectionalizing exercise must be performed. Using sectionalizing valves, which may be added, divide the system in half and apply a pressure test. Determine which half of the system the leak is located in, then divide that part of the system in half, and repeat the exercise until the leak is located.

Cleaning Sensors and Remote Bulbs

Many sensors depend on a flow of air over the temperature or humidity sensitive element in order to perform their sensing function. Buildups of dust or dirt on sensors and remote bulbs will result in delays in sensing and inaccurate measurements of sensed medias. Each type of sensor requires a different cleaning method to avoid damage or impairment of sensing function.

Humidity sensors may be cleaned with a soft brush, like a photographic lens brush, or by air jets such as those generated by a hand-held medical syringe. Do not use solvents in cleaning humidity sensors.

Temperature sensors of the wire wound type should be cleaned by the same methods as for humidity controllers, except that temperature sensors may be sprayed with a solvent, such as is used for cleaning TV tuners. Other temperature sensors may be cleaned with a cloth or brush and may be sprayed with a solvent.

COMMONLY FOUND CONDITIONS REQUIRING MAINTENANCE

Vibration-induced Control Component Damage

Vibration will cause excessive wear and premature failure of fragile control system components. Vibration-induced damage in control devices is difficult to detect. It may result in changes of accuracy, inability to maintain calibration, or failure to operate. It is desirable to mount control devices on a steady base which is not subjected to vibration from equipment operation.

Many control devices which are subject to excessive vibration are those in safety control circuits, such as fire safety thermostats and smoke detectors in air handling systems, and refrigerant high-low pressure cutouts on refrigerant compressors. These devices should be given a periodic functional test to assure proper operation and should be replaced on a routine "time-in-service" basis or on failure.

Some control devices may be found mounted on equipment which is subject to vibration, such as air handling units, fans, ductwork, piping, and compressors. Where possible, those control devices should be relocated to a point which is not subject to vibration. Remote bulb devices should be relocated to nonvibrating surfaces. Integral sensor devices should be relocated to points in the ductwork or piping past flexible connections.

Where relocation of control devices is not practicable, take action to minimize the effects of vibration, such as adding vibration absorbers and weighted bases to control instruments.

Loosening of Damper Linkage Fastenings

Damper linkages on multi-zone unit mixing dampers are subjected to vibration due to their location in turbulent air within the unit close to the fan. Connectors in damper linkages should be made to withstand vibration, using sharp-pointed set screws, lock washers, and locktite fasteners. Linkages should be given a periodic functional check to assure proper positioning of dampers.

Some damper actuators may be found to have been removed due to control system malfunction or equipment failure or simply to lack of knowledge of technician as to the purpose of the damper or the control sequence that controls it. It may be necessary to perform maintenance or repair work on the damper before the linkage can be reconnected.

Loosening of Control Wiring Connections

Electrical connections to control devices subjected to vibration may loosen, causing intermittent circuits, or they may break inside the jacket due to continued flexing, causing intermittent circuits or failure.

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Chapter 4

The Mathematics of Control Systems: Controller Equations

What are controller equations? Controller equations establish the mathematical relationship of output signals to input signals for various styles of controllers on electronic and pneumatic systems when set-up for direct action or reverse action, and using set-up parameters including throttling range, proportional band, and authority or ratio.

The purpose of controller equations is to provide a method for predicting the output values of automatic temperature control (ATC) system controllers for various input values as required in the control calibration procedure. The controller equations apply to both electronic and pneumatic control systems.

Electronic and pneumatic-type ATC systems are analog-type systems, where control voltage and control pressure are analogous to the sensed values of the media controlled by the system, temperature, humidity, or pressure. Twenty-six controller equations are presented in this chapter, each with a specific application.

Control Analogues

In electronic systems, the controller output voltage will have an operating range, such as 0 to 15 volts direct current (vdc) with a midpoint voltage of 7.5 vdc. Different system manufacturers use other ranges and midpoint voltages.

This chapter is based on a 0 to 15 vdc range with a 7.5 vdc midpoint. The principles may be applied to systems with other ranges and midpoint values.

In pneumatic control systems, the controller output pressure or branch pressure will have a range, such as between 3 to 13 psig, which gives a span of 10 psig and a midpoint pressure value of 8 psig. Systems by other manufacturers use other pressure ranges and midpoint values, such as output pressures which vary from 3 to 15 psig with a span of 12 psig and a midpoint pressure of 9 psig. For either range, the output pressure spans and midpoint values in a specific system cannot be changed.

The flexibility of analog systems comes from the use of specific analog values to represent the variable values for the controlled medium.

Electronic control systems are programmed by use of analog relationships between input and output voltages, including the throttling range and the ratio of secondary and primary throttling ranges.

Pneumatic control systems are programmed by use of analog relationships between the input and output pressures, including throttling range, proportional band, and authority.

Definitions of Control System Terms

Control system terms used in the study of controller equations are defined as follows:

Authority. The percentage relationship of the number of degrees change in secondary variable required to reset primary variable 1°F. Some manufacturers use the term authority ratio, which is a ratio of the same values.

Proportional band. The proportional band (PB) is a term similar to authority used with pneumatic systems where remote sensors or transmitters are used with multi-input controllers. PB is defined as the ratio of the controller throttling range to the sensor span, stated in percentage.

Ratio. The ratio of an electronic controller is the relationship of throttling ranges in a dual-input controller which determines the effect which a change in the secondary, or resetting variable, will have on the primary, or reset, variable.

Sensitivity, controller. The change in output of a controller per unit change in the controlled variable. A pneumatic controller with a 10 psig pressure range and a 4°F TR has a sensitivity of 2.5 psig per degree F.

Sensitivity, sensor. The change in pressure in a remote sensor or transmitter per unit change in the sensed medium. All sensors have the same pressure range for the assigned sensed medium span. A 12 psig pneumatic sensor or transmitter with an assigned sensed medium span of 100 units has a sensitivity of 0.12 psig per unit.

Sensor span. The value of the full assigned sensed medium span of the sensor which will result in a full change in sensor output pressure range. Typical sensor spans are 0°F to 50°F, 0°F to 100°F, 15% to 85% RH, and 0" to 2" water column.

Throttling range. The throttling range of a controller is the value of the specific change in the controlled variable which will cause the output signal of the controller to go from maximum to minimum or vice versa. Throttling range is a single value which is assigned in programming the controller and is stated as units of the controlled variable, such as °F, % RH, or inches water column (" wc). Typical values of throttling ranges might be 6°F, 10% RH, or 2" wc.

The Basic Electronic Controller Equation

In the basic electronic controller equation, the actual value of the controlled variable, as measured by the sensor, is related to the setpoint value for the controlled variable, which is the midpoint of the controller voltage range. That difference in value between measured and setpoint is multiplied by the controller sensitivity to give a voltage difference which is added or subtracted from the midpoint voltage to give the predicted output voltage value for the measured value.

The basic electronic controller equation is:

$$V_{out} = V_{sp} \pm \frac{\left(T_1 \pm SP_1\right)}{TR_1} \times VR \qquad (4\text{-}1)$$

Where:

V_{out} = Output voltage from the controller, volts dc.

V_{sp} = Voltage at setpoint or the voltage corresponding to setpoint temperature, 7.5 volts on 6 to 9 volts system.

SP_1 = Setpoint temperature, F.

T_1 = Measured temperature of the controlled medium, °F.

TR_1 = Throttling range, °F of the controller.

VR = Voltage Range of the controller as temperature changes through throttling range, 3 volts on 6 to 9 volts system.

± = Sign for voltage change due to action; additive (+) for direct action and subtractive (–) for reverse action.

The basic controller equation is also used when controlling other variables, such as relative humidity and static pressure.

Assigning Throttling Ranges

Throttling ranges are generally assigned rather than calculated in electronic control systems, as in pneumatic systems. The amount of change in the controlled variable which will take place during the control process must be considered in the assignment of a numerical value of throttling range to be set-up on a controller.

Output Voltage and Throttling Range

The output signal from an electronic controller is a direct current voltage. This output voltage varies with change in the controlled variable, typically in the range of 1 to 15 vdc. Because electronic actuators are generally built for a 3 degree range from closed to open, often from 6 to 9 vdc, electronic controllers are usually calibrated for 6 to 9 vdc at a 7.5 vdc midpoint voltage.

This principle is illustrated in the table below which tabulates the output signal in vdc for direct-acting and reverse-acting electronic controllers, each with setpoint of 75°F and throttling range of 6°F, with variations in sensed temperature as follows:

Sensed Temperature	Direct-acting Output Signal	Reverse-acting Output Signal
72°F	6.0 vdc	9.0 vdc
75°F	7.5 vdc	7.5 vdc
78°F	9.0 vdc	6.0 vdc

As shown above, with a direct-acting controller, when the sensed temperature increases by one-half the throttling range, such as from 72°F to 75°F, the output voltage of the controller will increase through one-half of its 3 vdc voltage range, such as from 6 vdc to 7.5 vdc. Therefore, as temperature changes through 6°F from bottom to top of the throttling range, the output voltage also changes from minimum to maximum. The same principle applies to the reverse-acting controller, with this difference: as temperature changes from bottom to top of the throttling range, the controller output voltage varies from maximum to minimum.

As an example, for a direct-acting controller, let the setpoint temperature = 75°F, setpoint voltage = 7.5 volts dc, throttling range = 6°F, voltage range = 3 volts, T = 76°F. Then, calculate the output voltage of the controller, using Equation 4-1:

$$V_{out} = 7.5\text{ vdc} + \frac{(76 \pm 75)°F}{6°F} \times 3\text{ vdc} = 8\text{ vdc.}$$

Output Voltage Beyond Throttling Range

If the measured value of the controlled variable increases or decreases beyond the limits of throttling range, the output voltage also increases or decreases within the limit of output voltage of the controller. That is, typically, dropping to 1 vdc or increasing to 15 vdc. As an example, consider the previous example and use the same equation to calculate the output voltage at 80°F for the direct-acting controller:

$$V_{out} = 7.5\text{ vdc} + \frac{(80 \pm 75)°F}{6°F} \times 3\text{ vdc} = 10\text{ vdc.}$$

Although the calculated output value is within the limits of output voltage of the controller, because the sensed medium value is outside the assigned throttling range limits, the control system has positioned the cooling or heating controlled devices to the limits of their operating ranges and the system is out of control. Unless the system is set up for other voltages, any output voltage less than 6 volts or greater than 9 volts will do no controlling because the actuator start-point potentiometer is factory calibrated at 6 vdc.

The span of 3 vdc is related to the design of the motor and cannot be changed after manufacture. Therefore, the actuator stem will always move between fully retracted and fully extended as the output voltage varies by 3 vdc. As was seen in the previous example, the output voltage of 9 vdc will occur at 78°F, which will fully extend the stem of a 3 vdc span actuator when set up with a starting point of 6 vdc.

Typical steps in setting and calibrating an electronic controller using Equation 4-1 are reviewed in these two problems:

PROBLEM 1

A single-input direct-acting electronic controller has setpoint temperature of 72°F, throttling range of 4°F, setpoint voltage of 7.5 volts, and voltage range of 3 volts. Find:

(a) What is the output voltage of the controller at a temperature of 73°F?

(b) If this controller is to control a normally closed damper, what is the position of the damper when output voltage of the controller is 6 vdc?

(c) What temperature corresponds to that voltage?

(d) What will be the output voltage of the controller if it is changed to reverse-acting output?

PROBLEM 2

An electronic controller is to control a normally closed steam valve for space humidity control. The setpoint voltage is 7.5 volts, voltage range is 3 volts, throttling range is 10% and setpoint relative humidity is 30%. Find:

(a) The output voltage of the controller at a relative humidity of 28%.

(b) The relative humidity in space when output voltage of the controller is 6 volts.

(c) Explain why a normally closed valve is used to control the space relative humidity.

Solutions to the above problems in setting and calibrating an electronic controller are:

PROBLEM 1

(a) $V_{out} = 7.5 \text{ vdc} + \frac{(73 \pm 72)°F}{4°F} \times 3 \text{ vdc} = 8.25 \text{ vdc}.$

(b) At 6 volts, the damper is fully closed.

(c) $V_{out} = 7.5 \text{ vdc} \pm \frac{(73 \pm 72)°F}{4°F} \times 3 \text{ vdc} = 6.75 \text{ vdc}.$

PROBLEM 2.

(a) $V_{out} = 7.5 \text{ vdc} + \frac{(28 \pm 30)°F}{10°F} \times 3 \text{ vdc} = 6.90 \text{ vdc}.$

(b) $\text{RH @ 6 vdc} = 7.5 \text{ vdc} + \frac{(T_1 \pm 72)°F}{10\%} \times 3 \text{ vdc} = 25\% \text{ RH}.$

(c) A normally closed valve is used so that in event of a control signal interruption, the valve will close to prevent uncontrolled steam input to the humidifier.

THE BASIC PNEUMATIC CONTROLLER EQUATION

In the basic controller equation, the actual value of the controlled variable measured by a sensor is related to the setpoint value for the controlled variable, which is the midpoint of the controller pressure range. That difference in value between measured value and the set-point or midpoint value is multiplied by the controller sensitivity rate to give a pressure difference. This difference is added to or subtracted from the midpoint pressure to give the predicted output pressure value for the measured value. The same equations are used for the calculation of set-up parameters for other variables, such as relative humidity and static pressure.

The basic pneumatic controller equation is:

$$P_{out} = P_{sp} \pm \frac{\left(T_1 \pm SP_1\right)°F}{TR_1} \times PR \qquad (4\text{-}2)$$

Where:

P_{out} = Output or branch pressure from the controller, psig.

P_{sp} = Pressure at setpoint or the pressure corresponding to setpoint temperature, 8 psig for 3 to 13 psig system or 9 psig for 3 to 15 psig system.

SP_1 = Setpoint temperature, °F.

T_1 = Measured temperature of the controlled medium, °F

TR_1 = Throttling range, °F, of the controller.

PR = Pressure Range of the controller as temperature changes through throttling range, 10 psig on 3 to 13 psig system or 12 psig on 3 to 15 psig system.

± = Sign for pressure change due to action; additive (+) for direct action and subtractive (–) for reverse action.

Assigning Throttling Ranges

Throttling ranges are generally assigned rather than calculated, because they are subject to adjustment during the control system set-up process to obtain a stable control system. The change in the controlled variable which will take place during the control process must be considered in the assignment of a numerical value of throttling range to be set up on a controller.

If a space controller is to position a cooling only VAV at 75°F plus or minus 2°F, the throttling range might be assigned as 4°F. With a 4°F throttling range, a change in space conditions of 2°F warmer will cause the VAV actuator to be at full output at 77°F and a change in space conditions of 2°F cooler will cause the actuator to be at zero output at 73°F.

That throttling range will probably give a fairly stable and comfortable system. If a space temperature controller is to position both cooling and heating control devices through their full ranges and the space temperature setpoints have been established as 75°F on cooling down to 70°F on heating, a desired throttling range can be worked out as follows.

Because there is a 5°F difference between cooling and heating setpoints, which should be the midpoints of the respective cooling and heating control actuators, it can be seen that a throttling range of 10°F, or twice the difference between cooling and heating space temperature setpoints, will cause the cooling actuator to be at full output at 77.5°F and the heating actuator to be at full output at 67.5°F. That may turn out to be too wide a throttling range for occupant comfort but will give a very stable system.

Throttling Range and Proportional Band

A pneumatic controller with integral sensor has a throttling range adjustment. A pneumatic controller with a remote sensor does not have a throttling range adjustment, but is set up by use of a proportional band adjustment. Throttling range and proportional band are closely related. The term "throttling range" is used with sensors having variable sensing ranges of sensed medium, while the term "proportional band" is used with sensors having fixed sensing ranges of sensed medium, which must be related to sensor pressure span.

The basic pneumatic controller equation used on controllers with integral sensors is modified for use on controllers with remote sensors to use PB as follows:

$$P_{out} = P_{sp} \pm \frac{(T_1 \pm SP_1)}{(PB \times Span)} \times PR \tag{4-3}$$

Where:

PB = Proportional Band, % of sensor span.

Span = Sensor span, expressed in °F, % RH, or " wc for output variation from 3 to 15 psig for 12 psig span system or from 3 to 13 psig for 10 psig span system.

Calculating Proportional Bands

The value of the PB is calculated for a specific sensor which is to be used on a controller with an assigned throttling range as follows:

$$PB = \frac{TR}{(Span)} \times 100 \tag{4-4}$$

Where:

TR = Throttling Range of Controller, expressed in °F, % RH, or psig.

Example of proportional band calculation. Consider a controller with an assigned throttling range of 4°F. Use Equation 4-4 to determine the PB in % when using a temperature sensor with a 100°F span.

$$PB = \frac{4°F}{100°F} \times 100 = 4\%$$

The proportional band setting for a controller varies for sensors with different spans but the throttling range stays the same. When a 50°F sensor is used with the controller, the proportional band setting is:

$$PB = \frac{4°F}{50°F} \times 100 = 8\%$$

If the sensor is changed to one having a span of 200°F, the proportional band setting becomes:

$$PB = \frac{4°F}{200°F} \times 100 = 2\%$$

Calculating Controller Sensitivity

The sensitivity of the controller in this set-up on a 3 to 13 psig system is determined as follows:

$$\text{Sensitivity} = \frac{\text{PR span}}{\text{TR}} = \frac{10 \text{ psig}}{4°F} = 2.5 \text{ psig}/°F$$

Output Pressure and Throttling Range

Take a controller with 3 to 13 psig or 10 psig output or branch pressure range, 78°F setpoint, 6°F throttling range, and a 3 to 13 psig range system. With the controller set at and sensing 78°F, the output pressure of a properly calibrated controller will be the midpoint value of 8 psig.

With a direct-acting (DA) controller, as the ambient temperature at the controller sensor drops through one-half the throttling range, or 78°F minus 3°F to 75°F, the controller output pressure will drop through one-half of its 10 psig pressure range to 3 psig. On warm-up, when the ambient temperature rises through one-half of the throttling range, or 3°F, to 81°F, the output pressure will rise through one-half of its pressure range to 13 psig.

Thus, as the temperature changes through 6°F from the bottom to the top of the throttling range, the output pressure of the controller will change through a 10 psig range from minimum to maximum. When a reverse-acting (RA) controller is used in the same example, the output pressure will be observed to be 13 psig at the lower end of the throttling range, and at the upper end of the throttling range the output pressure will be 3 psig.

For example, with the set-up described above, to determine the output pressure of a DA controller at 77°F, using Equation 4-2:

$$P_{out} = 8 \text{ psig} + \frac{(77 \pm 78)°\text{F}}{6°\text{F}} \times 10 \text{ psig} = 6.3 \text{ psig.}$$

Pressure Response Beyond Throttling Range

If the measured value of the controlled variable increases or decreases beyond the limits of the throttling range, then the output pressure will also change beyond the system pressure range PR to drop to zero or to increase to the main supply air pressure.

For example, to predict the output pressure of the controller when measuring 85°F with the previous set-up parameters, using Equation 4-2:

$$P_{out} = 8 \text{ psig} + \frac{(85 \pm 78)°\text{F}}{6°\text{F}} \times 10 \text{ psig} = 19.7 \text{ psig.}$$

Although the calculated output value is within the normal main air supply pressure range, if the controller air supply pressure is on a changeover system, with a daytime air supply of 13 or 18 psig, then the controller output cannot exceed the main air supply pressure. When the sensed medium value is outside the assigned throttling range limits, the control system has positioned the cooling or heating controlled devices to the limits of their operating ranges and the system is out of control.

Unless the control components are selected and the system is setup for higher pressures, any output pressure less than 3 psig or greater than 13 psig can do no controlling because the spring-compensated actuators move between fully retracted and fully extended as the branch pressure varies between 3 and 13 psig. From Equation 4-2, it can be predicted that, at 81°F, a 13 psig controller branch output pressure will occur, which will fully extend an actuator with a spring having an upper limit value of 13 psig.

Examples of Calculations

The following examples illustrate how to use the controller equations and how to calculate the other variables needed for calibration of a controller.

PROBLEM 1

Take a single-input direct-acting controller used to control space temperature and set-up for 72°F setpoint with an 8°F throttling range assigned.

Using the controller equations predict values for the following parameters:

(a) Controller PB setting when remote sensors with spans of 50°F, 150°F, and 200°F are used.

(b) Controller pressure range.

(c) Controller setpoint.

(d) Controller output pressure at T = 72°F using the same sensors as in (a).

(e) Controller output pressure at T = 76°F.

(f) Predict the output pressure of the controller at T = 80°F when the main air supply pressure to the controller is 18 psig.

(g) Predict the output pressure of a direct-acting controller at T = 71°F on a 3 to 15 psig system.

(h) Predict the output pressure of a reverse-acting controller at T =

75°F on a 3 to 15 psig system with the same throttling range and setpoint.

PROBLEM 2

Take a single-input reverse-acting control used to control space relative humidity and set-up for 30% RH setpoint with a 10% throttling range assigned. The system pressure range is from 3 to 13 psig. Predict the following:

(a) Controller PB setting of the controller with humidity sensor having 15% to 75% range.

(b) Controller output pressure, when space relative humidity is 35%.

(c) Space relative humidity when controller output pressure is measured to be 12 psig.

Solutions to Problems

PROBLEM 1

(a) Proportional Band for various sensor spans:

$$\text{For sensor with } 50°\text{F span}, \text{PB} = \frac{8°\text{F TR}}{50°\text{F}} = 16\%.$$

$$\text{For sensor with } 150°\text{F span}, \text{PB} = \frac{8°\text{F TR}}{150°\text{F}} = 5.3\%.$$

$$\text{For sensor with } 200°\text{F span}, \text{PB} = \frac{8°\text{F TR}}{200°\text{F}} = 4\%.$$

(b) Range is 13 psig minus 3 psig = 10 psig.

(c) The controller setpoint pressure is the midpoint pressure. Add 3 psig and 13 psig, or 16 psig, which, when divided by 2, equals 8 psig.

(d) The controller output pressure remains the same for all the different sensor spans.

$$P_{out} = 8 + \frac{(72°F \pm 72°F)}{8°F} \times 10 = 8 \text{ psig.}$$

(e) $$P_{out} = 8 + \frac{(76°F \pm 72°F)}{8°F} \times 10 = 13 \text{ psig.}$$

(f) $$P_{out} = 8 + \frac{(80°F \pm 72°F)}{8°F} \times 10 = 18 \text{ psig.}$$

(g) $$P_{out} = 9 \pm \frac{(71°F \pm 72°F)}{8°F} \times 12 = 7.5 \text{ psig.}$$

(h) $$P_{out} = 8 \pm \frac{(75°F \pm 72°F)}{8°F} \times 10 = 4.25\text{, say } 4.3 \text{ psig.}$$

PROBLEM 2

(a) $$PB = \frac{10\%}{(75\% \pm 15\%)} = 16.7\%$$

(b) $$P_{out} = 8 \pm \frac{(35°F \pm 30°F)}{10° \text{ TR}} \times 10 \text{ psig} = 13 \text{ psig.}$$

(c) Space relative humidity is the unknown in this problem. Solve the equation for % RH.

$$P_{out} = 8 \pm \frac{RH\% \pm 30\%}{10\% \text{ TR}} \times 10 \text{ psig} = 12 \text{ psig.}$$

Solving the above equation, we find that RH = 34%.

RESET CONCEPT IN CONTROL SYSTEMS

The reset concept is a method of matching HVAC system output with load. The output of HVAC cooling and heating components is proportional to the temperature difference between the cooling and heating medium and the controlled media. By establishing relationships between temperature differences and system output and between outdoor space temperature and required system output, a reset schedule can be constructed.

The reset schedule allows a controller setpoint to be reset within a specific range of values in response to changes in outdoor temperature or in building load. The controlled variable is called the *primary* or *reset variable.* The controlling variable is called the *secondary* or *resetting variable.*

The relative effect of the resetting variable on the reset variable, or secondary variable on the primary variable, is given several terms, including % authority and ratio. The numerical relationships of primary and secondary variables in accordance with the authority is called the reset schedule.

RESET CONTROL FOR ELECTRONIC SYSTEMS

Reset with an Electronic Controller

A dual-input electronic controller is used for resetting application. The primary variable sensor is called "A" and is connected to the input terminals marked "ISA," or a similar term, and the secondary variable sensor is called "B" and is connected to the input terminals marked "ISB," or a similar term.

The programming of electronic controllers is similar to programming pneumatic controllers except for the following:

1. The action of the controller for both primary and secondary variables is directly set on the electronic controller.

2. Electronic controllers have individual setpoint adjusting dials so that setpoints "A" and "B" can be set directly on the controller.

3. Electronic controllers have the throttling range of the primary variable set directly on the controller and a setting of the throttling range of the secondary variable is made by selecting and setting the ratio.

Ratio in electronic controllers is defined as the ratio of the secondary variable throttling range to the primary variable throttling range. Ratio in electronic systems is the reciprocal of authority in pneumatic systems when the spans of the pneumatic sensors are equal. The controller set-up includes a setting for ratio. The ratio setting may be as low as 0.5:1 to as high as 25:1. The procedure for calculating controller ratio settings is discussed in *Calculating Ratio*.

The output voltage of a dual-input electronic controller can be obtained by using the following equation:

$$V_{out} = V_{sp} \pm \frac{T_1 \pm SP_1}{TR_1} \times VR \pm \frac{T_2 \pm SP_2}{TR_2} \times VR \qquad (4\text{-}5)$$

Where:

T_1, T_2 = Temperatures of first and second variable respectively (°F).

SP_1, SP_2 = Setpoints for first and second variable respectively (°F).

TR_1, TR_2 = Throttling ranges for first and second variable respectively (°F).

Reset Action

The reset action which will occur depends on the actions of the two inputs which are used in the reset control for pneumatic systems.

Reset Schedules

A typical reset schedule for resetting supply air temperature on heating from outside air temperature would be:

Condition	Coil Air	Outside Air
A	75°F	65°F
B	95°F	10°F

Example of Reset Action

The determination of the type of reset action is illustrated in the following example for reset of hot water supply temperature from outside air temperature, by controlling a 3-way valve, bypassing return water to the circulating pump based, on the following reset schedule:

Condition	Hot Water Temperature	Outside Air Temperature	Output Voltage vdc	Bypass Port Position
A	90°F	60°F	9	open
B	210°F	0°F	6	closed

The primary or reset variable is hot water temperature supplied to the system and the secondary or resetting variable is outdoor air temperature. The reset schedule shows that a decrease in primary variable setpoint will be required upon an increase in secondary variable value, which is reverse reset. A study of the variation of voltage with outdoor temperature finds that output voltage increases as temperature increases, which is direct action. It is also seen that the valve bypass port is scheduled to go to closed position as hot water temperature increases to 210°F. Thus, for a valve that is normally open to bypass, the voltage must increase to close the valve.

Because an increase in hot water temperature is to cause an increase in the controller output voltage, direct action is required. The controller must be selected for direct-acting/direct-acting to give reverse reset.

Selecting the Throttling Ranges

The next parameters to be considered are the throttling ranges. A trial throttling range is assigned for the primary variable on the basis of experience factors. After the primary variable throttling range is assigned, the throttling range of the second variable is calculated according to the following equations:

1. For reverse reset; using DA/DA Controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\dfrac{\left(\text{VdcB} \pm \text{VdcA}\right)}{3\text{ vdc}} \pm \dfrac{\left(T_{1B} \pm T_{1A}\right)}{TR_1}} \tag{4-6}$$

2. For reverse reset; using RA/RA Controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\dfrac{\left(\text{VdcA} \pm \text{VdcB}\right)}{3\text{ vdc}} \pm \dfrac{\left(T_{1B} \pm T_{1A}\right)}{TR_1}} \tag{4-7}$$

3. For direct reset; using DA/RA Controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\dfrac{\left(\text{VdcA} \pm \text{VdcB}\right)}{3\text{ vdc}} \pm \dfrac{\left(T_{1A} \pm T_{1B}\right)}{TR_1}} \tag{4-8}$$

4. For direct reset; using RA/DA Controller:

$$TR_2 = \frac{(T_{2B} \pm T_{2A})}{\dfrac{(VdcB \pm VdcA)}{3\ vdc} \pm \dfrac{(T_{1A} \pm T_{1B})}{TR_1}} \qquad (4\text{-}9)$$

Where:

TR_1 = Throttling range of first variable, °F.
T_{1A} = Temperature of first variable at condition A, °F.
T_{1B} = Temperature of first variable at condition B, °F.
T_{2A} = Temperature of second variable at condition A, °F.
T_{2B} = Temperature of second variable at condition B, °F.
VdcA = Output voltage of the controller at condition A.
VdcB = Output voltage of the controller at condition B.

The voltage range of 3 vdc used in all the above equations indicates the voltage change between 6 to 9 volts. When using the equations for other voltage ranges, substitute the correct voltage range for 3 vdc.

Calculating Ratio

The throttling range for the second variable cannot be set up on the controller, so the ratio is set instead. Using the required throttling ranges for the primary and secondary variables, the ratio can be calculated as follows:

$$\text{Ratio} = \frac{TR_2}{TR_1} \qquad (4\text{-}10)$$

Entering the Set-Up Parameters

For dual-input electronic controllers, the setpoint for the first variable is selected and set directly on the controller. The setpoint of the second variable must be calculated by use of one of the following equations and set directly on the controller:

1. For reverse reset; using DA/DA Controller:

$$SP_2 = T_{2A} + TR_2 \left\{ \frac{(Vmp \pm VdcA)}{VR} + \frac{(T_{1A} \pm SP_1)}{TR_1} \right\} \qquad (4\text{-}11)$$

2. For reverse reset; using RA/RA Controller:

$$SP_2 = T_{2A} + TR_2 \left\{ \frac{(VdcA \pm Vmp)}{VR} + \frac{(T_{1A} \pm SP_1)}{TR_1} \right\} \tag{4-12}$$

3. For direct reset; using DA/RA Controller:

$$SP_2 = T_{2A} + TR_2 \left\{ \frac{(Vmp \pm VdcA)}{VR} + \frac{(T_{1A} \pm SP_1)}{TR_1} \right\} \tag{4-13}$$

4. For direct-acting reset; using RA/DA Controller:

$$SP_2 = T_{2A} + TR_2 \left\{ \frac{(Vmp \pm VdcA)}{VR} + \frac{(T_{1A} \pm SP_1)}{TR_1} \right\} \tag{4-14}$$

Where:

SP_1 = Setpoint temperature for primary variable, °F.
SP_2 = Setpoint temperature for secondary variable, °F.
Vmp = Midpoint voltage, 7.5 vdc for 6 to 9 vdc systems.
VR = Voltage range, 3 vdc for 6 to 9 vdc systems.

For controllers which are to be calibrated at any other midpoint voltage, substitute the correct midpoint voltage.

The final step is to enter the calculated setpoint parameters onto the controller dials.

EXAMPLES FOR SET-UP OF DUAL-INPUT ELECTRONIC CONTROLLERS

The following worked-out examples illustrate the steps in the setup and calibration of a dual-input electronic controller.

Example No. 1

Parameters for reset of hot water supply temperature from outside air temperature for the following reset schedule:

Hot Water	Outside Air	Output	Valve

Condition	Temperature	Temperature	Voltage	Position
A	90°F	60°F	9 vdc	open
B	210°F	0°F	6 vdc	closed

Step 1

Determine the type of reset. According to the rules discussed above, the DA/DA action gives reverse reset.

Step 2

Determine the secondary throttling range. Designate the hot water sensor as number 1 and the outdoor air sensor as number 2. Assign TR_1 = 6°F. Determine TR_2 using Equation 4-6:

$$TR_2 = \frac{(0° \pm 60°)F}{\frac{6 \pm 9 \text{ vdc}}{3 \text{ vdc}} \pm \frac{210°F \pm 90°F}{6°F}} = 3.1°F$$

Step 3

Determine the ratio from throttling ranges TR_1 and TR_2:

$$\text{Ratio} = \frac{3.1°F}{6°F} = 0.51.$$

This is satisfactory because a primary throttling range of 6°F and a ratio of 0.51 is compatible with a standard two-input controller.

Step 4

Select the setpoint for the first variable. For setpoints, two logical choices would be the minimum water temperature of 90°F or the maximum water temperature of 210°F. For the first trial, let SP_1 = 90°F.

$$SP_2 = 60 + 3.1 \left\{ \frac{(7.5 \pm 9) \text{ vdc}}{3 \text{ vdc}} + \frac{(90 \pm 90)°F}{6°F} \right\} = 58.5°F$$

Next, recalculate SP_2 when SP_1 = 210°F:

$$SP_2 = 60 + 3.1 \left\{ \frac{(7.5 \pm 9)\text{ vdc}}{3\text{ vdc}} + \frac{(90 \pm 210)°\text{F}}{6°\text{F}} \right\} = 38.5°\text{F}$$

Summary

The second trial gives a value for SP_2 which is not close to the actual controlling temperature, which makes it unrealistic. The first trial gives a more realistic value of SP_2. However, both values for SP_2 are compatible with a standard two-input controller.

Calibration instructions for reset controller:

Action = DA/DA
TR = 6°F
Ratio = 0.51
SP_1 = 90°F
SP_2 = 58.5°F

It is desirable to preserve the calibration instructions as calculated for each controller. An effective method is to use preprinted adhesive backed labels with blanks for the value of each parameter. The label may be filled out and mounted inside the controller cover.

Example No. 2

Reset of discharge temperature of an air heating coil from space temperature using the following reset schedule:

Condition	Air Outlet Temperature	Outside Air Temperature	Output Voltage	Valve Position
A	100°F	65°F	6 vdc	Open
B	70°F	70°F	9 vdc	Closed

Step 1

Determine the type of reset. Determine from reset schedule that, as room temperature increases, output voltage of the controller must increase, which is direct action. Note that, as air discharge temperature increases to 100°F, the valve must close, which requires increased output voltage from the controller. Note also that an increase in air discharge temperature requires an increase in output voltage, which is direct action. The controller must be setup DA/DA, to give reverse reset.

Step 2

Make a first trial calculation with the discharge air sensor as number 1 and with the room air sensor as number 2. Assign a throttling range of TR_1 = 8°F. Use Equation 4-6 to determine the required value of TR_2.

$$TR_2 = \frac{(70 \pm 65)°F}{\frac{(9 \pm 6\text{ vdc})}{3\text{ vdc}} \pm \frac{(70 \pm 100)°F}{8°F}} = 1.05°F$$

Step 3

Determine the ratio R:

$$R = \frac{1.05°F}{8°F} = 0.13$$

Because a standard two-input controller does not have available a ratio setting as low as 0.13:1, we must change the variable input values to keep the setup parameters within the controller ratio limits. One way is to reverse the designations of the primary and secondary variables and make a second try.

Repeat Step 2

Make a second trial calculation with the room air sensor as number 1, with the discharge air sensor as number 2, and with TR_1 = 3°F, as follows:

$$TR_2 = \frac{(70 \pm 100)°F}{\frac{(9 \pm 6\text{ vdc})}{3\text{ vdc}} \pm \frac{(70 \pm 65)°F}{8°F}} = 45.0°F$$

Repeat Step 3

Determine the ratio R:

$$R = \frac{45°F}{8°F} = 5.62$$

Step 4

Make first trial selections. Assign a first variable setpoint using the outside air temperature SP_1 = 65°F. Make a first trial selection for SP_2, using Equation 4-11.

$$SP_2 = 100°F + 45°F \times \frac{(7.5 \pm 6)\text{vdc}}{3\text{ vdc}} + \frac{(65 \pm 65)°F}{3°F} = 122.5°F$$

Make a second trial selection for SP_2, with SP_1 = 68°F.

$$SP_2 = 100°F + 45°F \times \frac{(7.5 \pm 6)\text{vdc}}{3\text{ vdc}} + \frac{(65 \pm 68)°F}{3°F} = 77.5°F$$

Make a third trial selection for SP_2, letting SP_1 = 70°F.

$$SP_2 = 100°F + 45°F \times \frac{(7.5 \pm 6)\text{vdc}}{3\text{ vdc}} + \frac{(65 \pm 70)°F}{3°F} = 47.5°F$$

From the above calculations, we find that the three pairs of setpoints from our trial calculations will produce the same control effect:

Trial	SP_1	SP_2
1	65°F	122.5°F
2	68°F	77.5°F
3	70°F	47.5°F

Although all the trial settings will provide the required performance, the first two pairs of setpoints are more practical on a common sense basis. Common sense would rule out the third pair as being illogical for setting up a heating controller with a 47.5°F supply air temperature to maintain a 70°F space temperature.

Step 5

Controller programming. In consideration of the previous comments, the controller would be set up using the second trial pair of setpoints, as follows:

Action	=	DA/DA
TR	=	3°F
Ratio	=	15
SP_1	=	68°F
SP_2	=	77.5°F

RESET CONTROL FOR PNEUMATIC CONTROLS

A dual-input pneumatic controller is used for reset control. The combined actions which determine the type of reset, or reset action, are similar to those discussed earlier under "The Basic Pneumatic Controller Equation."

The sensor for the primary variable is connected into the port marked "sensor," or a similar term, and the sensor for the secondary variable is connected into the port marked "reset." The controller set-up includes a setting for % authority, which is the percentage change in the secondary variable required to give a given change in the primary variable setpoint. The % authority setting may vary from as low as 10% to as high as 200% of primary sensor span.

As an example, a dual-input controller is to control temperature of air leaving a heating coil and is to be reset from space temperature. The discharge temperature is designated the primary or reset variable and the room temperature is designated the secondary or resetting variable.

According to the performance parameters given in the HVAC system design, a reset schedule is prepared. The reset schedule establishes the coil discharge air and space temperatures at each end of the scale and the required controller action, that is DA or RA.

The lowest primary variable temperature may be called Condition A and the highest primary variable temperature called Condition B. If the primary variable increases as the secondary variable increases, the action is DA. If the primary variable decreases as the secondary variable increases, the action is RA.

The output pressures of a two-input system are calculated using the basic pneumatic controller equations for dual-input controllers as follows:

$$P_{out} = P_{sp} \pm \frac{T_1 \pm SP_1}{TR_1} \times PR \pm \frac{T_2 \pm SP_2}{TR_2} \times PR \qquad (4\text{-}15)$$

$$P_{out} = P_{sp} \pm \frac{T_1 \pm SP_1}{PB_1 \times Span_1} \times PR \pm \frac{T_2 \pm SP_2}{PB_2 \times Span_2} \times \%A \times PR \qquad (4\text{-}16)$$

Calculating % Authority (%A). The % authority for a reset control system is calculated as:

$$\%\ Authority = \frac{PB_1}{PB_2} \times 100 \qquad (4\text{-}17)$$

From the definition of PB of a controller and sensor as being TR divided by Span, we can restate the above equation as follows:

$$\%\ Authority = \frac{TR_1/Span_1}{TR_2/Span_2} \times 100 \qquad (4\text{-}18)$$

When the spans of the two sensors are equal, the span values cancel and the % authority becomes the ratio of throttling ranges, as follows:

$$\%\ Authority_{equal\ spans} = \frac{TR_1}{TR_2} \times 100$$

The reset action which will occur depends on the actions of the two inputs which are used in the reset control. These combinations determine the reset action:

a. Direct-acting/direct-acting = reverse reset
b. Reverse-acting/reverse-acting = reverse reset
c. Direct-acting/reverse-acting = direct reset
d. Reverse-acting/direct-acting = direct reset

A typical reset schedule would be:

Condition	Coil Air	Outside Air	Sensor Span
A	75°F	65°F	50°F
B	95°F	10°F	100°F

An example of the method for determining the type of reset action is shown in the following reset schedule for control of heated water supply temperature leaving a convertor using open loop reset from outdoor air temperature:

Condition	Hot Water Temperature	Outdoor Air Temperature	Output Pressure
A	200°F	-10°T	3 psig
B	100°F	70°F	13 psig

The primary, or reset, variable is the water temperature leaving the convertor and the secondary, or resetting, variable is the outdoor air temperature. The reset schedule shows that a decrease in primary variable setpoint will be required upon an increase in secondary variable value, which is reverse reset.

To determine which combination is to be used to get reverse reset, the control action of the primary controlled device must be considered first. If a normally open hot water or steam valve with a 3 to 13 psig spring supplying heat to the convertor is to be controlled, the final control action will require an increase in output pressure to close the valve on increase in hot water supply temperature, which is direct action.

Examination of the table of action combinations on page 109 shows that the resetting control must be direct-acting to get reverse reset with a direct-acting controller for the heating valve.

A review of the change in the heating valve position (which follows a change in hot water temperature leaving the convertor) shows that the valve moves toward the closed position as the hot water supply temperature increases.

The air pressure signal required to close the valve is 13 psig. As the reset schedule shows, when the supply water temperature reaches 200°F, the controller output will be 13 psig and the valve will be fully closed. Thus we see that an increase in temperature causes an increase in controller output pressure, which is direct action. The controller must therefore be selected for direct-acting/direct-acting to give reverse reset.

Selecting the throttling ranges. The next parameters to be considered are the throttling ranges. A trial throttling range is assigned for the primary variable on the basis of experience factors. After the primary variable throttling range is assigned, the throttling range of the second variable is calculated according to the following equation:

1. For reverse reset; using DA/DA Controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\dfrac{\left(OPB \pm OPA\right)}{PR} \pm \dfrac{\left(T_{1B} \pm T_{1A}\right)}{TR_1}} \tag{4-19}$$

2. For reverse reset; using RA/RA Controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\dfrac{\left(OPA \pm OPB\right)}{PR} \pm \dfrac{\left(T_{1B} \pm T_{1A}\right)}{TR_1}} \tag{4-20}$$

3. For direct reset; using DA/RA Controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\dfrac{\left(OPA \pm OPB\right)}{PR} \pm \dfrac{\left(T_{1A} \pm T_{1B}\right)}{TR_1}} \tag{4-21}$$

4. For direct reset; using RA/DA Controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\dfrac{\left(OPB \pm OPA\right)}{PR} \pm \dfrac{\left(T_{1B} \pm T_{1A}\right)}{TR_1}} \tag{4-22}$$

Where:

TR_1 = Throttling range of first variable, °F.
T_{1A} = Temperature of first variable at condition A, °F.
T_{1B} = Temperature of first variable at condition B, °F.
T_{2A} = Temperature of second variable at condition A, °F.
T_{2B} = Temperature of second variable at condition B, °F.
OPA = Output pressure of the controller at condition A.
OPB = Output pressure of the controller at condition B.

The pressure range 10 psig, used in all the above equations, indicates the pressure change between 3 to 13 psig. When using the equations for other pressure ranges, substitute the correct pressure range for 10 psig.

Calculating % Authority

The throttling range for the second variable cannot be set up on the controller, so the % authority is set instead. Knowing the span of the sensors used and the throttling range of the primary and secondary variables, the % authority can be calculated. The next step is to calculate the percent authority.

Programming

The last step is to enter the set-up parameters. For dual-input pneumatic controllers, the setpoint for the first variable is selected and set directly on the controller. The setpoint of the second variable must be calculated by use of one of the following equations and the controller set-up for the two setpoints.

1. For reverse reset; using DA/DA Controller:

$$SP_2 = T_{2A} + TR_2 \frac{\left(P_{mp} \pm OPA\right)}{PR} + \frac{\left(T_{1A} \pm SP_1\right)}{TR_1} \tag{4-23}$$

2. For reverse reset; using RA/RA Controller:

$$SP_2 = T_{2A} + TR_2 \frac{\left(OPA \pm P_{mp}\right)}{PR} + \frac{\left(T_{1A} \pm SP_1\right)}{TR_1} \tag{4-24}$$

3. For direct reset; using DA/RA Controller:

$$SP_2 = T_{2A} + TR_2 \frac{\left(OPA \pm P_{mp}\right)}{PR} + \frac{\left(T_{1A} \pm SP_1\right)}{TR_1} \tag{4-25}$$

4. For direct reset; using RA/DA Controller:

$$SP_2 = T_{2A} + TR_2 \frac{\left(P_{mp} \pm OPA\right)}{PR} + \frac{\left(T_{1A} \pm SP_1\right)}{TR_1} \tag{4-26}$$

Where:

SP_1 = Setpoint of primary variable.
SP_2 = Setpoint of secondary variable.

P_{mp} = Pressure at midpoint, 8 psig for 3 to 13 psig system or 9 psig for 3 to 15 psig system.

Examples for Set-up of Dual-input Pneumatic Controllers

The following examples illustrate the steps in the setup and calibration of a dual-input pneumatic controller.

Assume a dual-input pneumatic controller with a 3 to 13 psig range. Determine all the factors required for setting and calibrating the controller for a sequence to reset the temperature of heated water leaving a convertor with reset from outdoor temperature in the following reset schedule:

Condition	Hot Water Temperature	Outdoor Air Temperature	Output Pressure
A	200°F	-10°F	3 psig
B	100°F	70°F	13 psig

Step 1

Determine the controller and reset action. Because the reset schedule requires the primary variable to be set downward as the secondary variable increases, the required reset action is reverse reset. If a normally open heating source valve is to be positioned, the output pressure must increase as the primary variable increases, which requires direct action on the primary controller. With one direct acting controller required, it is necessary to make the secondary controller direct acting also to give reverse reset. From the tables above we found that DA/DA = reverse reset.

Step 2

Determine throttling ranges: Make hot water temperature the primary variable with sensor 1. Assign a trial throttling range of 6°F to this input. With that throttling range and other parameters, use Equation 4-19 to calculate a throttling range for the secondary variable:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\dfrac{\left(OPB \pm OPA\right)}{10\text{ psig}} \pm \dfrac{\left(T_{1B} \pm T_{1A}\right)}{TR_1}} \qquad TR_2 = \frac{\left(70°F\right) \pm \left(\pm 10°F\right)}{\dfrac{\left(13 \pm 3\right)\text{ psig}}{10\text{ psig}} \pm \dfrac{\left(100 \pm 200\right)°F}{6°F}} = 4.5°F$$

Step 3

Select sensor ranges. Review of the HVAC system performance parameters shows that a hot water temperature sensor with a range of 200°F on a span of 40°F to 240°F and an outdoor air temperature sensor with a range of 100°F on a span of 25°F to 125°F will cover the temperature ranges to be expected. With those sensors, the proportional bands are:

$$PB_1 = \frac{6°F}{200°F} \times 100 = 3\%$$

$$PB_2 = \frac{4.5°F}{100°F} \times 100 = 4.5\%$$

$$\%\ \text{Authority} = \frac{3.0\%}{4.5\%} \times 100 = 67\%$$

Step 4

Select the secondary setpoint. Assume a primary setpoint of SP_1 = 100°F. Calculate the value of SP_2.

$$SP_2 = \pm 10 + 4.5\% \left(\frac{(8 \pm 3)}{10} + \frac{(200 \pm 100)°F}{6°F} \right) = 67°F$$

Step 5

Prepare calibration instructions for reset controller using values calculated above as follows:

1. Set the controller to DA/DA action.
2. Set PB to 3%.
3. Set % authority to 67%.
4. Set input to port 1 at 100°F or 6.6 psig (40° to 240°F).
5. Set input to port 2 at 67.6°F or 10.4 psig (–25° to 125°F).
6. Adjust the controller calibration point until the output is 8 psig.
7. Calibrate each sensor or compensate controller so that the inputs to the ports are correct for the measured temperatures.
8. Set the setpoint indicator to 100°F.

Chapter 5

Performance Prediction In ATC Systems

PERFORMANCE PREDICTION IN THE CALIBRATION PROCESS

Performance prediction is applicable to electric, electronic, and pneumatic type automatic temperature control (ATC) systems.

Performance prediction is the process of calculating what the output of the controller should be, based on the conditions being sensed and controlled. Performance prediction is one step in the overall calibration procedure. Calibration is the overall process of making the measured output agree with the predicted output. The four steps in the calibration process are:

1. Predict
2. Measure
3. Verify
4. Adjust

First, *predict* the output value at the current sensed media conditions by use of calculations as discussed in Chapter 4, "The Mathematics of Control Systems—Controller Equations."

Next, *measure* the actual output value and the current conditions of the sensed media.

Then, *verify* calibration of the controller by comparing the measured output value with the predicted output value.

Finally, if the measured output value does not agree with the predicted output value, *adjust* the controller calibration mechanism until the measured value does agree with the predicted value.

When the predicted value agrees with the measured value for the same sensed media conditions, the controller is said to be "in calibration."

EQUATIONS USED

For electronic control systems, the controller Equations 4-1 and 4-5 can be used to predict output voltage based on the condition measured, as long as they are within the throttling range of the controller. If the condition being sensed is outside the throttling range, the sensor must be disconnected and a simulated sensor input by means of a decade box.

For pneumatic control systems, the controller Equations 4-2, 4-3, 4-15 and 4-16 can be used to predict output pressure based on the condition measured, within the throttling range of the controller. The advantage of using the controller equations in calibration is that, because sensors usually do not have to be disconnected to perform the calibration procedure, the pressure losses in the sensor lines are calibrated out.

PREDICTING ELECTRONIC SENSOR RESISTANCE

When sensed conditions are outside the controller range, simulated conditions must be input to the controller. To do this, it is necessary to determine sensor resistance corresponding to the temperature desired.

To predict the resistance of a sensor at a given temperature, the following equation is used:

$$R_t = R_c \pm (X \times TD) \qquad (5\text{-}1)$$

Where:

R_t = Resistance (ohms) of the sensor at any temperature.

R_c = Resistance (ohms) of the sensor at reference temperature.

X = Resistance constant, resistance change per unit temperature change (ohms per °F).

TD = Temperature difference from reference temperature, °F.

Equation 5-1 shows how the specific resistance of the sensor at any temperature may be found by adding or subtracting the changes in resistance due to temperature difference (X × TD) to or from the basic sensor resistance (R_c) at its reference temperature.

For example, to calculate the resistance for a 1,000 ohm at 70°F sensor having a resistance constant x = 2.2 ohms/°F when sensing a temperature of 180°F, the equation is:

$$R_{180°} = 1{,}000 + 2.2\ (180 - 70°F)\ \text{ohms} = 1{,}242\ \text{ohms}.$$

A listing of resistance values at typical temperatures encountered in an HVAC system for a Balco sensor with a resistance of 1,000 ohms at 70°F and a constant X of 2.2 ohms/°F follows:

Temperature	Resistance
180°F	1,242 ohms
140°F	1,154 ohms
100°F	1,066 ohms
70°F	1,000 ohms
40°F	934 ohms
20°F	890 ohms
–10°F	824 ohms

A table of resistance values for sensors with other reference resistances and resistance constants can be obtained from the sensor manufacturers.

Input Simulation

The required sensor resistance as calculated above is input to the controller by use of a decade box. With a constant simulated sensor input, the technician can determine whether other components are functioning in accordance with the sequence of operation.

PREDICTING ELECTRONIC CONTROLLER OUTPUT VOLTAGE

Output Voltage Prediction

For each system made up of a sensor-controller-controlled device, the output voltage of the controller can be predicted under various conditions. When the condition being sensed is within the throttling range of the controller, it is not necessary to disconnect the sensor from the control system to perform calibration.

By predicting the output voltage for a measured parameter, such as temperature, humidity, or pressure, the performance of a particular controller may be examined. The procedure is to measure the output voltage, compare the output value with the predicted value, determine the difference between the predicted and observed values, and finally calibrate the controller to make the measured value agree with the predicted value.

For example, assume a system using an integral sensor controller, with a throttling range of 4°F and a setpoint of 72°F, and calculate the output voltages for both direct and reverse acting controllers using Equation 4-2.

Those output voltages are found to be:

Sensed Temperature	DA Voltage	RA Voltage
70°F	6.0 vdc min.	9.0 vdc max.
72°F	7.5 vdc	7.5 vdc
74°F	9.0 vdc max.	6.0 vdc min.

From these values it can be seen that the controller setpoint defines the center of the throttling range. A change in sensed condition of one-half of the throttling range will result in a change in output voltage (OPV) of one-half the voltage range (VR). A direct acting (DA) controller will increase OPV on increase in sensed condition. A reverse acting (RA) controller will decrease OPV on increase in sensed condition.

PREDICTING SINGLE-INPUT ELECTRONIC CONTROLLER OUTPUT VOLTAGE

Example 1

Assume an input of 72°F, a throttling range of 4°F, a setpoint voltage of 7.5 volts, and a voltage span of 3 volts, positioning a normally closed damper actuator.

(a) First, calculate the output voltage of the controller at a temperature of 73°F. It can be seen that the output voltage is the same as under

"Output Voltage Prediction" above.

(b) Next, calculate the actuator positions. When the sensed temperature is 70°F, one-half the throttling range below the setpoint, the output voltage will be 6 vdc, the bottom value of the VR, and the damper actuator will be in its normally closed position. At the setpoint temperature, the output voltage will be 7.5 vdc and the actuator will be in mid-stroke, 50% open. When the sensed temperature is 74°F, the temperature at the upper end of the throttling range, the actuator will be fully open.

Example 2

For another example, assume the control of steam supply to a humidifier using an electronic controller and a humidity sensor with a setpoint of 30% relative humidity, a throttling range of 10% RH, and a voltage span of 10 volts, positioning a normally closed valve actuator.

(a) First, find the output voltage of the controller at a relative humidity of 28%.

(b) Next, find the sensed relative humidity in the space when output voltage of the controller is 6 volts.

Calculations for Example 1:

(a) Using Equation 4-1:

$$V_{out} = V_{sp} \pm \frac{\left(T_1 \pm SP_1\right)}{TR_1} \times VR \tag{4-1}$$

$$V_{out} = 7.5\text{ vdc} \times \frac{\left(73 \pm 72\right)°F}{4°F} \times 3\text{ vdc} = 8.25\text{ vdc.}$$

(b) At 6 volts, the damper is fully closed.

$$6\text{ vdc} = 7.5\text{ vdc} + \frac{\left(T_1 \pm 72\right)°F}{4°F} \times 3\text{ vdc.}$$

Solving the equation results in T_1 = 70°F.

Calculations for Example 2:

(a) Using Equation 4-1:

$$V_{out} = 7.5 \text{ vdc} + \frac{(28 \pm 30)\%}{10\%} \times 3 \text{ vdc} = 6.90 \text{ vdc.}$$

(b) Again, using Equation 4-1.

$$6 \text{ vdc} = 7.5 \text{ vdc} + \frac{(\text{RH} \pm 30)\%}{10°\text{F}} \times 3 \text{ vdc.}$$

Solving the equation results in RH = 25%.

PREDICTING DUAL-INPUT ELECTRONIC CONTROLLER OUTPUT VOLTAGE

Assume a dual-input electronic controller used to control the temperature of hot water leaving a convertor. The controller setup parameters are:

Action = DA/DA
TR = 6°F
Ratio = 0.51
SP_1 = 90°F
SP_2 = 58.5°F

The controller voltage span is 3 volts dc and the setpoint is calibrated for 7.5 volts dc.

1. Predict the output signal from the controller with an outside temperature of 50°F and a hot water temperature leaving the convertor of 100°F.

Solution to Part 1:

In setting up a dual-input electronic controller, the throttling range for the primary variable is set directly on the controller and throttling range for the secondary variable is programmed by the ratio setting.

$$\text{Ratio} = \frac{TR_2}{TR_1} \text{ or transpose to } TR_2 = \text{Ratio} \times TR_1$$

$$TR_2 = 0.51 \times 6°F = 3.1°F$$

(a) Using Equation 4-5:

$$V_{out} = V_{sp} \pm \frac{T_1 \pm SP_1}{TR_1} \times VR \pm \frac{T_2 \pm SP_2}{TR_2} \times VR \tag{4-5}$$

$$V_{out} = 7.5 \text{ vdc} + \frac{(100 \pm 90)°F}{6°F} \times 3 \text{ vdc} + \frac{(50 \pm 58.5)°F}{3.1°F} \times 3 \text{ vdc}$$

$$V_{out} = 4.27 \text{ vdc.}$$

PREDICTING PNEUMATIC SENSOR OUTPUT PRESSURE

In order to predict the performance of a pneumatic receiver controller system it is necessary to start from the transmitter or sensor. When the sensor span is known, the corresponding pressure can be predicted at any point within the sensor span. When the sensor pressure for a particular condition is known, that pressure can be simulated as an input to the controller and the controller output pressure can be checked and adjustments made as necessary to meet the system operational requirements.

Sensor Span

The range of linear values that may be sensed by pneumatic sensors is called the sensor span. The span may be calibrated in units for measurement of temperature, humidity, or pressure. The sensor span is the range of values over which the pressure transmitted by the sensor will vary when the sensed parameters vary from minimum to maximum. Sensors are available in a variety of spans to allow selection of a span to give the best system operation. The specific spans may vary between manufacturers.

As an example, pneumatic temperature sensors are available from several manufacturers with spans including –40 to 160°F, 0 to 100°F, 40 to 240°F, and 0 to 200°F. The pressure range transmitted by the sensor for each of those spans is 3 to 15 psig. Similarly, the pressure range transmitted by a relative humidity sensor having a span of 15% to 75% will be 3 to 15 psig.

Sensor Sensitivity

The sensitivity of a sensor is defined as change in pressure transmitted by the sensor per unit of scale change. For a temperature sensor, the sensitivity is stated as the change in pressure per one degree change in temperature. The sensitivity S is a value calculated by dividing the output pressure range by the sensor span.

For example, a temperature sensor with a 40 to 240°F span and pressure range of 3 to 15 psig, the sensor sensitivity S is calculated to be:

$$S = (15 - 3) \text{ psig}/(240 - 40)°\text{F} = 0.06 \text{ psig}/°\text{F}.$$

Prediction of Transmitted Sensor Pressure

The pressure transmitted by a sensor at a specific temperature may be predicted by use of the following equation:

$$P_S = P_L + (T - T_L) \times S \tag{5-2}$$

Where:

P_S = Pressure transmitted at measured temperature T, psig.
T = Temperature measured, °F.
P_L = Pressure transmitted at lower end of the span, psig.
T_L = Temperature at the lower end of the span, °F.
S = Sensitivity of the sensor, psig/°F.

For example, using Equation 5-2, the pressure transmitted at a temperature of 190°F by a sensor with a sensitivity of 0.06 psig/°F is predicted to be:

$$P_S = 3 \text{ psig} + (190 - 40)°\text{F} \times 0.06 \text{ psig}/°\text{F} = 12 \text{ psig}.$$

It is important to note that the pressure equivalent to a specific temperature on a sensor of a given span will be different from the pressure equivalent to the same temperature on a sensor of a different span. Consider the case of two sensors measuring the same temperature, where sensor A has a span of 0 to 100°F, sensor B has a span of 40 to

140°F, and both sensors have a pressure range of 3 to 15 psig. At a temperature of 50°F, the pressure transmitted by sensor A will be 9 psig and the pressure transmitted by sensor B will be 4.2 psig.

PREDICTING PNEUMATIC CONTROLLER OUTPUT PRESSURE

Controller Equations

As with electronic controls, if the condition being sensed at the sensor location is within the throttling range of the controller, it is not necessary to disconnect the sensor from the control system to perform calibration. For a pneumatic controller, to find the controller output pressure with a sensor input for a specific temperature, use Equations 4-2 or 4-3 as follows:

$$P_{out} = P_{sp} \pm \frac{T_1 \pm SP_1}{TR_1} \times PR \tag{4-2}$$

or

$$P_{out} = P_{sp} \pm \frac{T_1 \pm SP_1}{PB \times Span} \times PR \tag{4-3}$$

As an example, assume a direct-acting, single-input controller with a 50 to 100°F temperature sensor, 6°F throttling range, 75°F setpoint, and branch pressure range of 3 to 13 psig or 10 psig. The midpoint output pressure for the 10 psig range system corresponding to the setpoint value is equal to the 3 psig lower value plus one-half of the 10 psig pressure range, or 3 psig plus (10/2) psig = 8 psig.

For systems with a 3 to 15 psig range, the midpoint pressure is 3 psig plus (12/2) psig = 9 psig. To determine the branch output pressure of this controller at a temperature of 77°F, use Equation 4-2 as follows:

For 10 psig pressure span,

$$P_{out} = 8\text{ psig} + \frac{(77 \pm 75)°F}{6°F} \times 10\text{ psig} = 11.33\text{ psig}$$

For 12 psig pressure span,

$$P_{out} = 9 \text{ psig} + \frac{(77 \pm 75)°F}{6°F} \times 12 \text{ psig} = 13 \text{ psig}$$

Verification of Predicted Controller Output Pressure

After predicting the controller branch output pressure at a sensed temperature, humidity, or pressure, it is necessary to measure and verify the controller output pressure for that specific condition. Using Equation 5-2, a table of controller output pressures for 6°F throttling range and 10 psig pressure range can be constructed for various temperatures as follows:

Temperature	Output Pressure
78°F	13.00 psig
77°F	11.33 psig
76°F	9.66 psig
75°F	8.00 psig
74°F	6.33 psig
73°F	4.66 psig
72°F	3.00 psig

Note that when the sensed condition value moves outside the throttling range, the output pressure also moves outside the operating range until the limits of the main air supply are reached. For example, if the measured temperature rises to 81°F, the branch pressure of a controller with 6°F throttling range will rise to 18.00 psig or until it is equal to the main air pressure if the main line pressure is less than 18 psig.

Similarly, if the temperature drops to 70°F, the branch pressure will drop to zero. Those changes in branch output pressure will not cause any change in the system output because the actuators will have run through their full travel over the 3 to 13 psig span of the controller.

PREDICTING DUAL-INPUT CONTROLLER OUTPUT PRESSURE

Use of Controller Equation

Equations 4-15 and 4-16 are used to predict the output of a dual-input controller:

$$P_{out} = P_{sp} \pm \frac{T_1 \pm SP_1}{TR_1} \times PR \pm \frac{T_2 \pm SP_2}{TR_2} \times PR \qquad (4\text{-}15)$$

or

$$P_{out} = P_{sp} \pm \frac{T_1 \pm SP_1}{PB_1 \times Span_1} \times PR \pm \frac{T_2 \pm SP_2}{PB_2 \times Span_2} \times \%A \times PR \qquad (4\text{-}16)$$

Examples of the use of these equations follow:

Problem 1

The temperature of hot water leaving a convertor is controlled based on outside temperature by means of a dual input pneumatic controller. The controller set-up parameters are:

Action	=	DA/DA
PB_1	=	3%
% Auth	=	67%
SP_1	=	90°F
SP_2	=	58.5°F

The setpoint pressure of the controller is 8 psig and the pressure span is 10 psig. The hot water and outside air sensor have temperature ranges of 200° and 100°F respectively. Find the following:

(a) Throttling range for the first variable.

(b) The output pressure of the controller when the outside air and hot water temperature are measured to be 52° and 100°F respectively.

Solutions

(a) Using Equation (4-4):

$$\%PB = \frac{TR}{Span} \times 100, \text{ or transpose to } TR = \frac{\%PB \times Span}{100} \qquad (4\text{-}4)$$

For the first variable, hot water temperature:

$$TR_1 = \frac{3 \times 200}{200} = 6°F.$$

For the second variable, the outside air temperature, using Equation 4-2:

$$\% \text{ Authority} = \frac{PB_1}{PB_2} \qquad (4\text{-}2)$$

Therefore:

$$\% \text{ Authority} = \frac{3\%}{PB_2} = 67\%$$

$$PB_2 = 4.5\%$$

$$\text{Using Equation 4-4, TR} = \frac{4.5\% \times 100°\text{F}}{100} = 4.5°\text{F}$$

b. Using Equation 4-15:

$$P_{out} = P_{sp} \pm \frac{T_1 \pm SP_1}{TR_1} \times PR \pm \frac{T_2 \pm SP_2}{TR_2} \times PR \times \% \text{ Auth.}$$

$$P_{out} = 8 \text{ psi} \pm \frac{(100 \pm 90)°\text{F}}{6°\text{F}} \times 10 \text{ psi} + \frac{(52 \pm 58.5)°\text{F}}{4.5°\text{F}} \times 10 \times 1.5\%$$

$$P_{out} = 3 \text{ psig.}$$

INACCURACIES IN ELECTRONIC SYSTEM MEASURING INSTRUMENTS

When calibrating or setting up an electronic control system, the technician must recognize the inaccuracies which exist in even the most accurate components and measuring equipment. These inaccuracies may result in actual performance being slightly different than the precise values predicted by equations.

Volt-Ohm-Milliampere (VOM) Meter

The typical accuracy for a digital VOM with a range of zero to 20.00 volts with 0.1 volt divisions, is plus or minus 0.2%. For 200 digits, the range of inaccurate readings is ± 0.2% × 200 digits = ± 0.4 digits or

0.04 volts. Thus it is seen that, when the meter is showing a voltage of 20.00 volts, the actual voltage may be as low as 19.96 volts or as high as 20.04 volts. The range of inaccuracy is 0.08 volts (20.04 - 19.96).

On a controller with 6 to 9 volts output voltage and 6°F throttling range, the sensitivity is 2°F/volt. An inaccuracy of 0.08 volts times a sensitivity of 2°F/volt gives an inaccuracy of 0.016°F. This is less than the smallest scale division on the typical electronic thermometer and is therefore negligible for temperature control calibration purposes.

Decade Box

The selectable resistance device, or decade box, shown in Figure 5-1, is often used to substitute resistance values for the analysis and simulation of conditions for set-up and calibration of electronic control systems.

A typical decade box has an accuracy to within 1%. When used with a typical VOM having an accuracy to within 0.2%, the combined accuracy of the two devices used together is calculated as:

$$\text{Combined accuracy} = [(1 - 0.01)][(1 - 0.002)] = 0.988 \text{ or } 98.8\%.$$

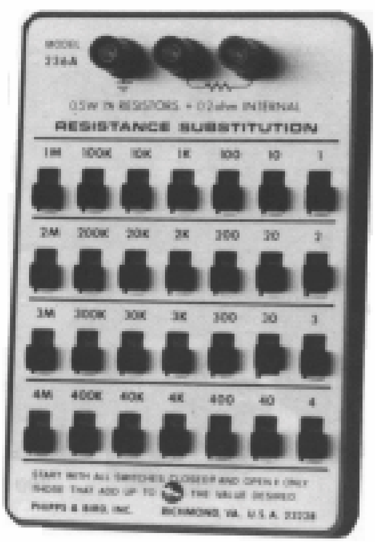

Figure 5-1. Decade Box (*Courtesy Davis Instruments*)

Sensor Inaccuracies

A typical Balco resistance sensor has an accuracy within 0.1%. Therefore, when a VOM having accuracy to within 0.2% is used to measure the voltage output of the controller which is used along with the sensor, the combined accuracy may be calculated as follows:

$$\text{Combined accuracy} = [(1 - 0.001)][(1 - 0.002)] = 0.997 = 99.7\%.$$

Other Inaccuracies

Further accuracy reduction may be caused by factors such as parallax error due to the alignment of the eye to the instrument scale when reading scale values on analog gauges and meters, resolution error due to the relationship of pointer width to scale divisions and scale length, and the accuracy of other control components in the circuit. Inaccuracies may be self-canceling, where one inaccuracy may compensate for another (for example, one reading is low by the same percent as the other one is high), but the accuracy of the measurement cannot be relied upon any more than the combined accuracy of the instruments used.

INACCURACIES IN PNEUMATIC SYSTEM MEASURING INSTRUMENTS

When a pneumatic control system is to be calibrated, the technician must be familiar with the accuracy of various pieces of testing equipment so that he can take into account the inaccuracies and modify his expectation from a particular system. If the instrument inaccuracy factors are not taken into consideration and performance expectation for a system is based solely on the values predicted by equations, it is impossible to calibrate a system which corresponds exactly to the theoretical predictions.

Inaccuracies in Pressure Gauges

Consider a typical pressure gauge with a dial diameter of 2.5 inches. The perimeter of this gauge is, therefore, pi times the diameter or 2.5″ × 3.14 = 7.85 inches. The dial extends only through about three-fourths of this perimeter or 5.89 inches.

For a 0 to 30 psi range gauge, calibrated in 1 psi divisions, the length of each division is about 0.196 inches. Considering a typical gauge with a pointer having a width at the tip of 1/16″ or 0.0625″, the pointer width corresponds to 0.32 psi. Thus, the inaccuracy obtained in misreading a gauge by a pointer width is about 1%. A basic gauge accuracy of plus or minus 2%, plus a pointer width accuracy of 1% could give a cumulative error of 3%.

Inaccuracies in Temperature-Calibrated Pressure Gauges

When simulating an input for a specific temperature on the controller using a temperature-calibrated pressure gauge, if the gauge has a basic 2% error and an additional 3% scale-type error is made in reading the controller input pressure, the combined accuracy of the reading may be calculated as:

$$\text{Accuracy} = (1 - 0.02\%)(1 - 0.03\%) \times 100 = 0.95\%.$$

Other Inaccuracies in the System

Other factors such as parallax, thickness of the indicator, and inaccuracy of other control components in the circuit may further reduce the accuracy of readings.

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Chapter 6

HVAC Control System Set-Up

This chapter explains how to perform the initial set-up of automatic temperature control (ATC) systems to design intent which gives the minimum acceptable level of performance. The "fine tuning" of the ATC systems follows a period of living with the building. The fine tuning program outlined in Chapter 11 shows operators of new and existing buildings how to improve control results for lower operating and maintenance costs.

HVAC CONTROL SYSTEM FAMILIARIZATION

The first step in planning the initial setup of an ATC system is to become familiar with the HVAC system by reviewing the original building drawings and the ATC system documentation.

The installing ATC system contractor may have provided operator sessions training and final documentation under the construction contract, in which case the documentation should be available in the office of the building engineer or manager.

If training in ATC system operation and maintenance was not included under the building construction contract, it may be helpful to negotiate a contract with the ATC system manufacturer for the necessary training.

It is essential that the control system technician be familiar with the control schematic diagrams, equipment schedules, performance information, and operating and maintenance literature. If the needed information cannot be found in the building manager's files, other possible sources are the installing contractor for the ATC system, the mechanical contractor for the HVAC system, and the various mechanical equipment suppliers.

Walk-Through Inspection

After a thorough review of the available documentation, a walk-through inspection must be made of the HVAC systems including a detailed inspection of each control system component. A good method is to place an inspection label or sticker with a check-off list against the control schematic or system schedules to make sure that every component has been inspected and is installed and working according to specifications. On new buildings, any deficiencies noted should be handled by the ATC system installation contractor under warranty.

COLLECTING AND MAINTAINING ATC SYSTEM DOCUMENTATION

A basic policy should be implemented to obtain and maintain control system documentation for all systems. The ATC system technician should have copies of documentation to take with him during his routine maintenance visits. The technician should be made responsible for updating the documentation and returning it to file after each use.

Documentation should include, as a minimum:

1. Documentation of design, corrected to "as built," including standardized symbols, diagrams, and sequences of operation with adequate documentation data on control diagrams to allow operation of the system in accordance with the design intent.

2. A fully labeled control piping-wiring schematic which shows point-to-point piping and wiring and includes all performance parameters such as setpoints, throttling ranges, actions, spans, proportional bands, and other control component adjustment or setting data. The system schematic piping-wiring diagram must be drawn to a large enough scale to allow ample space to document on the drawing all set up values. A large scale drawing is more easily read and understood by the ATC system technician who will be using these drawings as part of his maintenance documentation.

3. A fully labeled elementary electrical ladder diagram.

4. A sequence of operation. A sequence of operation is a verbal statement of how the control system functions. It must be complete, cross-referenced to the control schematic diagram and to the elementary diagram, with control component designations.

5. A functional description of each control component shown on the drawings. Manufacturers' part numbers alone do not meet this requirement. In the equipment list for each system, describe the generic performance of each component and write out the specific manufacturer's model number in full. Although a system probably was installed with all control components produced by a single manufacturer, in the field a mixture of manufacturers' devices will be found due to replacement of components during maintenance where a direct replacement for the original device was not available.

6. Notation of pneumatic test ports and electronic-system terminal strips cross-referenced between the control and the control schematic to facilitate troubleshooting and calibration.

7. Location of BAS interface equipment and interaction on BAS control capabilities.

8. Maintenance action sheets.

Steps in Collecting Documentation

- Collect existing documentation from sources listed in the section above, "HVAC Control System Familiarization."

- Determine what additional documentation is needed. Carefully examine the existing documentation to determine what needed documentation may be missing or what documentation is out of date due to ATC or HVAC system changes, and list the additional items needed.

- Develop additional documentation from the list. This may include revisions to control schematics, such as indicating the addition of DDC and BAS interfaces, making changes to the written sequence of operation, obtaining copies of equipment specification sheets for items which have been replaced by later models or other manufacturers, obtaining copies of installation and maintenance data sheets for each control system component, and adding documentation for modifications or extensions to the original ATC system which were not properly documented during the construction process.

- Calculate system set-up information. Refer to System Set-Up Equations below for information on how to develop set-up data, including reset schedules, primary setpoints, and secondary setpoints. Even when these data are already listed in the available documentation, the data should be re-verified by calculation.

- Prepare a permanent file copy of documentation. Assemble a complete set of documentation for a permanent file copy. That material must be in form that is suitable for reproduction and future revision, such as drawings reproduced on mylar film.

- Identify opportunities to improve HVAC control system performance. Examine the existing system diagrams and sequences in light of current practices to determine which parts of the system can be modified to provide better HVAC system performance.

- Prepare maintenance action sheets (MAS). These sheets will contain information abstracted from the manufacturer's installation and maintenance instructions for each component and from the installation itself. Prepare a MAS for each control system component giving specific procedures to be followed in performing periodic maintenance. Each MAS should list the routine maintenance procedures required, the time interval between procedures, a step-by-step description of the procedure, and any special tools and expendable supplies required for the maintenance procedures.

SYSTEM SET-UP EQUATIONS

The programming data or set-up parameters for controllers may be determined from the documentation obtained as mentioned previously, or the data may be calculated as discussed in this paragraph. The equations can be used to verify the accuracy of the setup values on the original documentation or to change the programming data based on decisions made as a result of fine tuning procedures described in Chapter 11.

Electronic Single-Input Controllers

The programming instructions needed for electronic single-input controllers are setpoint, throttling range, and action, whether direct or reverse. These terms are defined in Chapter 2.

Electronic Dual-input Controllers

- The programming instructions needed for electronic dual-input controllers are primary throttling range, primary setpoint and ratio. When preparing to set up a system, the following steps should be taken:
  a. Determine the required reset schedule as described in item 2 below.
  b. Evaluate whether the system is reverse reset or direct reset as described below.
  c. Assign a throttling range to the primary variable, based on experience, such as 8° to 10°F on air systems and steam or hot water converters, 6°F on mixed air sections.
  d. Calculate the throttling range of the secondary variable on the basis of the type of reset and information in the reset schedule, using the appropriate equations. Refer to "Electronic Dual-input Controller Set-up Equations" below.
  e. Calculate the ratio as described below.
  f. Assume values for the set-point of primary and reset variable and evaluate the set-point for the secondary or resetting variable.

The first step in determining set-up values is to construct a reset schedule. The reset schedule may be part of the documentation or may be developed based on decisions made as part of the fine tuning procedure. The reset schedule is used to set up the system.

Two temperature conditions are given: the primary temperature which is to be reset and the secondary temperature which is to do the resetting. A typical reset schedule for control of a steam or high temperature water (HTW) valve on a space heating hot water converter, where the leaving hot water temperature is to be reset in relation to outside air temperature, is:

Condition	Leaving HW Temperature	Outdoor Temperature	Controller Output Voltage
A	180°F	0°F	6 vdc
B	77.5°F	70°F	9 vdc

For this example, assume that a supply water temperature of 180°F is required at an outside air temperature of 0°F. This will require a 6 volt output signal to the normally open control valve. When a 3-way valve is used, the bypass port is normally open and the coil piping must be arranged for "fail safe" operation.

Ratio. Ratio is the arithmetic ratio of the secondary throttling range to the primary throttling range. The equation is:

$$\text{Ratio} = \frac{TR_2}{TR_1} \qquad (6\text{-}1)$$

Where:

TR_2 = throttling range of secondary sensor.
TR_1 = throttling range of primary sensor.

Although manufacturers do not use the term "throttling range" for the resetting sensor, it does in fact have a throttling range and that value is necessary in calculating values for performance prediction and set-up of controllers.

Differences in terminology. There are a number of similar terms used which can be confusing, even to the most experienced control system technician. One of these is *Authority Ratio.* This term is used in electronic control systems to describe the ratio of the two variables. The equation is:

$$\text{Authority Ratio} = \frac{\text{Change of secondary or resetting variable, °F}}{\text{Change of primary or reset variable, °F}} \qquad (6\text{-}2)$$

For an example of these values, refer to the reset schedule above and calculate the authority ratio:

$$\text{Authority Ratio} = \frac{(0 \pm 70)\text{°F}}{(180 \pm 110)\text{°F}} = 1{:}1$$

This authority ratio of 1:1 means that a 1°F change in the secondary or resetting variable will change the primary or reset variable by 1°F. This must not be confused with the term "authority" which is used in pneumatic control systems and shown in equation 6-11. That "authority" value is a percentage and defines the effect of changes in the secondary or resetting variable on the primary or reset variable. The term "Authority" used in pneumatic systems is a set-up parameter similar to the term "reset ratio" used in electronic systems.

Direct reset and Reverse reset. To calculate the set-up values, it is necessary to first determine the action of the controller, whether direct reset or reverse reset. In a direct reset system, the primary and the secondary variables increase or decrease together in a direct ratio. In a reverse reset system, the primary variable decreases or increases as the secondary variable increases or decreases, in a reverse ratio.

For example, consider the control of the air discharge temperature from a chilled water cooling coil with discharge temperature reset from space temperature by positioning an automatic valve in chilled water piping using the following reset schedule:

Condition	Primary Variable Discharge Air Temperature	Secondary Variable Conditioned Space Temperature	Controller Output Voltage
A	50°F	78°F	9 vdc
B	55°F	70°F	6 vdc

In this reset schedule, as the space temperature decreases, the discharge air temperature must increase, therefore the system must function in reverse reset action.

On the primary controller, as the coil discharge air temperature increases, with no change in the space temperature, the output voltage will increase to open the valve. Therefore, the primary controller is direct-acting.

On the secondary controller, as the space temperature increases, the output voltage must increase to open the valve, therefore the secondary controller is direct-acting.

To meet the requirements discussed above, the controller must then be set up as direct-acting/direct-acting to make the system function in reverse reset action.

The rule used to determine the reset function of a controller is that, when primary and secondary controllers are of the same action the controller will be reverse-acting and when primary and secondary controls are of different actions the controller will be direct-acting. That rule gives these reset actions:

- Direct-acting/direct-acting controllers give reverse reset.
- Reverse-acting/reverse-acting controllers give reverse reset.
- Reverse-acting/direct-acting controllers give direct reset.
- Direct-acting/reverse-acting controllers give direct reset.

Electronic Dual-input Controller Set-Up Equations

The values for primary and secondary throttling ranges and setpoints must be assigned or calculated in order to set up a controller.

Calculation of Throttling Range

a. For reverse reset action with a DA/DA controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\frac{(vdcB \pm vdcA)}{3}} \pm \frac{\left(T_{1B} \pm T_{1A}\right)}{TR_1} \tag{6-3}$$

b. For a reverse reset system with RA/RA controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\frac{(vdcA \pm vdcB)}{3}} \pm \frac{\left(T_{1B} \pm T_{1A}\right)}{TR_1} \tag{6-4}$$

c. For a direct reset system with DA/RA controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\frac{(vdcA \pm vdcB)}{3}} \pm \frac{\left(T_{1A} \pm T_{1B}\right)}{TR_1} \tag{6-5}$$

d. For a direct reset system with RA/DA controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\frac{(vdcA \pm vdcB)}{3}} \pm \frac{\left(T_{1B} \pm T_{1A}\right)}{TR_1} \tag{6-6}$$

Where:

TR_1 = Throttling range of the first variable, °F.
TR_2 = Throttling range of the second variable, °F.

T_{1A} = Temperature of first variable at condition A, °F.
T_{2A} = Temperature of second variable at condition A, °F.
T_{1B} = Temperature of first variable at condition B, °F.
T_{2B} = Temperature of second variable at condition B, °F.
vdcA = Output voltage of the controller for condition A.
vdcB = Output voltage of the controller for condition B.

Calculation of Setpoints

a. For reverse reset system with DA/DA controller:

$$SP_2 = \frac{(T_{2A} + TR_2)}{\frac{(7.5 \pm vdcA)}{3}} + \frac{(T_{1A} \pm SP_1)}{TR_1} \tag{6-7}$$

b. For reverse reset system with RA/RA controller:

$$SP_2 = \frac{(T_{2A} + TR_2)}{\frac{(vdcA \pm 7.5)}{3}} + \frac{(T_{1A} \pm SP_1)}{TR_1} \tag{6-8}$$

c. For direct reset system with DA/RA controller:

$$SP_2 = \frac{(T_{2A} + TR_2)}{\frac{(vdcA \pm 7.5)}{3}} \pm \frac{(T_{1A} \pm SP_1)}{TR_1} \tag{6-9}$$

d. For direct reset system with RA/DA controller:

$$SP_2 = \frac{(T_{2A} + TR_2)}{\frac{(7.5 \pm vdcA)}{3}} \pm \frac{(T_{1A} \pm SP_1)}{TR_1} \tag{6-10}$$

Where:

SP_1 = Setpoint of the first variable, °F.
SP_2 = Setpoint of the second variable, °F.
7.5 = Output voltage of controller at setpoint, vdc.
TR_1 = Throttling range of the first variable, °F
TR_2 = Throttling range of the second variable, °F.

T_{1A} = Temperature of first variable at condition A, °F.
T_{2A} = Temperature of second variable at condition A,° F.
T_{1B} = Temperature of first variable at condition B, °F.
T_{2B} = Temperature of second variable at condition B, °F
vdcA = Output voltage of the controller for condition A, vdc.
vdcB = Output voltage of the controller for condition B, vdc.

Note: The above equations assume a voltage span of 3 vdc and a controller range of 1 to 15 vdc, with a 7.5 vdc midpoint. For other spans and ranges, the voltage span value of 3 and the controller range value of 7.5 must be changed to the specific values shown in the manufacturer's instructions. For example, with a 4 to 7 vdc system range the midpoint voltage will be 5.5 vdc.

Examples Using Electronic Controller Set-Up Equation

Hot water supply temperature reset from outside air.

a. **Reset schedule.** A typical reset schedule for this system would be:

Condition	Hot Water Temperature	Outdoor Temperature	Controller Output Voltage
A	180°F	0°F	6 vdc
B	110°F	70°F	9 vdc

b. **Action.** The first step is to determine whether the system will be direct reset or reverse reset. The schedule shows that on an increase in the secondary variable, outdoor temperature, the controller output voltage also increases, which makes the secondary controller direct-acting. The schedule also shows that on increase in the primary variable, hot water temperature (at the same outdoor temperature), the control valve must close to hot water flow, which for a normally open valve will require an increase in output voltage. Because an increase in hot water temperature will cause an increase in output voltage, the primary control is direct-acting.

The controller should therefore be set as DA/DA to give reverse reset.

c. **Throttling range.** Assign a throttling range of 4°F for the primary variable, then determine the throttling range for the secondary variable using equation 6-3:

$$TR_2 = \frac{(T_{2B} \pm T_{2A})}{\frac{(vdcB \pm vdcA)}{3}} \pm \frac{(T_{1B} \pm T_{1A})}{TR_1} \tag{6-3}$$

Where:

T_{2B} = 70°F.
T_{2A} = 0°F.
vdcB = 9 vdc.
vdcA = 6 vdc.
T_{1B} = 110°F.
T_{1A} = 180°F.

Therefore,

$$TR_2 = \frac{(70 \pm 0)°F}{\frac{(9 \pm 6)\ vdc}{3\ vdc}} \pm \frac{(110 \pm 180)°F}{4°F} = 3.78°F$$

The ratio is calculated as Ratio = 3.78°F/4°F = 0.94.

Next, let SP_1 = 180°F and find SP_2 using equation 6-7:

$$SP_2 = \frac{(T_{2A} + TR_2)}{\frac{(7.5 \pm vdcA)}{3}} + \frac{(T_{1A} \pm SP_1)}{TR_1} \tag{6-7}$$

Therefore,

$$SP_2 = \frac{(0 + 3.78)°F}{\frac{(7.5 \pm 6\ vdc}{3\ vdc}} \pm \frac{(180 \pm 180)°F}{4°F} = 1.89°F$$

Setup parameters for the dual-input controller are:

Action = DA/DA.
TR_1 = 4°F.
Ratio = 0.94.
SP_1 = 180°F.
SP_2 = 1.89°F.

Programming instructions for the dual-input controller are:

1. Set the controller to direct-acting.
2. Set the throttling range to 4°F.
3. Set the ratio to 0.94.
4. Disconnect the remote sensor from the controller and by means of a decade box simulate 180°F (use 1,242 ohms for a sensor having a 1,000 ohms resistance at 70°F with 2.2 ohms/°F change) on port 1 of the controller.
5. Repeat step 4 on port 2, using 850 ohms to simulate 0°F.
6. Adjust the controller calibration for 7.5 vdc output voltage.
7. Calibrate each sensor so that the inputs to the ports are correct for the measured temperatures.
8. Adjust setpoint indicator A to 180°F.
9. Adjust setpoint indicator B to 1.89°F.

Comparing the values for SP_2 of 1.89°F as calculated above and 0°F as given in the reset schedule, we note that the difference is about one-half the 4°F throttling range. This may be considered reasonable.

Discharge air temperature reset from space temperature.

a. A typical reset schedule for this system is:

Condition	Discharge Air Temperature	Space Temperature	Controller Output Voltage
A	50°F	78°F	9 vdc
B	55°F	70°F	6 vdc

This reset schedule is the same as that given in discussion of Electronic Dual-Input Controllers under the heading System Set-up Equations above. A review of discussion on that schedule finds that when both primary and secondary controllers are direct-acting, the controller must be set up DA/DA to give reverse reset.

Assign a throttling range TR_1 to the primary variable, discharge temperature, of $TR_1 = 4°F$.

Then, calculate throttling range TR_2 using equation 6-3.

$$TR_2 = \frac{\left(T_{2B} - T_{2A}\right)}{\frac{(\text{vdcB} - \text{vdcA})}{3}} \pm \frac{\left(T_{1B} - T_{1A}\right)}{TR_1} \qquad (6\text{-}3)$$

Where:

T_{2B} = 70°F.
T_{2A} = 78°F.
vdcB = 6 vdc.
vdcA = 9 vdc.
T_{1B} = 55°F.
T_{1A} = 50°F.
TR_1 = 4°F.

Therefore,

$$TR_2 = \frac{(70 \pm 78)°F}{\frac{(6 \pm 9)\ vdc}{3}} \pm \frac{(55 \pm 50)°F}{4°F} = 3.55°F$$

Calculate the ratio as Ratio = 3.55°F/4°F = 0.88.

A value must be assigned for the primary variable setpoint, before the secondary variable setpoint can be calculated using equation 6-7. Therefore, try SP_1 = 50°F.

For a reverse reset system with DA/DA Controller:

$$SP_2 = \frac{(T_{2A} + TR_2)}{\frac{(7.5 \pm vdcA)}{3}} + \frac{(T_{1A} \pm SP_1)}{TR_1} \tag{6-7}$$

Therefore,

$$SP_2 = \frac{(78 + 3.55)°F}{\frac{(7.5 \pm 9)\ vdc}{3}} \pm \frac{(50 \pm 50)°F}{4°F} = 76.22°F$$

The dual-input controller set-up parameters are:

Action = DA/DA
TR = 4°F
Ratio = 0.88
SP_1 = 50°F
SP_2 = 76.2°F

Comparing the values for SP_2 of 76.2°F as calculated and 50°F as given in the reset schedule, we note that the difference of 26.2°F is approximately 6.5 times the 4°F throttling range. This is not as reasonable a set-up as the first.

Pneumatic Single-input Controllers

The programming instructions required for pneumatic single-input controllers are setpoint, proportional band, and action (direct or reverse). Proportional band was defined in Chapter 4 and is calculated using equation 4-4 as follows:

$$\text{Proportional Band PB} = \frac{\text{Throttling Range TR}}{\text{Sensor Span °F}} \times 100 \qquad (6\text{-}10)$$

Pneumatic Dual-input Controllers

The programming instructions needed for pneumatic dual-input controllers are setpoint of the primary variable, proportional band, % authority, and action (whether direct or reverse).

Proportional band PB is calculated using equation 6-10 as above.

Percent authority %A is calculated using equation 6-11.

$$\%\ \text{Authority} = \frac{PB_1}{PB_2} \times 100 \qquad (6\text{-}11)$$

Where:

PB_1 = Proportional Band for sensor 1.
PB_2 = Proportional Band for sensor 2.

Johnson Controls, Inc., uses the terms "gain" and "ratio" for the same relationship that other pneumatic control component manufacturers in the U.S. use the term "% Authority."

The terms gain and ratio are defined below for use when working with Johnson Controls, Inc. components:

$$\text{Gain} = \frac{\dfrac{PS}{PD_S}}{PB} \qquad (6\text{-}12)$$

Where:

PS = Pressure span of the controller, (psi)
PD_s = Sensor pressure span (or difference), (psi)
PB = Proportional Band

The pneumatic control components manufacturers in the U.S., except Robertshaw Controls, use a pressure range of 3 to 13 psi and

PS = 10 psi. For Robertshaw Controls, the pressure range is 3 to 15 psi and PS = 12 psi.

The term "ratio" as used by Johnson Controls, Inc. for pneumatic controls must not be confused with the term "ratio" as used in programming electronic controls; see equation 6-1. To distinguish between the two terms, we will use a subscript j to indicate Johnson Controls' definition of ratio, as follows:

$$\text{Ratio}_j = \frac{\text{Gain}_1}{\text{Gain}_2} = \frac{PB_2}{PB_1} \tag{6-13}$$

Steps in Set-up of Dual-input Pneumatic Controller

When performing the set-up of a dual-input pneumatic controller, the same basic steps are followed as described above for electronic systems in Electronic Dual-input Controllers. The steps are:

a. Determine the required reset schedule.

b. Evaluate whether the system is direct or reverse reset action.

c. Assign a throttling range to the primary variable.

d. Calculate the throttling range of the secondary variable on the basis of the type of reset and information in the reset schedule.

e. Calculate the proportional bands of the sensors and the % authority of the secondary sensor from the known throttling ranges and sensor spans.

f. Assume a value for the setpoint of the primary variable and then evaluate the setpoint for the secondary variable.

As with electronic controls, the first step in determining set-up values is to construct a reset schedule. Two different temperature pairs must be specified in a reset schedule: the primary temperature, which is reset, and the secondary temperature, which does the resetting.

As previously discussed for electronic controls, it is necessary to determine the action desired for the controls. Reset can be either direct or reverse. In a direct reset system, the primary and the secondary variable increase or decrease together. In a reverse reset system, the primary and secondary variables decrease and increase in opposite actions; as one increases the other decreases.

For example, consider reset control for a chilled water cooling coil with coil air discharge temperature being reset from space temperature by opening or closing an automatic valve in chilled water supply to coil using this reset schedule:

Condition	Primary Variable Discharge Air Temperature	Secondary Variable Conditioned Space Temperature	Controller Output Pressure
A	78°F	50°F	13 psig
B	70°F	55°F	3 psig

In this reset schedule, as the space temperature increases, the discharge air temperature must decrease, therefore the system is reverse reset.

You can predict that, when the air discharge temperature increases, the chilled water valve must open to allow more chilled water flow through the coil.

For a normally closed chilled water valve, an increase in water flow will require an increase in pressure on the actuator. This is a direct-acting control. Therefore, the controller must be set up as direct-acting/direct-acting to give the required reverse reset.

Pneumatic Dual-input Controller Set-Up Equation

Calculation of throttling range

a. For reverse reset action with a DA/DA Controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\dfrac{\left(OP_B \pm OP_A\right)}{10}} \pm \frac{\left(T_{1B} \pm T_{1A}\right)}{TR_1} \tag{6-14}$$

b. For a reverse reset system with RA/RA Controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\dfrac{\left(OP_A \pm OP_B\right)}{10}} \pm \frac{\left(T_{1B} \pm T_{1A}\right)}{TR_1} \tag{6-15}$$

c. For a direct reset system with DA/RA Controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\frac{\left(OP_A \pm OP_B\right)}{10}} \pm \frac{\left(T_{1A} \pm T_{1B}\right)}{TR_1} \tag{6-16}$$

d. For a direct reset system with RA/DA Controller:

$$TR_2 = \frac{\left(T_{2B} \pm T_{2A}\right)}{\frac{\left(OP_B \pm OP_A\right)}{10}} \pm \frac{\left(T_{1A} \pm T_{1B}\right)}{TR_1} \tag{6-17}$$

Where:

TR_1	=	Throttling range of first variable, °F.
TR_2	=	Throttling range of second variable, °F.
T_{1A}	=	Temperature of first variable for condition A, °F.
T_{2A}	=	Temperature of second variable for condition A, °F.
T_{1B}	=	Temperature of first variable for condition B, °F.
T_{2B}	=	Temperature of second variable for condition B, °F.
OP_A	=	Output pressure of controller at condition A, psig.
OP_B	=	Output pressure of controller at condition B, psig.

Calculation of setpoint

a. For reverse reset system with DA/DA controller:

$$SP_2 = \frac{\left(T_{2A} + TR_2\right)}{\frac{\left(8 \pm OP_A\right)}{10}} + \frac{\left(T_{1A} \pm SP_1\right)}{TR_1} \tag{6-18}$$

b. For reverse reset system with RA/RA controller:

$$SP_2 = \frac{\left(T_{2A} + TR_2\right)}{\frac{\left(OP_A \pm 8\right)}{10}} + \frac{\left(T_{1A} \pm SP_1\right)}{TR_1} \tag{6-19}$$

c. For direct reset system with DA/RA controller:

$$SP_2 = \frac{\left(T_{2A} + TR_2\right)}{\frac{\left(OP_A \pm 8\right)}{10}} \pm \frac{\left(T_{1A} \pm SP_1\right)}{TR_1} \qquad (6\text{-}20)$$

d. For direct reset system with RA/DA controller:

$$SP_2 = \frac{\left(T_{2A} \pm TR_2\right)}{\frac{\left(8 \pm OP_A\right)}{10}} \pm \frac{\left(T_{1A} \pm SP_1\right)}{TR_1} \qquad (6\text{-}21)$$

Where:

SP_1 = Setpoint of first variable, °F.
SP_2 = Setpoint of second variable, °F.
8 = Midpoint pressure, 8 psig at setpoint.
TR_1 = Throttling range of first variable, °F
TR_2 = Throttling range of second variable, °F.
T_{1A} = Temperature of first variable for condition A, °F.
T_{2A} = Temperature of second variable for condition A, °F.
OP_A = Output pressure of controller for condition A, psig.

Note that the above equations assume a pressure span PS of 10 psig for a controller range of 3 to 13 psig, with an 8 psig midpoint. For other spans and ranges, the pressure span value of 10 psig and the midpoint pressure value of 8 psig must be changed to the specific values shown in the manufacturer's instructions. For example, with a 3 to 15 psig system the pressure span will be 12 psig and the midpoint pressure will be 9 psig.

Examples Using Pneumatic Controller Set-up Equations

Hot water supply temperature reset from outside air.

A typical reset schedule for this type system is:

Condition	Primary Variable Hot Water Supply Temperature	Secondary Variable Outdoor Temperature	Controller Output Pressure
A	180°F	0°F	3 psig
B	110°F	70°F	13 psig

Next, determine the controller reset action. The reset schedule requires a hot water temperature of 180°F when the outdoor temperature is at 0°F, its lowest value, with the lowest output pressure. With a normally open valve having a 3 to 13 psi spring range, the 3 psig controller branch pressure will allow the spring to open the valve fully for maximum heat output.

As the hot water temperature increases, the controller output pressure must increase to close the valve, which gives direct-action. An increase in outdoor temperature requires a decrease in hot water temperature, which requires the controller output pressure to be increased to close the normally open valve.

When an increase in the temperature of the reset variable causes an increase in the output pressure of the controller, that is direct action. The controller should therefore be set as DA/DA to give reverse reset.

The appropriate equations, 6-14 and 6-18, must now be used to calculate the required data to set up the dual-input controller. Note that there is not enough information given so far to calculate the % authority, because the sensor spans must also be known. Sensor spans are selected to cover the temperature range to be expected.

For this example, we will try sensor spans of 200°F with a 0 to 200°F range for the hot water and 200°F with a –40°F to 160°F range for the outdoor air temperature sensor. We will also try a throttling range for the primary variable of 4°F.

Calculate PB_1 using equation 6-10:

$$PB_1 = (4/200°F) \times 100 = 2\%.$$

This 2% PB is too low to be used for controller set-up due to limitations in the adjustable range of most controllers. However, the PB can be increased by changing either the sensor span or the primary throttling range TR_1.

Assign a new TR_1 = 6°F and recalculate PB:

$$PB_1 = (6/200°F) \times 100 = 3\%.$$

This 3% PB should be acceptable for all controllers.

Next, calculate TR_2 using equation 6-16:

$$TR_2 = \frac{(70 \pm 0)°F}{\frac{(13 \pm 3)\ psig}{10}} \pm \frac{(110 \pm 180)°F}{4\ psig} = 1.89°F$$

Because the sensor spans are equal, the % authority cannot be calculated using the definition that the % authority is the ratio of the proportional band values. It is necessary to calculate the % authority using throttling ranges as follows:

% Authority = TR_1/TR_2 = 6°F/1.89°F = 317%.

Next, assign a value of SP_1 = 110°F and calculate SP_2 using equation 6-18:

$$SP_2 = \frac{(0 + 1.89)°F}{\frac{(8 \pm 3\ psig)}{10\ psig}} + \frac{(180 \pm 110)°F}{8\ psig} = 68°F$$

Note that the difference between the scheduled and the calculated values is equal to about one-half the throttling range.

This is a reasonable value.

The dual-input controller can be programmed as follows:

Action	=	DA/DA
PB	=	3%
% Authority	=	317%
SP_1	=	110°F
SP_2	=	68°F

The dual-input controller is calibrated as follows:

1. Set the controller to direct-acting.
2. Set proportional band (PB) to 3%.
3. Set % authority to 317%.
4. Using test instruments, set pressure input to port 1 for 110°F or 8.5 psig.
5. Using test instruments, set pressure input to port 2 for 68°F or 6.4 psig.
6. Adjust the controller until its branch pressure is 8 psig.
7. Change input pressure to port 1 for 112°F or 8.6 psig. Branch

(output) pressure should rise to 13 psig.

8. Change input pressure to port 1 for 108°F or 8.4 psig. Branch (output) pressure should drop to 3 psig.
9. If branch pressures in steps (7) and (8) do not occur, the PB scale is inaccurate. Adjust PB setting and redo steps (7) and (8).
10. To verify % authority setting, change inputs to both ports 1 and 2 to Condition A from the reset schedule. Set input 1 to 180°F or 12 psig and set input to port 2 to 0°F or 3 psig. Adjust the controller branch pressure to some middle pressure, about 8 to 10 psig.[1]
11. Change inputs to port 2 and adjust input to port 1 to values for Condition B from the reset schedule. Set input 2 to 70°F or 6.5 psig and then set input 1 to 110°F or 8.5 psig. The branch output pressure should increase then return to the branch pressure set in step 10 above.
12. Redo steps 10 and 11 as required until branch pressures reached in both steps are equal. (This rarely happens on the first try.)
13. Calibrate each sensor so that the pressure inputs to the ports are correct for the measured temperatures.
14. Disconnect test instruments and reconnect sensors to input ports.
15. Measure temperature of hot water supply and of outdoor air close to sensor location.
16. Solve the pneumatic dual-input controller equation for P_{out} using temperatures obtained in step 15. Note that if this step results in branch output pressures greater than 15 psig or less than 3 psig, the temperatures are outside the sensor span and test instrument inputs must be used for controller set-up.
17. Adjust controller calibration knob until the output predicted in step 16 is obtained.
18. Adjust the setpoint scale plate or indicator to 110°F.

Discharge air reset from space temperature

A typical reset schedule for this type system is:

Condition	Primary Variable Discharge Air Temperature	Secondary Variable Conditioned Space Temperature	Controller Output Pressure
A	50°F	78°F	13 psig
B	55°F	70°F	3 psig

According to the rules discussed above for this system, the controller action must be DA/DA to give reverse reset.

Try a throttling range of 4°F for the primary variable, which is the discharge air temperature.

Next, try a discharge air sensor with a range of 0 to 100°F and a span of 100°F, then calculate PB using equation 6-10:

$$PB_1 = (TR_1/span_1) \times 100 \qquad PB_1 = 4\%.$$

Calculate TR_2 using equation 6-14:

$$TR_2 = \frac{(70 \pm 78)°F}{\frac{(3 \pm 13)\ psig}{10}} \pm \frac{(55 \pm 50)°F}{4°F} = 18°F$$

An 18°F throttling range is generally too large to provide satisfactory space temperature control. It is necessary to try other combinations of sensors and primary-secondary variable designations to get an acceptable throttling range. An "acceptable" throttling range may be thought of as being equal to the range of acceptable temperature swing from full-load to no-load conditions on the HVAC system.

To reduce the calculated throttling range, redesignate the temperature in the conditioned space as the primary variable on sensor 1 and make the discharge air temperature the secondary variable on sensor 2 as shown in this revised reset schedule:

Condition	Primary Variable Conditioned Space Temperature	Secondary Variable Discharge Air Temperature	Controller Output Pressure
A	78°F	50°F	13 psig
B	70°F	55°F	3 psig

Assign a throttling range for sensor 1 as TR_1 = 4°F, then calculate a new TR_2 using equation 6-14:

$$TR_2 = \frac{(55 \pm 50)°F}{\frac{(3 \pm 13)\ psig}{10}} \pm \frac{(70 \pm 78)°F}{4°F} = 5°F$$

The new value of 5°F for TR_2 appears to be reasonable.

Proceed with the calculations using the new value for TR_2.

Try an alternate selection for sensor 1 with a 50°F span and a range of 50 to 100°F, and calculate values for PB_1 and PB_2 using equation 6-10:

$$PB_1 = (TR_1/span_1) \times 100 = (4°F/50°F) \times 100 = 8\%.$$

$$PB_2 = (TR_2/span_2) \times 100 = (5°F/100°F) \times 100 = 5\%.$$

Calculate % authority using equation 6-11 as follows:

$$\%\ Authority = (PB_1/PB_2) \times 100 = (8\%/5\%) \times 100 = 160\%.$$

Let SP_1 = 78°F, and then calculate SP_2 using equation 6-18:

$$SP_2 = \frac{(50°F + 5°F)}{\frac{(8 \pm 13\ psig)}{10\ psig}} + \frac{(78°F \pm 78°F)}{4°F} = 47.5°F$$

Note that the difference between the scheduled value and the calculated value for SP_2 is equal to about one-half the throttling range.

The dual-input controller should be set up as follows:

Action	=	DA/DA
PB	=	8%
% Authority	=	160%
SP_1	=	78°F
SP_2	=	47.5°F

The dual-input controller calibration instructions are:

1. Set the controller to direct-acting.
2. Set proportional band (PB) to 8%.
3. Set % authority to 160%.
4. Set pressure input to port 1 for 78°F or 7.08 psig.
5. Set pressure input to port 2 for 47.5°F or 5.85 psig.
6. Adjust the controller until its branch pressure is 8 psig.
7. Change input pressure to port 1 for 80°F or 7.8 psig. Branch (out-

put) pressure should rise to 13 psig.

8. Change input pressure to port 1 for 76°F or 7.56 psig. Branch (output) pressure should drop to 3 psig.
9. If branch pressures in steps 7 and 8 do not occur, the PB scale is inaccurate. Adjust PB setting and redo steps 7 and 8.
10. To verify % authority setting, change inputs to both ports 1 and 2 to Condition A from the reset schedule. Set input 1 to 78°F or 7.68 psig and set input to port 2 to 50°F or 6 psig. Adjust the controller branch pressure to a midpoint pressure, about 8 to 10 psig.[1]
11. Change inputs to port 2 and adjust input to port 1 to Condition B from the reset schedule. Set input 2 to 50°F or 6 psig and then set input 1 to 70°F or 7.2 psig. The branch output pressure should increase then return to the branch pressure set in step 10 above.
12. Redo steps 10 and 11 as required until branch pressures reached in both steps are equal.
13. Calibrate each sensor so that the pressure inputs to the ports are correct for the measured temperatures.
14. Disconnect test instruments and reconnect sensors to input ports.
15. Measure temperature of hot water supply and of outdoor air close to sensor location.
16. Solve the pneumatic dual-input controller equation for P_{out} using temperatures obtained in step 15. Note that if this step results in branch output pressures greater than 15 psig or less than 3 psig, the temperatures are outside the sensor span and test instrument inputs must be used for controller set-up.
17. Adjust controller calibration knob until the output predicted in step 16 is obtained.
18. Adjust the setpoint scale plate or indicator to 78°F.

[1]Note that the output pressures stated in the reset tables are given to permit setpoint selection and are not to be used as set-up values for % authority on the controller.

Chapter 7

Maintaining Electric and Electronic Control Systems

Electric and electronic control systems do not require as much maintenance as pneumatic control systems but they are not maintenance-free. The principal maintenance problems encountered in electric and electronic controls systems are electrical in nature for the controllers and electro-mechanical in nature for actuators and other controlled devices.

CLASSIFICATIONS OF MAINTENANCE

The several classifications of maintenance discussed in Chapter 3, "Operating and Maintaining HVAC Control Systems" are applicable to both electric and electronic control systems.

Periodic or routine maintenance for electric and electronic control controllers consists principally of cleaning contacts, checking terminals for loose connections, and cleaning sensors.

Loose and intermittent electrical connections will cause operating problems which are difficult to diagnose. A loose connection on an electronic sensor terminal will either cause an increase in the apparent resistance of the sensor, which will transmit a false signal to the controller indicating a higher than actual sensed condition, or will result in an intermittent signal, which will cause the controller to change outputs quickly and may result in actuator failure over a prolonged period.

Similarly, dirt buildup on the wire-wound bobbins used in slide-wire type electric controllers will indicate a higher resistance than the position of the slider should produce. An intermittent or interrupted signal caused by dirt will cause the actuator to move erratically or leave actuator in the last controlled position.

Actuators for electronic systems are essentially electric control motors with an electronic interface device to cause the motor to rotate, to stop, and to reverse direction. The interface devices or actuator drives built by some manufacturers have a series of relays which energize in sequence as the input signal voltage is increased and which are connected to the electric actuator's five input terminals to give 5-step proportional control. The drives are not accessible for maintenance but are field adjustable for voltage at starting point from 2 to 12 vdc with factory setting at 6 vdc.

Other control components in the system should be checked to verify that they are in calibration or are properly adjusted. The check should follow the predict-measure-adjust sequence described in Chapter 5, "Performance Prediction in ATC Systems." The output of each component at a given condition should be predicted, then the condition should be simulated on the device and the output value should be measured and recorded. If any discrepancy between the predicted and measured output values is found, that component should be recalibrated to bring the output values into agreement.

Preventive maintenance for electric and electronic control systems includes providing basic maintenance operations previously listed for dampers and valves and for verifying tight electrical connections.

Breakdown maintenance for electric and electronic control systems includes replacement of defective components and repairing wiring systems.

PREVENTIVE MAINTENANCE

Damper and Valve Actuator Operational Check

Required frequency. Damper and valve actuator operational check should be performed semi-annually, usually at the beginning of cooling and heating seasons, and after the receipt of any complaint indicating that the damper or valve is not functioning properly.

Procedure. The technician should follow the "Z to A Approach" as described in Chapter 12, "Troubleshooting ATC Systems."

Verifying electrical connection integrity. Required frequency: after receipt of complaint indicating inaccurate sensing of controlled media or chattering actuator relay contacts.

The technician should check the connections for tightness by measuring the resistance across the terminal joints using a volt-ohm-multimeter. A measurable resistance across the terminal joints is considered excessive and must be corrected. In tightening screw-post terminals, too much tightening can extrude solid wires or break stranded wires which will leave a current carrying conductor with less than the normal cross sectional area which will create a high resistance across the too-tight joint.

BREAKDOWN MAINTENANCE

Breakdown maintenance is done when the system does not function at all or when a particular subsystem will not operate. The first step in breakdown maintenance is to determine the defective wiring circuit or component. Procedures for troubleshooting ATC systems are given in Chapter 12, "Troubleshooting ATC Systems."

After the trouble point has been isolated and a determination made as to whether it involves a wiring system failure or a component failure, the necessary corrections to the system must be made. A faulty wiring system component must be replaced, as a repair may introduce a resistance value into the system which will cause false sensing or operation. Wiring must be replaced from terminal to terminal without splices. A faulty component should be removed from the system and "bench tested" to find out whether the actual component is not operating properly or whether the electric or electronic signal inputs to the component are not in accordance with the requirement.

"Bench testing" is carried out in a test facility either on the site or at a remote location where various instruments are available, as well as line voltage and low voltage power sources. The testing technician performs a functional test and performs a repair/replace analysis to determine whether to repair or replace the faulty component.

A facility with a substantial number of similar control components should set up a test bench in the control shop. The test bench should be equipped with copies of the Maintenance Action Sheets and manufacturers' installation and maintenance instructions for all control components in the system, the diagnostic and testing apparatus required for the particular group of components expected to be tested, an inventory of essential components, and an inventory of recommended repair parts for use in repairing components. A list of recommended spare parts to be held in inventory should be abstracted from the manufacturer's data sheets for each control component.

Where components are specifically designated as being serviceable only at the factory or where components are found to be not repairable on the bench, those components may be sent back to the factory for exchange or sent to an independent overhaul shop for exchange or repair. For components that require factory servicing and which are installed in sufficient numbers, it may be desirable to maintain an in-house reserve stock to allow replacement without delay.

A management level repair/replace decision should be made by comparing the cost of the repair versus the cost of the replacement, whether new or exchange, considering the expected useful service life for the new or the repaired component. Most repair facilities, whether operated by original equipment manufacturer or independent, publish price lists for new components and flat rate repair or exchange costs for used components. Some components may have a "core allowance" when traded in on a new or remanufactured device of the same model.

SUGGESTED RETROFITS FOR EASE OF MAINTENANCE

The following items of low effort and high return retrofit modifications are suggested to provide maximum reliability and ease of maintenance.

Provide a documentation sticker at each adjustable component giving the initial control set-up data. Honeywell routinely provides such stickers for pneumatic devices during initial installation.

Provide field test terminal strips in system control cabinets for each electrical terminal point, with wiring connected back to the individual devices. By use of these field test points, the status of each control device in the system can be determined, with analog values of voltage and digital indication for contact closure. This retrofit modification is useful for electrical components in pneumatic control systems also.

Chapter 8

Maintaining Pneumatic Control Systems

Pneumatic control systems require more maintenance work than electric-electronic systems, principally to ensure a clean and dry source of compressed air as the motive power to the system. Maintenance requirements are classified as periodic, preventive, and breakdown.

Many pneumatic control systems in service today were installed before the widespread use of components having very fine internal air passages and do not have specific provisions for cleaning and drying the air to the quality required by currently produced control components that may be used in replacement or retrofit operation. Later systems may have been installed with provisions for cleaning and drying the air but may not have been provided with means for draining oil and water from the control air piping system after an episode of oil or water contamination.

A summary of retrofit measures for pneumatic control system air supply source and distribution is included in this chapter.

PERIODIC OR ROUTINE MAINTENANCE

Compressor Oil Level

Observe the oil level in the compressor on a daily basis and add oil when required. When compressor oil must be added, make an immediate investigation to determine where the lost oil went. First, check for external leaks and then check the tank to see whether oil was blown out of the compressor and into the air tank. See "Routine Testing for Oil Contamination" below.

Check Compressor Running Time

Observe the time required for a compressor cycle from off to on and to off again. When compressor running time increases over the normal period, it may be due to system air leaks or to a waterlogged air tank. The normal period may be unknown in an older installation. In that case, it may be assumed that a compressor operating more than 20 to 30 minutes out of an hour on the average is operating too much. A method of checking for a waterlogged air tank is included below. A check for air system leaks requires more effort. A method of leak testing is described below under "Verifying Air Piping System Integrity."

Control Air Compressor Intake Filters

Check the condition of the filters weekly and clean or replace when necessary. Assure that intake air is being drawn from as clean and dry a source as is practicable.

Drain Control Air Receiver or Tank

The periodic tank draining functions are often performed by automatic tank drainers, but the system may depend on manual draining of moisture from the tank. The manual draining may be necessary to verify that the automatic drainers are working and that the tank is being drained properly. Occasional manual draining of the air tank and examination of the fluid discharged is recommended to determine whether a significant volume of oil is being discharged into the tank.

Check Particulate and Oil Filters

The first line of defense against oil and water contamination in a pneumatic system is a dual unit oil and water separator followed by a particulate filter, rated at 3 microns, which is generally found between the high pressure storage tank and the dehydrator. Observe the pressure loss across the filter with a portable precision gauge and replace filter media as required.

Check Operation of the Aftercooler or Dehydrator

Power. Verify that power is energized to the refrigerated dehydrator and both the compressor and condenser fan are running.

Filter cleanliness. Check the air filter over the face of the condensing coil and replace when loaded with dirt.

Coil cleanliness. Observe the cleanliness of the condenser coil and clean as required.

Moisture removal. Verify that the unit is removing moisture from the control air by manually positioning the moisture drainer to open, direct the discharge of water onto a paper towel or clean cloth, observe the volume of water discharged and examine the water for oil or particulate contamination.

Check Operation of Control Air Pressure Regulators

Use a portable precision gauge to observe downstream pressure while air is bled manually from an outlet downstream. If air pressure varies by more than 1 psig from the regulator setpoint, repair or replace regulator. This testing may be done on a monthly basis.

Check Sensors for Cleanliness

Observe buildup of dirt on air sensors and clean as required. Observe lint or dirt buildup on humidity sensors and clean very carefully when required, using a fine brush such as is used in camera lens cleaning or by air jet such as is produced by a hand-held rubber ear syringe. Do not use any cleaning agent on humidity sensors, not even water, as to do so will damage the humidity sensitive coating.

Cleaning may be done on a quarterly basis, or more frequently where sensors are subject to unusual buildup of lint, dirt, or other contaminants.

PREVENTIVE MAINTENANCE

Controls Air System Contamination Testing

Required frequency. Two conditions requiring contamination testing are: First, when contamination of the system is suspected due to observed changes in instrument operation and calibration stability; and second, when evidence of oil or water is found on instrument filters, at bleed ports, or in system dirt legs.

Testing for oil and water contamination. Control air supply lines leaving the air receiver should have dual-element particulate and coalescing oil filters installed. Each filter bowl has a manual drain valve. Observation of the glass bowl of the separator will usually detect the presence of globules of oil or droplets of water.

If major contamination has occurred, the separator may be full so that globules and droplets are not visible. In either case, actuate the blowdown feature on the separator and trap the air discharged from the drainer on a clean cloth or paper towel to verify the presence of oil or water or both.

Testing for particulate contamination. When observing the oil and water separator for liquid contaminants, watch for particulate contaminants in the liquid. Next, open the particulate filter and use a magnifier to closely examine the filter media for contamination. Contaminants frequently found include: carbon from seals, metal wear particles, copper chips, solder spatter, plastic tubing bits, plastic wear particles, and dirt.

Testing for general contamination. Many receiver-controllers have integral filters located on the component. When contamination is suspected, obtain a new filter element, remove the filter element in use and replace it with the new one, and break open the used filter. Interpret the observed conditions as detailed in the instructions which accompany the new filter.

Interpretation of test findings. When contamination is found, steps must be taken to stop further contamination, to clean up contamination in the air tank and tubing system, and to determine which control components must be repaired or replaced to restore the system to normal operation.

Sources of Contamination and Preventive Measures

Sources of contamination and usual preventive measures employed to stop further contamination include:

- *Source of oil.* Oil generally originates in oil-lubricated compressors. Replacement of oil-lubricated compressors with oil-free compressors is a positive contamination prevention measure.

- *Source of water.* Water generally originates as vapor in atmospheric air and is condensed out of air during the compression cycle. Water may be forced into the pneumatic control air distribution system by failure of the storage tank drainage system, which results in water-logging of the storage tank until water is forced out of the tank, overpowering both the oil and water separator and the dehydrator unit. Water may condense out in the system following failure of the dehydrator unit from causes such as inadvertent disconnection of electric power, a clogged condensing coil on refrigerated air dryers, or compressor failure on the dehydrator unit.

- *Compressor intake from dehumidified air supply.* The amount of water vapor introduced into the system can be greatly reduced by introducing conditioned supply air into the controls air compressor intake.

Changing Air Filters

Filters to be changed. Compressor air intake filters, particulate filters in dual main air line filter unit, and "finger" filters at individual control components.

Required frequency. Based on exposure to contaminants, pressure loss, and possibility of media blowout due to excess pressure drop. Determined by experience. Could range from a few months to several years.

Replacement units. Use exact replacement units supplied to original manufacturer's specifications. Obtain replacement unit before removing unit which is in use.

Use of filters is mandatory. Do not leave any part of the system unfiltered except under emergency conditions and then only for the shortest possible time.

BREAKDOWN MAINTENANCE

Control Component Repair/Replace Analysis

When a control component does not function properly, the instrument should first be tested in place using the field test methods described in Chapter 10, "HVAC Control System Checkout Procedures." If the component does not check out properly in the field testing, it should be removed and returned to the control shop for bench testing. In bench testing, the control technician will have a complete set of control tools and fixtures, testing instruments and regulated air supply at various pressures. The technician should first attempt to calibrate the device, following the manufacturer's calibration instructions, to determine whether the instrument has malfunctioned or whether there was a malfunction within the system.

If testing finds the instrument to be at fault, the technician must evaluate whether the instrument can be repaired or whether the device must be replaced. If the device is repairable, the technician will evaluate whether the device can be repaired "in-house" or whether it will be more cost-effective to send the device to the manufacturer for exchange or to a control instrument repair station for exchange or repair.

Cleaning Contaminated Pneumatic Control Piping Systems

When to clean the system. When a system is found to be contaminated, a clean-up program should be implemented as soon as possible.

Cleaning procedures:

a. Stop the contamination at the source.

b. Drain free oil from the system.

c. Introduce a vapor degreasing compound into the system and take all steps necessary to ensure that the compound flows into all parts of the system.

d. After a reasonable period, flush the vapor degreasing compound from the system with oil-free compressed air.

e. Replace air filters in the system.

f. Verify calibration of instruments in the system.

g. Recalibrate instruments when required.

h. Replace instruments which cannot be recalibrated.

Stopping Contamination

An oil-lubricated or oil-free compressor with scored cylinder walls or damaged seals or rings can pump several quarts of lubricating oil into the system before failure due to bearing damage from lack of lubrication.

The most positive way to stop oil contamination from compressors is to replace oil-lubricated or oil-free compressors with "oil-less" compressors having no lubricating oil.

Some manufacturers of compressors refer to their trunk piston compressors as "oil-free" but the compressors are oil-lubricated and as such can be expected to vaporize some oil in the lubrication process and to discharge that vaporized oil into the system. The oil will restrict the tiny openings in the control system components, some of which are as small as 0.006" diameter and located so as to be inaccessible for cleaning without dismantling the control component.

"Oil-less" compressors utilize low-friction synthetic materials for bearings and seals instead of oil lubrication.

Before replacing a failed oil-lubricated compressor, it is imperative that the pneumatic tubing system be "boiled out" to remove all traces of oil. This is done by flushing the system with a volatile but incombustible solvent.

When it is not practicable to replace the offending compressor, the best protection is to install a strainer and gravity type oil separator at the compressor outlet discharge and to install a high capacity coalescing type oil filter with prefilter downstream of the dehydrator. Those filters must be serviced regularly, changing media cartridges in the particulate filter and draining oil from the coalescing filter.

Draining Oil from a Contaminated System

All free oil must be drained from the system to allow the degreasing operation to remove the remaining oil in a reasonable period of time and with a reasonable volume of degreasing compound. Draining can be done through cocks installed on drip legs in older systems, through new openings made in newer systems to receive drain outlets, or by disconnecting tubing at instruments and components.

Oil drained from the system should be examined for other contaminants such as carbon. When carbon is found, additional procedures must be planned to clean the contaminated system.

Introducing Vapor Degreasing Compound

The most commonly used and most readily available vapor degreasing compound in the past was DuPont's Freon TF, a close relative of Refrigerant 11, a CFC which is no longer available.

The volume of vapor degreasing compound to be applied in a system must be determined by experience. A fairly large reservoir, say 350 gallons, is sometimes used, built as an unfired pressure vessel, with provisions for connection of a high pressure air hose from the tank and another hose connection to the system arranged to pass the dehydrator.

The vapor degreasing compound vaporizes at room temperature and will be condensed in a refrigerated air dryer. For that reason, the air dryer is electrically disconnected during the vapor degreasing operation. Some operators provide a bypass line with pressure regulator around the air dryer, including full valving.

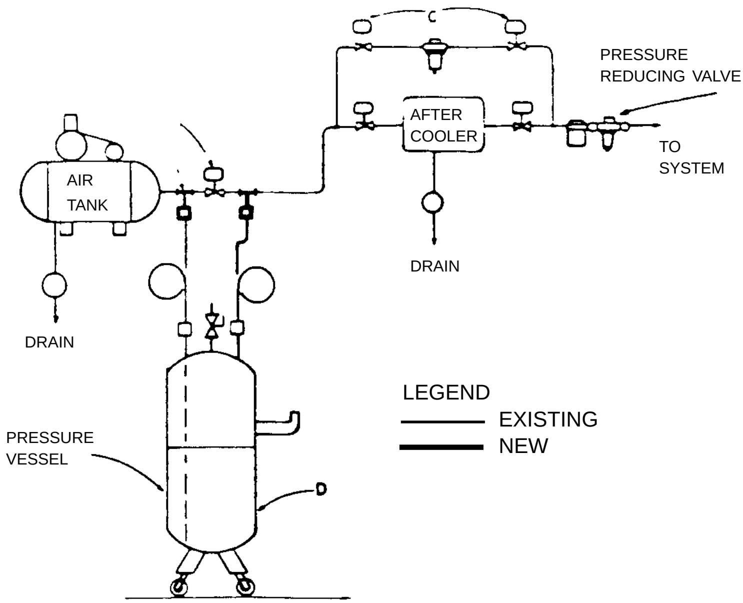
Refer to Figures 8-1 and 8-2 for the connections of the pressure vessel and for the construction of a pressure vessel. The high pressure vapor degreasing line should be connected through a restrictor fitting of about 0.005" bore in order to control the rate of flow of compound into the system.

Effect of Temperature on Cleaning Operation

The cleaning operation depends on "wastage" of air at the control components to cause the flow of vapor degreasing compound through the pressure reducing valve and filters, then out into the system. Air is "wasted" during normal system operation through the bleed ports of bleed-type and relay-type components. If an instrument or component is not "wasting" air, a flow of air through that branch must be established by manually manipulating the component to "waste" air or by adding a drain cock to the piping system. A flow of air, followed by degreasing compound, to all parts of the piping system is absolutely necessary to ensure that oil is removed from all parts of the system.

During cold weather the degreasing compound may condense and flow as a liquid, which can pose a problem due to hydraulic shock or "water hammer" if control devices close quickly. It is preferable to conduct cleaning operations when temperatures are above the vaporization temperature of the degreasing compound, usually above 75°F, throughout the control system.

Before placing the dehydrator and the air receiver back into operation on the system, cause a flow of the degreasing compound through the dehydrator compressed air passages to remove all traces of oil.



NOTES:

A. New tees for vapor degreasing—quick connect sockets coordinated with plugs on hoses.

B. Existing main air tank cut-off valve—relocate if necessary,

C. New dehydrator bypass with cut-off valves (optional)—dehydrator must be electrically disconnected during vapor degreasing operations.

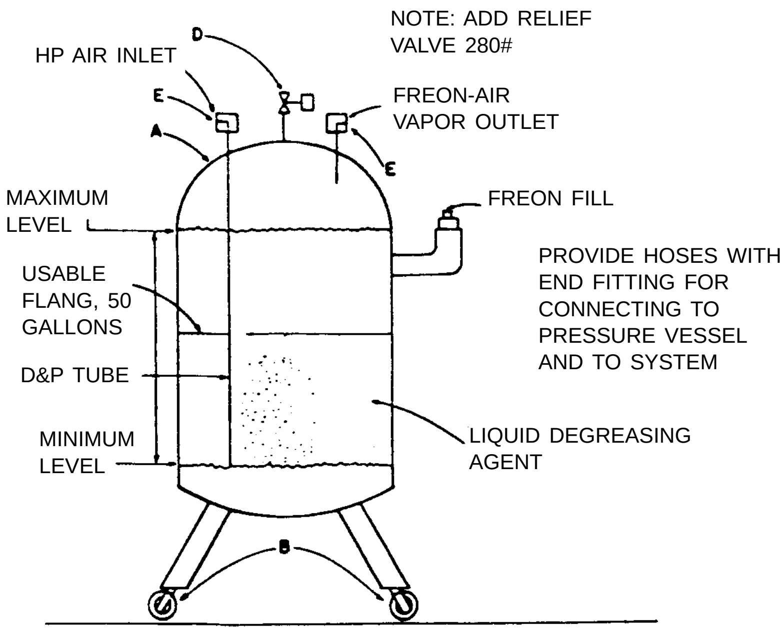
D. Pressure vessel—see Figure 8-2.

Figure 8-1. Connecting Piping for Vapor Degreasing of Control System Piping

Flushing Compound from the System

After degreasing compound has flowed through and been contained in the piping long enough to clean the system, the grease-containing compound must be flushed from the system by use of control air.

The air used after contaminants are removed must be the clean air obtained from Step 1. Although most of the compound will be flushed from the system by normal air "wastage" those points which required manual manipulation to get degreasing compound to flow into those points must be manipulated again to flush the oil-laden degreasing compound from the system.



BILL OF MATERIAL

A. Pressure vessel—60-gallon tank built to unfired pressure vessels code for 280#WWP with 3 legs for casters, 1/2″ IPS in and out.

B. Swivel plate casters, 6″ rubber wheels, Wagner #11F-3583-90 grease lube fitting.

C. Filler fitting, street filler 1-1/2″ x 2″ with pipe plug, 250# class.

D. Vent cock—1/2″ ball valve, Milwaukee model BB1-100.

E. Quick connect plug, FPT, Hansen 8200.

F. Hoses, Spiral braid, for R11, 1/2″ ID, 25' long.

Figure 8-2. Vapor Degreasing Pressure Vessel Construction Detail

Cleaning and Replacing Filters

After the system has been flushed, the control air filters must be cleaned or replaced to assure best results from the cleaning operation.

Control Instrument Operational Check

After the system has operated for at least a week after completion of cleaning, an instrument operational check must be performed.

In that operational check, each control device must be checked for calibration and proper operation. Where devices cannot be recalibrated or made to operate properly, they must be replaced.

At this time, at least one instrument finger filter, where such are installed, must be removed from the line and cut open for inspection. Remember that the media in a clean filter will be white, an oil-contaminated filter will be brown, and a carbon-contaminated filter will be gray.

ROUTINE TESTING FOR OIL CONTAMINATION

When required. In systems where oil lubricated control system air compressors are used, routine or periodic testing for oil contamination is required. Testing for oil contamination must be done at the central air supply location and at control locations throughout the system.

Checking for major oil contamination. When a major oil contamination episode has occurred, the pneumatic control tubing will actually have free oil inside. Testing can be done at low point drains and at instruments as described above. When clear plastic tubing is used for final connections at instruments, the oil may be visible in the tubing, giving the appearance of a U-tube manometer.

Oil-caused erratic operation. When only a small amount of oil has been carried into the piping system as an aerosol or mist, the aerosol may coalesce into droplets as it enters restrictions in area, such as restrictors or nozzles in controllers.

The oil will cause pressure variations as the restriction is alternately plugged and blown-out as the oil is pushed further along the system. The pressure variations will be reflected in unpredictable abnormal system operation.

Testing locations. The testing may be done at drain cocks provided in the tubing system or it may be done with oil testing ports installed at points in the system where oil might be expected to accumulate. An oil testing port is shown in Figure 8-3.

VERIFYING AIR PIPING SYSTEM INTEGRITY

Test procedure required

A test procedure to verify the integrity of control air piping system and control system wiring should be performed whenever excessive

Figure 8-3. Oil Testing Port (*Courtesy Johnson Controls*)

compressor operation indicates air leaks in the pneumatic tubing system or when checking calibration of pneumatic transmitters finds that a signal for a lower value of the controlled variable is being transmitted than was observed at the sensor location, which also indicates an air leak. When electrically controlled devices in the pneumatic system malfunction or fail to function, a check of the wiring system is indicated.

Air Distribution Piping System

Control system air piping is usually run in hard-drawn copper tubing or polyethylene tubing, either singly or in multiple parallel runs. Copper tubing is now used only where tubing is exposed to mechanical damage. Tubing which is concealed is often run in polyethylene (PE) plastic tubing.

Protection may be provided for PE tubing in exposed locations by using polyethylene tubing run in an electrical metallic tubing (EMT) system or in wireways with snap-on covers such as Panduit. This will often allow an entire system to be piped in plastic tubing.

Older systems piped in copper tubing usually had drip legs with drain cocks at critical points in the system. Newer systems which use refrigerated dehydrators may not have drip legs installed. Drip legs serve as oil-water traps and should be retrofitted into the main supply air line at each set of controls, with a manual drain cock.

The maintenance technician can make a periodic check, about monthly, for the presence of oil or water by opening the drain cock and blowing down onto a clean paper towel. When evidence of oil, water, or solid matter is found, the source must be identified and eliminated.

Checking for Minor Air Leaks

Air leaks cause inaccurate control system operation and must be identified and corrected. The general location of air leaks can often be found by listening for the tell-tale hiss of escaping air, even at 15 psig. Bleed-type control components make audible noise as they bleed air continuously in normal operation. Relay-type control components make audible noise only as they bleed air during the positioning sequence.

A hissing control device must be identified as to type and, when relay-type devices are found to be bleeding continuously, they must be repaired or replaced. The specific location of the leak may be immediately evident, or it may be necessary to check tubing joints using the bubble test with soapy water or with a leak detector applied from an aerosol can.

In concealed systems it may be necessary to install isolating and sectionalizing valves as described for major air leaks in order to determine the general location of air leaks.

The use of odorants in locating air system leaks must be avoided. The compounds formerly used as odorants have been found to sometimes cause illness in humans even at concentrations necessary to locate leaks by odor.

Checking for Major Air Leaks

Where major air leaks are suspected in pneumatic controls system air mains due to loss of air pressure, the system must be divided into section and a section-by-section test exercise must be performed. Sectionalizing valves may have to be added to the piping system.

To use sectionalizing valves in locating leaks, divide the system in half, such as right and left or near and far, then apply pressure test to each half. Determine which half of the system is leaking, then divide that part of the system in half, and repeat the exercise until the leak is located. Repair the leak or replace the defective portion of piping.

MAINTENANCE OF AUTOMATIC CONTROL SYSTEM AIR SUPPLY

Basic Requirements for Control Air

Maintenance of an automatic control system pneumatic control air supply system is planned to assure these four basic needs for control air:

1. Assure reliability of air supply by making the system free from breakdown.

2. Assure pressure of air supply by maintaining the compressor in proper working order with piston rings, shaft seals, valves, and other moving parts within proper tolerances.

3. Assure cleanliness of air supply by filtering makeup air at the compressor intake and by filtering air leaving the tank with a particulate filter in series with an oil filter.

4. Assure dryness of air supply by obtaining makeup air from the driest available source and then dehydrating high pressure air before pressure reduction.

System Reliability

System reliability applies to compressors, tanks, motors, motor starters, control devices, dehydrators, filters, and air distribution system.

The most common problems in system reliability stem from compressors and are lubrication related.

A common failure train is found when a system air leak occurs which is large enough to cause continuous compressor operation with no cool-down periods. As heat is generated in compression, the compressor builds up heat due to lack of off-time, and the lubricating oil heats up and loses its lubrication ability. Without lubrication, the compressor bearings and seals soon fail and cut into the rotating surfaces. Failures may occur in a single part or may progress to the point that the entire compressor requires repair or replacement after only one episode of overheating.

Bearing Temperatures

Motor and compressor bearing temperatures should be checked with a surface-reading thermometer during normal operation to establish baseline data on bearings before trouble occurs.

Motor Starters

Failure of electric motors due to burnout can be avoided by providing proper overcurrent and phase failure protection in motor starters. Motor starters may be thermal overload type manual switches on fractional hp single-phase motors or magnetic starters for large single-phase and three-phase motors.

The most common electro-mechanical starters are magnetic contactors with current sensing overload heater relays. Starters for 3-phase service may have overload heaters on only two phase legs. Should an excessive current flow occur in the unprotected phase leg, the motor can be damaged to the point of failure. An overload heater should be provided for the third phase leg. For 3-phase starters without phase-failure relays, retrofit current monitoring relays should be installed to open the starter contactor holding coil circuit on failure or reversal of any phase leg or under- or over-voltage of the electric service.

Maintenance operations for manual switches are:

1. Verify the proper overload heater rating for the motor size and ambient temperature.

2. Verify the security of wiring connections.

Maintenance operations for magnetic starters are:

1. Verify the proper overload heater ratings for the motor size and ambient temperatures of both the motor and starter.

2. Ensure smooth faces on current-carrying contacts. When rough contacts are found, either dress contacts in place with a burnishing tool or replace badly damaged contacts with a complete new set.

Control Devices

Compressor motor operation is controlled by a pressure switch sensing pressure in the air tank or receiver. Typical setpoints might be: cut-in at 70 psig to start compressor and cut-out at 80 psig to stop compressor. Compressors larger than about 15 hp may use solenoid unloader valves to relieve pressure in compressor to allow the next start to be unloaded.

Maintenance operations for controls include:

1. Verify settings of pressure control, test average off-time, adjust cut-in setpoint as needed to provide desired off-time.

2. Observe repeatability of cut-in and cut-out paints. Where control action is not repeatable, replace the pressure controller.

Dehydrators

Most pneumatic control systems installed in the past 25 years must have very dry air for proper operation. The water-cooled shell and coil aftercoolers used in older systems do not provide adequate moisture removal. A refrigerated dehydrator capable of cooling maximum system airflow rate to at least 10°F dew point is required. The most frequently used dehydrators are air-cooled refrigerated packages with an integral water drainer.

Maintenance operations for dehydrators include:

1. Ensure continuous electric service to the dehydrator.

2. Observe discharge from the water drainer to verify that the dehydrator is refrigerating the air. Take corrective action as required to make the dehydrator operate and provide dehumidification.

3. Assure a clean condensing coil. Provide an air filter cut from 1/2″ thick roll media to cover the air entering side of the air-cooled condensing coil. Change the filter regularly to assure adequate clean airflow.

Filters

Modem control systems require very clean air. Filters for particulates and oil vapor should be installed in the high pressure air line between the air tank and the pressure regulating valve, generally upstream of the dehydrator. The particulate air filter will trap particulates in sizes 5 microns and larger and the filter cartridge must be changed when pressure drop exceeds the manufacturer's recommended value.

Pressure drop testing can be done with pressure test ports on each side of the filter. The oil filter will trap oil in sizes 0.3 micron and larger and the coalescing oil filter must be changed regularly. Both filters may trap water droplets and must be fitted with drain outlets to allow manual draining of oil and water.

Maintenance operations for filters include:

1. Measure pressure drop across particulate air filter. When observed pressure drop exceeds value recommended by manufacturer, replace the filter element.

2. Measure pressure drop across coalescing oil filter. When observed pressure drop exceeds value recommended by manufacturer, replace the filter element.

SUGGESTED RETROFITS TO MAKE MAINTENANCE EASIER

System retrofits with low capital cost that can make maintenance work easier include:

1. Provide a documentation sticker at each adjustable component giving control set-up data. Some installing contractors routinely provide such stickers during initial installation. Provide a similar marking for spring range on each actuator.

2. Provide access ports on pneumatic receiver-controllers in main, sensor, and branch lines, either as Schrader valves or as needle-accessible resilient seals.

3. Provide a cock with tubing stub outlet on supply main in each control cabinet to allow connecting a plastic tube for simulating pressure inputs in calibration procedures.

4. Provide separate testing terminal strips in system control cabinets for each electrical terminal point with wiring connected back to the individual devices. By use of these test points, the status of each control device in the system can be determined, with analog values of voltage and digital indication for contact closure.

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Chapter 9

Maintaining Local Loop to BAS Interfaces

Building Automation Systems (BAS) may be Direct Digital Control Systems (DDC), Energy Management and Control Systems (EMCS), or Monitoring and Control Systems (MCS). Each of these is a centralized control system superimposed on the local control loop controlling a particular HVAC system. The BAS may range in complexity from a simple 10-channel system serving one building and costing several thousand dollars (Figure 9-1) to a multi-thousand-point minicomputer-based system serving hundreds of buildings and costing hundreds of thousands of dollars (Figure 9-2). In this book, we will refer to all these systems as BAS.

Definitions of Terms

Local loop controls—the ATC system for the HVAC system in the building.

BAS—the building automation system which serves the complex in which the local loop controls are located.

Interfaces—the points of connection between the local loop controls which serve the building HVAC systems and the BAS which serves the entire building or building complex.

Inputs and Outputs (AI, AO, DI, DO)—the signals which a BAS receives or transmits may be of analog or digital type, designated AI for analog input, AO for analog output, DI for digital input, and DO for digital output.

Figure 9-1. A 20-channel BAS (*Courtesy Honeywell, Inc.*)

Figure 9-2. A Minicomputer-Based BAS (*Courtesy Barber-Colman*)

BAS Actions

For the overall building complex, a BAS can overcall local loop control to provide special control programs, including:

- Scheduled start and stop of HVAC systems
- Optimum start-stop of HVAC systems
- Duty cycling of electric motor loads
- Demand limiting, electrical load shedding/restoring
- Day-night setback of space temperature
- Economizer cycle or "free" cooling
- Enthalpy control of cooling with outside air
- Ventilation and recirculation for warm-up and cool-down
- Hot deck/cold deck temperature reset
- Reheat coil temperature reset
- Boiler and chiller sequencing and optimization.

In this chapter, the term BAS is intended to include everything from the simplest energy management system (EMS), through the more complex energy management and control system (EMCS) and DDC systems to the most complex facilities management system (FMS).

An EMS usually provides time-of-day programming, duty-cycling, demand load control, and space temperature monitoring and alarm functions for HVAC systems in a building or group of buildings with about 40 control points as a maximum.

An EMCS provides centralized control of the HVAC systems in a building or a building complex with similar software-based control strategies including scheduled start-stop, optimized start-stop, duty cycling, demand limiting, day-night setback, economizer changeover, enthalpy changeover, ventilation and recirculation, hot deck and cold deck temperature reset, reheat coil temperature reset, steam boiler optimization, hot water outside air reset, chiller optimization, chilled water temperature reset, condenser water temperature reset, chiller demand limit, lighting control, remote boiler monitoring and supervision, maintenance management, and trend logging.

A BAS may include fire and smoke detection and building security functions as well as the energy related functions. When a BAS includes management functions, such as budgeting, cost accounting, and a building maintenance program, it may be called a facilities management system (FMS). Each system is custom designed for the specific application and will include only those functions deemed to be required for that particular site.

Control Imposed by BAS on Local Loop Controls

As mentioned above, a BAS may have many functions that will impose control on the local loop control system. Two types of analog controls which may be utilized in the applications software function are:

Control point adjustment (CPA) is implemented by using an AO or DO in conjunction with an AI signal from the sensed media to achieve changes in operating setpoints via a CPA port on the controller.

Position adjustment is implemented by using AO or DO in conjunction with AI signal from the controlled device to close the control loop.

BAS FUNCTIONS

Daily Start-Stop and Cycle Selection

The scheduled start-stop program consists of starting and stopping HVAC system equipment on a programmed schedule based on the time of day and day of week. This program provides energy conservation by turning off equipment or systems during unoccupied hours.

In addition to sending a start-stop command, it is important, although not mandatory, to have a feedback signal indicating the status, whether on-off or open-closed, from the controlled equipment. The feedback signal verifies that the start or stop command has been carried out and provides the BAS operator with an alarm in the event of equipment failure or when the equipment is locally started or stopped. Scheduled start-stop is the simplest of all BAS functions to implement.

Optimum Start-Stop

The optimum start-stop program is a refinement of the scheduled start-stop program described above, refined by automatically adjusting the equipment operating schedule on the basis of space temperature and outside air temperature and humidity. In the scheduled start-stop program, HVAC systems are restarted prior to occupancy to give enough time to cool down or heat up the space on a fixed schedule without regard for space and outside temperatures.

The optimum start-stop program automatically starts and stops the system on a sliding schedule. The program calculates precool or prewarm times required with prevailing indoor and outdoor temperatures by using the predictor-corrector technique, taking into account the thermal inertia of the structure, the capacity of the HVAC system to either increase or reduce space temperatures, and current space temperatures and OA conditions.

This accurately predicts the minimum time for HVAC system operation prior to start of the occupied cycle to just meet the space environmental requirements and to determine the earliest time for stopping equipment at day's end without losing control of space environmental conditions.

Duty Cycling

Duty cycling is defined as the shutting down of equipment for predetermined short periods of time during normal operating hours. This function is usually applied only to HVAC systems. Duty cycling operation is based on the fact that HVAC systems seldom operate at peak design conditions.

When a system is shut off for a short period of time when not at full design load, there is enough excess capacity to overcome the temperature drift which occurs during the shutdown period. Although the interruption may not significantly reduce the energy requirements for space heating or cooling, it does reduce energy inputs to auxiliary loads such as fans and pumps.

To the extent that duty cycling reduces the volume of outside air introduced by closing an outside air intake damper under local loop control while the air handling unit is "off," heating and cooling loads will also be reduced. Air handling systems may be cycled "off" for some maximum period of time, typically 15 minutes out of each hour of operation. The "off"-time period and its frequency must be program-adjustable so that "off"-times are decreased when space temperature conditions are not satisfied or increased when space temperature conditions remain satisfied.

The program must provide operating schedules for different classes of equipment. When the duty cycling program is used in conjunction with the demand limiting program it is necessary to interlock the "off" time period for each piece of equipment to prevent starting and stopping of equipment in excess of what is recommended by the manufacturer or appropriate standard such as NEMA

Standard MG-1 for electric motors.

When space temperature and humidity conditions cannot be maintained during the duty cycle "off" period with equipment shut down, the program may provide a fairness doctrine which will cause temperatures in all areas to deviate equally from established comfort levels, when necessary. Each particular priority group is programmed on a "first-off, first-on" basis. In that program, after a load has been the first to be turned off or shed in a group, it is turned back on or restored first and then moved to last in the group. The second load then becomes next to be shed and restored.

The duty cycling program may be used in conjunction with demand limiting, scheduled start-stop, and optimum start-stop programs. Duty cycling is not advisable for variable capacity loads, such as variable volume fans, chillers, or variable capacity pumps. For unitary apparatus without a variable output cooling section, it is usually desirable to duty cycle the cooling section only while leaving the fan in operation.

Demand Limiting

The demand limiting program consists of shedding electrical loads to prevent the electrical system metered kW demand from exceeding a peak value which has been programmed as a target. This is intended to keep system operation from setting a new maximum electrical demand. When utility rates have a separate demand charge, and the demands are "ratcheted," exceeding the targeted kW demand value can cause an increase in billings for electrical demand charges for a year. Metering of kW demand values may be established by the utility company using fixed demand intervals, sliding window intervals, and time of day schedules.

Many complex demand limiting and reducing programs have been devised. Those programs may continuously monitor power demand and calculate the rate of change of the demand value in order to predict future peak demand using predictor-corrector techniques. When the peak demand is predicted to exceed the targeted value or other preset limits, predetermined scheduled electrical loads are shut off on a prescheduled priority basis to reduce the connected load before the peak is exceeded.

The most commonly shed loads are HVAC systems. When space conditions cannot be maintained, the program provides a routine which causes temperatures in all areas to deviate equally from established comfort levels in allocating available HVAC capacity. Within a particular priority group, the load shedding order is changed by the program so that after a load was first to be shed in a group, it will be moved to last in the group and another load will become first.

The demand limiting program is used in conjunction with the duty cycling program in order to prevent any one load being cycled on or off during the wrong time interval or for an excessive number of times. The demand limiting program is also used in conjunction with scheduled start-stop, optimum start-stop, and chiller optimization programs.

Day-Night Setback

The cooling or heating energy required for the conditioned spaces during unoccupied hours is reduced by raising the cooling cycle temperature setpoints or lowering the heating cycle temperature setpoints. This program may also be programmed to close outside air dampers and shut down associated exhaust fans during unoccupied hours to avoid additional thermal loads for ventilating air. This program may not be applicable to facilities which operate 24 hours per day.

The day-night setback program operates in conjunction with the scheduled start-stop and optimum start-stop programs. Space temperature sensors must be located to preclude space temperature dropping below freezing during the night setback period.

Economizer Cycle

The use of the economizer cycle in air conditioning systems can be a cost-effective conservation measure, depending on climatic conditions and the type of mechanical system. An air-side economizer cycle utilizes outside air (OA) to reduce the building cooling requirements when the OA dry bulb temperature is less than the required mixed air temperature. A water-side economizer cycle utilizes an evaporative liquid cooling system, such as a cooling tower, to cool chilled water for circulation through the normal chilled water system to reduce the building cooling requirements when the OA wet bulb temperature is about 5° to 8°F lower than the required chilled water air temperature.

The air-side economizer changeover temperature is based on the OA dry bulb temperature. When the OA dry bulb temperature is above the changeover temperature, the outside air dampers, return air dampers, and relief air dampers are positioned to provide minimum required outside air. When the OA dry bulb temperature is below the changeover temperature, the OA, return air, and exhaust/relief air dampers are positioned to maintain the required mixed air temperature. This is similar to the enthalpy cycle changeover, discussed below, where the changeover point is determined by the total heat content of outside air compared to that of return air.

The water-side economizer changeover temperature is based on the OA wet bulb temperature. When the OA wet bulb temperature is above the changeover temperature, the water-cooled chiller operates to provide chilled water. When the OA wet bulb temperature is below the changeover temperature, the cooling tower water is diverted from the condenser to flow either directly into the chilled water piping system or to the low temperature side of a heat exchanger in the chilled water circuit. Chilled water coil controls function in a normal manner.

This economizer cycle program cannot be used where humidity control is required, or when the air-side economizer is to be controlled by the enthalpy cycle program.

Enthalpy Cycle

The enthalpy changeover cycle program for air-side economizer systems can be a cost-effective energy conservation measure, depending on climatic conditions and the type of mechanical system. The enthalpy changeover cycle uses OA to reduce the building's cooling requirements when the total heat content, or enthalpy, of outside air is lower than the enthalpy of the return air.

When the OA enthalpy is less than the return air enthalpy, the OA and return air dampers are allowed to modulate under local loop controls to admit sufficient OA to minimize cooling requirements and to relieve the unused return air by exhausting to outdoors. During the period when the OA dry-bulb temperature is greater than the required supply air dry-bulb temperature, the mechanical cooling system will be required to operate to maintain supply air conditions. When the OA enthalpy is greater than the return air enthalpy, the outside air dampers, return air dampers, and relief air dampers are repositioned to provide the required outside air volume and the system operates on mechanical cooling.

The enthalpy cycle is not to be used when a dry bulb changeover program is used for air-side economizer program control.

Ventilation and Recirculation

The ventilation and recirculation program controls the operation of the OA dampers when the introduction of OA would impose an additional thermal load during warm-up or cool-down cycles prior to occupancy of the building. This program is particularly useful in those facilities which must maintain environmental conditions such as electronic equipment installations during building unoccupied periods.

During unoccupied periods, the OA dampers remain closed. During building occupied cycles, the OA, return and relief/exhaust dampers are under local loop control. During cooling season operation, when the OA temperature is cooler than the space temperature, the OA and relief/exhaust air dampers are opened, and the fans are energized. During heating season operation, when the OA temperature is warmer than space temperature, the OA, return air, and relief/exhaust air dampers are allowed to modulate under local loop controls to admit sufficient OA to minimize heating requirements and to relieve the unused return air by exhausting to outdoors.

During the period when the OA temperature is greater than the required supply air temperature, the mechanical cooling system will be required to operate to maintain supply air conditions. On systems with enthalpy sensing, when the OA enthalpy is greater than the return air enthalpy, the OA dampers, return air dampers, and exhaust/relief air dampers are repositioned to provide minimum required outside air.

The ventilation and recirculation program operates in conjunction with scheduled start-stop and optimum start-stop programs prior to building occupancy.

Hot Deck and Cold Deck Temperature Reset

The hot deck and cold deck temperature reset program is applied to parallel path systems, such as dual duct and multizone HVAC systems, which utilize a parallel arrangement of heating and cooling surfaces, commonly referred to as hot and cold decks, for producing cooling and heating in the system at the same time.

Air in the cold deck is often cooled by chilled water coils with unregulated water flow or by mixed air section economizer temperature control to maintain the lowest required supply air temperature at all times.

Air temperature leaving the hot deck is often controlled from an averaging bulb sensor with a temperature controller reset from outside temperature.

Cold air and hot air streams from the respective decks are combined in mixing boxes or zone mixing damper plenums to satisfy the individual space temperature requirements. Without any means for controls system optimization, these systems mix the two air streams to produce the desired temperature. When the space temperature is acceptable, a greater difference between the temperatures of the hot and cold decks results in inefficient system operation.

The hot deck and cold deck temperature reset program compares input data, determines which areas have the greater heating and cooling requirements, then computes the optimum values of the coolest hot deck air and the warmest cold deck air temperatures which will meet the space requirements. Those optimized cold deck and hot deck temperatures give the lowest energy inputs when the cold deck and hot deck air streams are mixed. Air stream mixing is unavoidable in parallel path systems.

Program inputs from space temperature sensors and mixing box or plenum damper position sensors are used to determine the minimum and maximum deck temperatures necessary to satisfy the space temperature requirements. Where humidity control is required, the program will prevent the cooling coil from further upward cooling coil control when the space humidity setpoint is reached.

This program operates in conjunction with scheduled start-stop and optimum start-stop programs prior to building occupancy.

Reheat Coil Reset

The reheat coil reset program applies to terminal reheat systems which are designed to operate with a constant cold deck discharge temperature. Air supplied at temperatures below the individual space temperature requirements is elevated in temperature by reheat coils in response to the individual space temperature controls.

The reheat coil reset program selects the reheat coil with the lowest discharge temperature requirement, determined as the coil having the valve nearest to closed position, which indicates the lowest amount of reheat required, and resets the cold deck temperature upward until it reaches the supply air temperature required by the zone with the least demand for reheat.

Where humidity control is required, the program will prevent the cold deck temperature being reset upward past the point at which the maximum allowable humidity is reached. For air conditioning systems without reheat coils, the program will reset the cooling air temperature upward to that point where the space with the greatest cooling requirement is just satisfied.

Boiler Plant Optimization

The boiler optimization program is implemented in heating plants with multiple boilers. Optimization of boiler plants is accomplished through the selection of the most efficient boiler or combinations of boilers to satisfy the heating load. Boiler operating data must be obtained from the manufacturer, or developed by monitoring fuel input as a function of heat output.

Determination of steam boiler efficiency must also take into account the heat content of condensate return and make-up water.

Based on the efficiency curves, fuel input vs. heat output, the boilers with the highest efficiency can be selected to satisfy the heating load. Boiler plant may be energized manually by a boiler operator or automatically by BAS, depending on site requirements. Burner operating efficiency is monitored by measuring the O_2 or CO in each boiler flue. Care must be observed in programming automatic start-stop of boiler plant instead of operator supervised startups.

Chiller Plant Optimization

The chiller plant optimization program is implemented in chilled water plants with multiple chillers. Based on chiller operating data and the energy input requirements obtained from the manufacturer for each chiller, the program will select the chiller or chillers required to meet the load with minimum energy consumption.

When the chiller plant is started on a warm start, the chilling capacity must be held back to prevent the system from going to full load. The plant is held back for a predetermined period which is selected to allow the system to stabilize and allow the actual cooling load to be determined.

Comparison of trend logs for equipment operating characteristics can allow the operator to determine when heat transfer surfaces in evaporators and condensers are fouled and require cleaning to maintain the highest efficiency.

The program must follow the manufacturer's requirements for startup and shutdown sequences. Interlock circuits between chilled water pumps, condenser water pumps, oil pumps, and chiller must be wired in accordance with the requirements of the chiller manufacturer. Chillers may be started automatically by the BAS or manually by the chiller operator depending on the site requirements.

Chilled Water Temperature Reset

A principal determinant of the energy required to produce chilled water in a reciprocating or centrifugal refrigeration machine is the temperature of chilled water leaving the evaporator. The refrigerant suction temperature is directly related to the chilled water temperature: the higher the leaving chilled water temperature, the higher the suction temperature, and the lower the energy input per ton of refrigeration.

Chiller discharge water temperature is selected for peak design times; therefore, chilled water temperatures can be set upward during non-peak design operating hours to the highest value which will still satisfy space cooling and humidity control requirements.

The program resets chilled water temperature upward until the required space temperature or humidity setpoints can no longer be maintained. This determination is made by monitoring space temperature and relative humidity values or by monitoring positions of the chilled water valves on various cooling coils in the system.

Condenser Water Temperature Reset

Another determinant of energy required to produce chilled water in water-cooled condenser systems is the temperature of the condenser water entering the chiller. Heat rejection systems are designed to produce a specified condenser water temperature, such as 85°F, at peak wet bulb temperatures. Chiller units are designed to require a given condensing temperature in order to cause refrigerant flow at full load. In order to maximize the energy performance of the refrigeration systems, condenser water temperature is reset downward when OA wet bulb temperature will produce lower condenser water temperature. The minimum water temperature must be limited to meet the chiller manufacturer's requirements for minimum condensing temperature at a specific increment of capacity.

The program resets condenser water temperature downward by either operating cooling tower fans, opening cooling tower dampers, positioning cooling tower bypass valves, or a combination of these methods.

Chiller Demand Control Unit

Centrifugal water chillers are normally factory equipped with an automatic control system which can be adjusted to limit the maximum available cooling capacity and thus limits the power the machine can use. An interface between the BAS and the chiller controls allows the program to reduce the maximum available cooling capacity in several fixed steps in a demand limiting situation, thereby limiting the electrical demand to an acceptable value without completely shutting down the chiller.

The method of accomplishing this function varies with the chiller unit manufacturer. A nominal chiller percent capacity value is obtained by monitoring the chiller current input. When a chiller is selected for demand limiting, a single step signal is transmitted, reducing the chiller limit adjustment by a fixed amount. The chiller demand limit adjustment is performed by changing output taps of control power transformers or by resetting the control air pressure to the chiller compressor vane operator.

As further need arises, additional step signals are transmitted until the demand limiting situation is stabilized. Extreme caution must be exercised when applying this program, since incorrect capacity step control can cause the refrigeration machine to operate in a surge condition, which may result in considerable damage. The chiller manufacturer's recommended minimum cooling capacity limit must be incorporated into the program logic. In general, surge conditions will occur in centrifugal compressors at loads less than about 15 percent of the rated capacity.

INTERFACE DEVICES

Electric Relays

Electric control relays may be the enclosed dry contact type with silver-plated contacts rated for about 5 amperes at 240 volts (Figure 9-3). Available relay actions are single-pole-single-throw (spst), double-pole/double-throw (dpdt), or multipole/multiple-throw. Delay relays are available with timed-opening or timed-closing contacts. Electric-pneumatic (EP) relays are essentially solenoid air valves with normally open, normally closed, and common ports used to connect air supply to a system or to disconnect air supply from a system and exhaust the pressure to atmosphere (Figure 9-4).

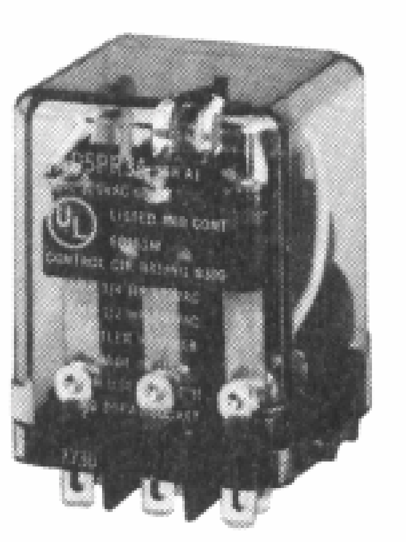

Figure 9-3. Electric Control Relay (*Courtesy Cutler-Hammer*)

Figure 9-4. Electric Pneumatic Relay (*Courtesy Johnson Controls, Inc.*)

Transducers

Transducers are electronic devices which transduce, or convert, a control signal of one type to a proportional signal in a system of another type (Figure 9-5). Transducer types include:

Electronic to pneumatic, 2-position and modulating—An electronic signal, such as 1 to 15 volts, is converted to a pneumatic signal either "on" or "off" or proportional in the system air pressure range.

Pneumatic to electric resistance—A pneumatic signal of 3 to 15 psig, or other system range, is converted to an electric resistance signal to suit the receiving system, such as 135 ohms slide wire for use with electric systems, or 1,000 ohms for use with electronic systems.

Pneumatic to electrical voltage—A pneumatic signal of 3 to 15 psig, or other system range, is converted to an electric voltage signal to suit the receiving signal, such as 1 to 5 vdc or 1 to 15 vdc.

Duct pressure to electrical amperage or voltage—A duct pressure signal of as low as 0.005" wc, such as is provided by a static pressure sensing station, is converted to a 4-20 mA 2-wire output or a 0-5 vdc or 0-10 vdc voltage output, as required as an input signal to a variable frequency drive or to damper actuators (Figure 9-6).

Damper Position Indicators

Potentiometer devices are connected by linkage to the damper actuating mechanism to give an analog output proportional to the damper position (Figure 9-7).

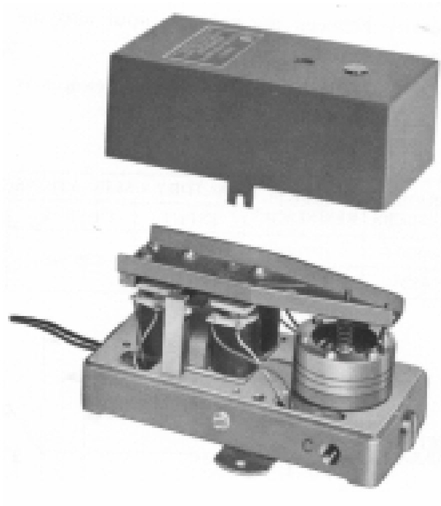

Figure 9-5. Electro Pneumatic Transducer (*Courtesy Johnson Controls, Inc.*)

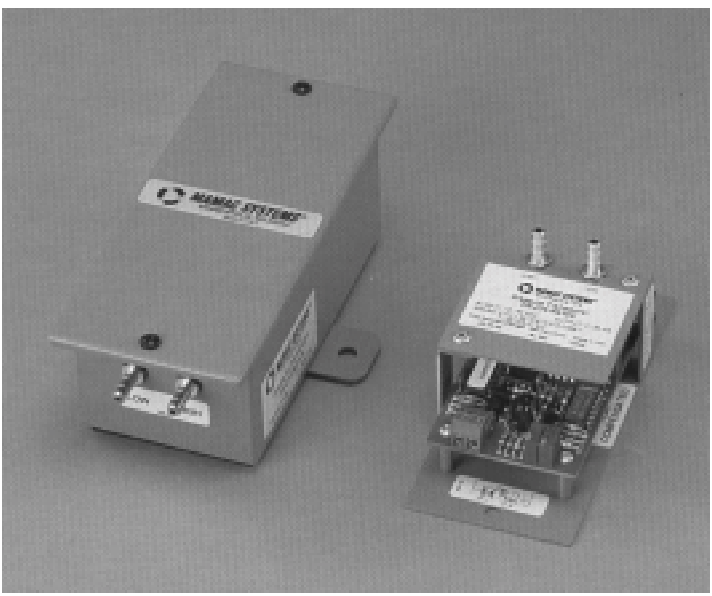

Figure 9-6. Pneumatic Set Point Control (*Courtesy Mamac Systems*)

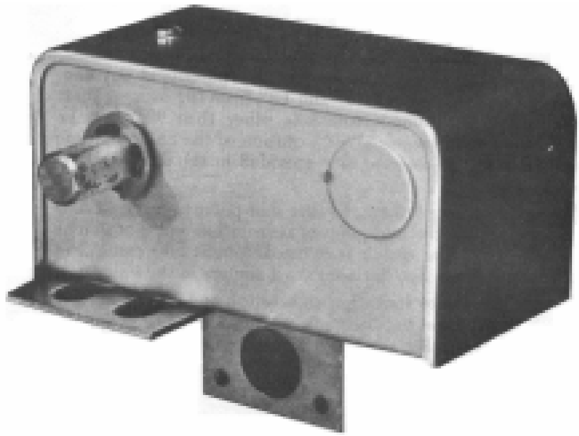

Figure 9-7. Damper Position Indicator (*Courtesy Robertshaw Controls Co.*)

INTERFACE METHODS

Motor Starting and Controls Energization

Electric motors on equipment and control sequences on HVAC components, such as boilers and chillers, are energized by electric relays interposed in the starting circuit wiring of magnetic starters or in the on-off controls for other items (Figure 9-8). An input signal from the BAS will start or stop the motor or energize or de-energize the controls. Care must be exercised in connecting interface devices to avoid bypassing equipment safety controls wired into the starting circuit.

Remote Setpoint Reset, Electric-Electronic Controller

The remote setpoint adjuster device is connected to the BAS and to the control point adjustment terminals of the controller (Figure 9-9). An input signal from the BAS will cause the setpoint to be adjusted upward or downward within the limits established by the hardware or by the program.

Remote Setpoint Reset, Pneumatic Controllers

The remote setpoint adjuster device is connected to the BAS and to the control point adjustment port of the controller (Figure 9-10). An input signal from the BAS will position the manual transmitter to cause

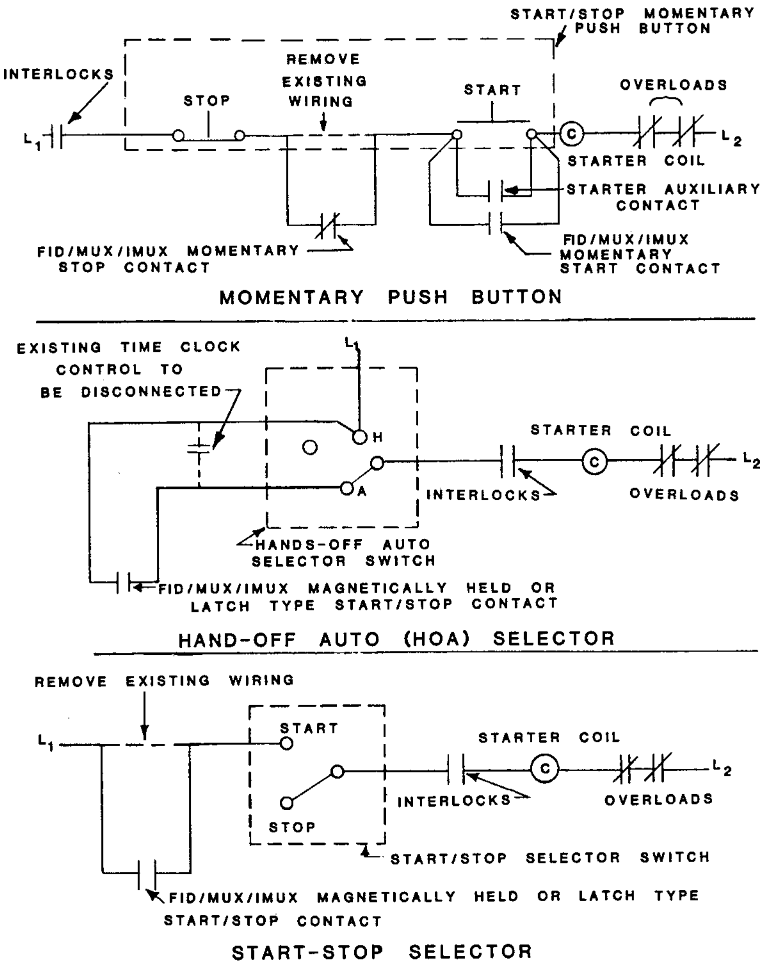

Figure 9-8. Typical BAS Starter Interfaces

the setpoint to be adjusted upward or downward within the limits established by the hardware or by the program.

Electrical Demand Measurements

The electrical demand measurements required by the demand limiting program may be done in several ways, depending on the electrical utility serving the building. The simplest system uses a pulsed signal from the utility's demand meter which can be interpreted by the BAS

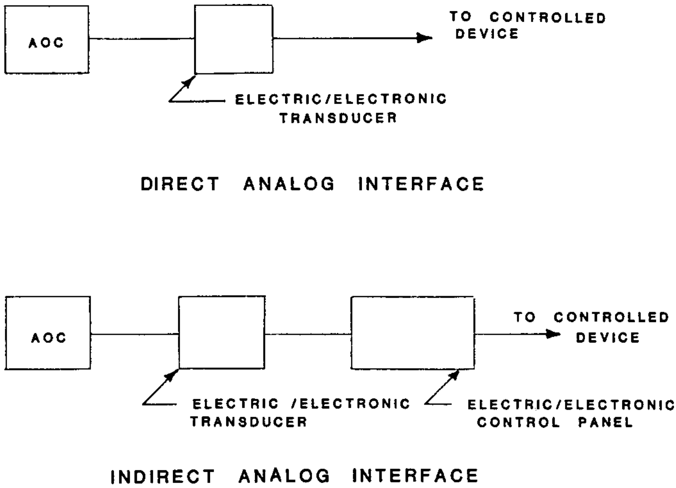

Figure 9-9. Typical Analog Electric/Electronic BAS Interfaces

and used to obtain the demand value targeted as the maximum. Other systems will utilize current transformers and potential transformers on the incoming electric service to the building which are connected either directly or through a watts transducer to the BAS.

Enthalpy and Temperature Measurements

The measurement of enthalpy or total heat content of air is a difficult task to perform accurately and repeatedly. The most common systems used to be wetted sleeves on temperature sensors to give wet bulb temperature readings. A number of relative humidity sensors have been developed which operate on various physical principles, such as measuring the electrical resistance of salt solutions, measuring the resistance of carbon particles contained in a hygroscopic envelope, measuring the capacitance of a thin film element, or measuring the opacity of a chilled mirror for dew point readings.

Dry-bulb temperature measurements are made with conventional electronic sensors such as resistance temperature detectors (RTDs), Balco resistance elements, or thermistors. The first two devices are stable over long periods and are preferred for use in BAS. The input signals from the enthalpy and temperature measuring devices may be conditioned before connection to the BAS.

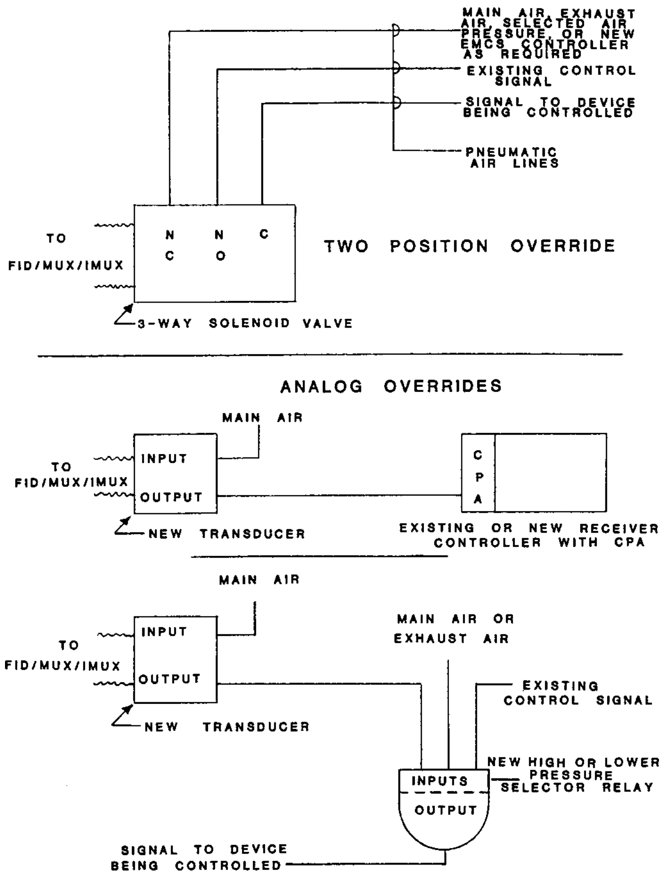

Figure 9-10. Typical Pneumatic Control BAS Interfaces

Damper Position Indication

Some programs require a feedback signal from the dampers being positioned by the BAS. A damper position indicator is attached to the damper linkage so that the same rotary motion is performed on the damper position indicator as is performed on the damper itself. The input signal to the BAS is an electrical resistance value which is calibrated to give damper position indication.

Boiler Operation Monitoring

The method for obtaining inputs to the BAS will vary with boiler plants.

Steam pressure indication is obtained using pressure transducers to generate an electrical resistance signal. Heated water temperature in hot water boilers is measured by a temperature measuring device such as an RTD. Boiler burner capacity indication may be obtained from a damper position indicator, connected to the linkage controlling the fuel valves and combustion air dampers, to provide an electrical resistance signal which is calibrated to give percentage of full fuel input to the burner.

Alarm circuits may be provided for emergency conditions, such as over-pressure in steam boiler, over-temperature in hot water boiler, fuel gas over- or under-pressure, low liquid fuel level, or burner flame failure.

Chiller Demand Limiting

The electrical demand on water chilling units may be controlled by a demand limiting switch in the chiller control panel or by an electrical resistance device interposed on the chiller control circuitry. On signal from the BAS, the demand limiting device is positioned to prevent the compressor drawing power beyond what electrical demand can be used without establishing a new demand peak for utility billing purposes.

Remote Temperature Monitoring

Temperature monitoring in the occupied space or on equipment such as boilers, chillers, and cooling or heating coils may be performed by using temperature measuring devices similar to the outside air measuring devices. The signals to the BAS may be used for trend logging, optimized start-stop program, or alarms for space high-limit or low-limit temperatures.

TROUBLESHOOTING EMCS TO LOCAL LOOP INTERFACE PROBLEMS

Determine the Current BAS Condition

The first step in troubleshooting is to determine what the BAS is calling for the controls to do. In facilities with a central BAS operating center, the control technician may call the BAS operator and receive a complete summary of the current BAS condition. For other systems, the control technician must go to the BAS panel and determine from the panel what the current BAS condition is.

Some panels may have indicator lights to show the current "on-off" condition of each output channel. Others may have to be polled from the BAS keyboard to determine the current BAS condition.

Determine BAS Failure Mode for Each Sequence

The BAS documentation should include an I-O summary in either tabular form or noted on the drawings. I-O summaries should explain the failure mode for each point. After determining the design intent for failure mode, it is advisable to verify the failure mode by asking the BAS operator to simulate a failure from the BAS console or to make a temporary field change to disconnect the wiring connections at the control component for long enough to determine the failure mode.

The failure modes usually include: "fail on," "fail off," or "fail to last command."

Determining BAS Sequence for Local Loop Override

The BAS documentation will usually include connecting diagrams and narrative descriptions of operation which detail the BAS sequence of operation for local loop override control. The local loop control system documentation should have been revised to "as built" when the BAS was installed to show the actual wiring connections for the BAS interfaces and to include a narrative description of the override sequences.

If the documentation was not so revised, it will be necessary to examine the actual interface devices, and make schematic diagrams of the internal circuitry of the interface devices and the electrical wiring and pneumatic tubing connections from and to the interface devices. With those diagrams and the original local loop control documentation, the control technician can trace the control system logic through the diagrams and determine the BAS sequence for local loop control override.

Correcting BAS Interface Problems

After the local loop control to BAS interface connections and sequences have been determined, the next step is to determine which devices are not functioning properly. This is done by predicting the output from the interface device, measuring the analog output value or checking the digital output status as "on" or "off," simulating the BAS signal to the local loop controls, verifying the proper operation of the local loop controls, determining which component is malfunctioning, and repairing or replacing the malfunctioning component.

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Chapter 10

HVAC Control System Checkout Procedures

This chapter presents procedures for use in checking out automatic temperature control (ATC) systems. These procedures may be used in commissioning new systems at time of building acceptance or as routine procedures to be used when existing control systems are to be recommissioned after modifications or to restore a poorly operated and maintained system to operation in accordance with the design intent.

This chapter is based on the assumption that a new ATC system installation has been completed and set up in accordance with the control system documentation. Documentation for existing systems must be corrected to "as built" or "as modified" and the system setup parameters must be rejustified in accordance with the current HVAC loads and modes of operation before performing the work of this chapter.

PLANNING CONTROL SYSTEM CHECKOUT

The checkout of an ATC system must be organized to assure that the appropriate tools and fixtures are available, that up-to-date controls system documentation is available, that equipment data sheets with calibration procedures for each control component are available, and that the control system technicians who are to perform the checking-out are properly trained.

Before beginning field work, a checkout form should be prepared for each component in the system, with specific data for that component. A set of checkout forms should be assembled in a booklet for each system. Each component will have a checkout form with a checklist and boxes to record test data.

CHECKING OUT THE PNEUMATIC CONTROL SYSTEMS

Checkout Procedures

A pneumatic control system may be divided into three principal parts for the check out procedure:

1. Control system air supply, including air compressor, dehydrator and filters, and air distribution system.

2. Controllers, including thermostats, humidistats, pressurestats, receiver-controllers, and transmitters.

3. Controlled devices, including actuators and relays.

Checkout Procedure for Control System Air Supply

Installation. Verify that installation has been completed and that all components are connected properly.

Air compressor. Verify that air compressor or compressors have been lubricated and are ready to run. Observe compressor crankcase oil level.

Control air receiver. Verify that control air receiver has a properly sized and rated safety relief valve. Perform a manual trip test of the relief valve and observe pressure lost in 1 minute; check for proper reseating.

Pressure controls. Verify appropriate settings of the air pressure control switch for cut-in and cut-out points. Observe several cycles and record running time and off time. Adjust or replace the pressure switch as required to provide desired pressure range and running time.

Air filters. Verify that the particulate air filter and coalescing oil filter elements are in place. Perform manual operation of drain valves under filter bowls and observe output.

Dehydrator. Verify that the dehydrator unit is operating, that the condensing coil intake filter is installed, and that electrical service is adequately labeled and secured to prevent unintentional disconnection of the dehydrator.

Checkout for Controllers

Controller calibration. Verify controller calibration by predicting controller output as described in Chapter 6. Predict performance of pneumatic control systems, then perform calibration checks. Connect testing apparatus, when required, and observe output pressure at the calibration point. If output pressure is not as predicted, recalibrate the controller as recommended by the manufacturer, when required.

Transmitter calibration. Verify transmitter calibration by reading the condition of the sensed medium, such as temperature, humidity, or pressure, and comparing predicted value of output pressure with actual value.

Controller set-up. Verify that the controller is set up with parameters such as TR, authority, and setpoints, as required in the control system documentation. Simulate control inputs with manual transmitters and a precision gauge, and observe controller output pressure. For dual-input controllers, use dual manual transmitters and gauges.

Controller output. Verify that controller output is as required in the documentation. Observe output pressure over full throttling range, including calibration point.

Checkout for Controlled Devices

Input signal. Verify input signal to each controlled device. Observe pressure at the inlet to the controlled device.

Normal position. Verify normal position of that controlled device to be as required by documentation. Observe the position of the controlled device with zero pressure input signal. That position is the "normal" position of the device.

Actuator spring range. Verify the spring range of actuators. Observe input signal pressure with gradual transmitter and precision gauge and compare with actuator motion for starting and stopping.

Controlled device motion. Verify proper motion of damper or valve linkage. Observe motion when the input signal is varied through full range. Simulate input pressure with a manual transmitter and precision gauge.

Controlled device positioning. Verify proper positioning of dampers or valves. When the input signal calls for full range of movement, observe damper or valve position. Adjust linkage as required to produce full range of movement between fully open and tightly closed.

Relay settings. Verify setting of limiting relays or minimum positioning relays. Observe the position of the actuator when control input is below minimum setpoint. Adjust the relay to produce required minimum actuator position. Mark the relay dial accordingly. For limiting relays, perform this procedure to observe output pressure of the relay when pilot pressure is below the minimum or above the maximum setting.

P-E switch settings. Verify setting of pneumatic-electric switches. Simulate input pressure with gradual input pressure with gradual transmitter and precision gauge. Observe cut-in and cut-out points of switches. Compare them with the required cut-in and cut-out point required by documentation. Adjust switch setpoints accordingly.

Operation of ratio and reversing relays. Verify proper operation of ratio and reversing relays. Simulate input or pilot pressure with gradual transmitter and precision gauge. Observe output pressure with precision gauge. Make observations of output pressure with various input pressure: 0%, 25%, 50%, 75%, and 100% input pressure. Adjust the relay to produce the required output pressure profile.

Operation of switching relays. Verify proper operation of switching relays. Simulate pilot pressure with manual transmitter and gauge. Observe pressure at which the common port is switched from normally open port to normally closed port on an increase in pilot pressure. Decrease pilot pressure and observe the point at which the common port is switched back to normally open. Record switching point pressure and differential pressure.

Operation of averaging relays. Verify proper operation of averaging relays. Simulate two input pressures with manual transmitters and gauges. Set one input pressure in low range and the other pressure in high range with normal supply main pressure, and observe output pressure. Compare observed output pressure with an arithmetic average of two input pressures. When output pressure is not within 0.5 psi of average of input pressures, replace the relay.

Operation of bias ratio relays. Verify operation of bias ratio relays. Simulate pilot signal with manual transmitters and gauges. Observe output pressure for delayed start to where output remains zero until pilot signal increases to bias pressure setpoint, then increases by ratio of relay. The ratio may be 1:1, where output pressure increases psi for psi with pilot pressure, or 1:2, where output pressure increases 0.5 psi for each 1 psi increase in pilot pressure. Adjust the bias setpoint as required. If setpoints are not stable and repeatable, replace the relay.

Operation of pressure selector or discriminator relays. Verify operation of pressure selector or discriminator relays. Provide caps or jumpers as recommended for unused ports. Simulate two input pressures with manual transmitters and gauges. Set one input pressure in low range and the other pressure in high range with normal main pressure, and observe output pressure. Make one test for each input. Compare output pressure with input pressures and determine that the relay is selecting higher or lower input pressure and switching to output as required by documentation. If selection is not consistent, replace the relay.

Operation of pilot or positive positioning relays. Verify operation of pilot or positive positioning relays. Simulate pilot pressure from the controller with manual transmitter and gauges with normal main pressure. Observe output pressure as pilot pressure increases and assure that output pressure begins to increase when pilot pressure reaches setpoint. Adjust setpoint as required by documentation. If the starting point is not stable or if output pressure is not consistent, replace relay.

Operation of transducers. Verify proper operation of pneumatic-to-electric and electric-to-pneumatic transducers. For pneumatic-to-electric, simulate pilot pressure from the controller with manual transmitter and precision gauge. For electric-to-pneumatic simulate input signal with decade box or fixed resistance. Observe output in ohms, volts dc, milliamperes, or psig as appropriate to the device. Predict output values for various input pressure values. Compare observed output values with predicted output values. If observed output values are more than 7% different from predicted output values, replace transducer.

CHECKOUT OF ELECTRONIC CONTROL SYSTEMS

Electronic control systems may be divided into four principal parts for the checkout procedure as follows:

1. Power supply and wiring system.
2. Sensors.
3. Controllers, including adapters.
4. Controlled devices, including actuators and relays.

Checkout Procedure for Power Supply and Wiring System

Power supply requirements. Verify requirements for power supply to control system. Review control system documentation and determine points where power supply to the system is required, electrical characteristics of each supply point, requirements for filtered and regulated power.

Power supply installation. Verify that power supply to system is as required. Assure that 120-volt power supplies are properly protected with circuit breakers and that breakers are properly identified as "24-hour circuit." Verify that transformers and power supplies are protected by fuses.

Verify proper wiring. Verify proper wiring connections between sensors, controllers, and controlled devices by procedures such as inspection of color-coding on individual conductors, "ringing-out" specific wires, and observing operation of the controlled device when controller output is wired. Make corrections of cross-connections and open circuits. Ensure that connections are properly made.

Checkout for Controllers

Controller calibration. Verify controller calibration by predicting controller output as described in Chapter 6, "HVAC Control System Setup," then performing calibration checks. Connect testing apparatus, when required, and observe output voltage at the calibration setpoint. If output voltage is not as predicted, recalibrate the controller as recommended by the manufacturer, when required.

Transmitter calibration. Verify transmitter calibration by reading the condition of sensed medium, such as temperature, humidity, or pressure, then predicting resistance or output voltage, and comparing predicted value with actual value.

Controller set-up. Verify that the controller set-up is complete. Verify that parameters such as TR, authority, and setpoints are as required in the control system documentation. Simulate control inputs with a decade box for resistance, or a potentiometer for voltage, and observe controller output voltage. For dual-input controllers, use dual manual position selectors and multimeters.

Controller output. Verify that controller output is as required in the documentation. Observe output voltage over full throttling range, including the calibration point.

Checkout for Controlled Devices

Input signal. Verify input signal to the controlled device. Observe voltage at inlet to controlled device.

Normal position. Verify normal position of the controlled device. Verify position to be as required by documentation. Observe position of the controlled device with zero voltage input signal. That position is the "normal" position of the device.

Spring range of actuators. Verify spring range of actuators. Observe input signal voltage with gradual transmitter and precision gauge, and compare with actuator motion for starting and stopping.

Motion of damper or valve linkage. Verify proper motion of damper or valve linkage. Observe motion when the input signal is varied through full range. Simulate input voltage with a manual transmitter and precision gauge.

Positioning of dampers or valves. Verify proper positioning of dampers or valves. When input signal calls for full range of movement, observe damper or valve position. Adjust linkage as required to produce full range of movement between fully open and tightly closed.

Setting of limit or minimum positioning relays. Verify setting of limit or minimum positioning relays. Observe position of the actuator when control input is below minimum setpoint. Adjust the relay to produce required minimum actuator position. Mark the relay dial accordingly. For limiting relays, perform this procedure to observe output voltage of the relay when pilot voltage is below the minimum or above the maximum setting.

Setting of pneumatic-electric switches. Verify setting of pneumatic-electric switches. Simulate input pressure with a gradual transmitter and precision gauge. Observe cut-in and cut-out points of switches. Compare with the required cut-in and cut-out point required by documentation. Adjust switch setpoints accordingly.

Operation of ratio and reversing relays. Verify proper operation of ratio and reversing relays. Simulate input or pilot voltage with a gradual transmitter and precision gauge. Observe output voltage with a precision gauge. Make observations of output voltage with various input voltage, 0%, 25%, 50%, 75%, and 100% input voltage. Adjust the relay to produce the required output voltage profile.

Operation of switching relays. Verify proper operation of switching relays. Simulate pilot voltage with a manual transmitter and gauge. Observe voltage at which the common port is switched from normally open port to normally closed port on an increase in pilot voltage. Decrease pilot voltage and observe the point at which the common port is switched back to normally open. Record switching point voltage and differential voltage.

Operation of averaging relays. Simulate two input voltages with manual transmitters and gauges. Set one input voltage in low range and the other voltage in high range with normal supply main voltage, and observe output voltage. Compare observed output voltage with arithmetic average of two input voltages. When output voltage is not within 0.5 psi of average of input voltages, replace the relay.

Operation of bias ratio relays. Verify operation of bias ratio relays. Simulate pilot signal with manual transmitters and gauges. Observe output voltage for delayed start to where output remains zero until pilot signal increases to bias voltage setpoint, then increases by ratio of relay. Ratio may be 1:1, where output voltage increases psi for psi with pilot voltage, or 1:2, where output voltage increases 0.5 psi for each 1 psi increase in pilot voltage. Adjust bias setpoint as required. If setpoints are not stable and repeatable, replace relay.

Operation of voltage selector or discriminator relays. Verify operation of voltage selector or discriminator relays. Provide caps or jumpers as recommended for unused ports. Simulate two input voltages with manual transmitters and gauges. Set one input voltage in low range and the other voltage in high range with normal main voltage, and observe output voltage. Make one test for each input. Compare output voltage with input voltages and determine that the relay is selecting higher or lower input voltage and switching to output as required by documentation. If selection is not consistent, replace the relay.

Operation of pilot or positive positioning relays. Verify operation of pilot or positive positioning relays. Simulate pilot voltage from the controller with manual transmitter and gauges with normal main voltage. Observe output voltage as pilot voltage increases and assure that output voltage begins to increase when pilot voltage reaches setpoint. Adjust setpoint as required by documentation. If starting point is not stable or if output voltage is not consistent, replace relay.

Operation of transducers. Verify proper operation of electric-to-pneumatic, electronic-to-electric, and pneumatic-to-electric transducers. For electric-to-pneumatic and electronic-to-electric transducers, simulate input amperage, voltage, or resistance from the controller with a manual power supply or decade box for 135 ohm input. For pneumatic-to-electric, simulate input pressure with a manual hand pump bulb. Observe output in ohms, volts dc, milliamperes, or psig as appropriate to the device. Predict output values for various input voltage values. Compare observed output values with predicted output values. If observed values are more than 7% different from predicted output values, replace the transducer.

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Chapter 11

Fine-tuning Program for Pneumatic Control Systems

This chapter provides an outline for a fine-tuning program for a pneumatic type automatic temperature control (ATC) system, with specific steps to be taken for several types of subsystems in the building HVAC system. The fine-tuning program provides a methodology for operators of new and existing buildings to provide optimum control results and to minimize operating and maintenance costs.

The procedures presented in this chapter were planned for pneumatic control systems; however, the basic concepts of fine-tuning automatic temperature control systems are similar for all types of ATC systems.

The procedures presented here are based upon the assumption that the ATC systems were installed by a qualified control systems contractor, were inspected and accepted by the owner or operator as being installed in compliance with contract requirements, have been properly maintained, and are fully operational.

PLANNING THE FINE-TUNING PROGRAM

An effective way to implement a fine-tuning program is to include it in the building maintenance program. By following that procedure, the periodic maintenance of ATC systems for each HVAC system will be included in the procedures of the maintenance program, to be performed either by building engineering staff or by an outside ATC maintenance contractor. The elements of the maintenance program covering the ATC systems should already include periodic inspection and adjustment, cleaning and lubrication, and replacement of worn or defective parts. It is practicable to expand this maintenance program to include the inspection and adjustment operations required for a fine-tuning program.

The tasks required to carry out a fine-tuning program are beyond the normal scope of work for the installation and checkout that is performed during construction by the control system contractor. The fine-tuning program must be made up of activities which result from "living with the building" as compared to preplanned initial installation and checkout activities.

Ranking Fine-tuning Projects

When planning a fine-tuning program it is necessary to first identify the areas which can be fine-tuned and determine those that have the greatest potential for savings. Examine each of those areas for cost and savings potential. Next, prepare a ranking of fine-tuning efforts, identifying those activities which should be pursued first as offering the greatest potential for savings, and listing the rest in descending order of potential, down to those fine-tuning activities which may provide only marginal results.

Cost/Benefit Analysis

Make an estimate of labor costs to be expended and operating cost savings to be expected from each element of the fine-tuning program, calculate the potential payback for each element, and make a determination of those fine-tuning activities which will provide the greatest cost/benefits ratio.

HVAC SYSTEM FAMILIARIZATION

Examination of Documentation

The first step in designing a fine-tuning plan is to become familiar with the system. If the installing ATC system contractor provided staff training and final documentation under the construction contract, there should be documentation available in the office where contract documents are maintained.

If staff training in ATC system operation and maintenance was not included under the building construction contract, it may be desirable to negotiate a contract with the installing control system contractor to return to the site and provide such training.

It is essential that the technician working with ATC systems become familiar with the control schematic diagrams, equipment bills of material and schedules, and operating and maintenance literature, in order to gain the thorough understanding of the system which is required in the fine-tuning effort.

Walk-through Inspection

The examination and familiarization with the documentation must be followed by a walk-through inspection of the building to identify and make a physical examination of each control system component, inspect the connecting piping and wiring, and perform a system functional operating test.

On newly commissioned buildings, any deficiencies noted should be handled by the ATC system installation contractor under warranty. On older buildings, any operating problems should be described on a deficiency list that will be turned over for correction in the maintenance program.

One method of documenting the findings of this inspection is to place a dated and coded inspection label or sticker on each component, accompanied by a check-off against the control schematic or system schedules. This procedure will ensure that every component of the system has been inspected, verified to be currently installed, and the system certified to be operating according to documentation.

COLLECTING ATC SYSTEM DOCUMENTATION

Steps in Collecting ATC System Documentation

- Collect existing documentation.
- Determine what additional documentation is needed.
- Develop additional documentation as required.
- Prepare a permanent file copy of documentation.
- Calculate system performance parameters.
- Identify opportunities to improve HVAC control system performance.
- Prepare preventive maintenance routines for periodic inspection and retuning.

Collecting existing documentation. As mentioned above, if the installing ATC system contractor provided training and final documentation under the construction contract, documentation should be available on the site, often in the engineering office. Copies of all available documentation should be obtained and organized in a format suitable for reference use by technicians performing the fine-tuning program.

Determine what additional documentation is needed. Assemble all available documentation. Carefully examine the documentation to determine whether any data are missing or whether conditions have changed which will require the preparation of new documentation. Prepare a list of additional items of documentation which are required to complete the set.

Develop additional documentation. Use the list to develop additional documentation. This may include tasks such as revising the original control schematic diagrams to show the addition of BAS interfaces, revising narrative sequence of operation to describe current operating sequences, obtaining copies of equipment cut sheets for items which have replaced original models (including equipment by other manufacturers), obtaining copies of specific installation and maintenance data sheets for each control system component in the system, and adding documentation for extensions to an original ATC system which were not properly documented in the construction process.

Prepare a permanent file copy of documentation. After the additional documentation has been prepared, assemble a complete set of documentation for a permanent file copy. This material should be in format suitable for day-by-day reference in the office, suitable for reproduction by technicians for on-site reference, and suitable for future revisions to document system modifications and changes in operating sequences.

Calculate system performance parameters. Refer to Chapter 5, "Performance Prediction in ATC Systems," for techniques used in developing set-up parameters, including reset schedules, primary controller setpoints, and secondary controller setpoints.

Identify opportunities to improve HVAC control system performance. Examine the existing system diagrams and sequences, compare to current practices and determine whether parts of the system can be retrofitted to provide increased HVAC system performance and improved ATC system performance.

Prepare preventive maintenance routines for use in periodic retuning. Assemble specific installation and maintenance data sheets for each control system component, prepare tables showing the periodic maintenance procedures recommended for each control component, list time interval for each procedure, prepare description of each procedure, and list the tools and consumable items required for the maintenance procedures.

INSTRUMENTS AND TOOLS

Instruments

The basic instruments required in a building controls maintenance shop will depend on the type of controls systems installed in the building.

In addition to the basic instruments, the following instruments may be required:

Electronic thermometer. A high quality, fast responding digital thermometer for temperature measurement is recommended. The digital thermometer should have an internal calibration means, should be of sufficient temperature span to cover all system measurements (at least –20 to +250°F), should have a resolution of 0.1°F, and should be portable. The thermometer should be in a case with room for accessories including a battery charger, an insertion sleeve for access into pressure and temperature measuring stations, a surface temperature measuring shield, wicks and a small container of distilled water for use in making wet bulb temperature measurements, and a small container of heat transfer compound for use in making accurate surface temperature measurements.

Psychrometer. When humidity control is involved, a humidity measurement device is recommended, such as an accurate motorized electronic psychrometer. In general, the accuracy obtainable from a sling psychrometer is too dependent upon the user's skill to be used in the fine-tuning program.

Portable recorders. The use of microprocessor based portable recorders for parameters such as multiple point temperatures, single point temperature and humidity, electrical current, and air or water pressure can be invaluable in fine-tuning. The output of these recorders can be downloaded to a microcomputer and analyzed by the month, week, day, hour or fractions of an hour, then printed out for a permanent record.

Tools

In addition to the usual HVAC maintenance technicians tools, special control tools and fixtures will be needed for the specific control system components which are installed in the building. A listing of special control tools and fixtures is recommended to be generated under the work of collecting documentation.

USING THE BAS AS A FINE-TUNING TOOL

Analog Variables Recording

When the BAS which serves the building can record temperatures and other analog variables, those recordings can be a very valuable tool in fine-tuning.

Trend Log

When the BAS includes a trend log function, the trend log can be set up to provide multi-point measurements to record system performance and evaluate the effectiveness of the fine-tuning adjustments.

FINE-TUNING METHODOLOGY

The final element of a fine-tuning plan is to define the methods to be used.

Discipline in Fine-tuning

A temperature control system is a complex and highly interrelated system, where adjustments of one element of the control system frequently cause interaction with other portions of the system. Therefore, the methods employed in fine-tuning a system must be highly disciplined and done by trained, knowledgeable individuals, who understand the theory of control systems in general and the intent of this HVAC control system in particular.

Basic Rules

The following rules should be observed:

1. Record the settings on all control components before making the first adjustment.

2. Predict the anticipated results from the adjustment before making the adjustment.

3. Make adjustments to a system one at a time, then record the adjusted values.

4. Evaluate results over a sufficient period of time to insure that results are valid.

USE OF FINE-TUNING PROCEDURES

A series of procedures covering specific areas of HVAC temperature control are presented in this chapter, including:

- Room thermostats
- Terminal units
- Volumetric control systems
- Mixed air control systems
- Discharge air control systems
- Humidity control systems
- Cooling control systems
- Converter control systems

Each procedure is organized in a similar format including these topics or items:

- Subject of procedure
- Objective of procedure

- Background information on procedure
- Test procedures and conditions
- Evaluation
- Adjustment procedures

Procedure No. 1—Room Temperature Controller

Objective: To fine-tune room thermostats to provide precise calibration and system stability.

Discussion: Room thermostats are the most visible evidence of a control system and provide an interface between the occupant and the control system. Modern pneumatic thermostats are highly optimized in performance and stability and when properly maintained will provide many years of trouble-free service. To fine-tune a room thermostat, a minimum of one 24-hour room temperature recording should be made for each thermostat location for weekdays and weekends, plus any special occupancy days.

Test conditions: This recording should be made under conditions where the controlled element, such as mixing box or reheat coil, is active and preferably operating under light to medium load.

Test procedures: Determine the location of each temperature sensor to be fine-tuned. A minimum of a 24-hour room temperature recording should be made for each temperature sensor or thermostat location.

Evaluation: Study recording of room conditions and evaluate for these criteria:

1. Is the system stable in the control mode, allowing for duty cycling or power demand load shed activities if they may be occurring?

2. Is the night setback or other reset feature occurring on schedule?

3. Is the system controlling at set point?

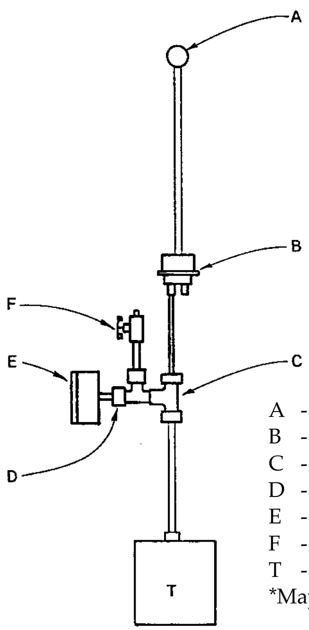
4. Is the system affected by external events such as significant changes in occupancy, sun load, lighting, or power usage?

Adjustments: Based on the evaluation, decide what changes might be made to improve performance. Changes might include:

1. If the system appears to hunt, increase the throttling range or the proportional band. A good guideline to follow in adjusting throttling range or proportional band is to make changes in increments equal to 25% of the initial throttling range. For example, if a room thermostat has a throttling range of 4°F, an incremental change of 1°F would be appropriate.

2. If the system does not respond to the setback in the proper manner, evaluate the setback system to make sure it is occurring at the specified time. Evaluate the individual thermostat according to the published data to assure that the setback adjustments are properly made.

3. A simple setback evaluation fixture may be made as shown in Figure 11-1. Set main for night cycle then bleed main pressure with valve to give 13 psi for day cycle and observe action.



A - Pneumatic Air Main
B - In-line Restrictor, 0.005 Orifice
C - Brass Branch Female Tee, 1/4″ x 1/4″ x 1/8″ FPT*
D - Brass Angle Gauge Tee, 1/8″ MPT x 1/8″ FPT x 1/4″
E - 1-1/2″ Dial Pressure Gauge, 0 to 30 psi range*
F - Needle Valve, 1/4″
T - Thermostat
*May be purchased in Add-a-Gauge Kit

Figure 11-1. Setback Evaluation Fixture

4. If the thermostat calibration appears to be off, recalibrate.

5. Evaluate external events or heat sources/sinks in the space to determine whether these are having an adverse affect on the temperature sensor. If the temperature sensor is so affected, relocation may be required.

After adjustments or corrections are made to the space temperature sensor, the results should be documented with another 24-hour recording and the results reevaluated.

Procedure No. 2—Terminal Unit Control

Objective: Although terminal units will vary widely in configuration ranging from simple terminal reheat systems, dual-duct mixing boxes, variable air volume boxes, induction units, and unit ventilators, the objectives of any terminal unit are approximately the same. They are:

1. Deliver heating or cooling to the space in exact response to the needs of the space sensing thermostat.

2. Perform in a stable manner.

3. Respond to seasonal changeover commands.

Discussion. Terminal units generally represent the final controlled element serving the space. Since the occupants of the space are most affected by the terminal unit output, stability is of paramount importance. The purpose of fine-tuning is to provide responsiveness of terminal unit to room thermostat. Each fine-tuned terminal unit should produce the necessary quantities of properly conditioned air to satisfy space temperature requirements.

Test conditions: Perform testing activities when the terminal unit is actively in control, preferably under light load or medium load conditions.

Test procedures:

Test 1.

a. Set space temperature controller for "no-load" position, that is high setting for cooling or low setting for heating.

b. Measure discharge temperature and observe position of the air volume controller actuator of the terminal unit to determine whether or not the terminal unit is producing a "no-load" output, which with a terminal reheat under heating conditions would be a low temperature or with a variable air volume box would be minimum airflow.

c. Set the space temperature controller for "full-load" position, that is, low setting for cooling or high setting for heating.

d. Test the system to determine whether the terminal unit is responding to space temperature control for "full-load" conditions.

e. Note results for evaluation.

Test 2. Test the performance of the low-limit temperature discharge controller for evaluation.

Evaluation:

Evaluation of Test 1. Evaluate testing to measure terminal unit responsiveness under "no-load" and "full-load" conditions:

1. With room temperature controller indexed to the "no-load" position, verify the appropriate terminal unit output, such as temperature or air volume, as constituting a minimum energy input into the system.

2. If the unit fails to respond to either the "no-load" or "full-load" condition, determine the cause, such as:
   a. Terminal unit not connected to proper space controller.
   b. Mechanical problems in terminal unit, typically valve stuck in either open or closed position, pneumatic control system air leakage, or dampers stuck in open or closed position.

Evaluation of Test 2. Review testing results to verify proper operation or to determine causes of malfunction:

1. The low limit controller should operate in a stable manner with no short term changes of over 2°F to 3°F within a 5-minute period.

2. The low limit discharge temperature should be ± 2°F of the discharge temperature setting. However, under either extreme of load conditions, light or heavy, with a proportional controller for the limit device an offset equal to 1/2 of the throttling range will be observed. That is a normal condition.

Adjustments:

Adjustment 1. If the terminal unit is not responsive to a room thermostat, corrective action must be taken to make the unit respond.

Adjustment 2. If the terminal unit shows control instability, increase the throttling range of the low limit thermostat in increments equal to 25% of the original throttling range. Note that, when throttling range changes are made, recalibration of the low limit thermostat will be necessary. Repeat adjustment 2 until stability of the low limit controller is achieved.

Procedure No. 3—Fan Volume Control

Objectives:

- Validate and fine-tune static pressure control.
- Validate and fine-tune fan tracking.
- Evaluate system "turndown" performance.

Discussion: Stability is probably the most essential element in a volumetric control system. Stability is established by the static control of the supply fan. This functions as the primary control element in the system and all other functions track this function. Major causes of instability in a volumetric control system are improper adjustment of the static control and improper operation of vortex dampers on the fan. Another element of instability occurs when the system turndown exceeds 70%.

Test conditions: Observations must be made during times when variable volume boxes are being controlled, as well as during start-up conditions and no-load conditions.

Test procedures:

Test 1. Static pressure control testing.

a. Make observations during normal load conditions when variable volume terminal boxes are throttling at light or medium loads.

b. Observe static pressure indicating gauge for stability.

c. Variation in static pressure greater than 0.3″ from setpoint constitutes an unstable condition.

d. Short term variation in branch line pressure to the supply fan variable inlet damper actuator in excess of 1 psi constitutes an unstable condition.

e. Simulate a system "upset" by closing the derivative action restrictor, which is an in-line restrictor to the supply fan vortex damper motor, and then observe whether the control reestablishes system control recovery. Recovery should occur within 10 minutes. If system instability is observed with the derivative action restrictor closed, then the instability is due to a hunting VAV box near the static pressure sensor, rather than the static pressure control system itself.

Test 2. Fan tracking test.

Make readings of the supply cfm and return cfm gauges. The difference between the two gauges should be at a minimum 10% of the supply fan volume.

Test 3. Fan turndown test.

a. Make observations with supply fan and return fan set for full load conditions such as during warm start-up, and at minimum load conditions, such as with building unoccupied during mild weather conditions. Note the minimum and maximum cfm values.

b. Calculate "turndown" by subtracting the minimum cfm value from the maximum cfm value and dividing the result by the maximum cfm value. This expresses the percent of turndown.

Evaluation:

Evaluation of Test 1.

a. Readings should be stable, with variations of no greater than 5% of the total span of the system for either reading.

b. Next, evaluate the control system. The biggest factor in establishing stability of the control system is the derivative action restrictor on the output of the static pressure control.

c. If the system is observed to be unstable, close down the integral action restrictor until the system becomes stable.

Evaluation of Test 2.
If the differential between supply and return is less than 10%, the return setpoint should be reduced so that the differential is at least 10%.

Evaluation of Test 3.
If the turndown of the system exceeds 70%, unstable fan operation may be encountered. Adjust the minimum airflow stops on variable air volume boxes so that the turndown does not exceed 70%.

Adjustments:
Adjustment 1. If observations indicate the system is unstable, it may be due to the control system itself or to an improperly operating variable inlet vane damper actuator. Check the damper actuator first to verify that it operates smoothly over full stroke while the damper is under load with the fan operating.

The derivative action restrictor is the final control element before the damper motor. It should be closed and then opened 3/4 of a turn to observe the resulting upset and recovery to determine the system stability in recovering from an upset.

The integral action restrictor, which is the one leading to the feedback port on the controller, may also be adjusted. Closing the restrictor down will increase the system stability. If the restrictor adjustments do not produce stable results, examine the quality of the static pressure input signal. The quality of the static pressure signal may be reduced by a hunting VAV box near the static pressure sensor or by improper placement or connection of the static pressure sensor.

Procedure No. 4—Mixed Air Control System
Objectives:
- Validate mixed air control system stability.
- Fine-tune mixed air control system stability.
- Measure and adjust quantity of outdoor air.

Discussion: Mixed air section control systems are generally fairly stable. However, the accuracy and stability of the system depends to a great degree on the related factors of air side system stratification, sensor placement, and controller throttling range.

On systems not equipped with fan volume control and fan tracking, the outdoor air volume must be calculated and adjusted to provide the actual minimum outdoor air flow rate required for the ventilation of the building. The actual amount of outdoor air introduced into a system should be determined by air volume measurement or by mixed air temperature measurement rather than by arbitrary settings of damper positions. The actual volume of outdoor air which will be introduced is highly dependent upon exhaust flow rates, outdoor air damper performance, and the performance of the mixed air section control system. All these factors affect the building pressurization.

Test conditions: Tests should be made when the mixed air control system is active. This should be when outdoor air temperature is below 55°F, but not lower than 10°F, and when return air temperature is greater than 65°F.

Test procedures:

Test 1. Damper and damper inspection.

a. With system off and dampers in their normal position, inspect all dampers for proper close-off. If the blades are within 1/8" of closing, the dampers are satisfactory, unless they are performance leakage dampers, which must be checked in accordance with specific instructions accompanying the dampers.

b. Verify that return air dampers open to about 60% opening at full travel. Observe damper action through full stroke. At end of the stroke, verify that return air damper is closed and outdoor air damper is open about 60%.

c. When determining "full-stroke" of damper motors, allow for approximately 1/4" "loading" of the spring at the end of the stroke.

Test 2. Mixed air section control stability.

a. Measure temperature with a digital thermometer, being careful to measure at the mixed air sensor location. Temperatures should not vary more than 2 to 3 degrees and branch line pressure of the mixed air sensor should be stable within 1 psi.

b. If the mixed air sensor is an averaging sensor, measure temperature center of the area covered by the averaging sensor.

Test 3. Measurement of outdoor air percentage.

a. Take measurements for actual minimum outdoor air percentages with supply fans, return air fans, and normally operated exhaust fans, running in their normal mode and with the building occupied.

b. Adjust the control system until dampers are at their minimum position setting when the mixed air section control system is not controlling the dampers.

c. Measure return air temperature, outdoor air temperature and mixed air temperature. Make certain that measurements represent a representative or average measurement for each duct. Read the thermometer to an accuracy of 0.1°F.

d. Use the air mixture formula to calculate the actual percentage of outdoor air as follows:

$$\%\ OA = \frac{T_{\text{Return Air}} \pm T_{\text{Mixed Air}}}{T_{\text{Return Air}} \pm T_{\text{Outdoor Air}}} \times 100$$

Evaluation:

Evaluation of Test 1.

a. If dampers do not close properly or are open more than 60% at full stroke, adjust dampers and damper motors so this condition is achieved. Eliminate any binding through lubrication or adjustments of the damper and linkage.

b. Verify that return air dampers open to about 60% opening at full travel. Observe damper action through full stroke. At end of the stroke, verify that the return air damper is closed and outdoor air damper is open about 60%.

Evaluation of Test 2.

a. If mixed air section control pressures show short term variations of more than 1 psi, the control system is considered unstable.

Evaluation of Test 3.

a. Compare the measured and calculated outdoor air percentage with the desired outdoor air percentage. The outdoor air percentage value should be justified by review of building occupancy type, number of occupants, and special requirements for makeup air to exhaust ventilation systems.

Adjustments:

Adjustment 1.

a. If the blades are not within 1/8″ of closing when the actuator is at full stroke, they must be adjusted or repaired to provide closure within 1/8″, except for performance leakage dampers, which must be adjusted in accordance with the manufacturer's specific instructions.

b. If the dampers do not open to the desired position at full travel, adjust the damper linkage. Be certain that fastenings are secure before leaving damper.

c. Verify the setting of the minimum positioning relay which is intended to open the outdoor air damper to minimum position without positioning return air and relief air dampers.

Adjustment 2.

a. If mixed air section controls are evaluated to be unstable, adjust throttling range of mixed air temperature controller in about 25% increments of initial throttling range until control stability is achieved.

Adjustment 3.

a. If outdoor air percentage is not equal to the desired value, adjust the mixed air section dampers to bring the outdoor air percentage as close to the desired value as is possible with the system as installed. It may be necessary to perform additional air balance work or sheet metal work to achieve the desired outdoor air percentage.

Procedure No. 5—Discharge Air Control System

Objective: Evaluate stability and reset schedule of discharge air control systems.

Discussion: The emphasis here is on fine-tuning of the discharge temperature control of heating coils, because heating coils require good control to maintain stability in discharge applications and constitute good candidates for fine-tuning. When discharge air temperature controller is reset from outdoor air temperature, the reset schedule can be fine-tuned.

Test conditions: Conduct tests on heating coils when the control system for the heating coils is active and during moderate load conditions, such as with entering air to heating coil below 65°F.

Test procedures:

Check of Reset Schedule.

a. Observe performance of a representative sample of terminal units during extremely heavy loads and again during extremely light loads. Note the branch pressures of the terminal unit temperature controllers during both periods.

b. Observe the discharge temperature of a heating coil being reset during periods of both extremely heavy loads and light loads. Record the temperature extreme values.

Evaluation procedures:

a. If the terminal unit is not calling for full heating during extremely heavy heating load, the supply air temperature is too high. Fine-tuning requires that the coil discharge temperature be set to a temperature just high enough to supply heat to maintain conditions when the terminal unit having highest load is fully open.

b. If the discharge temperature of the heating coil does not show extreme values which are expected with the reset schedule, the reset sequence setpoints are not correct.

Adjustment procedures:

a. Measure the branch pressure to the actuators and the sensor pressures, then recalculate the set-up parameters using formulas given in Chapter 5, "Performance Prediction in ATC Systems." Set up the controls using the new parameters and retest.

Procedure No. 6—Humidity Control System

Objective: Fine-tuning of humidity control systems should be limited to the prevention of condensation on building surfaces, such as windows, rather than maintaining a precise relative humidity.

Discussion: Humidity control system calibration should not be attempted unless the controls technician has the proper humidity measuring equipment, such as a motorized solid-state sensor type psychrometer which has been recently recalibrated in a calibration lab. If self-test features are used in lieu of calibration check, a routine check of the self-test feature is still required for accuracy in readings.

Test conditions: Make evaluations when humidity control system is in active control, with outdoor temperature below 20°F if possible.

Test procedures:

Test 1.

a. Observe system stability by taking readings from the branch pressure gauge from the humidity controller.

Test 2.

a. Observe windows for evidence of internal condensation when humidifier is active. Test the temperature reset signal to determine its effect on branch pressure through the humidity output device.

Evaluation:

Evaluation of Test 1.

a. Branch pressures under normal stable conditions should not vary by more than 1 to 2 psi on a modulating system, but 2-position controls may vary as much as 5 psi. Systems showing larger variations are considered to be unstable.

b. If branch pressures do not show at least 1 psi change over a 5% change in space relative humidity, the system is considered to be unresponsive.

Adjustments:

Adjustment Procedure 1.

a. If system is unstable, increase throttling range in increments of 25% of initial range until stable operation is achieved.

b. If system is unresponsive, decrease throttling range until system becomes unstable, then repeat adjustments as described under a. above.

Adjustment Procedure 2.

a. If condensation is observed on windows during cold weather, it is an indication that the setpoint is too high.

b. Adjust the authority setting on the controller in accordance with the manufacturer's instructions.

c. If dry conditions with high static conditions are experienced during cold weather, it is an indication that the setpoint is being reset down too much. Reduce the temperature compensation on the controller to give higher humidity at lower temperatures. Observe the results of the adjustment and repeat adjustments until setpoint is satisfactory.

Procedure 7—Cooling Control System

Objective: To fine-tune the stability of the cooling control system and to evaluate and fine-tune the dehumidification capabilities of the cooling system.

Discussion: Generally, cooling systems are relatively stable and can operate with fairly narrow proportional bands with good results. One of the main fine-tuning efforts is in controlling capacity to obtain maximum dehumidification.

Test conditions and procedures: The system should be actively controlling cooling under light to medium load.

Test 1.

a. Observe discharge temperature of the cooling coil for at least 15 minutes while taking and noting readings every 1 minute.

Test 2.

a. On direct expansion (DX) systems, time the duty cycle of the refrigerating compressor. Typical duty cycle under light to medium loads should not be under about 75%, which means 75% "on" and 25% "off."

Evaluation procedures:

Evaluation of Test 1.

a. Observed discharge temperature should not vary more than ± 2 degrees, except for load changes, and branch line pressure should not vary more than 1 psi.

Evaluation of Test 2.

a. Observed duty cycle times should be in the range listed above. If "off" times are too long, dehumidification will be inadequate and space humidity will rise.

Adjustment procedures:

Adjustment 1.

a. If the modulating cooling coil appears to hunt, increase controller throttling range 25% of original setting. Observe results of adjustments and repeat adjustments until stable operation is achieved.

Adjustment 2.

a. On DX systems, if the duty cycle of the compressor is less than 75% "on" and 25% "off," adjust compressor capacity control to achieve the desired duty cycle.

Procedure No. 8—Convertor Control Systems

Objectives:

1. Validate the stability of the hot water convertor control.
2. Validate and adjust the outdoor reset schedule.

Discussion: Stability of hot water convertors is extremely important because of the possibility of mechanical damage due to water hammer and steam flashing on unstable systems. The outdoor reset schedule, when applied to a steam or high temperature water heated heat exchanger or convertor, used for perimeter radiation can improve occupant comfort and lower utility costs.

Test conditions:

- Perform Test 1 when the convertor is actively controlling under light to medium loads.
- Perform Test 2 during heavy load heating conditions, such as extremely cold weather.
- Perform Test 3 during mild weather, when the terminal units have a very light heating load.

Test procedures:

Test 1—Convertor performance.

a. Using either an insertion sleeve or a contact sensor tip with a digital thermometer, measure pipe temperature at the temperature access point or other convenient location. Although contact temperature readings are generally considered to be inaccurate, in those situations where the medium under measurement is at a temperature substantially different from ambient temperature, such as measuring hot water supply temperature, accuracy may be obtained within ± 5%.

b. Measure the temperature of water leaving the convertor and branch pressure from the controller, making readings every minute for at least 15 minutes.

Test 2. High end of reset schedule verification.

a. Observe and record the branch pressure output from the temperature controllers serving a representative sample of terminal units located in the space served by the perimeter radiation. The terminal units do not need to be connected directly to the perimeter radiation. The purpose of this test is to measure the heating system loading factor.

Test 3. Low end of reset schedule verification.

a. During light load heating conditions, measure the branch pressure of several terminal unit thermostats and note result.

Evaluation:

Evaluation of Test 1.

a. Except when adjusting for load changes, water temperature changes greater than 5°F per minute or controller branch pressure changes greater than 1 pound per minute are considered unstable.

Evaluation of Test 2.

a. The purpose of Test 2 is to determine the effect of perimeter radiation on the entire system during heavy load conditions.
b. If the sample terminal unit thermostats are near zero psi output, it indicates that the perimeter radiation temperature as reset by the schedule is too low. The normal condition which should be found is for the terminal units to be near setpoint temperature, indicating they are in control while the radiation is providing the additional heating to meet the perimeter exposure load. In this case, when the terminal unit branch pressures are too low, it indicates that the reset schedule should be changed to increase the high range reset temperature.
c. If the terminal unit branch pressures are found to be too high, it indicates that the radiation is delivering too much heat and that the reset schedule should be changed to decrease the high range reset temperature. Excessive space temperature indicates high branch pressure. This is a possible indication that radiation is providing too much heat, in which case the high range reset temperature should be reduced.

Evaluation of Test 3.

a. The purpose of this test is to evaluate the low end of the reset scale.

b. If the sample terminal units indicated a high branch pressure under light load conditions, the perimeter radiation should be investigated for temperature output.

c. If the radiation is delivering heat so that the temperature appears to be affecting the terminal unit, then the low end of the reset should be adjusted downward. If the sampling of terminal unit outputs produced a low branch pressure, investigate the possibility of resetting the low end of the range upward.

Adjustments:

Adjustment 1.

a. If the convertor unit is not stable, increase throttling range by approximately 25% of the initial throttling range and observe the results. Repeat the adjustments until stable operation is achieved.

Adjustment 2.

a. Refer to Chapter 5, "Performance Prediction in ATC Systems," for techniques to develop new set-up parameters, including reset schedules, primary setpoints, and secondary setpoints.

b. Make adjustments to the reset schedule as indicated. Adjustments to the reset schedule of the converter are made by adjustment of the authority setting in accordance with the manufacturer's instructions. All adjustments to reset range must be verified and entered into the permanent system documentation records.

Adjustment 3.

a. Make adjustments to reset schedule as indicated by evaluation and as described in b. above.

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Chapter 12

Troubleshooting ATC Systems

THE Z TO A APPROACH

Complaints about lack of comfort in HVAC systems are often considered to be "thermostat" complaints and the principal efforts toward remedying the problem are aimed at the thermostat, with little attention given to other parts of the system. Too often the thermostat and the controlled devices are functioning properly and the problem is in the HVAC system itself.

To avoid false starts in troubleshooting, the Z to A approach is recommended. The Z to A approach to troubleshooting is one of starting at the end of the process, the controlled media, rather than at the beginning of the process, the control sensor. The Z to A approach requires the technician to start his troubleshooting by determining whether the HVAC system output is responsive to the ATC system inputs.

For example, when answering a "no cooling" complaint, the technician will check to see whether the cooling system is doing any cooling. If the system is not doing any cooling, the technician next checks to see whether the controlled device is properly positioned, such as whether the chilled water valve or the liquid line solenoid valve is open. If the controlled device is properly positioned, then the problem can be approached as an HVAC system problem rather than a control system problem.

If the controlled device is not positioned to provide cooling, then the technician can check to see whether the controller output is calling for cooling by measuring the controller output signal and comparing it to the setup characteristics of the controlled device. If the output is calling for cooling but the controlled device is not opening to provide cooling, then the problem can be approached as a controlled device malfunction.

If the controller output is not calling for cooling, then the technician can check the sensor in the controlled media to see whether the sensor output signal is correct for the sensed condition. If the sensor output signal is correct for the sensed condition, then the problem can be approached as a controller problem. If the sensor output signal is not correct for the sensed condition, then the problem can be approached as a sensor problem.

In all cases, the actual problem is addressed first. Then, working back toward the space, the possible causes are examined one by one and discarded until the real cause is found. That is the Z to A approach.

RECEIVING THE COMFORT COMPLAINT

Put It In Writing

A procedure should be implemented requiring that all comfort-related complaints be made in writing.

A typical complaint report form will include information as to where, when, and what is or is not occurring to be the basis for the comfort complaint. The conditions of "too hot" and "too cold" are the most common complaints and are the simplest to troubleshoot. Conditions of "too humid," "too dry," "too drafty," "stuffy," and "smelly" are more difficult to appraise objectively and may require a more subjective approach. In any event, when the complaint is put into writing, the written complaint should include as much detail as possible on the complaint report form.

Causes of Comfort Complaints

A complaint is usually initiated by the building occupants. The occupants may feel generally uncomfortable or they may have specific complaints as noted on the complaint report form. The problem may be one of overall poor indoor air quality. In buildings with large expanses of glass or floors over open areas such as parking decks, temperature complaints may be caused by problems with mean radiant temperature rather than free air temperature. In those cases, special procedures should be followed to determine the prevailing mean radiant temperature at the complaint site.

What is Done with a Complaint Work Order?

When the complaint report form is received in the maintenance engineering office, the maintenance supervisor or dispatcher may be able to use the BAS or a basic knowledge of the systems to diagnose the problem and write a work order for an appropriate action immediately. In some instances, when the BAS shows all the HVAC components to be operating properly, he may decide that the ATC or BAS system is possibly malfunctioning and will assign a control system technician to the problem. The technician who receives the complaint work order will review the complaint as to location and possible causes, make a BAS check of systems performance, and then work out a plan of action for a system checkout using the Z to A approach.

Familiarity with Equipment and Systems

In working out a plan of action, it is very important that the ATC system technician be familiar with the various systems and components in the building. Knowing the fundamentals of how a particular system operates and how the individual control components function to control the HVAC equipment can be of tremendous help in diagnosing the problem.

Although the basic functions for a given item of HVAC equipment will be the same when built by different manufacturers, each item will have specific sequences of operation which are peculiar to that manufacturer. The control technician needs to be familiar with the specific equipment which is installed in each system. For example, controls for some air terminal units will be electronic while controls for others may be pneumatic. Awareness of the specific features of the equipment installed makes for easier diagnosis and correction of operational problems.

ANALYZING THE PROBLEM

Using Control Diagrams and Sequences of Operation

Almost every HVAC control system was installed from a control piping or wiring diagram that also showed sequences of operation and a bill of material. Review of a control diagram will show how the system is connected and how the system is intended to operate.

The drawing will also tell the make and model of the control components used, where they are located, the initial setup parameters, and how they should function. It is important to arrange for copies of the control diagrams to be accessible so that the technician can become familiar with the system before going to the building to begin troubleshooting procedures.

Inspect the System

After becoming familiar with the control diagram, the technician should make a walk-through inspection on all parts of the system to verify such items as whether the system is intact and to see whether anything unusual can be observed. As an example, in an air handling system, verify that the damper linkages on the mixed air section are connected and that the dampers are in the appropriate positions relative to each other, whether the casing access doors are closed, and whether the fans are turning in the right direction.

Check the Control Components

The control system components include the sensors, controllers, relays, and controlled devices. The sensors, controllers, and relays are relatively delicate devices which need special attention. Controllers should be checked for calibration regularly but the controlled devices, whether damper or valve actuators or relays, do not need as much attention.

The inspection of the operation of a controlled device is much easier than the inspection of the operation of a controller. For example, consider a chilled water valve actuator. When the sensed temperature varies through the throttling range set on the controller, the valve goes from fully open to fully closed, or vice versa. The position of the valve and the sensed temperature are directly related, so that by observing the valve position, the sensed temperature can be predicted and by reading the temperature on a thermometer, a determination can be made as to whether the system is under control or not.

CORRECTING CONTROL SYSTEM PROBLEMS

Sensor Calibration

Most types of sensors are factory-calibrated and cannot be calibrated in the field. When a pneumatic sensor is found to be slightly out of calibration, the discrepancy can be compensated-out at the controller.

Recalibration of Controllers

Controllers are the components which most often require field calibration. The component manufacturers publish specific instructions and recommendations for tools, fixtures, and procedures required to calibrate controllers. Copies of those instructions and recommendations should be obtained and examined and the necessary tools and fixtures obtained. The basic calibration procedure should follow the procedures given under Chapter 4, "The Mathematics of Control Systems: Controller Equations," and in Chapter 10, "HVAC Control System Checkout Procedures."

COORDINATING CORRECTIONS TO HVAC SYSTEM PROBLEMS

Influence of HVAC Problems on the Control System

When the cooling system is unable to maintain conditions in the space due to overload or equipment malfunctions, both the temperature and humidity in the space will rise. After the space temperature rises above the top of the throttling range of proportional controls or above the cut-in point on 2-position controls, the control system cannot provide any more cooling. The space temperature and humidity will respond to the available cooling and the load.

When the heating system is unable to maintain conditions for similar reasons, the space temperature will drop. After the heating system dampers and valves are positioned for full heating, the control system cannot provide any more heat although anti-freezeup safety controls may operate to reduce load by closing outside air dampers or stopping fans. When an air handling system problem occurs, such as motor or drive failure, or reduction in air delivery due to slipping belts, the delivery of cooling or heating to the space will be stopped or reduced.

Differentiating HVAC Problems from Controls Problems

An HVAC system problem will appear to be a system overload although the temperatures of the cooling and heating mediums will be normal. This is a simple problem to differentiate because the temperatures are easy to measure, particularly with a BAS in the building.

Influence of Control Problems on HVAC System Operation

Control system problems can adversely affect HVAC system operation. One of the most commonly encountered problems is a malfunction of economizer cycle controls, which causes a sudden introduction of large quantities of outside air to the system and results in a freezeup of chilled water and heated water coils before the safety controls can respond. Another problem occurs when the output of a boiler or a chiller is limited by a malfunctioning safety control which causes a complaint for lack of heating or cooling.

These problems can be overcome by using the Z to A approach, starting at the controlled device and working back through the controller to the sensor.

USING CONTROL SYSTEM INSTRUMENTATION

The instrumentation typically installed in an ATC system may include some devices which may be used in analyzing and troubleshooting a controls system, such as pressure gauges, temperature indicators, and humidity indicators. Other instruments needed to troubleshoot an ATC system are described in Chapter 13, "Tools & Fixtures for ATC Systems Operation & Maintenance." An energy management and control system can provide useful data for use in troubleshooting, particularly trend logging of space conditions.

Temperature Measurements

Temperature in a pneumatic system using transmitters can be measured using a pressure gauge calibrated in both psig and °F. The accuracy of the sensor can be checked by making simultaneous readings of the sensed medium temperature using a test thermometer or a digital thermometer. Some manufacturers' sensors can be field-calibrated, but most sensors must be replaced if they go "out of calibration."

Temperature in an electronic system using resistance elements can be measured by disconnecting one wire to the sensor, reading the resistance across the sensor, and looking up the temperature corresponding to that resistance using the temperature-resistance table for the specific resistance element used or by predicting the temperature using equation 5-1 in this book.

Test thermometers of the etched stem type are accurate enough for troubleshooting measurements but bi-metal type test thermometers have too small a dial to give accurate readings.

Electronic digital thermometers with 0.1°F divisions are desirable for most testing purposes, particularly in reading chilled water temperature differences across cooling coils. The probe on electronic test thermometers is delicate and must be protected when using it in pressure and temperature testing ports. A sleeve is available for this purpose.

Humidity Measurements

Humidity in a pneumatic system using transmitters may be measured in the same manner as temperature measurements, described above. In electronic systems, the humidity measuring devices often require a special power supply, such as 5 volts square wave ac, with an output which cannot be used to predict the sensed media condition values.

A humidity meter with calibrations in % RH is needed to read the output from that type humidity sensor. Other sensors use different operating principles and each requires a specific type meter to read the sensor output.

Pressure Measurements

Pressure measurements can be made in same manner as the temperature and humidity measurements. In a pneumatic system, gauges are used which are calibrated in terms of the sensed variable, which might be inches of water for air static pressure measurements or feet of head or psi for hydronic system measurements.

Hydronic system measurements, such as flow rates, are often made with portable differential pressure meters which may be calibrated in inches or feet of water column, or inches of mercury, pounds per square inch gauge. The meters are used to measure the pressure drop across a fixed or adjustable calibrated resistance element such as an orifice plate or a calibrated cock.

The measured pressure differential is used in a look-up table for the specific resistance element on which the measurements were made to find the corresponding flow rate in gallons per minute. Some heat exchange vessels require flow determination by measuring the pressure drop from the look-up table or flow coefficient values (C_v) provided by the manufacturer. Access to the piping system for pressure measurements may be obtained by use of hose connections to gauge cocks or by hollow needle access into pressure and temperature (P&T) measuring stations.

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Chapter 13

Tools & Fixtures for ATC Systems Operation and Maintenance

Operation of automatic temperature control (ATC) systems and building automation systems (BAS) requires instruments and tools for control component testing and adjusting, testing HVAC system performance in response to control inputs, and testing and programming microprocessor-based control components. Maintenance of those systems requires the use of specialized tools and fixtures for testing, adjusting, repairing, and reprogramming control components. Some of the required tools are basic HVAC system performance measuring instruments used in HVAC system testing and balancing work.

Operation and maintenance of pneumatic and electronic control systems requires specific fixtures and tools for the control components.

The tools and appliances required will vary with each installation and may include any or all of the following, plus system specific fixtures or tools not listed.

SYSTEM PERFORMANCE MEASURING INSTRUMENTS AND TOOLS

Electronic Thermometer with Digital Readout

An electronic thermometer with digital readout to 0.1°F (see Figure 13-1) and with probe suitable for use with pressure and temperature (P&T) measurement access ports (known in the trade as Pete's Plugs) is a very basic instrument. There are many models available at reasonable prices. Some are more accurate than others, some are more stable over time. Temperature range should cover the lowest outside temperature to the highest heating medium temperature expected to be encountered.

Accessories should include a battery charger, wet bulb kit, surface measurement device, and probe shield for use in pressure and temperature measuring stations.

Electronic Temperature/Humidity/Dew Point Meter with Digital Readout

A hand-held electronic instrument with simultaneous digital readout of temperature and relative humidity or temperature and dew point (see Figure 13-2) has a probe suitable for remote readings or on-instrument readings. Temperature range of –20° to +120°F or –30° to +50°C with humidity range from 0% to 100% RH should cover the lowest outside conditions to the highest indoor or outdoor conditions expected to be encountered. Accessories should include a humidity calibration kit and a spare 9-volt alkaline battery.

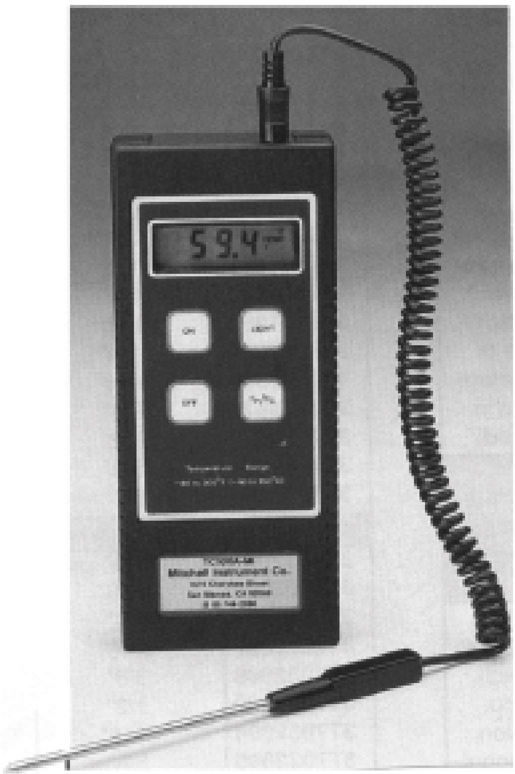

Figure 13-1. Electronic Thermometer with Digital Readout to 0.1°F. (*Courtesy Mitchell Instrument Co.*)

Electronic Data Loggers

Electronic data loggers with on-board temperature and humidity sensors or with remote sensors for temperature, pressure, electric current flow, or pulse signals (see Figure 13-3) are useful in monitoring and recording and with probe suitable for use with pressure and temperature (P&T) measurement access ports is a very basic instrument. There are many models available at reasonable

Figure 13-2. Electronic Temperature/Humidity/Dew Point Meter with Digital Readout. A hand-held electronic instrument with simultaneous digital readout of temperature and relative humidity or temperature and dew point. (*Courtesy Mitchell Instrument Co.*)

prices. Some are more accurate than others, some are more stable over time. Temperature range should cover the lowest outside temperature to the highest heating medium temperature expected to be encountered. Accessories should include a battery charger, wet bulb kit, surface measurement device, and probe shield for use in pressure and temperature measuring stations.

Bi-Metal Thermometer, Recalibrator Type

Several bi-metal thermometers of recalibrator type (Figure 13-4) with stem diameters and lengths suitable for insertion in test wells or in P&T measurement access ports are desirable. For hydronic systems, thermometers with at least 3" diameter dial are needed to allow readings accurate to about 1°F. Thermometers with a span of 100°F on a range from 25°F to 125°F with 1°F divisions are useful for most air temperature readings. When a larger span on a higher temperature range is desired, 2°F divisions are commonly available, such as for a 250°F span on a range of 50°F to 300°F. This is usually adequate for the hot water measurements.

Glass Testing Thermometers

Etched glass stem testing thermometers (Figure 13-5) are readily available in the stem lengths and scale ranges used in HVAC work. Glass thermometers are fragile and must be used carefully to avoid separation of the liquid column or stem breakage. For testing water chilling system performance, which requires at most 0.1°F resolution, 21" stem length thermometers are used having 0.1°F divisions and a range of about 25°F to 125°F.

Figure 13-3. Electronic Data Loggers have on-board temperature and humidity sensors or with remote sensors for temperature, pressure, electric current flow, or pulse signals. (*Courtesy ACR Systems Inc.*)

Figure 13-4. Bi-Metal Thermometers, Recalibrator Type. (*Courtesy H.O. Trerice Co.*)

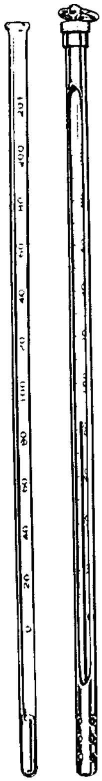

Figure 13-5. Etched Glass Stem Testing Thermometers.

Sling Psychrometer

Sling psychrometers with glass thermometers (Figure 13-6) for reading simultaneous dry-bulb and wet-bulb temperatures should have thermometers protected from breakage during sling operation, with a water reservoir for the wet-bulb thermometer wick, and a psychrometric scale moulded into the case to allow the operator to make quick calculations of relative humidity % from dry-bulb and wet-bulb temperatures. A useful accessory is a plastic 35 mm film container of distilled or deionized water which will wet the wick for more than 100 wet-bulb readings. In order to avoid buildup of solids left upon evaporation of water never use tap water on wet-bulb wicks. Distilled water is available in most supermarkets.

Temperature and Humidity Recorders

Temperature and humidity recorders (Figure 13-7) are very useful in judging the validity of complaints of poor temperature and humidity control. Portable recorders are available with battery-operated motors for use with 24-hour, 7-day, and 31-day charts and with field-selectable measuring ranges of –20° to +120°F, –20° to +50°C, +40° to +110°F, +5° to +40°C. The measuring accuracy of about ± 2°F and ± 2% RH is only fair, but the ability to provide a graphic trend log on 8" di-

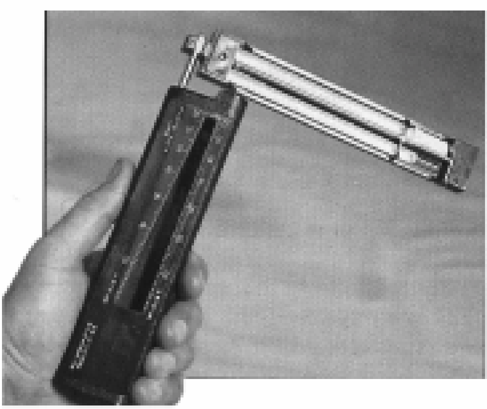

Figure 13-6. Sling Psychrometer with glass thermometer. (*Courtesy Mitchell Instrument Co.*)

ameter charts showing the time, duration, and magnitude of temperature and humidity changes in the conditioned area is the important function. Accessories should include a supply of charts for each temperature range and time period and a spare set of alkaline batteries.

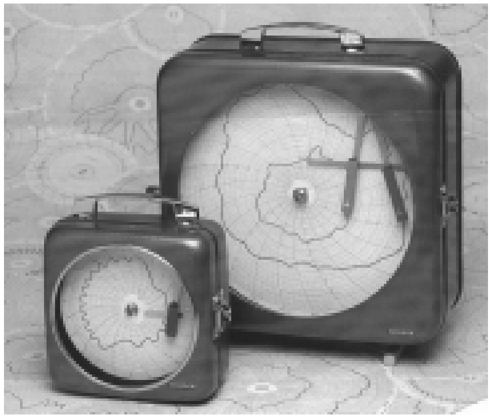

Figure 13-7. Temperature and Humidity Recorders. (*Courtesy Dickson Instruments.*)

Electronic Digital Pyrometers

Electronic digital pyrometers (Figure 13-8) are available with thermocouple surface probes and are useful for measuring temperatures in boilers and heating systems and for determining performance of steam traps. Several thermocouple types are available which will allow selection of ranges from –50°F to 1,400°F. Dual-range pyrometers are available that will provide resolution switching to give 0.1°F divisions in low range and 1°F divisions in high range.

AIR SYSTEM TESTING AND BALANCING INSTRUMENTS

Magnetic Dial Gauges for Air Pressure and Velocity Measurement

Dial gauges of magnetic helical type (Figure 13-9), often called by the trade name Magnehelic, are available in several pressure ranges to suit duct pressures to be measured. Gauges for differential pressure are useful for measuring air pressure differences across coils and filters using static tip

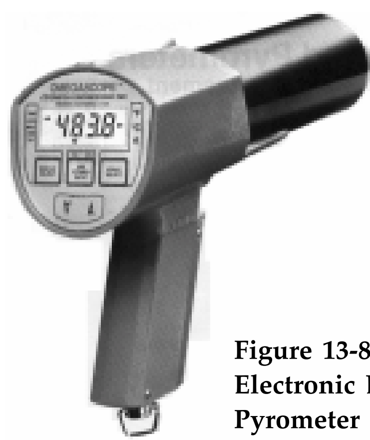

Figure 13-8. Electronic Digital Pyrometer

type probes. Dial scales may be obtained with dual graduations in inches, static pressure and air velocity in feet per minute for dual use in pressure measurement and in measuring velocity using Pitot tubes. Plastic carrying cases are available with room for carrying gauge, Pitot tube, and connecting hoses.

Air Velocity Measuring Kit

Hand-held digital manometer with range to 19.99" water gage on 0.5" liquid crystal display (LCD) readout, battery-powered, with accessories including 6" long flexible Pitot tube, static pressure tips, stepped bit for drilling 3/16" to 1/2" diameter holes in ductwork, rubber hoses for connecting to Pitot tubes and static tips, slide rule for converting velocity pressure in inches w.g. to velocity in feet per minute, and carrying case with instructions. The cost for the complete kit is about $400.

Pitot Tubes for Air Velocity Measurement

Stainless steel tubes are available in lengths from 6" to 60" with markings on the tube to indicate insertion distance from the center of the impact tube to the surface of the duct or other point of insertion. Pitot tubes are coaxial, with the inner tube to measure total pressure at the impact tip, and with the outer tube perforated in several areas to measure static pressure at the side of the impact tube. Hoses are slipped over the end of the impact tube and over the side outlet from the static tube for connection to a dial gauge or manometer. The side outlet tube also serves as a handle to allow precise alignment of impact tube into the airstream.

Static Pressure Monitoring Tips

Stainless steel and brass monitoring tips are available with threaded ends for permanent

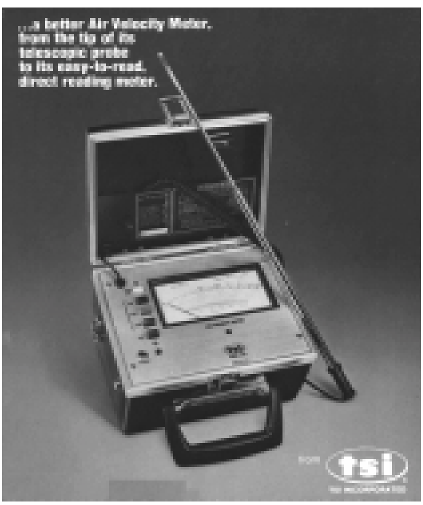

Figure 13-9. Magnetic Dial Gauges for Air Pressure and Velocity Measurement. Dial gauges of magnetic helical type. (*Courtesy TSI Inc.*)

mounting on sheet metal surfaces between sealing washers and nuts. Tips for temporary mounting are also available, with a magnet to hold the tube to magnetic sheet metal. Connections are available for rubber hoses or metal tubing.

Manometers of Inclined Vertical Type

Manometers of inclined/vertical type are available with red-reading dual scales for pressure in inches of water and velocity in feet per minute at 70°F. These manometers may be machined from acrylic plastic with a bubble level and leveling screws, and use red guage oil. A range of 400 to 9,000 feet per minute with 0.01" water column divisions in the inclined section, and 0.10" water column divisions in the vertical section, will cover most needs. Ranges up to 19,000 feet per minute are available but with less precision in scale divisions when using blue guage oil. Steel carrying cases with space for hoses, extra guage oil, and Pitot tubes up to 36" are available and are necessary to properly carry the manometer.

Balancing Cones

Cones for airflow measurement through air distribution products, such as ceiling and wall inlets and outlets, are available in sets of graduated sizes to fit over various sizes of inlets and outlets. The cones direct airflow over a direct-reading airflow meter in the apex of the cone. The accuracy of these devices is adequate for the usual measurement of airflow in HVAC systems. A suitable light duty substitute cone can be fabricated of artists' beadboard with taped seams, about 24" square at large end and 12" square at small end by about 36" long, and with velocity readings made using Pitot tube or anemometer in the small end.

Hot Wire Anemometers

Anemometers using the hot-wire principle are available in velocity ranges from zero to over 6,000 feet per minute. The instruments are fairly expensive but are available in a broad range of costs with the cost varying with the ability of the instrument to measure velocity and temperature. These devices are necessary when measuring velocities below about 100 feet per minute in order to achieve reasonable accuracy. The sensor can be mounted on a wand with a curly-cord for getting to hard-to-reach points. Some models can read temperature by means of a switch on the meter box.

Rotating Vane Anemometers

The old standby rotating vane anemometer (Figure 13-10) is fairly inexpensive and simple to use. For accurate measurements, the readings must be corrected from the calibration chart furnished with the meter and the meter should be recalibrated periodically to provide a current calibration chart.

Deflecting Vane Anemometers

A deflecting vane anemometer (Figure 13-11) is not as accurate as other types of anemometers but is accurate enough for performing routine airflow measurements in HVAC systems. Models are available in the $100 range.

HYDRONIC SYSTEM TESTING AND BALANCING INSTRUMENTS

Flow Sensors

These devices (Figure 13-12), frequently called by the trade name "Annubar," are very useful for measuring flow in piping using differential pressure gauges, u-tube manometers, or permanent flow meters. The flow sensors are similar to Pitot tubes with double pressure chambers contained in a stainless steel tube inserted into the piping through a half-coupling or saddle welded to the piping. Sensors are available for a range of pipe sizes from 2" to 42". For sizes 1/2" through 2" pipe size, a nipple-mounted sensor is available. Because

Figure 13-10. Rotating Vane Anemometer. (*Courtesy Davis Instruments*.)

these devices can usually be installed in less than 30 minutes, they are cost-effective in retrofit applications as well as new construction.

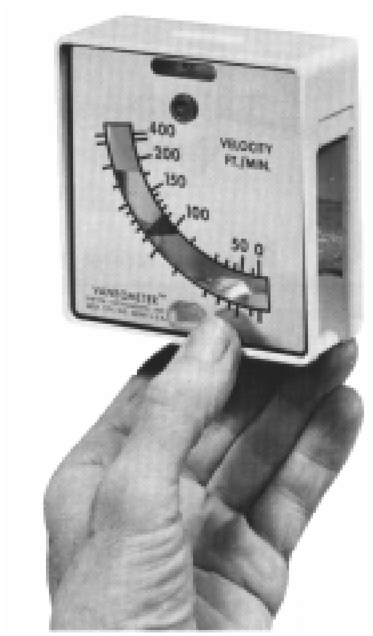

Figure 13-11. Deflecting Vane Anemometer. (*Courtesy Dwyer Instruments, Inc.*)

Pressure and Temperature Testing Ports

These devices (Figure 13-13), frequently called "Pete's Plugs," are very useful for getting access to piping systems to measure temperature and pressure. They are nicely machined devices with a high-temperature polymer plastic seal, similar to a football bladder valve, in a body threaded for 1/2" pipe thread and with a hex-head gasketed cap over the seal. Test ports can be installed on copper, plastic, or steel piping systems by drilling and tapping an opening in the pipe wall or by welding a half-coupling to steel pipe, then boring an opening in the pipe wall and mounting the device in the coupling. Pressure gauges and thermometers are available with about 3/32" diameter stems for use with the ports, but the dials on these instruments are too small to give accurate readings. A useful accessory is a pressure access probe with hose connections for connecting to a precision pressure gauge.

U-Tube Manometers

Manometers are available in glass-tube or flexible-tube models with over-pressure safety traps (Figure 13-14) for measuring positive, negative, or differential pressures in fluid flow systems. Mercury is used when measuring pressure differential across orifice plates in piping systems and red guage oil is used when measuring static and velocity pressures in air handling systems. Ranges are available from 8" to 36" of mercury or water.

Figure 13-12. Flow Sensors. These devices are called by the trade name Annubar. (*Courtesy Ellison Co.*)

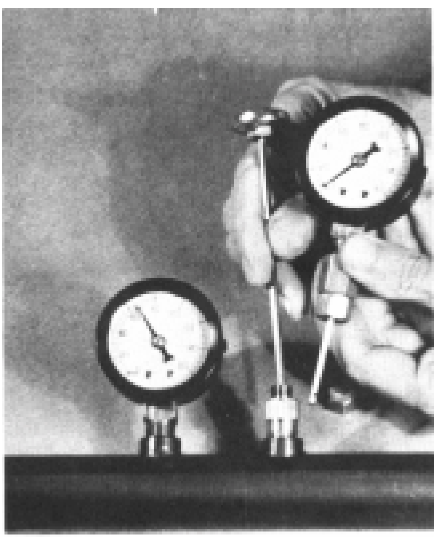

Figure 13-13. "Pete's Plug" pressure or temperature test plug. (*Courtesy Peterson Equipment Co., Inc.*)

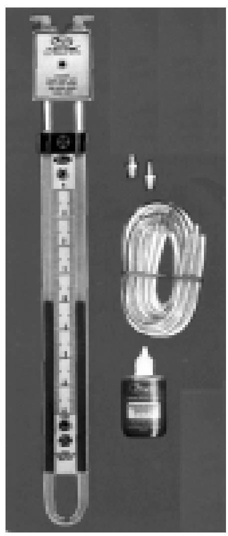

Figure 13-14. U-Tube Manometers. Glass-tube or flexible-tube models with over-pressure safety traps. (*Courtesy Dwyer Instruments, Inc.*)

Differential Pressure Gauges

Gauges are available in complete kits in carrying cases, including valve manifolds with quick-connect type fittings (Figure 13-15) for measuring pressure differential across flow measuring devices in piping systems. These are for use with calibrated cocks, Pitot tubes, and venturi sections for fluid flow measurement.

ELECTRIC AND ELECTRONIC CONTROL SYSTEM TESTING TOOLS

Volt-Ohm-Milliampere (VOM) Meters

Analog VOM meters (Figure 13-16) are available in many styles and types. Ranges of 0 to 1,000 volts dc in 7 steps and 0 to 100 volts ac in 6 steps are available on moderate cost meters. These meters are not as convenient to use as digital meters. A simple VOM may be purchased from a radio hobby store for as little as $15.

Digital Multi-Meters (DMM)

DMMs (Figure 13-17) are available over a broad price range. A meter suitable for checking electronic controls may be purchased for about $75. Meters with more features such as autoranging, a beeper for continuity checks, and higher measurement precision are available at prices up to about $250.

Decade Boxes

Decade boxes (Figure 5-1) are switchable precision resistor banks used to simulate sensor resistance in calibrating and testing electric and electronic controllers. The decade box consists of a bank of slide switches which can be positioned to engage resistances with 1% accuracy above 9 ohms. Boxes are available as portable units in a broad range of capacities and prices. A basic model, with a resistance range from 1 through 11,000,000 ohms and a 0.5 watt power rating at up to 250 volts will cover the range of values needed for ATC systems and is available for about $60.

Electronic Manual Positioners

Electronic manual positioners (Figure 13-18) are precision potentiometers or variable resistors used to position actuators during checkout

Figure 13-15. Differential Pressure Gauges. Complete kits in carrying case with quick-connect type fittings on valve manifolds. (*Courtesy Gerand Engineering Company*.)

Figure 13-16. Volt-Ohm-Milliampere (VOM) Meters. Analog VOM meters. (*Courtesy Davis Instruments*.)

Figure 13-17. Digital Multi-Meters (DMM). (*Courtesy Transcat*.)

procedures. Positioners are usually mounted in a box with leads for making test connections. These devices do not have a scale of resistance being used.

Fixed Resistance Devices

Fixed resistance devices are precision resistors (Figure 13-19), with 0.1% tolerance, fitted with leads for making test connections and are used to simulate the 70°F base temperature used in calibrating electronic controllers.

Control Instrument Tools

Special purpose tools such as wrenches and screwdrivers are required to service control components. A complete set of tools to service the specific control components installed in the systems should be on hand.

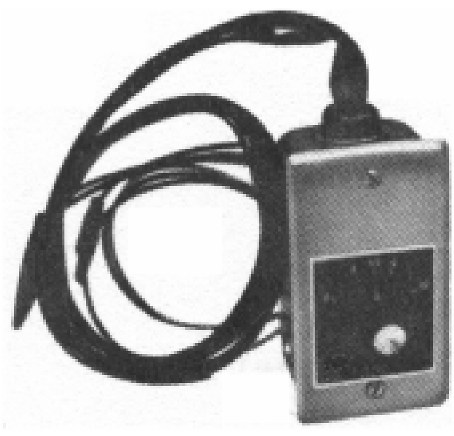

Figure 13-18. Electronic Manual Positioners. (*Courtesy Barber-Colman.*)

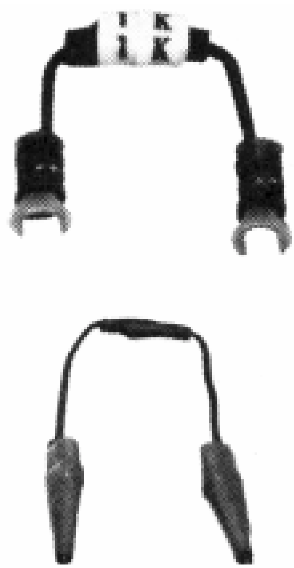

Figure 13-19. Fixed Resistance Devices are precision resistors. (*Courtesy Barber-Colman.*)

Figure 13-20. Pneumatic Control Calibration Kit. A typical calibration kit. (C*ourtesy Barber-Colman.*)

PNEUMATIC CONTROL SYSTEM MEASURING TOOLS

Pneumatic Control Calibration Kit

A typical calibration kit (Figure 13-20) contains basic pressure measuring equipment, devices for simulating pressure inputs, and tools for adjusting the control devices. Kits for receiver-controllers may include a box with multiple inputs to dual precision pressure gages, circuit selector valve-switches, and sequence selector switches, or may simply use a modified refrigerant charging manifold. A calibration box can be made in the shop using stock parts from a control system supply house to provide at least four inlets and one outlet, each connected to a panel gauge, two manual transmitters, and a selector switch to apply any of the inputs to a box-mounted pressure gauge or to the output line to another instrument. Each control system manufacturer packages calibration kits for manufacturer-specific control components.

Control Instrument Tools

Special purpose tools, such as wrenches and screwdrivers, are required to service control components. A complete set of tools to service the specific control components installed in the systems should be on hand.

Pneumatic Manual Positioners

Manual positioners (Figure 13-21) are hand-held squeeze bulbs used for pumping-up pressure on actuators to test linkage operation. A manual valve holds the manually pumped pressure until released, either gradually or quickly.

Manual Transmitters

Manual transmitters (Figure 13-22) are precision valves used to meter output pressures to be used in simulating control inputs to controllers. They may be mounted in a calibration box or may be used as portable devices with hose connections to the main air supply and to deliver regulated output pressure.

Pneumatic Testing Ports

Testing ports, tank valves by some manufacturers, are similar to the tire chuck or Schrader valves used in automotive tires. Test ports may be installed in 1/8" ips tapped openings, such as in a receiver-controller, or in a tee with 1/8" tapped opening installed in the tubing system. To use a testing port, a hose connector is threaded over the male threads of the port and connected to a pressure gauge or a calibration kit. These devices are inexpensive, and should be installed in the system permanently rather than each time they are required for use.

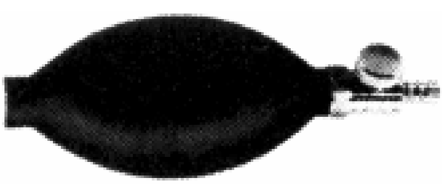

Figure 13-21. Pneumatic Manual Positioners. (*Courtesy Barber-Colman.*)

Figure 13-22. Manual Transmitters

Chapter 14

Training Operating & Maintenance Personnel

The personnel working in the operation and maintenance of control systems must have adequate training to make them capable of diagnosing problems in HVAC control systems and initiating the appropriate actions. A trained control technician must be knowledgeable in the several different types of controls as well as in basic HVAC systems, and must also have a good knowledge of electric circuits, motors, and related components.

OPERATING AND MAINTENANCE PERSONNEL

In buildings and building complexes, it is essential to have technicians available at all times to take care of maintenance problems as they occur. It may be economical as well as more convenient to have someone available at the building site rather than having a maintenance contract with an outside organization.

Certain maintenance procedures require little or no expertise, such as replacing light bulbs, changing filters, and cutting the grass. However, HVAC system and related controls system problems require a high degree of expertise and experience.

At the present time, many people in charge of HVAC maintenance know very little about control systems. With increased requirements for energy efficiency in HVAC systems, the industry is much more aware of the role that control systems play in the energy efficiency in buildings. No matter how efficient the HVAC system design and how little energy a system can theoretically use, if the control systems do not function properly, the system will not deliver the predicted performance.

One recent laboratory study shows that the common problem of sensors being out of calibration can increase energy usage of a building by 30% over the calculated amount. If we consider the energy wastage which can be caused when controllers and relays are allowed to drift out of calibration and remain out of calibration, the total energy wastage may be a much higher fraction. Current trend is to have either single trained technicians, one for the HVAC system and the other one for the controls system, or one cross-trained technician having expertise in both fields.

TYPES OF TRAINING

The best type of training is that which provides the trainee with hands-on experience and training in theory and principles.

Types of basic training include on-job-training, self-study, and formal training. Some facilities may use all types of training.

On-Job-Training (OJT)

On-job-training may be informal, where the trainee acquires training on the job under the supervision of an experienced person, or part of a formal training program, as described below for DDC systems.

In an informal program, the supervisor familiarizes the trainee with the system and assigns simple tasks to the trainee. The supervisor observes the trainee's work step-by-step and provides additional instructions as necessary to ensure that the task is accomplished properly.

As the trainee progresses, he is assigned more demanding tasks with continuing supervision by an experienced instructor. The training is complete when the instructor finds that the trainee knows the subject well enough to do the work alone. This type of training provides the trainee with both specific instructions and hands-on experience.

In addition to gaining hands-on experience, the trainee should study and become familiar with the theory and principles of both ATC and HVAC systems.

Formal or Classroom Training

Formal or classroom training is usually conducted by control system manufacturers for their own newly hired employees. Some of these courses are made available to field operating personnel. These courses usually begin with the basics of control theory and progress into hands-on training. These courses can familiarize the trainee with a manufacturer's specific types of systems and hardware.

Training operating and maintenance personnel on DDC systems requires more detailed classroom work, using complete documentation and training aids, followed by hands-on training first using demonstration modules on a trainer panel, then using the installed system.

Documentation should be prepared for a series of training courses to be given in the operation and maintenance of the HVAC and DDC systems. Materials in the documentation should include the training schedule for each course, a syllabus for each course, and copies of any training materials to be provided for trainees.

When training courses are to be given by an outside party, it is desirable to submit copies of the course documentation and biographical data for each proposed instructor to the building management for review and acceptance at least 45 days prior to the proposed date for start of training.

In selecting instructors, it is very important to verify that the instructor has learned the right way to do the work that is to be taught. Many experienced personnel get their job done by using their native intelligence rather than formal training and cannot effectively teach the subject matter to another who does not have the same degree and type of intelligence.

The courses should be planned to comply with requirements given below for Operator Training Course I, Operator Training Course II, and Operator Training Course III.

The planning of the training courses should be oriented toward the specific DDC and HVAC systems installed in the building. Data for planning the HVAC training sessions may be taken from the HVAC systems Operations and Maintenance manuals. Data for planning the DDC system training sessions may be obtained from the DDC system training manuals.

Include in DDC system training manuals a schedule of lessons, a statement of objectives for each lesson, and a detailed description of the subject matter for each lesson. For guidance, the planner should assume the students will be high school graduates and are familiar with the basics of HVAC systems.

One set of training manuals should be provided for each trainee with two additional sets provided for archiving at the project site. Any special audio-visual equipment and all other training materials and supplies should be provided by the training agency.

For new systems, the installing contractor should provide separate operator and maintenance training sessions.

Operator training courses may be planned in three parts:

- Operator Training Course I will be a general familiarization course on the theory of DDC and HVAC systems.
- Operator Training Course II will be a hands-on training course to demonstrate the theory taught in Course I and will be taught on classroom trainer panels and equipment.
- Operator Training Course III will be final hands-on training on the installed system.

Operator training will cover the basic theory of DDC system operation, the system hardware architecture including interface with controlled equipment, operation of the system reviewing graphic and narrative sequences of operation, operator commands with proper syntax, control sequence programming, database entry procedures, system operation reports and logs, alarm reports and messages, and system diagnostic procedures.

The first course of operator training should be taught in a classroom environment. For new systems, the first part should be given at least a month before the system performance verification test. The intent of the first part of operator training is to bring the student to a level of understanding adequate to allow the student to describe the general architecture and functioning of the system and to, under supervision, perform elementary system operations.

The second course of operator training is given hands-on the installed system and will duplicate the content of the first part as applied to the operating system. The intent of the second part is to make the student fully proficient in the operation of each system function.

The third course of operator training is intended to be structured to bring up and answer any questions that the student may have on the system operation, and should be given at the system site between 4 to 6 months after the system endurance test. Upon completion of the third course, the student is expected to be fully proficient in the system operation.

DDC system maintenance training courses may be planned in two parts:

- Maintenance Training Course I will be a formal classroom course using DDC system training aids including trainer panels and equipment.

- Maintenance Training Course II will repeat the training learned in Course I but will be performed as operations on the installed system.

The maintenance training will cover the physical layout of the system to familiarize the operator with the locations of the control system components and the controlled systems, troubleshooting and diagnostic procedures for each control component and the overall system, repair instructions for each field-repairable component, calibration procedures for each recalibratable component, and preventive maintenance procedures and schedules.

The maintenance training should be done after conclusion of the system endurance test. Eight hours in the classroom and eight hours in the field at the system site should provide adequate training for a normal system.

Self-study courses are also available. These are in the form of study guides that are suitable for use either with a trainer panel or for reading and reference after OJT or formal training sessions.

DURATION OF TRAINING SESSIONS

For OJT sessions, the duration of training may be varied according to the nature of the control system, the trainee's ability and experience, the ability and experience of the supervisor, the manner in which the training is conducted, and the duties which are assigned to the trainee at various levels during the training period.

For formal training on non-DDC systems, courses may vary in duration from one day to one week. One-day courses are usually seminars conducted by the manufacturer's agents which present new hardware or systems which have come to the market. Longer courses are usually conducted at manufacturer's training center and may be structured as basic control theory, specific system training, or specific operation and maintenance procedures, and may include lectures, homework, and hands-on experience.

For formal or classroom training, the length of each course will be scheduled in the course description and expressed in training days. A training day is defined as 8 hours of classroom or lab instruction, including two 15 minute breaks but excluding lunch time, Monday through Friday. Generally training is conducted during the daytime shift that is in effect at the training facility. For facilities operating more than one shift, it may be necessary to provide training during the other shifts.

For a moderate sized DDC system, the length of training sessions might be 5 days for the first part, 2 days for the second part, and 3 days for the third part. The optimum class size is about 5 students to an instructor. The training aids used in operating and maintenance personnel training should include instruction manuals from manufacturers of control components used in the system, trainer panels including examples of digital controllers, terminal unit controllers, sensors, actuators, and other controlled devices, test equipment such as decade box and multimeter, and interface tools such as notebook computer, hand-held terminal, and panel-mounted display and keypad for field communication with the digital controller.

When training is to be performed as a part of recommissioning an existing system for which original training was not adequate for replacement operators, the several parts of training should be scheduled at intervals adequate to allow the student to become familiar with the application of what has been learned before going on to the next part.

DOCUMENTATION FOR TRAINING PROGRAMS

Documentation for training programs should be prepared to ensure adequate coverage of the required subject material for both initial and recurrent training.

Documentation content should include an agenda for each part with a detailed description of the subject matter for each lesson and definition of objectives of each lesson, copies of any audio-visual aids, and drawings and parts list for each type of trainer panel.

OPERATOR TRAINING COURSE I

Plan the first operator training course to be given over a period of 5 consecutive training days in a suitable facility, preferably in the building. The course should be completed at least 1 month prior to the Performance Verification Test, if scheduled.

Plan the training to be performed in a classroom environment with hands-on operation of similar digital controllers mounted on trainer panels. For optimum instructor-trainee contact, a maximum of 10 personnel should attend this course at one time.

The course syllabus should include:

- Theory of operation
- Hardware architecture
- Operation of the system
- Operator commands
- Control sequence programming
- Data base entry
- Reports and logs
- Alarm reports
- Diagnostics procedures.

Upon completion of this course, each student, using appropriate documentation, should be able to perform elementary operations, with guidance, and describe the general hardware architecture and functionality of the system.

OPERATOR TRAINING COURSE II

The second operator training course should be planned to be taught in the field in 4-hour blocks during the Performance Verification Test for a total of 16 hours of instruction per student. Where a Performance Verification Test is not planned, a similar demonstration should be arranged for training purposes. The work included in a Performance Verification Test is described in Chapter 16.

The course content will follow the theory taught in Operator Training Course I but Course II will be taught "hands-on" using the installed system.

The course should be planned to provide one-on-one training in at least 2 of the 4 hour blocks to ensure full and individual training for each student. A maximum of 10 personnel should be scheduled for this course.

The training must be conducted under the constant monitoring of the instructor when using operating installed equipment. The one-on-one aspect of the training is very important because it is expected that the instructor will determine the password level that is to be issued to each trainee before each session.

The instructor should prepare a written report describing the skill level of each student at the end of this course.

The purpose of this course is to make the students fully proficient in the operation of each system function upon completion of this course.

OPERATOR TRAINING COURSE III

Plan the course to be conducted for a total of 3 training days and to be taught in the field at a time between 4 and 6 months after completion of Operator Training Course II. A maximum of 10 personnel should be scheduled to attend this course.

The course content should be structured to address specific topics that the students need to discuss, to generate questions on DDC system operation in normal and emergency operating modes, and to answer all questions concerning operation of the system.

Upon completion of the course, students should be fully proficient in system operation and should have no unanswered questions regarding operation of the installed system.

MAINTENANCE PERSONNEL TRAINING

The DDC system maintenance course should be planned to be taught at the project site for a period of 2 training days within one month after completion of Operator Training Course II. A maximum of 10 personnel should be scheduled to attend the course.

The DDC system maintenance course will include troubleshooting, checkout, and calibration sessions. The first sessions will be conducted in a classroom setting using trainer panels fitted with digital controllers of the same manufacture and model as those in the working system. The final sessions will repeat the operations of the first sessions but will be conducted on the operating system.

The course should be planned to include:

- Physical layout of each piece of hardware
- Troubleshooting and diagnostics procedures
- Component repair instructions
- Preventive maintenance procedures and schedules
- Calibration procedures.

INITIAL AND RECURRENT TRAINING

Initial training of control system operating and maintenance personnel is of the utmost importance in ensuring that the newly hired personnel understand the specific system that they are responsible for operating and maintaining. Although a person may have extensive experience in operating and maintaining control systems, unless that experience has included DDC systems of the same manufacture and type as those in a specific system, initial training on the specific system should be mandatory.

Recurrent training of control system technicians is also very important. Operating and maintenance personnel must keep up with the state of the art in the industry, including new systems, new operating and maintenance procedures, and new developments in energy conservation.

As new control devices and systems come to the market, and are installed in the building, personnel will need to become familiar with these new developments in order that they may perform their work more effectively. Recurrent training may be conducted by any of the methods listed above.

Training is expensive, both in time spent to plan the courses and in time spent by instructors and students during the courses. In many cases, an investment in professional videotaping of the lectures and instructions during "hands-on" sessions can pay off in a few years use in initial and recurrent training.

SOURCES OF DATA

Magazines and Newspapers

Technical magazines and newspapers are very useful sources of data. Such magazines and newspapers, published weekly or monthly, include: *Air Conditioning, Heating and Refrigeration News; Building Operating Management; Engineer's Digest; Heating/Piping/Air Conditioning;* and *Maintenance Technology.* Many articles are concerned with HVAC controls. It is recommended that these publications be made available in the facility for reading by the operating and maintenance personnel.

Manufacturer's Literature

Literature provided by the manufacturers is of significant value to the operating and maintenance personnel. Most of the control manufacturers provide specific operating and maintenance instructions with flow charts for troubleshooting. These instructions also provide information as to the proper application and setup of specific hardware, with calibration procedures.

Chapter 15

Installing Hybrid Pneumatic and Direct Digital Control Systems

This chapter discusses the installation of devices for modification of existing pneumatic control systems to operation as hybrid systems by adding direct digital control (DDC) signal sensing and control algorithms to existing pneumatic actuators for dampers and valves. The DDC system positions a transducer in the pneumatic control line to deliver the pneumatic pressure required to move the pneumatic actuator to the desired position. The transducer then provides a feedback signal to the DDC system indicating that the pneumatic actuator has been repositioned.

These modifications are often desirable to allow DDC control of systems that may be of the original all-pneumatic operation or that may be pneumatically actuated but with previously retrofitted with non-DDC type control systems. Systems of Energy Management and Control System (EMCS) or Energy Management System (EMS) types are typical examples of non-DDC type building automation systems (BAS). This approach is often desirable to replace defective pneumatic receiver-controllers or to allow implementation of the remote signal sensing and distributed processing that is provided by DDC for temperature and humidity control functions in building operation.

HYBRID SYSTEMS ARCHITECTURE

Hybrid pneumatic and DDC systems use electronic and microelectronic devices for signal sensing and conversion, microprocessors for logic control, and pneumatic apparatus for actuation of controlled devices. In some systems, electric and electronic control actuators may be incorporated into the hybrid system.

In converting all-pneumatic and EMCS or EMC type systems to allow distributed processing, new digital controllers are located adjacent to the controlled equipment with a new local area network (LAN). The new local controllers may be of either the stand-alone controller (SAC) type or of the terminal controller unit (TCU) type. The differences between TCUs and SACs and in the operation of distributed processing and centralized processing systems are explained in Chapter 16, Operating Direct Digital Control Systems.

SYSTEM FAMILIARIZATION

Before undertaking the modification to a hybrid pneumatic/DDC system, it is necessary to become completely familiar with original design of the existing control systems. The familiarization must cover all control systems to determine each system's architecture, installed hardware, and the present and desired future programming.

The system familiarization study must provide a careful coverage of these subjects:

- Basic system familiarization
- Study of system documentation
- Hands-on operating system familiarization

Basic System Familiarization

This part of the study must include a walk-through inspection of all the systems to be modified and controlled, identifying each existing control component and controlled device. Where existing control devices are not identified by an alpha-numeric identifier, those devices must be assigned an identifier. The report on findings of the inspection must document the system identification with an exact listing for each controlling device, such as "T-1"; the location, such as "on the supply duct over the center of the Auditorium"; the manufacturer's name and model number, "such as XYZ T-1224; the setpoint range, present setting, and controlled value if available, such as "40 to 80 degrees, set 72 degrees, holding 73 degrees"; and any suggestions that may come to mind during the inspection, such as "Thermostat should be moved to another point due to localized heat."

In performing the basic system familiarization study, it is desirable for the person responsible for the study to arrange to be accompanied at least part-time by one or more of these persons: a knowledgeable control system operator from the building's maintenance force, the person who has done most of the control system troubleshooting, and the original system designer. One purpose of this part of the work is to determine the conditions that have brought about the desire by the owners to modify the systems. The person planning the system modifications has the opportunity to correct problems that may have existed from the time the systems were started years ago. In some cases, the familiarization must rely in part on a verbal description of the system given by operators of the existing system, a representative of the original system vendor, or the original system design engineer.

The familiarization study may also be supplemented through one or more of these procedures: a training session conducted by the control system contractor, a verbal description of experience with the existing system by an operator or by the original system vendor's representative, or by the original system designer.

When the familiarization study is performed as a part of the operator training syllabus, these subjects should be included: the theory of the system operation; system hardware architecture; actual system operation; operator commands; control sequence programming; data base entry; system reports and logs.

The documentation expected to be available for an existing control system includes: control system schematic drawings; list of abbreviations and symbols used in the drawings; narrative sequences of operation; graphic sequence of operation; electrical equipment ladder diagram; pneumatic system piping and wiring diagrams; electric/electronic component wiring diagram; electric/electronic component terminal strip diagrams; I/O points list of EMCS and EMC systems; equipment components list; ac power requirements table; copies of field test reports; copies of the original control system operation and maintenance manuals; copies of field test reports on the system made by the test and balance agency along with any control system checkout that may have been made as a part of that work; and copies of any third-party software documentation.

Control system schematic drawings will depict the process flow diagram for each system showing existing and new components such as dampers, coils, and fans, with notation for location of each input and output device, the name or symbol for each control component such as valve V-1, temperature sensor TS-1, or damper actuator DA-1, set points for each adjustable device, range and span for each sensor, range for each actuator, dampers schedule listing size, type, and normal positions, valve schedules with model number, flow rate, flow coefficient (CV) and normal positions, and switching points for input switches.

List of abbreviations and symbols will include all abbreviations and symbols used in the documentation, based on industry standards, or on the manufacturer's discrete designations where no industry standards exist.

Narrative sequences of operation will describe individual operating functions such as daily start/stop, unoccupied cycle override, emergency shut-down, seasonal changeover, supply air temperature control and reset, space or zone temperature control, terminal unit control, humidity control, duct pressure control, building pressurization control, automatic filter control, electrical interlocks, chilled water temperature reset, chiller plant control, heated water temperature control and reset, boiler plant control, and piping system pressure control. The sequences will also list alarm conditions, actuating points, and rest schedules.

Graphic sequences of operation are pictorial process flow diagrams covering the same systems as the narrative sequences of operation. These diagrams are incorporated into the graphics program on the operators work station.

Electrical system ladder diagrams are step-by-step graphical representations used to depict the electrical control and interlock wiring for starting and stopping motors in the controlled system.

A typical ladder diagram for an air handling unit is shown in Chapter 2, HVAC Equipment-to-Control Interactions, Figure 2-3.

Component wiring diagrams depict wiring connections between controllers, input and output devices, field-connected devices such as boiler or chiller control panel, and each required power supply with current characteristics, such as filtered 24 volts dc, and power draw in milliamperes (Ma), with each connection point identified by number and functional designation. Individual component wiring diagrams are obtained from the manufacturer of the component. Where an internal wiring diagram is not available from the manufacturer of a component, a serviceable diagram can be derived from study of the documentation and examination of the hardware item.

Terminal strip diagrams show the terminal designations for each controller and control component with terminal designations for each controller and control component with terminal strip location, terminal numbers, and associated point names. A list of system I/O points will provide for each input and output device physically connected to a controller, on a controller-by-controller basis, point description such as mixed air controller or supply fan start/stop, point type whether AI, AO, DI, or DO, point range such as 3 to 15 psi, 4 to 20 Ma, 1,000 ohm platinum RTD, or thermistor, sensor range associated with point range such as 0 to 100 degrees F or 0 to 1.0 inches water gauge, software associated with point such as temperature reset, and terminal number to which point is connected.

System components lists will schedule all controllers and connected devices shown on a schematic drawing on a system-by-system basis with control system components designation and name such as MAC-1 Mixed Air Controller, component description such as terminal control unit, manufacturers name and part number, size and flow coefficient (CV) for valves, and normal position, energy source and operation range for actuators such as normally-open 3 to 7 psi pneumatic. AC power requirements table will list the source of power to each controller and powered device including circuit breaker panel and circuit designation and physical location of panel box.

Original installation field test reports should provide data on results of three basic test sets: 1) initial system check-out; 2) performance verification; and 3) opposite-season testing.

The material expected in test set 1, initial system checkout report, includes findings of detailed system inspection by installer or design personnel, results of input calibration accuracy and operation test, outputs test, actuator range adjustment test, digital controller start-up and memory test, surge protection test, and application software operation test. Where test results are not available to the operator, the desired tests can be run again following procedures detailed in Chapter 15 DDC

System Maintenance.

The material expected in test set 2, test documentation includes expected and actual response of actuators, controllers, and sensors with trend reports to document control loop stability and accuracy, proper execution of sequences of operation, and proper operation of equipment interlock, including emergency shutdown from fire, smoke, and freeze detectors.

The material expected in test set 3, opposite season testing, includes the results of the same testing as reported in test set 2 but performed in the opposite season. If the initial testing is performed during the cooling season, the opposite season testing will be done during the heating season, and vice versa.

The system specifications may include limits to define the seasons, such as "within 5°F of the designed dry bulb temperature and within 3°F of the designed wet bulb temperature for cooling season" and a similar dry bulb temperature limit for heating season. These seasonal temperature definitions are intended to ensure that the system will be checked out in true operating conditions rather than in the intermediate seasons when there may be limited need for cooling or heating.

DDC system operating and maintenance manuals should include a functional design manual, the DDC hardware manufacturer's manuals, sensor and control components manual, operator's manual, and workstation equipment manufacturer's manuals.

<u>Functional design manuals</u> should include a glossary of terms used in the control system documentation, a narrative DDC system description describing the hybrid system as to system size, the system architecture, a narrative description of how the pneumatic and DDC components interact, and the overall system functions, graphical and narrative sequences of operation abstracted from the original building system design documents, a complete set of hybrid system schematic and ladder drawings modified to "as built," and reports on field testing such as were described above.

<u>DDC hardware manufacturer manuals</u> should contain a collection of manufacturer's printed data covering specifications for components, installation instructions, operating instructions, test and service procedures, and DDC-specific software documentation.

<u>Sensor and control component manuals</u> should contain a collection of manufacturer's printed data for components external to the DDC

controllers such as sensors, actuators, relays, and transducers. The data will include detailed specifications and instructions for installation, testing, servicing, and calibration of each component.

The operator's manual should provide information necessary to operate the specific hybrid pneumatic and DDC system. The basic requirements for this manual are included in Chapter 16, Operating Direct Digital Control

It will be necessary to include information from the original pneumatic control system operating manuals as is necessary to provide adequate coverage of the reused pneumatic control system components.

Work-station equipment manufacturer's manuals should include individual manuals for each major component, such as computer, monitor, printer, and power line conditioner, and peripheral equipment, such as modem and pointing device, either mouse or track-ball, work-station software documentation manuals, graphics creating and editing instruction manual, and narrative description of work-station operation.

Manuals should include adequate instructions for the set-up and initialization of work-station hardware from scratch, including formatting the hard drive, loading work-station software, setting dip-switches, communicating by LAN and modem, accessing the DDC system, using the pointing device, and troubleshooting the workstation hardware.

Third-party software documentation required is dependent of any third-party software that is installed on the system. Such software may be used for reports and trend logging. Typical programs used for this purpose include Microsoft Windows© with Excel© and Word©.

Study of System Documentation

A detailed study of the existing system documentation is necessary to determine the design intent of the original control systems. In order to make this study it is necessary to locate copies of the original system documentation along with documentation of any system changes.

The system documentation should also include a copy of the specification sections from the Project Manuals issued when the building was originally constructed or when the control system was modified by extension or by upgrade to EMCS/EMC operation.

Following the detailed study of system documentation, the new system planner will have determined what parts of the original system documentation are available and must determine any additional information that will be needed to plan the new hybrid system. The planner may have to go to some great lengths to locate and obtain copies of any missing items of documentation. In very old building installations, the search for a copy of the original Project Manual may seem impossible but a careful investigation will often turn up a copy.

After all the control system documentation is assembled, it will be necessary to make a detailed study of the documentation, complemented by examination of system hardware and maintenance tools.

A study of the original system test and balance (T&B) field reports will determine whether they contain a listing of alarm reports and a summary of complaints received from the building occupants and operators. Hopefully, each complaint will include data as to "who, what, when, and how much."

Hands-on operating system familiarization. The hands-on operating system familiarization may be accomplished as part of the retrofit control system contractor's operator training program or it may be done through an on-job-training (OJT) program, either at the facility or part-time at an educational center supplemented by site visits to the facility.

The required steps in a hands-on operating system familiarization are described in Chapter 14, Training Operating and Maintenance Personnel.

Chapter 16

Operating Direct Digital Control Systems

This chapter discusses the operation of true direct digital control (DDC) systems of the distributed processing type. Energy Management and Control Systems (EMCS) and Energy Management Systems (EMS) types of building automation systems (BAS) are non-DDC systems that employ centralized processing rather than distributed processing and are not discussed here. Hybrid systems employing DDC signal sensing with pneumatic control actuation are discussed in Chapter 15, Hybrid Pneumatic and Direct Digital Control Systems.

DDC SYSTEMS ARCHITECTURE

DDC systems use electronic and microelectronic devices for signal sensing and conversion, microprocessors for logic control, and electric, electronic, and pneumatic apparatus for actuation of controlled devices.

In distributed processing, digital controllers are located adjacent to controlled equipment and connected to a local area network (LAN). Local controllers may be stand-alone controllers (SACs) or terminal controller units (TCUs). TCUs are similar to SACs, but do not include a time clock and resident software, which requires that TCUs be served from SACs.

Distributed processing differs from centralized processing in that local digital controllers perform the processing and communicate through a multi-level local area network (LAN) with other controllers to perform control functions in accordance with logic from high level controllers whereas centralized processing is done with a central microcomputer connected in a multiplexed circuit to local signal sensing and conditioning modules at controlled equipment. Failure of communications link on a DDC system returns local controller to programmed functions. Failure of the communications link in multiplexed non-DDC systems may either return local controls to operate on "last command" or may result in total loss of control.

SYSTEM FAMILIARIZATION

A DDC system operator must be totally familiar with the system, its architecture, hardware, and programming.

The best way for an operator to become familiar with the system is through a 3-part training program, including:

- Part 1 - basic system familiarization
- Part 2 - detailed study of system documentation
- Part 3 - hands-on operating system familiarization

In Part 1, Operator's basic system familiarization, the operators may achieve basic system familiarization through either the contractor's training session or by a verbal description of the system by another operator, a system vendor's representative, or the system designer. When performed as operator training by the contractor, the familiarization should include these elements: theory of operation; system hardware architecture; system operation; operator commands; control sequence programming; data base entry; system reports and logs; alarm reports; and diagnostic routines. When verbal descriptions are given by other persons familiar with the system, they should be planned to follow this outline. The intent of Part 1 training is to bring a new operator to a level of understanding adequate to allow the operator to perform elementary operations and to describe the basic hardware architecture and functional operation of the system.

In Part 2, detailed study of system documentation, a new operator is required to investigate all the documentation that is available for the system, determine any additional documentation that is needed, obtain missing items of documentation, and make a detailed study of the documentation, complemented by examination of hardware and maintenance tools. The documentation usually prepared for a system includes: control system schematic drawings; list of abbreviations and symbols used in the drawings; narrative sequences of operation; graphic sequence of operation; electrical equipment ladder diagram; component wiring diagram; component terminal strip diagram; I/O points list; equipment components list; ac power requirements table; copies of field test reports; copies of control system operation and maintenance manuals; and copies of third-party software documentation. These items of documentation are described in detail in Chapter 15, Hybrid Pneumatic and DDC Systems.

The documentation prepared by the installing contractor will generally include the drawings depicting the control system schematic diagrams, a list of abbreviations and symbols used in the drawings, narrative sequences of operation explaining how each component positions other devices in the system, a graphic sequence of operation depicting the interconnections between equipment items and controlled devices, an electrical equipment ladder diagram showing how the electrical power is controlled by the control devices, a control component wiring diagram showing the control system wiring with wire numbers, a control component terminal strip diagram showing where each wire connects with both contact designations and control wire numbers, an I/O points list tabulating all the input and output connections in the system, an equipment components list with manufacturer's model numbers in adequate depth to allow the ordering of exact replacement parts, and an ac power requirements table to allow coordination with the building electrical system engineering design.

The *field test reports* are reports based on three basic sets of tests: 1) initial system checkout; 2) performance verification; and 3) opposite season testing. Although each of the test sets is described under Chapter 15, Hybrid Pneumatic and DDC Systems, they are repeated here for the reader's convenience.

For test set 1, initial system checkout, this report should list findings of detailed system inspection by installer or design personnel, results of input calibration accuracy and operation test, outputs test, actuator range adjustment test, digital controller start-up and memory test, surge protection test, and application software operation test. Where test results are not available to the operator, the desired tests can be run again following procedures detailed in Chapter 17, Testing Direct Digital Control Systems.

For test set 2, test documentation, this report should include a tabulation of expected and actual response of actuators, controllers, and sensors along with trend reports to document control loop stability and accuracy, proper execution of sequences of operation, and proper operation of equipment interlock, including emergency shutdown from fire, smoke, and freeze detectors.

For test set 3, opposite season testing, this report should include a tabulation of the results of the same operations as test set 2 when performed in the opposite season. If the initial testing is performed during the cooling season, the opposite season testing will be done during the heating season, and vice versa.

The system specifications may include limits to define the seasons, such as within 5°F of the designed dry bulb temperature and within 3°F of the designed wet bulb temperature for cooling season and a similar dry bulb temperature limit for heating season. These seasonal temperature definitions are intended to ensure that the system will be checked out in true operating conditions rather than in the intermediate seasons when there may be limited need for cooling or heating.

The *DDC system operating and maintenance manuals* should include: functional design manual; DDC hardware manufacturer's manuals, sensor and control components manual; an operators' manual; and workstation equipment manufacturer's manuals.

The functional design manuals should include a glossary of terms used in the documentation, a narrative DDC system description describing the system size, the system architecture, a narrative description of how the components interact and the overall system functions, graphical and narrative sequences of operation abstracted from the system design documents, a complete set of system schematic and ladder drawings modified to "as built," and reports on field testing such as were described above.

The DDC hardware manufacturers' manuals should contain a collection of manufacturer's printed data covering component specifications, installation instructions, operation instructions, test and service procedures, and DDC-specific software documentation.

The sensor and control component manuals should contain a collection of manufacturer's printed data for components external to the DDC controllers, such as sensors, actuators, relays, and transducers. The data will include detailed specifications and instructions for installation, testing, servicing, and calibration of each component.

The operator's manual should provide the information necessary to instruct the operators in the operation of a specific DDC system. The manual is intended to include all the instructions necessary such as how to initialize digital controllers; how to upload and download controller software; how to perform point set-ups; how to adjust scheduling and setpoints; how to perform controller diagnostic routines; how to perform PID loop tuning; and a list of alarm conditions with the related alarm messages that are now or may be programmed into the digital controllers.

The *instructions for initializing digital controllers* will cover the sets of procedures required to set-up each new digital controller to a point that it will accept control programs from a computer, including documentation of cable connections, dip-switch settings, and each equipment setting essential for proper operation of the controller.

The *instructions for uploading and downloading computer software* will include step-by-step procedures for performing data exchange to and from digital controllers, each work-station computer, and each handheld computer.

The *instructions for point set-up programming* will include step-by-step procedures for set-up of point addresses and values.

The *instructions for scheduling and setpoint adjustment* will explain procedures for programming schedules and adjusting setpoints.

The *instructions for controller diagnostic procedures* will include step-by-step procedures for running and analyzing controller diagnostic routines, including an explanation of each LED indication.

The *instructions for PID loop tuning* will explain the procedures used to tune PID loops in the control system.

The *listing of alarm conditions and associated alarm messages* will include an explanation of anticipated alarms and probable cause for each alarm.

The work-station equipment manufacturer's manuals should include individual manuals for each major component, such as computer, monitor, printer, and power line conditioner, and peripheral equipment, such as modem and pointing device, either mouse or track-ball, workstation software documentation manuals, graphics creating and editing instruction manual, and narrative description of work-station operation.

Equipment manuals should include adequate instructions and software necessary to perform the set-up and initialization of work-station hardware from scratch, including formatting the hard drive, loading work-station software, setting any dip-switches, communicating by LAN and modem, accessing the DDC system, using the pointing device, and troubleshooting the work-station hardware.

The Third-party Software documentation required is dependent on any third-party software that is installed on the system. Such software is that which may be required for preparing reports and for trend logging. Typical programs used for this purpose include Microsoft Windows (with Excel(, Money(, and Word(.

The Hands-on Operating System Familiarization may be accomplished as part of the installing contractor's operator training program or it may be done through an on-job-training (OJT) program.

The steps in hands-on operating system familiarization are described in Chapter 14, Training Operating and Maintenance Personnel.

Chapter 17

Testing Direct Digital Control Systems

New DDC systems should be thoroughly tested and proven before being placed in normal operation. This testing is most effective when performed by trained technicians in the employ of the DDC system manufacturer. When existing systems are being recommissioned after extensions or modifications, the systems should be retested by control system technicians who have received the manufacturer's factory training courses and have been working with the original system on the site, by trained technicians in the employ of the DDC system manufacturer, or by a composite team of both experience levels.

REQUIRED TESTS

The testing of new or modified existing systems being recommissioned should be performed in these three parts. First, perform a basic field test. Second, perform a system performance verification test. Third, perform an opposite season test.

Basic Field Test

For a new system, the basic field test is performed before the system is placed on-line. For an existing system being recommissioned, whether modified or not, the system must be taken off-line and deenergized before performing the basic field test. When testing existing systems, the controlled systems and equipment will have to be shut down during the basic field test procedures if there is no local loop control left after the system modifications.

The basic field test includes these seven separate procedures:

- A basic *controlled systems inspection* will be performed during system shutdown condition to verify the *normal position* of dampers and valves and the shutdown of interlocked devices.

- A *calibration accuracy and operation of inputs test* will be made using precision testing equipment to accurately measure the input value of the sensed media at the sensor and the input value received by the digital controller.

- An *operation of outputs* test will be made for each output to command analog outputs through the full range of the device, such as 4 mA minimum to 20 mA maximum, then to measure and record output values corresponding to each input, and finally to command the digital outputs between on and off to verify appropriate outputs for each range of input values.

- An *actuator range adjustment test* will be performed for each actuator by applying a control signal to the actuator and verifying that the actuator operates properly through its full range of stroke position, then verifying the spring range on pneumatic actuators and recording the spring ranges along with the normal positions of dampers and valves.

- A *digital controller memory and startup test* will be performed to verify that controller memory will retain programming during an electrical power interruption and will restart the system properly when the electrical power is restored.

- A *surge protection verification test* will verify by visual observation that surge and transient protective devices are installed on incoming power and communications lines to the system and are properly connected.

- An *application software operation test* will verify the ability of DDC software to communicate with digital controllers in uploading and downloading control programs, to edit control programs off-line, to report to workstation all alarm conditions simulated at sensor, and to receive and save to memory all trend log and system status reports.

Performance Verification Test

The system performance verification test is an endurance test performed as a week-long procedure that will include a sequence of operation demonstration and a control loop stability and accuracy demonstration to prove that the control loops are tuned and that the controllers are programmed for the correct sequence of operation.

The testing includes performing the specified sequences of operation for each system from beginning to end, verifying the stability and accuracy of the control loops, and generating graphed trend logs during the *sequence of operation test* and the control loop stability and accuracy test.

Sequence of Operation Demonstration

In the *sequence of operation execution demonstration*, each of the controlled systems is caused to operate through the full range of each sequence of operation, including simulated seasonal changes in temperature and humidity, occupied and unoccupied cycle, cooling and heating mode changeover, operation of interlock circuits, system safety shutdown, and control restoration after power loss. The sequence of operation demonstration will also prove proper response to unusual conditions for which there are specified responses by simulating each of the unusual conditions.

Control Loop Stability and Accuracy Demonstration

The purpose of the *control loop stability and accuracy demonstration in the system performance verification test* is to generate graphs of trends during the week-long test to verify that each control loop is stable, that control setpoints are maintained, and that loop response to control setpoint changes will stabilize within one minute. A recording of trend data is logged on an instantaneous basis at not greater than one minute intervals.

Opposite Season Test.

In the *opposite season test*, the *performance verification test* described above will be performed in the season opposite that in which the first test was performed. For best results, it must be ensured that the weather conditions during the opposite seasons will be reasonably close to the system design temperature and humidity conditions.

The allowable offset values for weather conditions between actual and design values during opposite season testing will have to be determined for each building or project.

TEST REPORTS

Prepare and execute report forms to document the results of the tests. Prepare the forms for each of the tests to include:

Basic Field Test

1) A tabulation of all the dampers and valves in each system to verify the position of each device during shutdown condition and to verify the shutdown of interlocked devices.

2) A tabulation of all the controllers in the system documenting the measured input value of the sensed media at the sensor and the input value that was received by the digital controller, with an analysis of the controller calibration accuracy and a verification of the operation of inputs test. A listing of the make and model of the precision test equipment used in the testing with data of last calibration is desirable.

3) A tabulation of all the controllers in the system with test data proving the satisfactory completion of the operation of outputs test. Data for analog devices will include the range of input values required to command analog outputs through full range, and the value of output values for each input. Data for digital devices will include input values required to command the digital outputs between on and off.

4) A tabulation of all the actuators with data to prove satisfactory completion of the actuator range adjustment test. Data will include normal position for each damper and valve, values of control signal applied to the actuator, and verification that the actuator operates properly through its full range of stroke position. For pneumatic actuators, data will include spring range values.

5) A tabulation of all the digital controllers with data to prove satisfactory completion of controller memory and startup test. Data will include verification that controller memory will retain programming during power interruption and will restart the system properly when power is restored.

6) A tabulation of all incoming power and communications lines to the system with descriptive data of the surge and transient protective devices that are installed thereon, with verification that such devices are properly connected.

7) A report on testing of application software operation with verification of satisfactory completion of tests to verify the ability of DDC software to communicate with digital controllers, to edit control programs off-line, to report to workstation all alarm conditions simulated at sensor, and to receive and save to memory all reports. Include copies of all trend log and system status reports generated during the testing.

8) A report on the testing of the specified sequences of operation for each system with verification of the stability and accuracy of the control loops will be based on the graphed trend logs generated during the testing.

Performance Verification Test.

1) A set of reports recording periodic readings made during the endurance test as required to demonstrate the sequence of operation of each control loop with data to prove control loop stability and accuracy.

2) A set of reports including graphed trend logs made during the endurance test as required to demonstrate stability and proper tuning of control loops.

3) A set of reports including graphed trend logs made during the endurance test as required to demonstrate that controllers are programmed for the correct sequence of operation specified for the system.

Opposite Season Test.

1) A set of reports as required for the *performance verification* test performed in the season opposite that in which the *performance verification* test was performed.

2) Coordinate with the director of the system testing to establish allowable offset values for weather conditions between actual and design values during opposite season testing before commencing testing.

Chapter 18

A Short Course in Psychrometrics

The ability to diagnose and correct HVAC system control problems requires a working knowledge of the processes of cooling and heating, as well as dehumidification and humidification, as performed by the components in HVAC systems of various types. Investigation of HVAC system design problems may find the complaints are based on ATC control system operation.

In order to be certain that the control system is operating properly to control the various processes, the technician must know how each control strategy is intended to function before making a field check to answer an HVAC complaint call. A determination of proper system operation requires a basic knowledge of the science of moist air or *psychrometrics*.

USING PSYCHROMETRICS IN DIAGNOSING HVAC CONTROL PROBLEMS

Partial Load Operation

HVAC systems must be designed with capacity to satisfy the maximum cooling and heating loads at the extremes of design conditions, including external factors, such as weather and solar load, and internal factors such as from occupancy and lighting. Because of the variable intensity of the load factors, HVAC systems do not operate at full capacity very often. Many systems will be found to operate at about half-capacity for most hours of the year.

The required system capacity changes from hour to hour due to changes in outside conditions for time-of-day and time-of-year and due to daily usage of internal loads from lights, processes, and people.

Therefore the control system must regulate the output of the HVAC systems to keep the temperature and humidity within the desired ranges.

Because most HVAC systems perform cooling and dehumidification simultaneously, when no cooling is required humidity control is lost.

Terms Used in Psychrometrics

Psychrometric chart—A chart which depicts the psychrometric relationships of moist air such as is used in HVAC processes. A typical psychrometric chart is shown in Appendix A. The commonly used relationships shown on the chart are dry bulb temperature, wet bulb temperature with enthalpy or total heat scale, dew-point temperature with humidity ratio or moisture content scale, saturation temperature curve, % relative humidity curves, specific volume lines, and sensible heat to total heat ratio or enthalpy to humidity ratio slope lines. These relationships are identified on the skeleton psychrometric chart in Figure 18-1a.

These relationships are used to determine the conditions of the air-water vapor mixture as it goes through various conditioning processes.

Any air-conditioning process can be visualized by use of the psychrometric chart. When any two known basic values are plotted on the chart, values for the other relationships can be read directly from the chart.

The psychrometric chart is an indispensable tool for system performance analysis and for control system set-up calculations. The examples in this chapter are based on the ASHRAE psychrometric chart. A blank copy of this chart is provided in Appendix A. The ASHRAE chart is typical of the charts available. Major HVAC equipment manufacturers publish psychrometric charts that are arranged in different formats but which contain the same information. Some of those charts may be obtained encased in matte finish plastic which allows one to draw the processes on the chart, make a copy, then erase the markings to be ready for the next problem.

Dry bulb temperature (DB)—The temperature obtained when air is passed over the bulb of an ordinary thermometer.

Wet bulb temperature (WB)—The temperature obtained when air is passed over the bulb of an ordinary thermometer, which is covered by a water soaked wick, until the temperature reading is lower than the dry bulb temperature of the air. The temperature difference occurs because air passing over the wick gives up heat in evaporating water from the

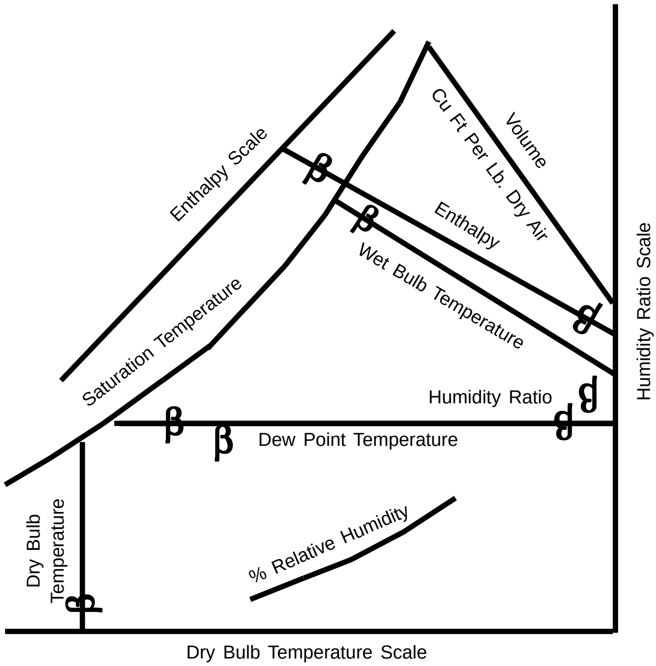

Figure 18-1a. Schematic ASHRAE Psychrometric Chart "Copyright by the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., from Cooling and Heating Load Calculation Manual. Used by permission."

wick. That energy is called the latent heat of vaporization for the evaporation process. As heat is drawn from the air in the evaporation process, a decrease in the enthalpy occurs.

Enthalpy is the total heat content of the air, expressed in Btu per pound of dry air. When the enthalpy changes, the wet bulb temperature changes in the same direction, that is an increase in enthalpy will result in an increase in wet bulb temperature. Enthalpy tables or the enthalpy scale on psychrometric charts show the total heat of air for each wet bulb temperature. Enthalpy values are determined from the wet bulb temperatures and vice versa. When calculating mixed air wet bulb temperatures, the proportions are not linear. It is necessary to convert the wet bulb temperatures of each airstream to enthalpies, calculate the enthalpy of the air mixture, and then use the enthalpy of the mixture to convert back to wet bulb temperature.

Specific humidity or humidity ratio—The moisture content or mass of water vapor present in an air-water vapor mixture is called specific humidity when stated in grains of moisture per pound dry air and is called humidity ratio when stated in pounds of water per pound dry air.

Relative humidity (RH)—The ratio of partial vapor pressure of an air-water vapor mixture to the pressure of saturated steam at the same dry bulb temperature is called relative humidity and is stated in percent. It is a measure of the relative ability of the air to absorb moisture at a specific dry bulb temperature.

Dewpoint (DP)—The temperature point where a mixture of air and water vapor exists but where any further cooling will result in condensation of water vapor from the air. This is the phenomenon observed outdoors as dew. That temperature point is called the dewpoint and the temperature corresponding to the point is called the dewpoint temperature.

Sensible heat (SH)—Heat which brings about a change in dry bulb temperature of the mixture, when added to or removed from an air and water vapor mixture at constant specific humidity, is called sensible heat.

Latent heat (LH)—Heat which brings about a change in moisture content of the mixture, when added to or removed from an air and water vapor mixture at constant dry bulb temperature, is called latent heat.

Total heat (TH)—The sum of sensible heat and latent heat in an air and water vapor mixture is called the total heat or enthalpy of the mixture.

Sensible heat to total heat ratio (SHR)—The ratio of sensible heat to total heat to be removed in a cooling process is often called sensible heat ratio and is represented on the psychrometric chart by a condition line connecting the space condition with the supply air condition and marked SHR. This may also be called sensible heat factor (SHF) or Enthalpy to humidity ratio.

Bypass factor—When air passes over the cooling coil surface, a portion of the air contacts the coil and gives up some of its heat content while the remainder goes through the coil unchanged. The proportion of the air which leaves the coil unchanged to the total air flow through the coil is called the bypass factor. Each type of coil surface has a bypass factor, which varies with air velocity, number of tube rows deep in direction of airflow, surface characteristics of fin material, and spacing of coil fins.

Determining Conditions of
Air Entering and Leaving a Cooling Coil

The skeleton psychrometric chart in Figure 18-1a shows the relationships of the moist air. An outline of all the psychrometric processes on a psychrometric chart is shown in Figure 18-1b. The key to the psychrometric processes is:

- Line A illustrates humidification without dry bulb temperature change
- Line B illustrates heating and humidification
- Line C illustrates sensible heating
- Line D illustrates heating and dehumidification
- Line E illustrates dehumidification without dry bulb temperature change
- Line F illustrates cooling and dehumidification
- Line G illustrates sensible cooling
- Line H illustrates cooling and humidification, often adiabatic
- Line J illustrates saturation curve
- Line K illustrates cooling to super-saturation
- Line M illustrates air mixing.

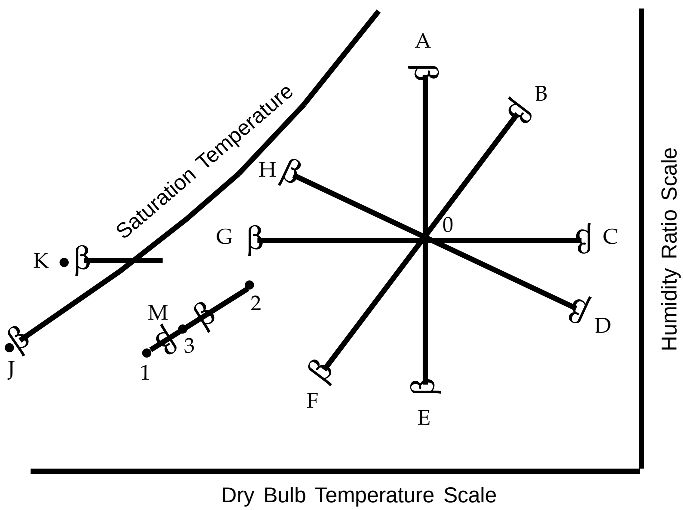

Figure 18-1a. Basic Air-Conditioning Processes. "Copyright by the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., from Cooling and Heating Load Calculation Manual. Used by permission."

The control of cooling and heating coils may involve these four psychrometric processes:

1. *Heating Only*. The heating only process, shown by line C, is drawn as a straight line of constant dew point temperature and humidity ratio moving to the right with increasing dry bulb temperature.

2. *Sensible cooling only*. When air passes over a cooling coil where the coil surface temperature is lower than the air dry bulb temperature but warmer than the air dewpoint temperature, the air is cooled but the moisture content stays unchanged. This process is called sensible cooling. The sensible cooling only process, shown by line G, is drawn as a straight line of constant dew point temperature and humidity ratio moving to the left with decreasing dry bulb temperature.

3. *Simultaneous cooling and dehumidification*. When a part of the coil surface is colder than the air dewpoint temperature, sensible cooling of the air will occur at first, then as the air cools below its dewpoint temperature, further cooling will result in condensation of water vapor from the air on the coil surface as free water, called condensate. When all the coil surface temperature is lower than the air dewpoint temperature, there will be both sensible heat and latent heat removal. The heat removed from the moist air by the condensation of water vapor is called latent heat. The sum of the sensible heat and latent heat is called total heat. That process is called simultaneous cooling and dehumidification. The simultaneous cooling and dehumidification process, shown by line F, is drawn as a line of decreasing dew point temperature and humidity ratio moving down and to the left with decreasing dry bulb temperature.

4. *Air mixing*. Mixing of two air streams, shown by line M, is drawn as a straight line connecting the conditions of the two air streams, with the resulting mixture plotted on the line at a point distant in inverse ratio to the condition plotted.

Determining Conditions in Air Mixing

The air which enters a cooling coil to be delivered to the conditioned space is usually a mixture of outside air and return air that is called mixed air. The mixed air condition can be shown on a psychrometric chart by graphically plotting the outside air (OA) and return air (RA) conditions, connecting the condition points with a straight line, and locating the mixture point on the line between points.

Because the mixture condition varies inversely with the ratio of outside air or return air to total air, the conditions will be closer to the base air stream conditions having the largest percentage in the mixture. That is, if a mixture of air with 50% OA at 95°F and 50% RA at 75°F is plotted, the mixture point will be halfway between the two original condition points, or 85°F. If the same air streams are plotted with 25% outside air and 75% return air, the mixture point will be 25% of the distance from the return air condition or 80°F. That illustrates the inverse relationship.

The formula used to obtain the dry bulb temperature of the mixture is:

$$(CFM_1)(T_1)+(CFM_2)(T_2) = (CFM_t)(T_m) \tag{18-1}$$

Where:

CFM_1 = Volume flow rate of outside air, cfm.
CFM_2 = Volume flow rate of return air, cfm.
CFM_t = Volume flow rate of mixture, cfm.
T_1 = Outside air temperature, °F.
T_2 = Return air temperature, °F.
T_m = Mixture temperature, °F.

As noted above, the wet bulb temperature cannot be determined using this formula because the heat content is not constant for each degree change in wet bulb temperature. The enthalpy values must be solved graphically or computed from enthalpy or total heat values which one expressed in Btu/pound of dry air. To compute the wet bulb temperature of a mixture, the enthalpy of each of the parts must be determined, then the enthalpy values are proportioned similar to temperature values, and the resulting enthalpy value becomes the enthalpy of the air mixture.

For example, to determine the wet bulb temperature of a mixture of 25% outside air at 77°F wet bulb and 75% return air at 63°F wet bulb, the enthalpy of each part is determined and multiplied by the percentage of that part, then the two values are added and become the enthalpy of the mixture, as follows:

Enthalpy of OA at 77°F wb = 40.57 Btu/lb; × 25% =	10.14 Btu/lb
Enthalpy of RA at 63°F wb = 28.57 Btu/lb; × 75% =	21.43 Btu/lb
Enthalpy of Mixed air =	31.57 Btu/lb.

By reference to the enthalpy table, we find that an enthalpy of 31.83 Btu/lb corresponds to a wet bulb temperature of about 67.3°F.

When any two moist air properties are known, all other properties of the mixture can be read directly from the chart. Figure 18-2 shows the conditions of outside air and return air as analyzed above, and mixture conditions for 25% outside air, plotted on a psychrometric chart.

DETERMINING CONDITIONS WITH COIL FACE AND BYPASS CONTROL

When cooling coil face and bypass damper control of supply air temperature to the conditioned space is used, the supply air is always a mixture of air passing through the coil and air passing through the bypass. That is due to the leakage rate of bypass dampers being as much as 5% to 10% even for dampers in excellent condition. In order to have the supply air at the conditions required to absorb the sensible and latent cooling loads, the air mixture conditions must be computed.

If the OA and RA mixture from the example above is to be cooled, the entering conditions will be 80°F dry bulb and 67°F wet bulb. Those conditions are the standard conditions that the Air Conditioning and Refrigerating Institute (ARI) uses as basis for rating capacities of many types of conditioning apparatus and which manufacturers use as the basis for nominal unit capacities. If the supply air temperature is required to be 55°F dry bulb and 90% relative humidity, plotting that condition on the chart will find an enthalpy of 22.20 Btu/lb and a 53.3°F wet bulb temperature. The air leaving the coil must be colder than 55°F in order for the supply air to be at that temperature after mixing with the air which bypasses the cooling process, as determined by the bypass factor.

Referring to Figure 18-3, and plotting a straight line from the entering mixture condition through the supply air condition to the satura-

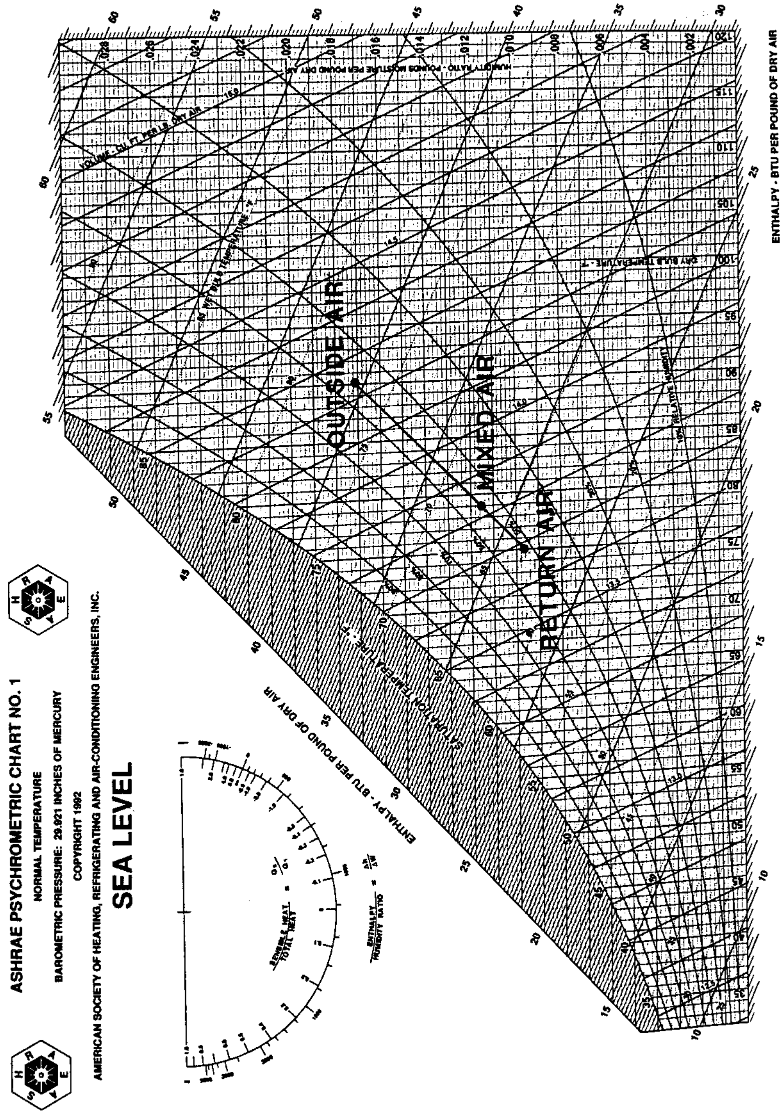

Figure 18-2. Psychrometric Chart. Conditions of outside air and return air, and mixture conditions forr 25% outside air.

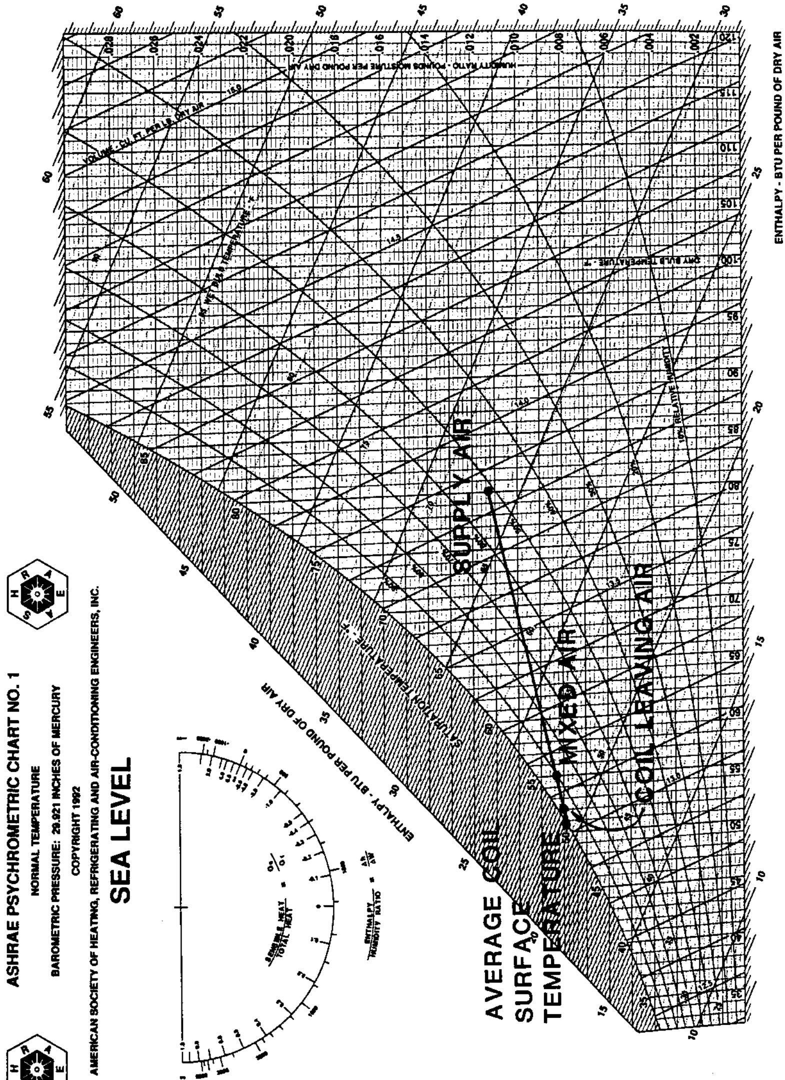

Figure 18-3. Psychrometric Chart. Requirerd coil leaving air conditions.

tion curve, the required coil leaving air conditions may be plotted on the line to the left of the required mixture conditions. The temperature difference between mixed air and supply air is 80°F minus 55°F, or 25°F. If that difference is to be 90% of the plotted length on the line, then the total distance will be 25°F divided by 0.9, for 90%, or 27.8°F.

When that temperature difference is subtracted from the mixture temperature, the remainder is the temperature of air leaving the cooling coil, or 80°F minus 27.8°F equals 52.2°F. Plotting that condition on the straight line finds a required wet bulb temperature of 51.7°F and an enthalpy of 21.26 Btu/pound. The difference between coil air leaving dry bulb and wet bulb temperatures is called the wet bulb depression and is an index of coil performance. In this case, 52.2°F dry bulb less 51.7°F wet bulb gives a 0.5°F wet bulb depression, which will require a moderately deep coil with medium fin spacing.

When cooling load in the space decreases, the temperature controller will position the face and bypass dampers to decrease air flow through the cooling coil face damper and to increase airflow through bypass damper. A typical psychrometric chart is seen in Figure 18-4, showing mixed air condition for return air and outside air with a portion of the mixed air flowing through the cooling coil to be cooled to about 90% RH and the remainder of the air flowing through the bypass damper without change. The two airstreams mix downstream of the coil/damper section to form the supply airstream.

The formula is used to predict the temperature of mixed air leaving coil is:

$$CFM_1 \times T_1 + CFM_2 \times T_2 = CFMt\ T_m \tag{18-1}$$

Where:

CFM_1 = Volume flow rate of air bypassing the coil (Ft^3/min.)
T_1 = Temperature of air bypassing the coil (°F)
CFM_2 = Volume flow rate of air passing through the coil (Ft^3/min.)
T_2 = Temperature of air leaving the coil (°F)
T_m = Temperature of resulting mixture (°F)
CFM_t = $CFM_1 + CFM_2$ = Volume flow rate of resulting mixed airstream (Ft^3/min.)

This point lies on the line connecting the conditions of the two air streams.

Air bypassing cooling process = $CFM_{SA} \times BF$.
Air through cooling process = $CFM_{SA} \times (1\text{-}BF)$.

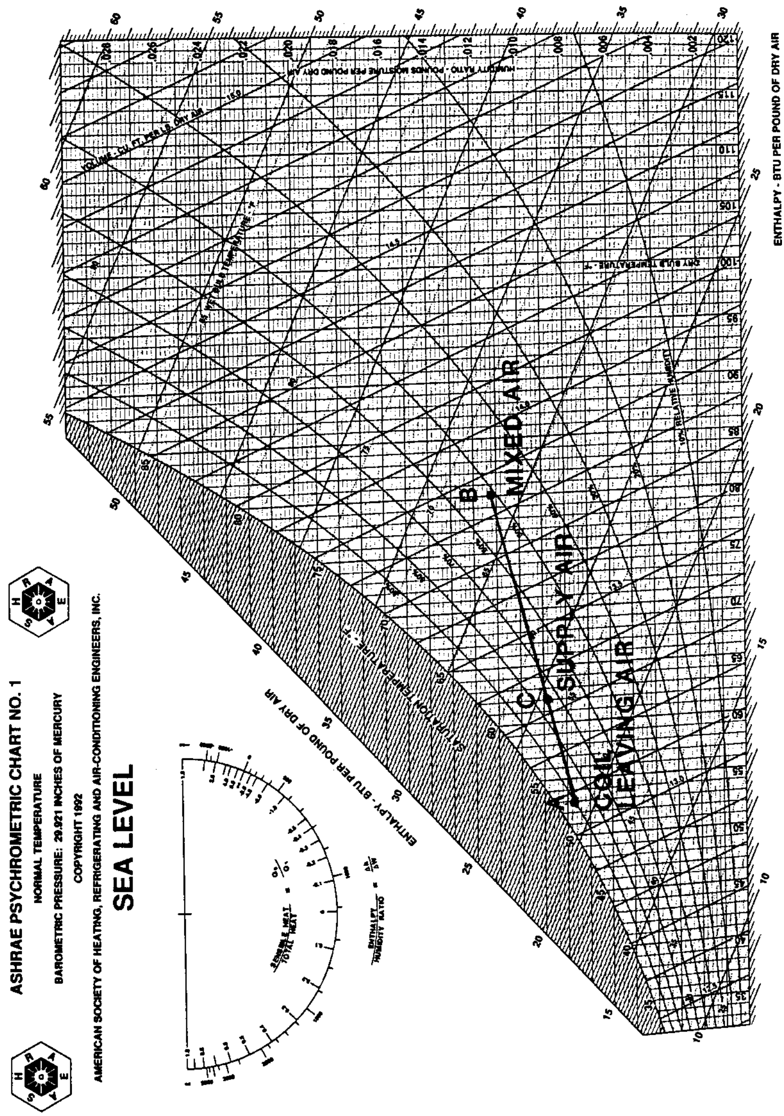

Figure 18-4. Psychrometric Chart. Mixed air condition for return air and outside air with bypass.

Glossary of HVAC Terms Used in Controls System Operation and Maintenance

ACTUATOR—a controlled device such as a motor, relay, or solenoid in which the central energy source is converted into a rotary, linear, or switching action as required to position a final control element to cause a change in the controlled variable. Valves and dampers are examples of final control elements positioned by actuators.

ADAPTIVE DUTY CYCLING—a technique to automatically change the duty cycling program based on actual environmental conditions, usually temperature and humidity.

ADIABATIC PROCESS—a thermodynamic or conditioning process in which no heat is extracted from or added to the system.

ADJUSTABLE DIFFERENTIAL—a means of changing the difference between controller cut-in and cut-out points.

AIR CLEANER—a device used to remove airborne impurities from air, such as dust, gas, vapor, fume, and smoke. Air cleaners include devices such as air washers, air filters, electrostatic precipitators, and charcoal filters.

AIR CONDITIONING, COMFORT—treating air to control its temperature, relative humidity, cleanliness, and distribution to meet the comfort requirements of the occupied space.

AIR CONDITIONING, INDUSTRIAL OR PROCESS—air treatment for an industrial process rather than for the comfort of occupants.

AIR CONDITIONER, ROOM—encased assembly designed as a unit for mounting in a window, through a wall, or as a console.

AIR CONDITIONER, SPLIT SYSTEM—a 2-piece system with an indoor section with fan, evaporator coil, and filter and an outdoor section having compressor and air cooled condenser.

AIR CONDITIONER, UNITARY—a fan, evaporator coil, filter, compressor, and condenser combination designed in a single unit.

ALARM—a signal, audible or visible to warn of an abnormal and critical operation condition.

ALERT—a form of alarm to warn of an abnormal but not critical operating condition.

AMBIENT AIR—the surrounding air, may be outdoor air or air in an enclosure under study.

AMBIENT-COMPENSATED—a control design such that varying temperatures of air at the control do not affect the control setting.

AMBIENT TEMPERATURE—the temperature of the ambient air.

ANALOG DATA—data as an analog of the variable represented, presented in a continuous form, as compared to binary or digital data presented in discrete or discontinuous form (on, off), variable value to a BAS or DDC system from a sensing device.

ANALOG INPUT—a control input in analog form, such as variable pressure or voltage, transmitted to a controller from a sensor or other control device.

ANALOG OUTPUT—a control output, such as a variable pressure or voltage, transmitted from a controller to an actuator or another control device.

ANALOG POINT—a point that has a variable value, such as temperature, which will be measured by a sensing device to provide an analog input to a control system.

ANEMOMETER—a device to sense and measure velocity of air flow at a point.

ANTICIPATING CONTROL—a method of reducing the operating differential of the system by adding a small resistive heater inside the thermostat to raise the internal temperature of the thermostat faster than the surrounding room temperature. This causes the thermostat to shut off the heating equipment and start the cooling equipment sooner than it would if affected only by the room temperature.

AQUASTAT—a thermostat used in water.

AUXILIARY CONTACTS—a secondary set of electrical contacts mounted on a modulating motor or magnetic starter whose operation coincides with the operation of the motor or starter. Usually low ampere rating for pilot duty.

AUXILIARY POTENTIOMETER—a potentiometer, usually 135 ohm resistance, on an electric modulating motor, which is used to control other modulating devices in response to the position of the original motor. May be called a "follow-up pot."

AUXILIARY SWITCH—an electric switch, usually spst, mounted on end of an actuator motor. May also be called an "end switch."

AUTOMATIC CONTROL—a system that reacts to a change or unbalance in the controlled condition by adjusting the variables, such as temperature and humidity, to restore the system to the desired balance.

AVERAGING ELEMENT—a temperature sensing element that responds to the average temperature of the sensed medium, usually air.

BIMETAL ELEMENT—formed of two metals having different coefficients of thermal expansion; used in temperature control devices.

BLOWER—an air moving device of centrifugal type, may also be called a "fan."

BOILER—a closed vessel in which a liquid is heated with or without vaporization; boiling need not occur.

BRITISH THERMAL UNIT (BTU)—a measure of heat approximating the heat energy required to raise the temperature of one pound of water from 59°F to 60°F.

BULB, CONTROL—portion of a temperature sensing system that is placed in the controlled or measured variable.

BYPASS—a pipe or duct, usually controlled by valve or damper, for conveying a fluid around an element of a system.

CAPACITY—maximum load for which a machine, apparatus, or system is designed; the cooling or heating potential of a system is usually stated in tons of refrigeration (TR) or Btu/hour for cooling systems and in Btu/hour or MBH for heating systems.

CAPILLARY TUBE—a tube of small internal diameter. Used as a liquid refrigerant flow control or expansion device between high and low sides in refrigeration systems. Also used to transmit pressure from the sensitive bulb of temperature controls to the operating element.

CAPITAL INVESTMENT—an expenditure for an investment whose returns are expected to extend beyond one year.

ccf—hundreds of cubic feet, standard measurement for natural gas flow.

CENTRALIZED CONTROL—see Distributed Control.

CENTRAL FAN SYSTEM—an air conditioning system in which the air is processed at a central location outside the conditioned space and distributed by means of a fan and duct system.

cfm—cubic feet per minute; a measurement of volume flow.

CHANGEOVER—the process of switching an air conditioning system from heating cycle to cooling cycle, or vice versa.

CHANNEL—a separate, programmable control function in a BAS or DDC system, usually controlling more than one point.

CHILLED WATER SYSTEM—a cooling system which conveys heat through chilled water as the secondary refrigerant.

CHILLER—a refrigerating machine, usually comprised of a compressor, condenser, refrigerant flow control device, and evaporator in a package, that cools the liquid in a secondary refrigerant system.

CIRCUIT—see Channel.

CLOSE-OFF PRESSURE—a value of the maximum allowable pressure difference to which a valve may be subjected while fully closed without overcoming actuator power to keep the valve closed.

COEFFICIENT OF PERFORMANCE—a term used to measure the efficiency of a heat transfer system. For a heat pump or an electrical element, it is defined as the heat output divided by the heating value of power consumed in watts at standard test conditions. Abbreviated: COP.

COIL—a heat transfer element made of pipe or tubing. Air coils for cooling or heating are generally extended-surface type with aluminum fins on either copper or aluminum tubing.

COLD DECK—the cooling section of a multi-zone or dual-duct central station apparatus.

COMBUSTION—the act or process of burning, as in fuels.

COMMUNICATION PORT—the input port on a DDC control system component through which communication flows to the remainder of the system; may be a local area network or telephone lines.

COMMUNICATIONS-BASED SYSTEM—a BAS or DDC system that can be programmed and controlled from a distant point, usually over ordinary telephone lines.

COMPRESSION—in mechanical refrigeration, the process by which the pressure of the refrigerant is increased.

COMPRESSOR, HERMETICALLY SEALED REFRIGERANT—a motor-compressor unit consisting of a compressor and a motor enclosed in the same housing, without external shaft seals, and with the motor operating in the refrigerant atmosphere. May be made as serviceable hermetic type.

COMPRESSOR, REFRIGERANT—the component of a mechanical refrigeration system which compresses the refrigerant vapor into a smaller volume, thereby raising the pressure of the refrigerant and consequently its boiling temperature.

COMPUTER—a programmable electronic device that can store, retrieve, and process information.

COMPUTER-BASED SYSTEM—a BAS or DDC system in which a computer is the central controlling device.

CONDENSATE—the liquid formed by condensation of a vapor. In steam heating, water condensed from steam; in air conditioning, water extracted from air, as by condensation on the cooling coil of a cooling cycle.

CONDENSATION—the process of changing a vapor into liquid by the extraction of heat.

CONDENSER—arrangement of pipe or tubing inside a containing shell in which a vapor is liquefied by removal of heat.

CONDENSER, AIR-COOLED REFRIGERANT—a condenser cooled by circulation of atmospheric air, usually fan-forced circulation.

CONDENSER COIL—in mechanical refrigeration, a section of coiled tubing where gas refrigerant is cooled below its boiling point by circulating fluid, such as condenser water.

CONSUMPTION—the total amount of energy used, usually measured in kilowatt hours (kWh). On the average, about 80% of a typical commercial or industrial utility bill is based on consumption and about 20% on demand.

CONSUMPTION CHARGE—see Energy (Consumption) Charge.

CONTACTOR—an electromagnetic switching device.

CONTROL—any device for regulation of a system or component in normal operation, manual or automatic. If automatic, it is responsive to changes of pressure, temperature, or other property whose magnitude is to be regulated.

CONTROL PANEL—an electrical cabinet that contains control devices and/or indicating devices.

CONTROL POINT—the value of the controlled variable maintained by operation of the controller.

CONTROLLED DEVICE—the control component, such as damper, valve, or relay, which is positioned to effect control of controlled medium.

CONTROLLED MEDIUM—the substance, such as air, water, or steam, whose temperature, pressure, flow rate, volume, or concentration, is being controlled.

CONTROLLED SPACE—the volume of the controlled medium: for example, a room in which the air temperature is being controlled.

CONTROLLED VARIABLE—that quantity or condition of a controlled medium which is measured and controlled: for example, temperature, pressure, flow rate, volume, or concentration.

CONTROLLER—a control component which translates signals from sensors to output signals to actuators.

CONVECTION—transfer of heat by movement of fluid.

COOLING SYSTEM, CHILLED WATER—a closed, circulating system in which a mechanical refrigeration system at a central location cools water which is then piped to various parts of the building.

COOLING SYSTEM, DIRECT EXPANSION (DX)—a cooling and dehumidification process which cools air or other fluids by the evaporation of mechanically compressed gas in an evaporator. A condenser then removes this transferred heat to a different space. See Refrigeration System, Mechanical.

COOLING SYSTEM, EVAPORATIVE—an adiabatic cooling system, generally housed in a cabinet containing a pump, distribution tubes, filter pads, and a blower. The pump supplies water to the distribution tubes which carry the water to pads on sides of the cabinet. The blower draws outdoor air through the moist filter pads. Some of the water in the pads absorbs heat from the air and evaporates, cooling the air. The air is nearly saturated and cannot be recirculated. This system works most effectively in relatively dry climates.

COOLING SYSTEM, MULTI-STAGE—a cooling system that changes its capacity by stages in response to changes in cooling demand.

CPU—the central processing unit or microprocessor in a computer that controls a BAS or DDC system.

Cv—the flow coefficient for valves, representing the flow rate in gallons of water per minute at 62°F that will cause a pressure drop across the valve of 1 psig.

CYCLE—a complete course of operation of working fluid back to a starting point, measured in thermodynamic terms (functions). Also used in general for any repeated process on any system.

CYCLE, COOLING—the functions in an HVAC system which provide heat removal, or cooling, from a conditioned space.

CYCLE, HEATING—the functions in an HVAC system which provide heat addition, or heating, to a conditioned space.

CYCLE, REFRIGERATION—complete course of operation of refrigerant back to a starting point, evidenced by a repeated series of thermodynamic processes, or flow through a series of apparatus, or a repeated series of mechanical operations.

CYCLING RATE—the number of complete cycles that the system goes through in one hour. One complete cycle includes both on and off times.

DAMPER—an adjustable metal plate, louver, or set of louvers that controls airflow, especially through an air inlet, outlet, or duct.

DAMPER LINKAGE—linkage used to connect an actuator to a damper, usually consisting of a pushrod, two crank arms, and two ball joints.

DAMPER, OPPOSED BLADE—louver-type damper with alternating blades rotating in opposite directions. Provides an equal percentage flow characteristic in which successive equal increments of rotation produce equal percentage increases in flow. Used for throttling and mixing applications where the sum of two airflows must remain nearly constant and where accurate control of airflow is necessary.

DAMPER, PARALLEL BLADE—damper with all blades rotating in the same direction. Provides a non-linear airflow characteristic in which flow is not proportional to damper shaft rotation. Used in two-position service.

DATABASE—the data in memory in the CPU that controls a BAS or DDC system.

DDC SYSTEM—a distributed control system made up of one or more digital controllers and providing control and energy management functions for complete operation of HVAC and process systems in a system linked in a communications network composed of one or more levels of local area networks (LAN). No conventional control devices, pneumatic or electronic, such as receiver/controllers, thermostats, or logic units are present within or interface with a DDC control loop.

DEADBAND—in HVAC control terminology, a temperature range in which neither heating nor cooling are turned on.

DEGREE DAY—a unit, based upon temperature difference and time, used in estimating building environmental system energy usage. For example, on any one day, when the mean temperature is less than the base temperature, usually 65°F for heating degree days, there exist as many heating degree days as there are degrees F difference in temperature between the mean temperature for the day and the base temperature.

DEHUMIDIFICATION—the condensation of water vapor from air by cooling below the dew point or removal of water vapor from air by chemical or physical methods.

DEHUMIDIFIER—an air cooler or washer used for lowering the moisture content of the air passing through it. An absorption or adsorption device for removing moisture from the air.

DEHYDRATION—the removal of water vapor from air by the use of absorbing or adsorbing materials. The removal of water from stored goods. In refrigeration terminology, the removal of water vapor from refrigerant by use of molecular sieves.

DELTA SERVICE—a 3-wire or 4-wire 3-phase electrical wiring configuration commonly noted by a triangle.

DEMAND—the average rate of electrical usage, measured in kilowatts demand (kWD), over a given period of time, called the demand interval. An electric utility must determine its required generating and distribution capacity from the total demand of all its customers. The utility thus bases its charges not only on total consumption but also on the measured peak demand.

DEMAND CHARGE—that part of an electric bill based on kW demand and the demand interval. Expressed in dollars per kilowatt demand per month. Demand charges offset costs for construction and maintenance of a utility's generating and distribution capacity.

DEMAND CONTROL—a device that controls the kW demand level by shedding loads to prevent the kW demand from exceeding a predetermined set point, called the "target."

DEMAND INTERVAL—the period of time on which kW demand is monitored and billed by a utility, usually 15 or 30 minutes long.

DEMAND LIMITING—a technique to reduce demand by measuring incoming electrical power and turning off specified loads so as to keep the rate of electrical usage under a present level.

DEMAND READING—highest or maximum demand for electricity an individual customer registers in a given interval, for example a 15-minute interval. The metered demand reading sets the demand charge for the month.

DEVIATION—the difference between the set point and the value of the controlled variable at any instant.

DEW-POINT TEMPERATURE—the temperature at which moisture would begin to condense out of the air if the air should be cooled to that temperature. The temperature corresponding to saturation (100 percent relative humidity) for a given absolute humidity at constant pressure. The moisture content of the air establishes the dew-point temperature. See Moisture Content and Humidity Ratio.

DIFFERENTIAL—in a control, the difference between cut-out and cut-in points.

DIFFERENTIAL, INTERSTAGE—in a sequencing system, the amount of change in the controlled medium required to sequence from "on" point of one stage to "on" point of successive stage.

DIGITAL CONTROLLER—a microprocessor-based control module, programmable by user, with integral I/O, that performs stand-alone operations.

DIGITAL POINT—a point that has an "either/or" value, such as on/off, which will be sensed to provide direct input to the BAS or DDC system.

DIRECT CURRENT—a source of electrical power that flows in one direction only. Abbreviated: dc.

DIRECT DIGITAL CONTROL (DDC)—a control system where digital controllers directly sense building environment and make control decisions based on user defined, controller resident programs, and output control signals that directly operate valves and damper actuators and motor controllers, with controller output converted to the appropriate type of signal for electric or pneumatic actuators.

DIRECT EXPANSION (DX) SYSTEM—see Cooling System, Direct Expansion.

DISCHARGE AIR—conditioned air that is distributed to the controlled environment.

DISTRIBUTED CONTROL—a control system built up of stand-alone controllers, with controllers installed near the controlled equipment to distribute the processing to each stand-alone DDC panel, with a limited number of utilized sensor inputs and control outputs to a controller, often 48 or less, so failure of any single module will not cause the loss of more than the number of points served by that module.

DISTRIBUTED PROCESSING SYSTEMS—a control system with a number of microprocessor-based modules, each performing its own specified task, yet working together as an integrated system under the supervision of a central microprocessor or computer.

DRY AIR—air without water vapor; air only.

DRY BULB TEMPERATURE—the temperature of a gas or mixture of gases indicated by a thermometer. Air temperature as read by any ordinary dry bulb thermometer.

DRYER—device containing a desiccant, placed in the refrigerant circuit to collect and hold moisture in the system in excess of the amount that can be tolerated by the system refrigerant.

DUCT—a passageway made of sheet metal or other suitable material, not necessarily leaktight, used for conveying air or other gases at low pressure.

DUTY CYCLING—energizing a load for part of a specified time period. Accomplished by a duty cycler.

DYNAMIC CONTROL—a process that optimizes operation of HVAC system components, such as air handling units, converters, chillers, and boilers, by increasing and decreasing setpoints or starting and stopping equipment in response to heating and cooling needs of downstream equipment. A requirement of dynamic control is input data as to heating/cooling demand status of downstream equipment, therefore dynamic control requires controllers connected in a communications network.

ECONOMIZER CYCLE CONTROL—a form of control that positions dampers in an HVAC system to introduce up to 100% outside air for free cooling whenever the outside temperature is below the required supply air temperature, often about 55°F.

ELECTRIC CONTROL SYSTEM—a system of controls utilizing electric devices for sensing controlled parameters and for positioning actuators on controlled devices.

ELECTRICAL BILLING CHARGE, UTILITY—a charge for the use of a unit of electricity. See Demand Charge. See also Watt, Kilowatt, and Kilowatt-hour.

ELECTRICAL CIRCUIT—a power supply, a load, and a path for current flow are the minimum requirements.

ELECTROMECHANICAL—a term used to describe devices which contain both electrical and mechanical components.

ELECTRONIC AIR CLEANER—a device that cleans circulating air by producing an electric field to ionize particulate contaminants in the air and then collect ionized particles on electrically charged plates.

ELECTRONIC CONTROL SYSTEM—a system of controls utilizing electronic devices for sensing controlled parameters and for providing input to devices for positioning actuators on controlled devices.

ELEMENT, ELECTRIC DUCT HEATING—a unit assembly consisting of electric resistance coils, insulated supports, and duct mounting frame with control box mounting operating and safety controls with terminals for connecting the assembly to electric power.

EMCS—acronym for energy management and control system.

ENERGY (CONSUMPTION) CHARGE—that part of an electric bill based on kWh consumption. Expressed in cents per kWh. Energy charge covers the cost of utility fuel, general operating costs, and part of the amortization of the utility's equipment.

ENERGY EFFICIENCY RATIO—a term used to measure the efficiency of air conditioning equipment components, abbreviated EER. It is defined as the number of Btus removed, divided by the power consumed in watts at standard test conditions. See also Seasonal Energy Efficiency Ratio (SEER).

ENERGY MANAGEMENT—the process of managing energy consumption, usually in a building, to conserve energy.

ENERGY MANAGEMENT SYSTEM—a system based on a microprocessor, microcomputer, or minicomputer whose primary function is to control energy-using equipment so as to reduce the amount of energy used.

ENTHALPY—the total energy or heat content of the air. Includes sensible heat due to air temperature and latent heat due to moisture content. Expressed in Btu per pound of dry air.

ENTHALPY-BASED ECONOMIZER CONTROL—a system of air-side economizer control in which 100% outdoor air and mechanical cooling are used simultaneously for the most economical operation.

ENTHALPY CHANGEOVER CONTROL—a system of changeover between natural cooling with outdoor air and mechanical cooling with refrigeration. Control devices compare enthalpy or total heat values of return air and outdoor air, then position the economizer cycle to admit air with lowest enthalpy. This may cause mechanical refrigeration of 100% outside air when outside air enthalpy is lower than return air enthalpy, although dry bulb temperature is not low enough for supply air to space.

ENVIRONMENTAL CONTROL SYSTEM—the process of controlling the environment by heating, cooling, humidifying, dehumidifying, or cleaning the air. This book uses the term HVAC control system for the same process.

EVAPORATION—a change of state from liquid to vapor.

EVAPORATOR COIL, REFRIGERANT—in mechanical refrigeration, the part of the refrigeration system where the refrigerant produces a cooling effect by vaporizing or absorbing heat from air or water, a section of coiled tubing where liquid refrigerant absorbs heat and evaporates.

EXHAUST AIR—that air which is removed from the conditioned space by the ventilation system and discharged outdoors.

EXPANSION DEVICE—in a mechanical refrigeration system, a restriction or orifice which regulates the flow of refrigerant into the evaporator coil. May be in the form of a thermal expansion valve or a capillary tube.

FACE AND BYPASS DAMPER SYSTEM—an airflow system in which the airflow is divided to flow through the cooling or heating coil and face damper and around the coil through the bypass damper. Dampers work in opposition, face damper closes while bypass damper opens, and vice versa to regulate the amount of air that is conditioned. Used with either a chilled or hot water coil. Proprietary systems include internal face and bypass dampers in steam coil.

FACILITY AUTOMATION SYSTEM—see Building Automation System.

FAIL-SAFE—in HVAC controls terminology, placing damper or valve in normal position which will minimize damage to building in case of controls failure, such as placing heating valves open and humidifier valves closed upon loss of control power; in BAS terminology, returning all controlled devices to conventional control in case of load management panel failure.

FAN COIL UNIT—a complete unit located in the room being conditioned consisting of a coil through which hot or chilled water is circulated, a fan that circulates room air through the coil, a filter to remove lint and dust, a cabinet, a grille, and a control system. The chilled water or heated water is supplied from equipment located remotely from the unit.

FIELD INTERFACE DEVICE—see Module.

FILTER—a device that removes contaminants from liquids or gases such as air.

FIRMWARE—software programmed into read only memory (ROM) and erasable programmable read only memory (EPROM) chips. Software may not be changed without physically altering the chip.

FLOW RATE—the rate at which fluids or gases will flow over a specified amount of time. Units are gallons per minute (gpm) for water, pounds per hour for steam, cubic feet per hour (cfh) for natural gas, and cubic feet per minute (cfm) for air.

FLUID—gas, vapor, or liquid.

FULL LOAD CURRENT—see Running Current.

GRAPHIC SEQUENCE OF OPERATION—a drawing or graphical representation of the sequence of operation, showing all interlocks and control loop sequences between input and output points, and inputs, outputs, and logic blocks.

GRAPHICS—a pictorial representation on a computer screen of material, often control diagrams or building system schematics.

HAND-HELD TERMINAL—a portable device, control system manufacturer-specific, which can be connected directly to a communications port on a digital controller and through which the digital controller can be interrogated and/or programmed.

HARD WIRING—permanent wiring.

HEADER—a manifold or supply pipe to which a number of branch pipes are connected.

HEAT EXCHANGER—a device specifically designed to transfer heat between two physically separated fluids.

HEAT OF FUSION—latent heat involved in the change between solid and liquid states. For ice melting to water—144 Btu/pound at 32°F.

HEAT OF VAPORIZATION—latent heat involved in the change between liquid and vapor states. For water—970 Btu/pound at 212°F.

HEAT PUMP—mechanical refrigeration system with the added capability of reversing the normal cooling cycle so the evaporator removes heat from outdoor air and the condenser rejects that heat plus the heat of compression to indoor air to heat the space. During cooling, the functions are normal.

HEAT RECLAMATION—the process of reclaiming waste heat from such sources as exhaust fans, condenser coils, and hot water drains to do useful work, such as heating makeup air and heating domestic or process water.

HEATING SYSTEM, DIRECT FIRED—a heating system for outside air in which combustion takes place in the airstream being introduced into the building. The outdoor air temperature is increased by direct contact with the flame of the fuel. Recirculation is restricted by code. Fuel efficiency is 100 percent.

HEATING SYSTEM, DUCT HEATER—a heating system in which the heater is installed directly in the distribution duct of a central air conditioning or heating system. May be either electric, gas-fired, or oil-fired.

HEATING SYSTEM, ELECTRIC—a heating system that consists of one or more stages of resistive heating elements installed in a duct, central furnace, or boiler.

HEATING SYSTEM, HEATED WATER COIL—a heating system in which heated water is supplied by a central hot water boiler.

HEATING SYSTEM, INDIRECT FIRED—a heating system in which combustion takes place in a boiler or furnace. The fuel is burned in a combustion chamber and the flue gases do not mix with the air delivered to the space.

HEATING SYSTEM, RADIANT—a heating system in which only the heat radiated from the heat exchanger is effective in providing the heating requirements. The term radiant heating may include both radiant panels and radiant strips.

HEATING SYSTEM, STEAM—a heating system in which heat is transferred from the heat source, such as a boiler, to the heating units by means of steam. Steam pressure may be above atmospheric pressure or at, or below atmospheric pressure.

HEATING SYSTEM, WARM AIR—a warm air heating plant consisting of a heating unit (electric or fuel burning furnace) enclosed in a casing, from which the heated air is distributed to various rooms in a building through ducts.

HIGH LIMIT CONTROL—a device that normally monitors the condition of the controlled medium and interrupts system operation if the monitored condition becomes excessive.

HIGH SIDE—parts of the refrigerating system subjected to condenser pressure or higher; the system from the compression side of the compressor through the condenser to the expansion point of the evaporator.

HORSEPOWER—unit of power in foot-pound-second system; work done at the rate of 550 ft-lb per sec, or 33,000 ft-lb per min.

HOT DECK—the heating section of a multi-zone or dual-duct system.

HUMIDIFICATION—the process of increasing the water vapor content of the conditioned air.

HUMIDIFIER—a device to add moisture to the air.

HUMIDISTAT—a regulatory device, actuated by changes in humidity, used for the automatic control of relative humidity.

HUMIDITY—water vapor within a given space.

HUMIDITY RATIO—see Specific Humidity.

HUNTING—an undesirable condition where a controller is unable to stabilize the state of the controlled medium causing rapid cycling.

HVAC—Heating, Ventilating, and Air Conditioning.

HYBRID CONTROL SYSTEM—a system of controls utilizing electric devices or electronic devices for sensing controlled parameters and using pneumatic actuators for positioning controlled devices.

HYDROMETER—an instrument that, by the extent of its submergence, indicates the specific gravity of the liquid in which it floats.

HYDRONIC SYSTEM—a heating and/or cooling system that uses a liquid (usually hot or cold water) as the medium for heat transfer.

HYDRONICS—the science of heating and cooling with liquids.

HYGROMETER—an instrument responsive to humidity conditions, usually calibrated in percent relative humidity of the atmosphere.

"IN" CONTACTS—those relay contacts which complete circuits when the relay armature is energized. Also referred to as "Normally Open Contacts."

INDOOR AIR QUALITY—the condition of air within the built environment, measured in multiple parameters including temperature, humidity, air motion, and presence of gaseous and particulate contaminants. Abbreviated IAQ.

INDUCTIVE LOADS—loads whose voltage and current are out of phase. True power consumption for inductive loads is calculated by multiplying voltage, current, and the power factor of the load.

INFILTRATION—in air conditioning, the natural leakage of unconditioned outdoor air into a building.

INPUT/OUTPUT (I/O)—The acronym I/O refers to inputs and outputs of a digital controller; analog inputs (AI), digital inputs (DI), analog outputs (AO), and digital outputs (DO). Analog inputs (AI) are from analog sensors of temperature, pressure, humidity, flow. Digital inputs (DI) are from digital sensors such as motor status contacts, flow switches, switch position indicators, and pulse output devices. Analog outputs (AO) position modulating devices. Digital outputs (DO) operate on/off or open/close controlled devices.

INRUSH CURRENT—the current that flows the instant after the switch controlling current flow to a load is closed. Also called "Locked Rotor Current."

INTERSTAGE DIFFERENTIAL—in a multistage HVAC system, the change in temperature at the thermostat needed to turn additional heating or cooling equipment on.

I/O UNIT—device installed on a digital controller to provide additional point capacity and communicate with the stand-alone digital controller on a LAN. An I/O unit itself is not stand-alone because the control program does not reside in the microprocessor of the I/O unit.

INPUT DEVICE—device to provide input to control system, such as temperature sensor or operating status device.

ISOTHERMAL PROCESS—a process in which there is no change in dry bulb temperature.

KILOWATT—1,000 watts. Abbreviated kW.

KILOWATT-HOUR—a measure of electrical energy consumption: 1,000 watts being consumed per hour. Abbreviated kWh.

kW DEMAND—the maximum rate of electrical power usage for a 15- or 30-minute interval in a commercial building for each billing period. A utility meter records this maximum rate, and customers are billed for this peak rate usually once per month. Abbreviated kWD.

kWh CONSUMPTION—the amount of electrical energy used over a period of time; the number of kWh used per month. Often called "Consumption."

LADDER DIAGRAM—a wiring diagram showing the system connections between two conductors, represented with system conductors run vertically and with connections run across, as rungs on a ladder.

LAG—a delay in the effect of a changed condition at one point in the system on some other condition to which it is related. Also, the delay in action of the sensing element of a control, due to the time required for the sensing element to reach equilibrium with the property being controlled; i.e., temperature lag, flow lag, etc.

LATENT HEAT—the amount of heat necessary to change a quantity of water to water vapor without changing either temperature or pressure, when water is vaporized and passes into the air along with the vapor. Likewise, latent heat is removed when water vapor is condensed.

LIGHT EMITTING DIODE—a low current and voltage light used as an indicator. Abbreviated LED.

LIMIT—control applied in the line or low voltage control circuit to break the circuit if conditions move outside a preset range. In a motor, a switch that cuts off power to the motor windings when the motor reaches its full open position.

LIMIT CONTROL—a temperature, pressure, humidity, dew-point, or other control that is used as an override to prevent undesirable or unsafe conditions in a controlled system.

LIMIT SHUTDOWN—a condition in which the system has been stopped because the value of the temperature or pressure has exceeded a pre-established limit.

LINE VOLTAGE—in the control industry, the electric supply voltages as opposed to low voltage.

LIQUID LINE—the tube or pipe carrying the refrigerant liquid from the condenser or receiver of a refrigerating system to the evaporator or other pressure-reducing device.

LOAD—that part of an electrical circuit in which useful work is performed. In a heating or cooling system, the heat transfer that the system will be called upon to provide. Any equipment that can be connected to a load management system.

LOAD FACTOR—a comparison of kilowatt-hours of electricity consumed to the peak rate at which power was consumed. Load factor is always a number between zero and one and is expressed as the kilowatt-hours consumed over the specified period divided by the product of the kilowatt peak demand registered times the number of hours in the period.

LOAD SHEDDING—the process of turning off electrical loads under specified conditions, primarily to reduce demand.

LOCAL AREA NETWORK (LAN)—a communications bus that interconnects digital controllers for peer-to-peer communications with different levels of LANs within a single DDC system. In this case a digital controller on a higher level LAN acts as a network controller to the controllers on the lower level LAN. The network controller must have at least two LAN communications ports with one port supporting peer-to-peer communications with other digital controllers on the higher level LAN and the other port supporting communications with the digital controllers on the lower level LAN. LANs permit sharing global information, making it possible to apply building-wide control strategies, such as peak demand limiting, permit dynamic control strategies, allow coordinated response to alarm conditions, and allow remote monitoring and programming of digital controllers.

LOCAL LOOP CONTROL—an existing control, such as a thermostat system, that will continue to function after the installation of a BAS or DDC system when the latter is not operating.

LOCKED ROTOR CURRENT—see Inrush Current.

LOUVER—an assembly of sloping vanes intended to permit air ventilation to pass through and to inhibit the transfer of water droplets.

LOW LIMIT CONTROL—a device that normally monitors the condition of the controlled medium and interrupts system operation if the monitored condition drops below the desired minimum value.

LOW SIDE—the refrigerating system from the expansion point to the point where the refrigerant vapor is compressed; where the system is at or below evaporator pressure.

LOW VOLTAGE—in the control industry, a power supply of 25 volts or less.

MAIN—a pipe or duct for distributing to, or collecting from, various branches.

MAKEUP AIR—outdoor air that is brought into a building to compensate for air removed by exhaust fans or other methods.

MAKEUP AIR SYSTEM—a ventilating system used to replace exhausted air with outdoor air that is then heated or cooled. The system includes a supply fan, a filter section, a heating section (either indirect or direct heat), and automatic controls to regulate the air temperature.

MANIFOLD—portion of a main in which several branches are close together. Also, a single piece in which there are several fluid paths. Also called a "Header."

MANOMETER—an instrument for measuring pressures. Essentially a U-tube partially filled with a liquid, usually water, mercury, or a light oil, so constructed that the amount of displacement of the liquid indicates the pressure being exerted on the instrument.

MECHANICAL REFRIGERATION SYSTEM—a cooling system consisting basically of a refrigerant compressor, condenser coil, expansion device, and evaporator coil. In a basic cycle, the refrigerant is compressed, liquefied and cooled in an expansion device in the condenser, below its boiling point. It then enters the evaporator coil where it boils, absorbing heat from its surroundings. It is then compressed again and a new cycle begins.

MEDIUM, HEATING—a solid or fluid, such as water, steam, air or flue gas, used to convey heat from a boiler, furnace or other heat source, and to deliver it, directly or through a suitable heating device, to a substance or space being heated.

MICROPROCESSOR—the central processing unit (CPU) of a DDC system that contains all the registers and logic circuitry that make it possible for digital controllers to compute; in EMCS systems, a small computer used in load management to analyze energy demand and consumption so that loads are turned on and off according to a predetermined program.

MINIMUM ON-TIME—the shortest period of time that a load can be energized when it is being duty cycled.

MINIMUM OUTSIDE AIR REQUIREMENTS—the code-mandated volume of outside air or equivalent outside air needed to replenish interior space air to maintain acceptable indoor air quality.

MIXED AIR—a mixture of air in an air handling system composed of return air and outdoor air.

MIXING BOX—a container, located at the room being conditioned, in which hot and cold air is mixed as required to maintain the desired room temperature.

MODULATING CONTROL—a mode of automatic control in which the action of the final control element is proportional to the deviation, from set point, of the controlled medium.

MODULATING MOTOR—an electric motor, used to drive a damper or valve, which can position the damper or valve anywhere between fully open or fully closed in proportion to deviation of the controlled medium.

MODULATING—tending to adjust by increments and decrements.

MODULATING RANGE—see Proportional Band.

MODULE—a microprocessor-controlled device in a distributed processing system that performs a specific task under the supervision of the central computer.

MODUTROL MOTOR—Honeywell's trade name for a line of electric and electronic two-position and modulating motor actuators used to position dampers or valves.

MOISTURE CONTENT—amount of water vapor in a given amount of air, usually expressed in grains of moisture per pound of dry air. (7,000 grains are equal to 1 lb.) Also called Specific Humidity.

MORNING PICKUP OR WARMUP—a control system that keeps outside air dampers closed after night setback until the desired space temperature is achieved.

MULTISTAGE THERMOSTAT—a temperature control that sequences two or more switches in response to the amount of heating or cooling demand.

MULTIZONE SYSTEM—centralized HVAC system that serves several zones from a multi-zone unit with each zone having a thermostat.

NC—normally closed; in relays, normally closed contacts are closed when the relay is de-energized; in dampers and valves, the position assumed when the actuator is de-energized.

NIGHT SETBACK—the ability to reduce heating expense during unoccupied hours by lowering temperature, closing outside air dampers, and intermittently operating blowers.

NO—normally open; in relays, normally open contacts are open when the relay is de-energized; in dampers and valves, the position assumed when the actuator is de-energized.

NOTEBOOK COMPUTER—a small personal computer.

OFFSET—a sustained deviation between the actual control point and the set point under stable operating conditions.

ON-OFF CONTROL—a simple control system, consisting basically of a switch, in which the device being controlled is either fully on or fully off and no intermediate positions are available.

OPTIMUM START/STOP—a refined form of HVAC control that automatically adjusts the programmed start/stop schedule depending on inside and outside air temperature and humidity, resulting in the latest possible start and earliest possible stop of the HVAC equipment.

ORIFICE—an opening or construction in a passage to regulate the flow of a fluid.

"OUT" CONTACTS—those relay contacts which complete circuits when the relay coil is de-energized. Also referred to as "Normally Closed Contacts."

OUTPUT SIGNAL CONVERSION—the changing of one kind of control output into a proportionally related signal appropriate for direct actuation of the controlled device, such as 4 to 20 mA analog output signals converted by a transducer to 3 to 15 psig pneumatic pressure or a contact closure originating in a digital controller converted into an on/off or open/close signal to a 2-position device.

OUTSIDE AIR—air that is brought into the ventilation system from outside the building and, therefore, has not been previously circulated through the system. Also called "fresh air."

OVERRIDE—a manual or automatic action taken to bypass the normal operation of a device or system.

PACKAGED SYSTEM—a complete set of components and controls factory-assembled for ease of installation. A packaged system may perform one or more of the air conditioning functions.

PACKAGED TERMINAL AIR CONDITIONER (PTAC)—a single-package air conditioning unit in a decorative cabinet for mounting in the conditioned space, with electric-drive, air-cooled refrigerating system and heating system as either electric resistance coil, reverse-cycle heat pump, or hydronic coil.

PEAK DEMAND—the greatest amount of kilowatts needed during a demand interval.

PEAK DEMAND LIMITING—see Demand Limiting.

PEAK LOAD CONTROL—see Demand Limiting.

PEAK LOAD LIMITING—see Demand Limiting.

PEER-TO-PEER COMMUNICATION—the relationship of controllers connected on a communications LAN that act independently and communicate with each other as equals to pass information which facilitates control.

PHASE—an electrical term used to describe the number of distinct harmonic waves in alternating current electrical services. Residential service is single-phase; commercial facilities are usually three-phase.

PID—an acronym referring to the three types of control action, proportional, integral, and derivative, that are used in controlling modulating equipment.

PILOT-DUTY RELAY—a relay used for switching loads such as another relay or solenoid valve coils. The pilot duty relay contacts are located in a second control circuit. Pilot duty relays are rated in volt-amperes (VA).

PLENUM CHAMBER—an air compartment connected to one or more distributing ducts.

PNEUMATIC—operated by air pressure.

PNEUMATIC CONTROLS—a system of controls utilizing air pressure for sensing controlled parameters and for positioning actuators on controlled devices.

POINT—an individual monitor, control, or sensing device connected to a BAS or DDC system, such as a temperature sensor or a relay.

POTENTIAL TRANSFORMER—a voltage transformer. The voltage supplied to a primary coil induces a voltage in a secondary coil according to the ratio of the wire windings in each of the coils.

POTENTIOMETER—an electromechanical device having a terminal connected to each end of the resistive element, and third terminal connected to the wiper contact. The electrical input is divided as the contact moves over the element, thus making it possible to mechanically change the resistance.

POWER—in electricity, the watt. A time rate measurement for the use of electrical energy. Joules per second.

POWER FACTOR—a ratio, sometimes expressed as a percent of actual power (watts) in an ac circuit to apparent power (volt-amperes). A measure of power loss in an inductive circuit. When the power factor is less than 0.8, the utility may impose a penalty, as prescribed in the utility rate structure.

POWER FACTOR CHARGE—a utility charge for "poor" power factor. It is more expensive to provide power to a facility with a poor power factor (usually less than 0.8).

POWER FACTOR CORRECTION—improvement of power factor on a building's electrical service by installation of capacitors on the utility's supply line.

POWER LINE SUBCARRIER—a device to allow the use of a building's existing electrical power system to carry the signals of the BAS or DDC system.

POWER SUPPLY—the voltage and current source for an electrical circuit. A battery, a utility service, and a transformer are power supplies.

PREHEAT—a process of raising the temperature of outdoor air before incorporating it into the rest of the ventilating system. Used when large amounts of very cold outdoor air must be used.

PRESSURE—the normal force exerted by a homogeneous liquid or gas, per unit of area, on the wall of its container.

PRESSURE, ABSOLUTE—the sum of gauge pressure and atmospheric pressure. Absolute pressure can be zero only in a perfect vacuum.

PRESSURE, ATMOSPHERIC—the pressure exerted in every direction at any given point by the weight of the atmosphere. It is the pressure indicated by a barometer. Standard Atmospheric Pressure or Standard Atmosphere is the pressure of 76 cm of mercury having a density of 13.5951 grams per cubic centimeter, under standard gravity of 980,665 cm per sec. It is equivalent to 14.696 psi or 29.921 inches of mercury at 32°F.

PRESSURE, SUCTION—the refrigerant pressure as measured at the inlet of a compressor in a direct expansion refrigeration system. Also known as "backpressure."

PRESSURE CONTROLS—used as limit protectors in the cooling system. They establish pressure control limits to protect the system from extremes in refrigeration suction and discharge line pressures. If the pressure deviates from normal, the pressure control breaks the circuit to the compressor until the pressure returns to normal. Pressure controls have automatic or manual reset, depending upon the construction of the equipment and preference of the manufacturer.

PRESSURE DROP—the difference between the upstream pressure and the downstream pressure of a fluid or gas passing through a pressure loss causing device, such as a damper or valve.

PRESSURE GAUGE—pressure measured above atmospheric pressure; indicated by a pressure gauge. Units are pounds per square inch gauge (psig).

PRESSURE HEAD—operating pressure measured in the discharge line at a compressor outlet.

PRESSURE REGULATOR—automatic valve between the evaporator outlet and compressor inlet that is responsive to pressure or temperature. It functions to throttle the vapor flow when necessary to prevent the evaporator pressure from falling below a preset level.

PRIMARY CONTROL—a device that directly or indirectly controls the control agent in response to needs indicated by the controller. Typically, a motor, valve, relay, or similar device.

PROPORTIONAL BAND—the range of values of a proportional positioning controller through which the controlled variable must pass to move the final control element through its full operating range. Commonly used equivalents are "throttling range" and "modulating range."

PROPORTIONAL CONTROL—see Modulating Control.

PSYCHROMETER—an instrument with wet and dry bulb thermometers, for measuring the amount of moisture in the air. See Wet Bulb Temperature.

RADIATION, THERMAL (HEAT)—the transmission of energy by means of electromagnetic waves of very long wavelength. Radiant energy of any wavelength may, when absorbed, become thermal energy and result in an increase in the temperature of the absorbing body.

RADIATOR—a heating unit exposed to view within the room or space to be heated. A radiator transfers heat by radiation to objects within visible range, and by conduction to the surrounding air which in turn is circulated by natural convection; a so-called radiator is also a convector, but the term radiator has been established by long usage.

RAPID CYCLING—see Hunting and Short Cycling.

RECEIVER—storage chamber for liquid refrigerant in a mechanical refrigeration system; often the bottom part of the condenser.

RECIRCULATED AIR—return air passed through the conditioner before being again supplied to the conditioned space.

RECLAMATION—the process of reclaiming and reusing discharged heat from such sources as exhaust fans, condenser coils, and hot water drains to do useful work.

REFRIGERANT—a substance with a large latent heat of vaporization and low boiling point that produces a refrigerating effect by absorbing heat while expanding or vaporizing (boiling).

REFRIGERATING SYSTEM, ABSORPTION—a refrigerating system in which the refrigerated gas evolved in the evaporator is taken up in an absorber and released in a generator upon the application of heat.

REFRIGERATING SYSTEM, CENTRAL PLANT—a system with two or more low sides connected to a single, central high side; a multiple system.

REFRIGERATING SYSTEM, CHILLED WATER—an indirect refrigerating system employing water as the circulating liquid.

REFRIGERATING SYSTEM, COMPRESSION—a refrigerating system in which the pressure-imposing element is mechanically operated.

REFRIGERATING SYSTEM, DIRECT-EXPANSION—a refrigerating system in which the evaporator is in direct contact with the refrigerated material or space or is located in air circulating passages communicating with such spaces.

REFRIGERATING SYSTEM, MECHANICAL—a system where the evaporator coil produces cooling by absorbing heat from the surrounding air, raising the refrigerant to its boiling point and causing it to vaporize. The superheated vapor flows through the condenser, which condenses it into a liquid and gives off heat picked up in the evaporator coil. Then the liquid flows to the expansion point, where it expands (lowering its temperature and pressure) to start the cooling cycle again.

REFRIGERATING SYSTEM, SINGLE-PACKAGE—a complete factory-made and factory-tested refrigerating system in a suitable frame or enclosure, which is fabricated and shipped in one or more sections and in which no refrigerant-containing parts are connected in the field.

REFRIGERATION SYSTEM—combination of interconnected refrigerant-containing devices in which the refrigerant is circulated for the purpose of extracting heat to produce cooling.

REHEAT—the process of adding heat to air to maintain the correct temperature after it has previously been cooled to some specified dew point to control humidity.

RELATIVE HUMIDITY—the ratio of the existing vapor pressure of the water in the air to the vapor pressure of water in saturated air at the same dry bulb temperature.

RELAY—an electromechanical switch that opens or closes contacts in response to some controlled action. Relay contacts are normally open (NO) and normally closed (NC).

RELAY, MAGNETIC—solenoid-operated relay or contactor; a switching relay that utilizes an electromagnet (solenoid) and an armature to provide the switching force.

REMOTE TEMPERATURE SET POINT—ability to set a temperature control point for a space from outside the space. Often used in public areas.

RESET—a process of automatically adjusting the control point of a given controller to compensate for changes in the outdoor temperature. The hot deck control point is normally reset upward as the outdoor temperature drops. The cold deck control point is normally reset downward as the outdoor temperature increases.

RESET RATIO—the ratio of change in outdoor temperature to the change in control point temperature. For example, a 2:1 reset ratio means that for every 2 degrees change in outdoor temperature the control point will increase 1 degree.

RESISTANCE—the opposition that limits the amount of current that can be produced by an applied voltage in an electrical circuit. Measured in ohms, abbreviated with the Greek letter omega.

RESISTANCE TEMPERATURE DEVICE (RTD)—a wire-wound electronic temperature sensor device with stable temperature coefficient, such as a 1,000 ohm Balco sensor with a resistance constant of 2.2 ohms per °F.

RESISTIVE LOADS—electrical loads whose power factor is one. Usually contain heating elements.

RESOLUTION—the number of possible states an input value or output value can take; a function of the digital controller I/O circuitry, an analog-to-digital (A/D) converter for input and a digital-to-analog (D/A) converter for output. Ten-bit resolution has 1,024 possible states; eight-bit resolution has 256 possible states.

RESTORE—to energize a load that has been shed.

RETURN AIR—air that is drawn back into the ventilation system from the controlled space.

ROOFTOP UNIT—HVAC system placed on a roof and connected to ducts that supply conditioned air to the area below it.

RUNNING CURRENT—the current that flows through a load after inrush current. Usually called "Full Load Current."

SEASONAL PEAK—the maximum demand placed on the utility's capacity resulting from seasonal factors. Some utilities have summer peaks, some have winter peaks, some have both.

SELF DIAGNOSTICS—the function of a control system, usually DDC, to detect errors, diagnose the cause of the errors, and notify the operator of the problem.

SENSIBLE HEAT—that heat which changes the temperature of the air without a change in moisture content. Changes in dry bulb thermometer readings are indicative of changes in sensible heat.

SENSING ELEMENT—the first system element or group of elements. The sensing element performs the initial measurement operation.

SENSOR—a control system sensing element.

SEQUENCER—an electronic device that may be programmed or set to initiate a series of events and to make the events follow in sequence.

SEQUENCING CONTROL—a control that energizes successive stages of heating or cooling equipment as its sensor detects the need for increased heating or cooling capacity. May be electronic or electromechanical. See Sequencer and Step Controller.

SETBACK—reduction of heating or cooling at night or during hours when a building is unoccupied.

SET POINT—the value on the controller scale at which the controller indicator is set.

SHIELDED CABLE—special cable used with equipment that generates a low voltage output. Used to minimize the effects of frequency "noise" on the output signal.

SHORT CYCLING—unit runs and then stops at short intervals; generally, this excessive cycling rate is hard on the system equipment.

SINGLE-ZONE SYSTEM—HVAC system controlled by one thermostat.

SPACE THERMOSTAT—a thermostat whose sensor is located in the space.

STAND-ALONE CONTROL—the ability of a digital controller to perform required control and energy management functions without connection to another digital controller or central site computer. Stand-alone ability requires a time clock, a microprocessor, microchip resident control programs, PID control, a communications port for interfacing with and programming the controller, firmware for interrogation and programming, and I/O for sensing and effecting control of its control environment.

STAND-ALONE SYSTEM—a BAS or DDC system that performs all control functions without direction from a central unit.

STANDARD AIR—a measure of air conditions used in psychrometric calculations. In the inch-pounds (I-P) system, dry air at 70°F and 14.696 psi. At these conditions, dry air has a mass density of 0.075 pounds per cubic foot.

START/STOP SCHEDULING—see Time Based Scheduling.

STARTER, MAGNETIC MOTOR—an adaptation of the basic contactor with overload relays and selector switches or pushbuttons for start-stop. Combination starters are a combination of starters and disconnect devices, either switches or circuit breakers, in a common enclosure. Starters for large motors may be reduced voltage type with reactors, step resistors, and other features required for the specific application.

STEP CONTROLLER—an electromechanical device used with electric or pneumatic systems, which may be set to initiate a series of events and to make the events follow in sequence.

SUBCOOLING—liquid temperature and pressures are directly related; subcooling is cooling the liquid line below the saturation temperature corresponding to pressure. Subcooling is measured by comparing the temperature of the liquid line to what the liquid temperature would ordinarily be at the measured discharge pressure.

SUBLIMATION—change of state directly from solid to gas without appearance of liquid.

SUCTION LINE—the tube or pipe that carries the refrigerated vapor from the evaporator to the compressor inlet.

SUPERHEAT—refrigerant vapor temperature and pressure are directly related; superheating is raising the temperature of the vapor above the saturation temperature corresponding to the pressure. Superheat is measured by comparing the temperature measured with that which would correspond to the measured pressure.

SURGE—an increase in electric energy on a conductor, such as would be caused by lightning or by starting a large motor.

SWITCHING RELAYS—relays are devices that operate by a variation in the conditions of one electrical circuit, to affect the operation of devices in the same or another circuit. General purpose switching relays are used to increase switching capability and isolate electrical circuits, such as in systems where the heating and cooling equipment have separate power supplies, and provide electrical interlocks with the system.

SYSTEM, FORCED-CIRCULATION—a heating, air conditioning, or refrigerating system in which the heating or cooling fluid circulation is effected by a fan or pump.

SYSTEM, GRAVITY CIRCULATION—a heating or refrigerating system in which the heating or cooling fluid circulation is effected by the motive head due to difference in densities of cooler and warmer fluids in the two sides of the system.

TEMPERATURE—the thermal state of matter with reference to its tendency to communicate heat to matter in contact with it. If no heat flows upon contact, there is no difference in temperature.

TERMINAL CONTROL UNIT (TCU)—an off-the-shelf, stand-alone digital controller equipped for communication with digital controllers on a lower level LAN and that may deviate from the stand-alone controller only in receiving energy management and time information from a stand-alone controller. A TCU is commonly application specific and is used for distributed control of specific HVAC subsystems, such as for control of small air handling units (AHUs), variable air volume (VAV) boxes, fan coil units, and heat pumps.

TERMINAL REHEAT SYSTEM—centralized blower and cooling system that supplies cool air to multiple zones. Each zone contains a hot water coil or electric heater that reheats the cooled supply air as determined by the zone thermostat.

THERM—measurement used by gas utilities for billing purposes. A therm is equal to 100,000 Btus or about 100 cubic feet of natural gas.

THERMISTOR—semiconductor material that responds to temperature changes by changing its resistance.

THERMOCOUPLE—a junction of two wires of dissimilar materials, not necessarily metal, but with the property of generating an electromotive force related to the temperature of their junction.

THERMOSTAT—an automatic control device responsive to temperature; a temperature actuated switch; an instrument that responds to changes in temperature and directly or indirectly controls temperature. The thermostat serves as the basic controller for the HVAC system.

THROTTLING RANGE—the range of values of a proportional controller through which the controlled variable must pass to drive the final control element through its full operating range. Also called "Proportional Band." In a thermostat, the temperature change required to drive the potentiometer wiper from one end to the other, typically 3 to 5°F.

TIGHT SHUTOFF—virtually no flow or leakage through a valve in its closed position.

TIME BASED SCHEDULING—the process of scheduling electrical loads on and off based on the time of the day, the day of the week, the month, and the date.

TIME CLOCK—a mechanical, electrical, or electronic timekeeping device connected to electrical equipment for the purpose of turning the equipment on and off at selected times.

TIME SCHEDULING—see "Time-based Scheduling."

TON OF REFRIGERATION—refrigerating effect equal to 12,000 Btus per hour, the amount of heat required to melt one ton of ice in 24 hours.

TOTAL HEAT—the sum of the sensible and latent heats. Changes in wet bulb thermometer readings are indicative of changes in total heat. For convenience total heat is measured from 0°F.

TRANSFORMER—the system power supply. A transformer is an inductive stationary device that transfers electrical energy from one circuit to another. The transformer has two windings, primary and secondary. A changing voltage applied to one of these, usually the primary, induces a current to flow in the other winding. A coupling transformer transfers energy at the same voltage; a step-down transformer transfers energy at a lower voltage, and a step-up transformer transfers energy at a higher voltage.

TRANSIENT—a current or voltage change that is not related to the normal system characteristics.

TRANSMITTER—a control input device, such as a pneumatic temperature transmitter that sends a pneumatic pressure signal proportional to the sensed temperature.

TREND LOG—a graphic representation of trends, either on screen or in printout form.

TRENDING—an accumulation of observed data points from DDC or BAS that is plotted to show the trend changes in observed values.

TURNKEY INSTALLATION—an installation of a BAS or DDC system in which the equipment manufacturer takes responsibility for all elements including design engineering, application engineering, provision of the BAS or DDC system and related equipment, general contracting, installation acceptance training, documentation, and system maintenance.

TWO-POSITION CONTROL—see On-Off Control.

UNIT COOLER—a direct-cooling, factory-made, encased assembly including a cooling element, fan and motor (usually), and directional outlet.

UNIT HEATER—a direct-heating, factory-made, encased assembly including a heating element, fan and motor, and directional outlet.

UNITARY SYSTEM—an HVAC system that uses packaged or unitary equipment. May use a central fan system for ventilating air.

UNLOADER—device on or in a compressor for equalizing the high and low side pressures for a brief period during starting, in order to decrease the starting load on the motor; also a device for controlling compressor capacity by rendering one or more cylinders ineffective.

UTILITY SERVICE—a description of the characteristics of electrical service supplied by a utility company. Service characteristics frequently found include 120/208 volt, 3-phase, 4-wire wye, 230/460 volt, 3-phase, delta, and 277/480 volt, 3-phase, 4-wire wye.

UTILITY TRANSFORMER—a transformer, owned by the utility company, which is used to step-down the distribution voltage to the utilization voltage for a facility.

VALVE—a device in a pipe or tube that diverts, mixes, or stops fluid flow by means of a flap, lid, plug, etc., acting to open and/or block passages.

VALVE, AUTOMATIC CONTROL—a combined valve body and actuator or motor, actuated by an automatic control signal from a remote point to position the valve either to open or close, or to proportion the medium flow rate through the valve.

VALVE BODY—the portion of the valve through which the medium flows.

VALVE, CHECK—a valve that allows fluid to flow in one direction only.

VALVE, EXPANSION—a valve that controls the refrigerant flow to an evaporator.

VALVE, MODULATING—a valve that can be positioned anywhere between fully on and fully off to proportion the rate of flow in response to a modulating controller. See Modulating Control.

VALVE, ON-OFF—see Valve, Two-Position.

VALVE, SOLENOID—an electrically operated, two-position valve, either normally open or normally closed, positioned by action of an electromagnet.

VALVE, THERMOSTATIC RADIATOR—a self-contained device that combines a temperature-sensitive power unit with a valve. Mounts in the hot water or steam supply pipe adjacent to a convector. May also be applied to baseboard and finned-tube radiation. Requires no electricity.

VALVE, TWO-POSITION—a valve that is either fully open or fully closed, with no positions between. Also called an "On-Off Valve."

VARIABLE AIR VOLUME (VAV) SYSTEM—a centralized HVAC system that supplies conditioned air at a fixed temperature to zones where a temperature controlled airflow regulator varies the volume of air delivered to the space.

VELOCITY—a vector quantity that denotes at once the time rate and the direction of a linear motion.

VELOCITY, OUTLET—the average discharge velocity of primary air being discharged from the outlet, normally measured in the plane of the opening.

VELOCITY, ROOM—the average sustained residual air velocity level in the occupied zone of the conditioned space, measured in feet per minute.

VELOCITY, TERMINAL—the highest sustained airstream velocity existing in the mixed air path at the end of the throw.

VENTILATION—the process of supplying or removing air, by natural or mechanical means, to or from any space. Such air may or may not have been conditioned.

VENTILATION CONTROL—the process of limiting outside air makeup for dilution ventilation of contaminants or heat based on level of contaminants or heat in space.

VIRTUAL POINT—a point that only resides in software. A virtual point allows transfer of calculated values between software programs, such as enthalpy.

VOLTAGE—the electromotive force in an electrical circuit. The difference in potential between two unlike charges in an electrical circuit is its voltage.

WATT—a measure of electric power equal to a current flow of one ampere under one volt of pressure. One joule per second. About 1/746 horsepower. Abbreviated W, w.

WATT TRANSDUCER—a device that converts a current signal into a proportional millivolt signal. Used to interface between current transformers and a load management panel.

WET BULB TEMPERATURE—the temperature of air as indicated by a thermometer with the bulb covered by a water-saturated wick over which air is caused to flow at approximately 900 feet per minute to reach equilibrium temperature of water evaporating into air when the heat of vaporization is supplied by the sensible heat of the air.

WORK STATION—a microcomputer used to operate a DDC system.

WYE SERVICE—a four-wire, three-phase electrical wiring configuration. Commonly shown as "Y."

ZONING—the practice of dividing a building into subsections, or zones, each with like thermal response characteristics for internal and weather-sensitive loads, for heating and cooling control.

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