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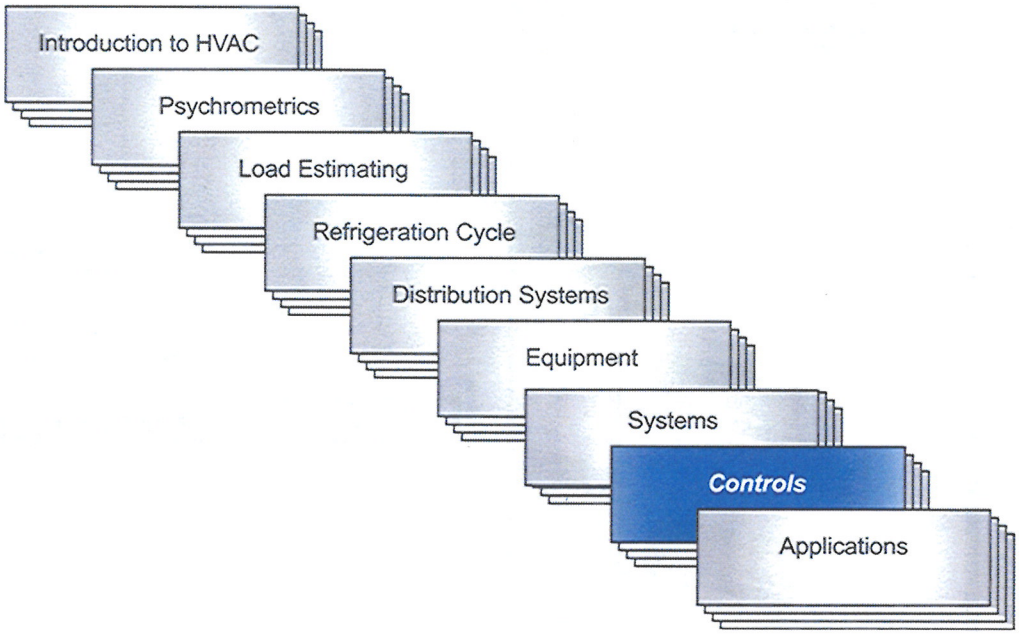
CONTROLS

Controls Level 2: DDC Networking

Technical Development Program

Technical Development Programs (TDP) are modules of technical training on HVAC theory, system design, equipment selection and application topics. They are targeted at engineers and designers who wish to develop their knowledge in this field to effectively design, specify, sell or apply HVAC equipment in commercial applications.

Although TDP topics have been developed as stand-alone modules, there are logical groupings of topics. The modules within each group begin at an introductory level and progress to advanced levels. The breadth of this offering allows for customization into a complete HVAC curriculum – from a complete HVAC design course at an introductory-level or to an advanced-level design course. Advanced-level modules assume prerequisite knowledge and do not review basic concepts.



The networking of HVAC DDC controls includes the basic concepts of controls interoperability and the benefits of tying HVAC control systems into the greater network of building system controls. This TDP includes a refresher of the elements and building blocks of HVAC controls and presents basic control strategies used to create the desired equipment responses for maintaining space environmental condition set points. This module will explain the workings of control system networks, present four key management methods available through DDC control networks, and show how to specify network configuration and functionality.

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Introduction

This Technical Development Program (TDP) describes the features and functions of a general purpose direct digital controller that is used to control heating, ventilating, and air-conditioning (HVAC) systems. This TDP also discusses how direct digital controllers work in a stand-alone environment and on a network, and how they interact with other building systems (see Figure 1).

This book will be useful to HVAC direct digital control (DDC) system designers, installers, service personnel, and end users. The TDP will refresh your understanding of DDC terminology and concepts, as well as outlining the tasks involved in putting a DDC control system together. If the concepts in this book are mastered, you will be able to identify jobs where a general purpose DDC controller can be used.

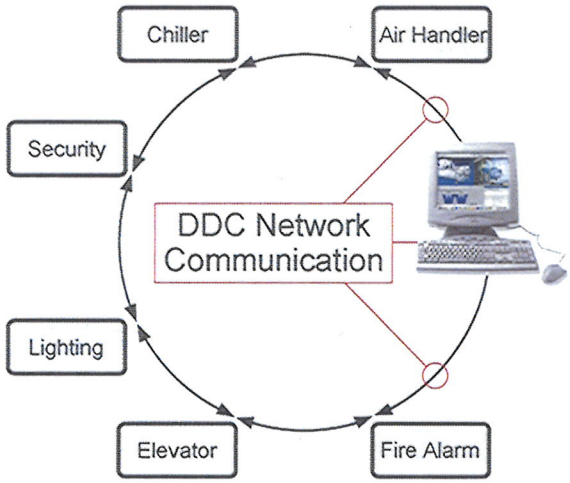


Figure 1

Building Systems DDC Network

In addition, if the reader is already equipped with basic HVAC knowledge, the information presented here will enable the user to specify a general purpose DDC controller for an HVAC system.

This program is not intended as qualification training for control system technicians. Computer literacy or knowledge of microprocessor technology is not a prerequisite. When computer or control terminology is used, it will be defined as necessary.

Traditionally, the HVAC system design process involved load estimating, air and water system design, equipment selection, then consideration of piping and electrical subsystems, followed by design and selection of the controls and control sequences of operation. However, control system design was often treated as an afterthought, since it was usually handled by ATC (automatic temperature control) specialists.

Today, comfort, energy, and building management benefits, along with rapid advances in computer-based technology, have dictated that DDC system aspects be considered much earlier in the design process (see Figure 2). In addition, these system integration trends have demanded that the DDC system be designed at the same time as the rest of the HVAC system. In many cases, the basis of design DDC system features influence the selection of the mechanical system itself. For example, when the

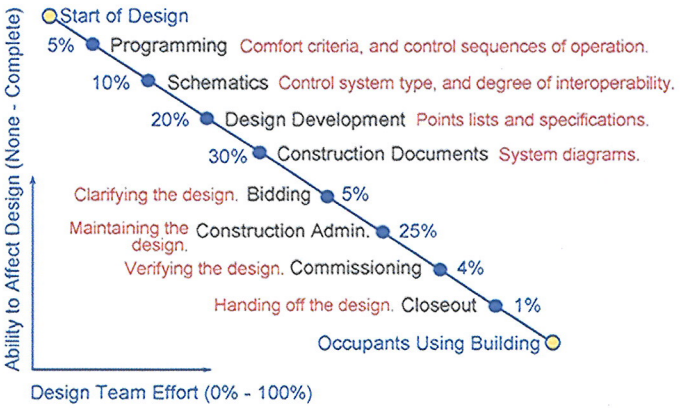


Figure 2

HVAC Controls Design Phases

mechanical designer chooses to provide a variable air volume (VAV) system, the control system can impact the following aspects of the architectural/mechanical design:

- maximum number of zones
- variable frequency drive (VFD) control versus inlet guide vane (IGV) control
- temperature sensors versus temperature/set point displays (thermostats).

What is DDC?

The term ***DDC (direct digital control)*** has been used (and misused) for many years now. The term originated in the 1970s when newly emerging computer technology was first applied to HVAC control systems. Back then, most large building HVAC systems used pneumatic devices for comfort control. When some companies tried to apply computer technology to these systems, the computer systems provided "overlay" control only. The pneumatics still did the basic control, but the computers monitored and, only occasionally, intervened in the pneumatic control processes.

The DDC breakthrough came when a task force at Hamilton Standard (a predecessor of Carrier Corporation's present Carrier Electronics Division) bypassed pneumatic control devices, such as receiver-controllers, with computer modules and innovative software to provide *direct* control using *digital* (microprocessor-based) techniques. See Figure 3.

Direct Digital Control

These device types provide direct control using digital (microprocessor based) techniques.

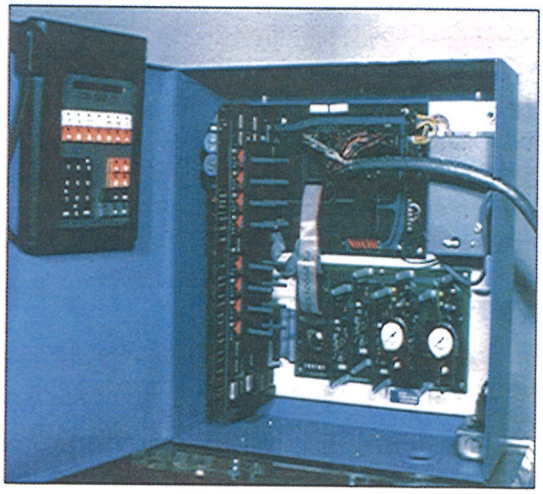


Figure 3

Early DDC Microprocessor

focus on equipment first.

DDC Controllers

There are two types of DDC controllers: product-integrated and general purpose (Figure 4). ***Product-integrated controls*** (***PIC***s) are DDC controllers which are factory-mounted on specific pieces of equipment such as chillers, air handlers, or packaged units. The controllers are designed and programmed to control the inner workings of that particular product. General purpose DDC controllers are field-installed and, therefore, are sometimes called ***field-installed devices*** (***FID***s).

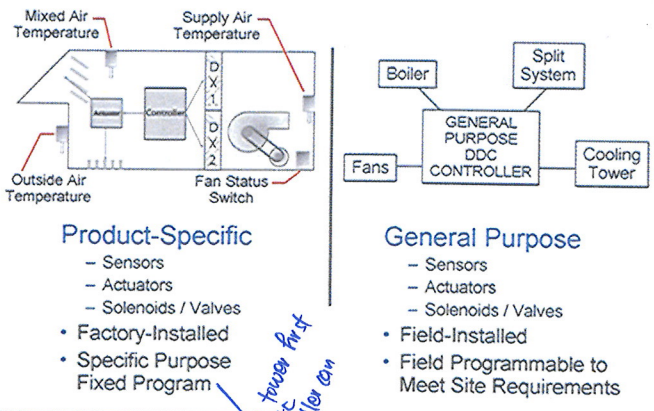


Figure 4

DDC Controllers

eg run tower first etc before chiller on.

General purpose controllers are microprocessor-based modules applicable to a wide variety of new construction, replacement, and retrofit HVAC system equipment. This book will focus on general purpose DDC controllers.

Applications and Characteristics

A typical application that uses a general purpose DDC controller would be an air handler with a supply fan, dampers, heating and cooling coils, and filter section. Such units require a general purpose DDC controller because of the many combinations of control types and sequences. Other new HVAC system equipment which are candidates for general purpose DDC controller FIDs are certain split or rooftop systems, cooling towers, boilers, pumps, fan coils, fan-powered mixing boxes, and other products shipped to the job site without PICs. See Figure 5.

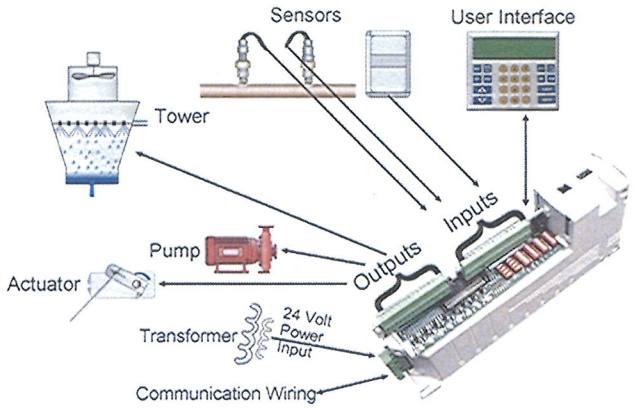


Figure 5

General Purpose DDC Controller Usage

Another common application for general purpose DDC controllers is the retrofit of HVAC equipment or systems in existing buildings, many of which have obsolete or inefficient pneumatic, electric, or electronic controls that are badly in need of upgrade or replacement.

Most DDC controllers can extend applications beyond the traditional system realm into non-HVAC areas such as lighting and security. Interoperability, where a common protocol is used to provide communication between disparate systems, has made integrating with lighting controllers, card access systems, and other, non-traditional HVAC building systems more and more popular.

Physically, a general purpose DDC controller is a module or "black box" which has a microprocessor (computer chip) inside. The controller includes all the electronics needed to support it and the signal conditioning necessary to interpret sensor readings (inputs) and to drive the actuators (outputs). The controller needs a source of power and usually incorporates communications ports for networking and human interface.

DDC Controllers

A control system module that has a microprocessor (computer chip), I/O terminals, and communications ports that allow networking is called a DDC controller.

As with any microprocessor-based device, the DDC controller is dependent on its software, or internal programming, for proper operation. The operating system software allows the computer processor to communicate, process data, store information in memory, and maintain an internal clock to provide timing functions. The main concern, however, with the software is how it has an impact in the HVAC world. To this end, general purpose DDC controllers use a family of ***algorithms***, which are control routines or programs specific to HVAC needs. For example, a program designed to modulate a cooling coil valve between open and closed in response to space

temperature is called a ***cooling coil algorithm***. The hallmark of well-designed general purpose DDC controllers includes such features as:

- flexibility of the input/output complement
- versatility of the control algorithms to apply to the widest variety of field situations
- custom programming capability for non-standard control applications

Internal Programming

Algorithms are mathematical procedures that solve recurrent computations. They are used for all control actions and control types.

Configurations

The simplest arrangement for a general purpose DDC controller is in a standalone configuration. See Figure 6. This occurs when the controller manages a single system, without the use of a communication wiring network connecting it to the controls of another system. The basic configuration for a single zone packaged or applied heating/cooling air handling unit with economizer cycle is shown in Figure 6. The controller communicates with I/O devices in the system through a pair of twisted wires. The controlled devices (damper actuator, coil valve actuators, etc.) receive commands from the controller and respond back with reports of their actions. If a controlled device does not respond to the controller's command, an error message is displayed.

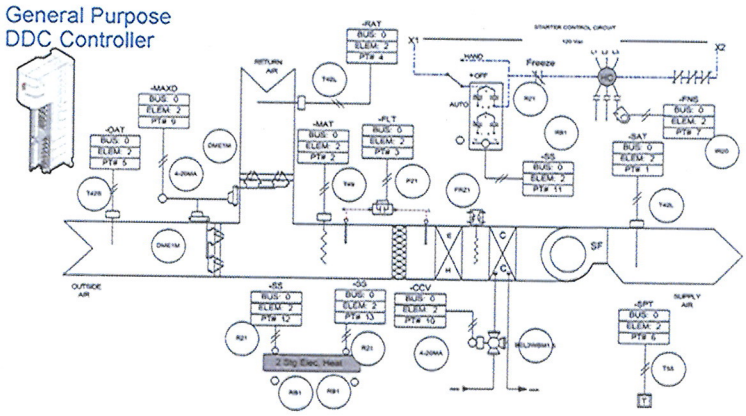


Figure 6

Standalone DDC Controller

Sensing-input
valve_output

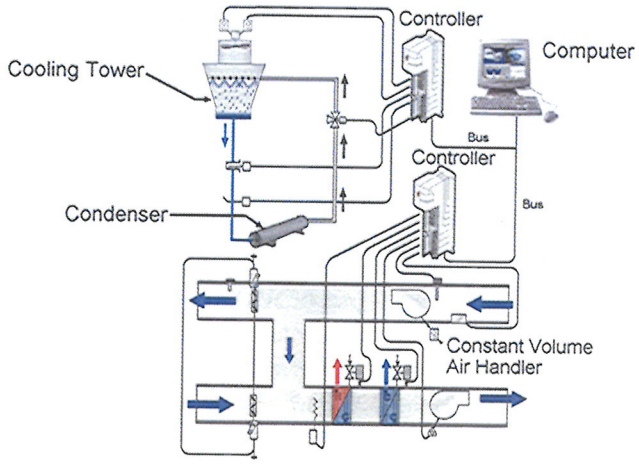


Figure 7

Networked DDC Controllers

This section will concentrate on the standalone aspects and capabilities of these controllers, but it should be noted that they are designed to function and communicate in a ***network*** with other control modules, systems, and computers which serve as supervisory and monitoring stations. See Figure 7. A network can be defined as a group of communicating devices (standalone or not) that share data, command, and control functions over a defined physical communication infrastructure. The types of infrastructure can include a twisted pair cable, telephone connection, the Internet, and even satellite communication. The system illustrated in Figure 7 is part of a network because it communicates with a personal computer or other standalone systems.

Control Actions

There are three basic ***control actions*** for operating DDC ***control loops***. They are proportional (P), integral (I), and derivative (D). The proportional, integral, and derivative terms are used in mathematical formulas which reside in the microprocessor software. The proportional, integral, and derivative terms are adjusted, as needed, to achieve the desired loop control response. The adjustment is made either by user configuration or automatically, using a special loop tuning software program. If loop tuning software is used, the loop is called a ***self-tuning loop***.

DDC controls operate by means of mathematical formulas. Therefore, when compared to traditional pneumatic, electric, or electronic controls, they are unique in the way they operate regardless of the control strategy.

A PI loop is the most popular ***control strategy*** for HVAC systems, with few exceptions. See Figure 8. Even though a PID loop has a quicker response time, most HVAC systems demonstrate a relatively slow response to a change in the controller output. Therefore, a PI loop's longer settling time and gradual elimination of offset is usually not a disadvantage with slow-moving HVAC systems. A notable exception to this general rule is central steam heat, which benefits from the quicker response and reduced oscillation of PID control.

Application Strategy	Action or Algorithm
Mixed Air Dampers	PI
Chilled Water Coil Valve with Discharge Sensor	PI
Hot Water Coil Valve with Discharge Sensor	PI
Static Pressure Control of Supply Fan	PI
Flow Tracking Control of Return Air	PI
Hot Water Converter (Mixing/Diverting Valve)	PI
Temperature Control	P
Steam Heating Valve	PID
P = Proportional PI = Proportional + Integral PID = Proportional + Integral + Derivative	

Figure 8

Common HVAC Control Strategies

Proportional + Integral Applications

PI control action is more than adequate for most HVAC control applications like valves, dampers, and actuators.

Likewise, the control loops for clean rooms, laboratory facilities, or any application demanding precision and quick response should use PID control. It is always best to use a controller and algorithms that can function in the PID mode. Since the derivative term is user-selectable, the term can always be set to zero to achieve PI control, when desired.

However, a controller or algorithms with only PI capability cannot be made to function in the PID mode. Figure 9 summarizes the characteristics of the three basic control actions used in common HVAC control strategies: proportional, integral, and derivative, showing the concept, benefit(s), and response of each.

Control Action	Deals with	Control Concepts	Added Benefit	Response to Disturbance
Proportional (P)	Error	Signal proportional to error	Control signal proportional to error (demand based)	P OFFSET
Integral (I)	Time	Integrates error over time to respond to small error	Eliminates offset over time (accuracy)	P + I UNDERSHOOT
Derivative (D)	Rate	Responds to rate at which set point is approached	Shortens settling time (quick response) and lessens overshoot/ undershoot (precise)	P + I + D OVERSHOOT

Figure 9

Comparison of Control Actions

Control System Elements

The key elements in any control system are the input, process, and output elements.

Processes

In the case of a room thermostat which controls a furnace (Figure 10), the input is room temperature, the output is an "on" or "off" switching action, and the process is something inside the thermostat which performs the following function:

If input <68° F, switch output "on"

If input >72° F, switch output "off"

Traditionally, this on/off process has been performed with a bi-metal coil which makes or breaks a set of contacts in the thermostat in response to temperature change. However, we do not have to know how the process is accomplished to understand how the system and occupant benefit from the process.

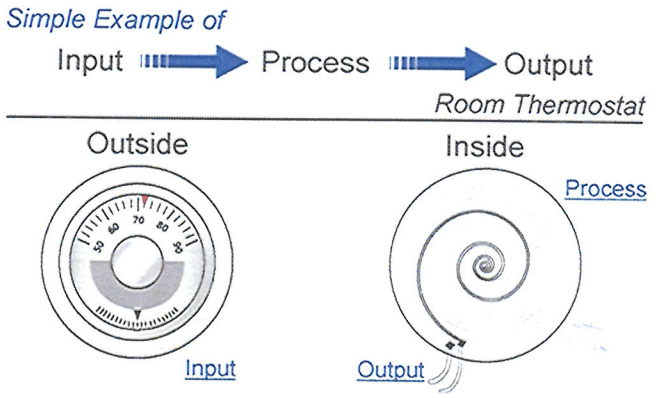


Figure 10

Room Thermostat Process

This on/off function could also be performed by a pneumatic switch, electronic amplifier, or microprocessor-based controller. The point is that we are mainly interested in the results or logic of the process, not what it takes to get the job done.

Algorithms

In the case of DDC, the control process is performed by continuously running algorithms, or specific control routines, which have been selected for an application. See Figure 10. Algorithms consist of a series of logic statements, continuously repeated at high speed. For example, part of a cooling coil algorithm might be something like this:

Step 1 - Read the space temperature.

Step 2 - Compare space temperature to the set point.

Step 3 - If too high, energize output signal or wait a calculated time period based on PID loop status.

Step 4 - If required time period has elapsed, add X to the output signal.

Step 5 - After another calculated time delay, go back to Step 1.

Control algorithms for specific tasks have been developed over the years and several control system manufacturers include a library of algorithms to choose from. Most HVAC control tasks such as cooling coil control, mixed air damper control, fan start/stop, and many more are available with the controller. Typically, once an algorithm is chosen, it is a simple matter of filling in decisions about how the algorithm is to function (should the cooling coil control look at space temperature or return air temperature, for example), then tuning the algorithm to the specific installation. This decision logic approach, where the installer does not write code, but just fills in decisions on how the algorithm is to function, can save tremendous amounts of time during start-up and checkout. Since the algorithm has been factory-tested, there is no debugging of code or making basic changes to the algorithm in the field.

DDC Operation

The algorithm process continuously considers input conditions, and decides what, if anything, needs to change on the outputs.

In a DDC controller, there may be several algorithms working concurrently, including some that may have been customized for the application. There is a continuous algorithm process of considering input conditions and deciding what, if anything, to change on the outputs. By contrast, the electric or pneumatic control loop allows the process to come to rest when the controlled variable achieves the set point.

Inputs and Outputs

General purpose DDC controllers, as opposed to PICs, must be able to be applied to a wide variety of applications. General purpose DDC controllers must provide flexibility in the number and types of inputs and outputs they can accommodate. Experience has dictated that many typical stand-alone applications can be handled with a controller which has eight input channels and eight output channels. See Figure 11. This comes from the fact that most air handlers can typically be controlled with this point complement. Air handlers make up the overwhelming majority of DDC installations. Controllers with fewer channels are also available as economics dictate, and applications which require more inputs and outputs can be accommodated by adding expansion modules which extend the I/O channel count without requiring additional processors.

8 Inputs	
Channel Numbers	**Specifications**
1 to 4	Discrete or analog (0 to 10 VDC)
5 & 6	Temperature
7 & 8	Discrete, analog, or temperature
	Discrete
	Dry contact
	Pulsed dry contact
	Analog
	4 to 20 mA
	0 to 10 VDC
	Temperature
	5K & 10K ohm thermistors
	1 K ohm nickel RTD

8 Outputs	
Channel Numbers	**Specifications**
1 to 4	Discrete
5 & 6	Analog
7 & 8	Discrete or analog
	Discrete
	24 VDC At 80 mA
	Analog
	4 to 20 mA
	0 to 10 VDC

* Each channel is a two-wire connection for a sensor input or actuator output

Figure 11

General Purpose Controller Inputs and Outputs

Controllers usually can accommodate two types of input or output signals: analog and discrete. An analog signal is any signal which is continuously variable over a range, such as temperature, pressure, voltage, or contaminant concentration. A discrete signal is any signal which is in one state or another, such as on/off, open/closed, energized/de-energized, or flow/no flow. Sometimes discrete inputs or outputs are called ***digital*** or ***binary*** but, to avoid confusion with microprocessor terminology, the best term is ***discrete***.

Generally speaking, inputs come from sensors while outputs go to actuators. Typical parameters sensed (inputs) or actuating devices used (outputs) include the following:

AI (analog input)

- Temperature (by far the most common)
- Humidity
- Pressure
- Flow
- Voltage
- Current
- Air quality (CO_2, O_2, etc.)
- Time

DI (discrete input)

- Switch contact (open/closed)
- Power (on/off)
- High/low limit switch (on/off)
- Wattmeter pulses (counts)

AO (analog output)

- Damper actuator
- Positioning (stepper) motor
- Modulating valve

DO (discrete output)

- Relay coils
- Pulsed or stepped actuators
- Indicator lights
- Solenoid valves

The left side of Figure 12 shows an example of sensor input wiring at the DDC controller's terminal strip. This is the general approach for all four input types: discrete, analog 0–10 vdc (zero to 10 volts direct current), analog 4–20 mA (four to twenty milliamps), or temperature. However, internally powered sensors are wired differently. Consult the manufacturer's installation recommendations for specific guidance.

The right side of Figure 12 shows an example of actuator output wiring at the DDC controller's terminal strip. This is the general approach for all three output types shown: discrete, analog 0–10 vdc, or analog 4–20 mA.

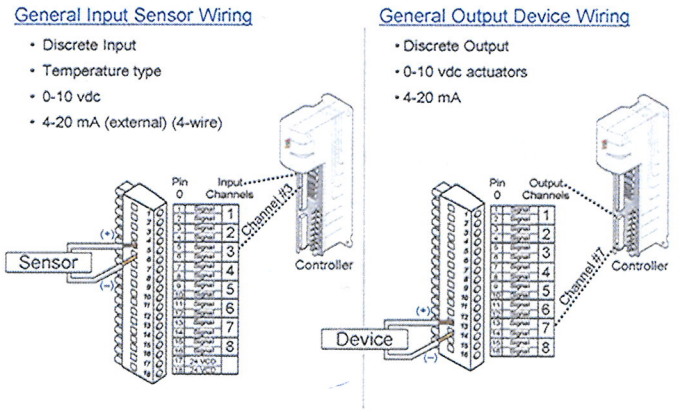


Figure 12

Typical Input/Output Wiring

Sensor Conditioning

Some types of input and output devices may be able to be wired directly to the controller I/O terminals, but others may need an intermediate device to condition the signal first.

An electronic or microprocessor-based controller can only interpret electrical phenomena such as voltage, current, or resistance. The DDC controller cannot directly interpret temperature, humidity, or damper position. The controller needs an electrical representation of these parameters, and has to take into consideration such factors as sensitivity, accuracy, resolution, linearity, and range.

Sensors and Actuators

Sensors and actuators are control devices that either input signals to the controller or output action commands from the controller. See Figure 13. They differ from controlled devices, like valves, fans and dampers, which implement the actions requested by the logic within the controller.

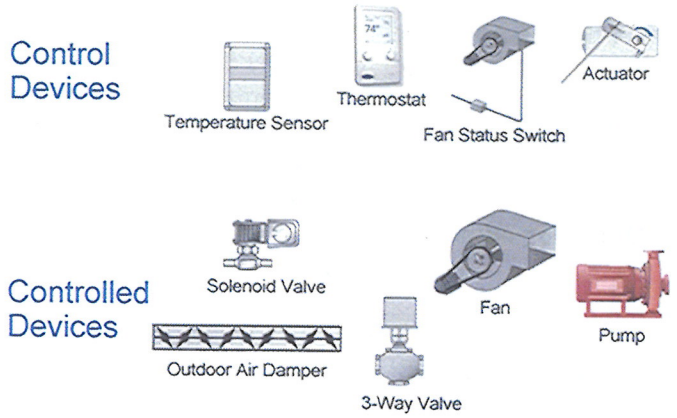


Figure 13

Sensors and Actuators = Control Devices

Temperature Sensors (AI)

Since temperature is the most common parameter to be sensed and controlled in HVAC applications, let's examine some of the considerations involved in matching a temperature sensor with a controller.

One common type of temperature sensor is a resistance temperature device (RTD). A change in temperature will result in a corresponding change in resistance, which a controller can then measure and interpret. A typical RTD characteristic curve is shown in Figure 14. The RTD sensor is somewhat low in sensitivity (1 ohm/°F) but it has advantages in certain applications.

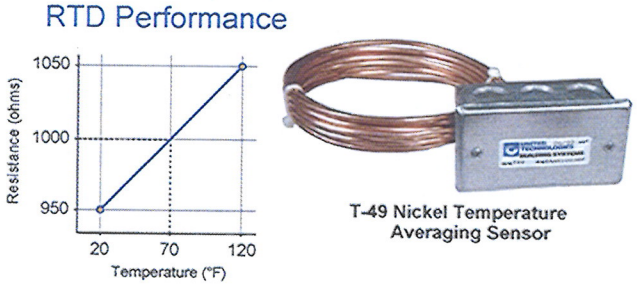


Figure 14

RTD Temperature Sensor

For example, a long length of resistive nickel wire, or a long copper sensor tube, might be used as an RTD as shown in Figure 15. This wire or tube can criss-cross a section of ductwork which receives stratified air from several sources of varying temperatures (e.g., outdoor air and return air). Since the element is sensitive to temperature throughout its length, this provides a good way to detect average temperature of a large cross-section of ductwork.

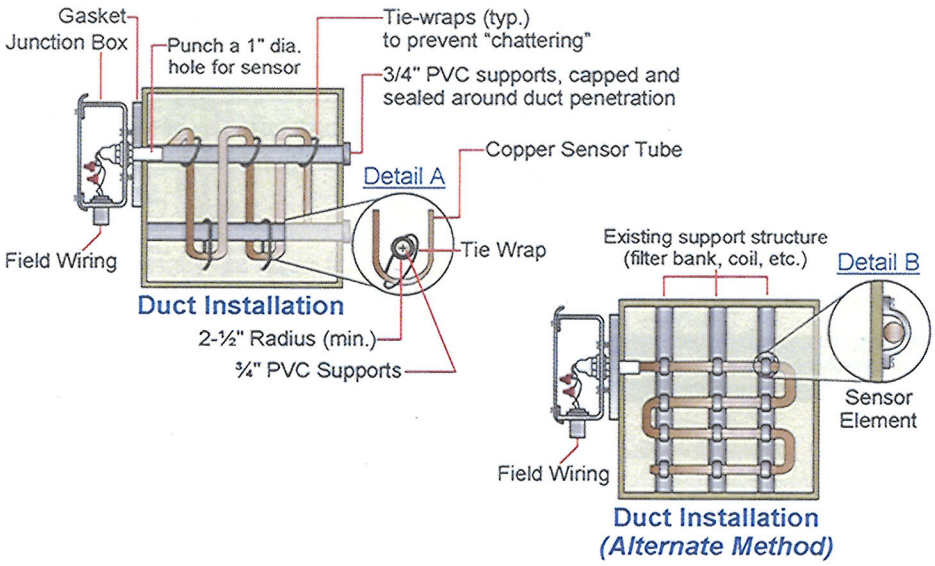


Figure 15

RTD Temperature Sensor Duct Installation

Another common type of temperature sensor is a thermistor. Types of thermistors are shown in Figures 16 to 18. This type of sensor only senses temperature at its tip, rather than across its length. Like an RTD, a thermistor changes resistance with temperature, but its characteristic curve is non-linear and quite different than that for an RTD. Thermistors are widely used in HVAC applications because of their sensitivity.

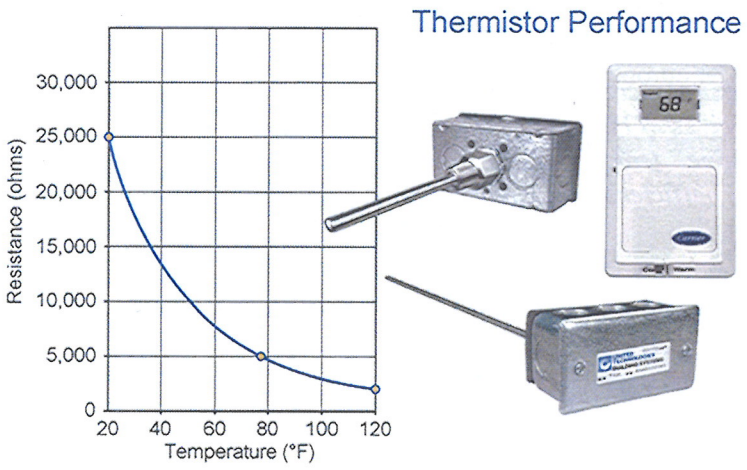


Figure 16

Thermistor Temperature Sensor

Thermistors can be used to sense the fluid temperature within a pipe. An immersion sensor does so directly, while a pipe clamp sensor senses temperature indirectly. Air duct temperatures are taken at a single point with the air duct sensor. Location is important. The outside air temperature sensor is also a popular thermistor application.

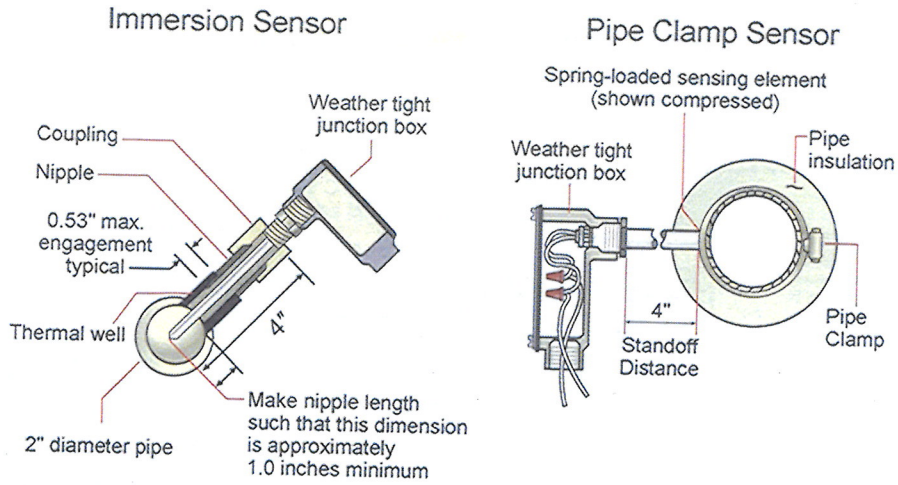


Figure 17

Thermistor Fluid Temperature Sensor Location

As shown in Figure 16, a relatively large change in resistance results from a relatively small change in temperature (150 ohms/°F near 77° F) which lends itself to control stability. Note that as opposed to the RTD, the thermistor curve is non-linear, so scaling software in the controller must take this into account to ensure accuracy. Also, unlike the RTD, resistance falls as temperature rises, another factor which the controller needs to consider. This thermistor property is known as *NTC*, or *negative temperature coefficient*.

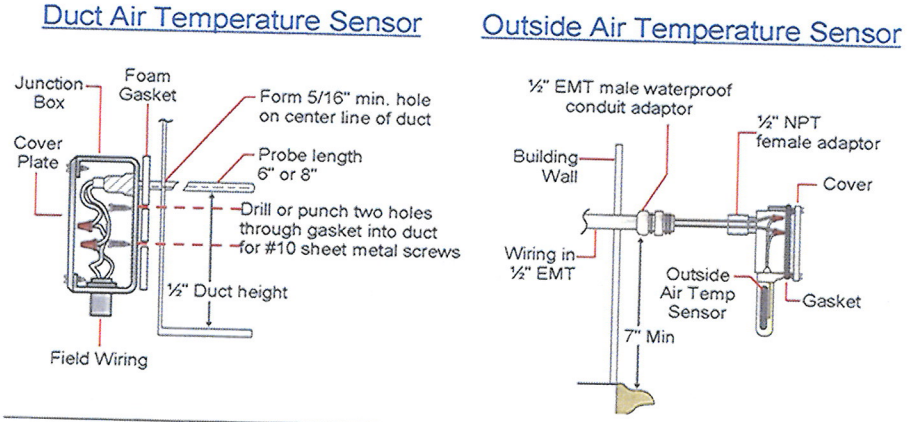


Figure 18

Thermistor Air Temperature Sensor Location

Another way to sense temperature is to use a transmitter. A transmitter is a device that senses a certain range of temperature using a thermocouple or RTD, and produces a proportional current or voltage signal which can be used as an input to the DDC controller. These transmitters are typically 4–20 milliamp (mA) or 0–10 vdc devices. See Figure 19. A temperature transmitter is used for special applications, particularly when high accuracy and linearity are important.

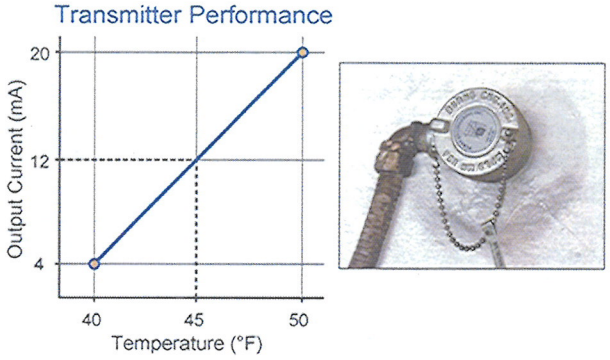


Figure 19

Temperature Transmitters

Figure 20 summarizes the three temperature sensing methods discussed. The general purpose DDC controller makes provisions for all these applications by accepting each type of input and by providing internal means to select the scale for the desired range of measurement.

Method	Typical Applications	Desired Characteristics	Typical Input Signals to Controller
Thermistor	Space of Duct Temperature, Chilled Water Temperature, Most HVAC Control Points	Stability, Good Resolution, Reliability	5K ohm or 10K ohm at 77° F
RTD	Mixed Air Temperature	Can Sense Average Temperature	1K ohm at 70° F
Transmitter	Process Cooling Fluid Temperature	High Accuracy Over Limited Range	4 to 20 mA 0 to 10 vdc

Figure 20

Temperature Sensing Characteristics

Other Analog Inputs

While temperature is the primary AI used for HVAC control, other parameters which are useful include relative humidity, pressure, air and water flows, current, and air quality. See Figure 21. Since measurement of most of these inputs is somewhat complex, transmitters or transducers (similar to the temperature transmitter cited above) are used for sensing. These devices provide a standardized current or voltage input proportional to the sensed parameter.

An industry-standard current signal ranges from 4 to 20 mA across its control range. An industry-standard voltage signal is 0 to 10 vdc. Any sensing device which can produce either of these signal ranges is acceptable as an analog input to the DDC controller.

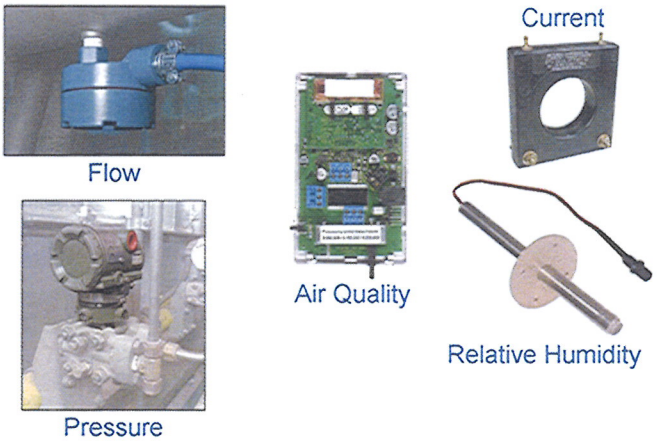


Figure 21

Other Analog Input Devices

Discrete Inputs (DI)

Discrete inputs are used to monitor two-stage events such as on/off and opened/closed, etc. as shown in Figure 22. Discrete inputs are useful when it makes sense to employ a limit switch rather than to detect the analog parameter. For example, a settable high/low pressure switch (discrete) is much more economical than pressure-to-current (P/I) transducer (analog), if the only important information is that limits have been exceeded rather than knowing the actual pressure itself.

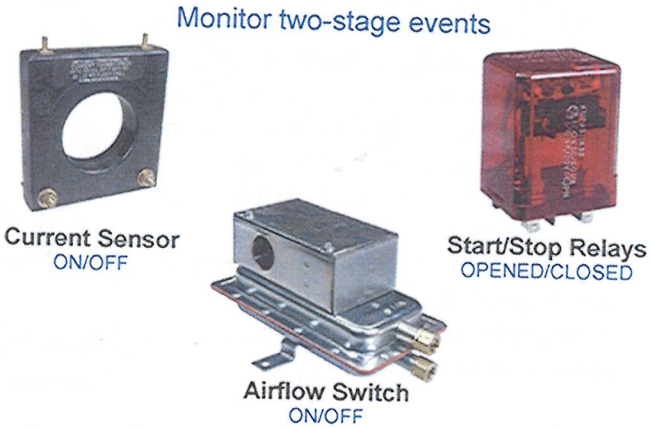


Figure 22

Discrete Input Devices

Analog Outputs (AO)

Commonly used analog output actuating devices for DDC control systems are true proportional 24-volt motors that are modulated by either a 4 to 20 mA or 0 to 10 vdc signal. See Figure 23.

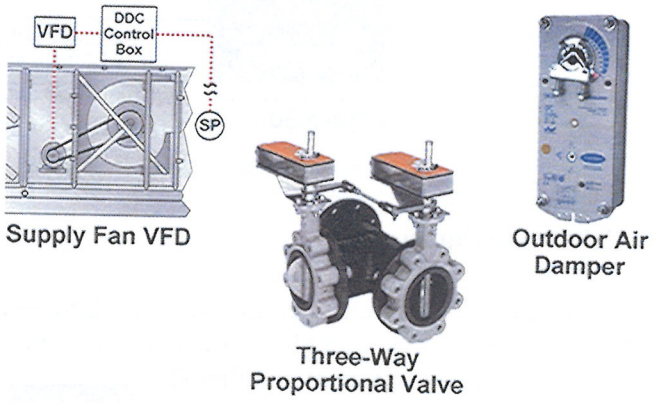
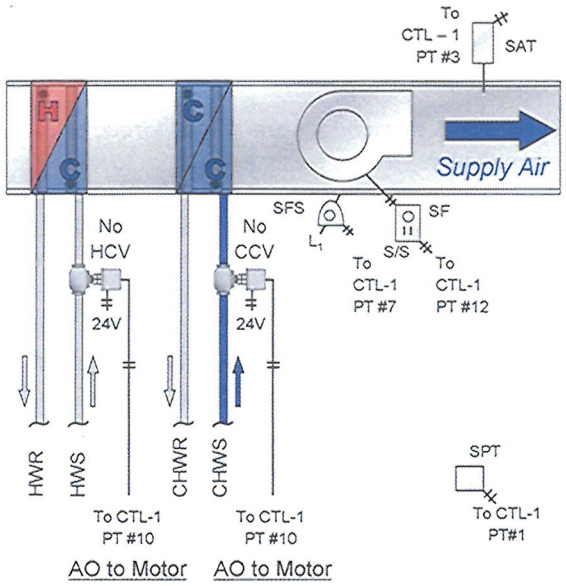


Figure 23

Analog Output Devices

In the schematic shown in Figure 24, the valve which modulates the flow of chilled water to the cooling coil and the valve for the heating coil are driven by such a motor. The actuator includes a spring return feature that allows the motor to return to the normal position upon power loss. In our example, the cooling coil valve is normally closed, so the actuator drives the valve open and the spring return closes the valve when deactivated. The motor that drives the valve is a proportionally reversible motor that can stop and hold its position anywhere in the stroke.





Valve

Figure 24

Analog Output to Proportional 24-Volt Motors

For the sake of standardization, most available actuating devices, such as damper motors and control valves (as shown in Figure 25), will accept the industry-standard signals of 4 to 20 mA and 0 to 10 vdc, so this is what is normally provided at the controller output channels.

At times, large systems use pneumatic actuating devices. See Figure 26. The use of current-to-pressure (I/P) transducers is common in these applications. A 4 to 20 mA (AO) signal from the controller will generate a 3 to 15 psig air signal from the I/P transducer which is used to drive a pneumatic piston. This piston positions a mechanical device such as an air damper or water valve.

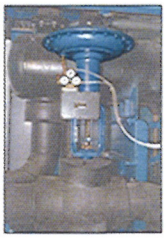
Pneumatic Actuating Devices

Pneumatic controls are best suited for device control and not complete system control.

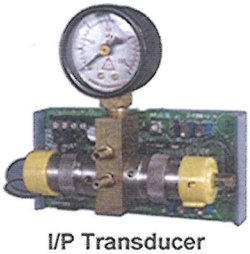
AI	DI
• 10,000Ω (@77° F) thermistor	• Relay closure
• 5,000Ω (@77° F) thermistor	• Can be pulsed
• 1,000Ω (@70° F) RTD	
• 4-20 mA current	
• 0-10 vdc voltage	
AO	**DO**
• 4-20 mA current	• Relay closure
• 0-10 vdc voltage	• 24V contact closure

Figure 25

Typical I/O Channel Signals



Three-Way Mixing Valve



I/P Transducer



Damper

Figure 26

Analog Output to Pneumatic Operators

Typically, newer applications will use actuators that directly receive 4 to 20 mA or 0 to 10 vdc signals, thus eliminating the I/P transducer interface found in older applications.

Pneumatic controlled devices will probably never completely disappear from buildings. While electronic actuators are continually improving in both reliability and performance, there are some applications where pneumatics still outperform electronic:

- Very large valves (greater than 6-in. pipe size) require a tremendous amount of torque to move smoothly and reliably. Pneumatic actuators can provide a greater amount of torque than electronics.
- Areas where the actuator is exposed to the weather or corrosive environments usually are better suited for pneumatic actuators.

Note that even though a pneumatic actuator is being used, the control is still DDC. DDC provides the signals to the I/P transducer, which converts them to a pneumatic signal.

Discrete Outputs (DO)

A DO is a 24-volt output signal that turns a device on or off. This is typically used to turn on and off pilot relays that start or stop motors such as fans and pumps. The signal can also be used to open or close two-position valves and damper actuators, etc.

Power

An important, but sometimes overlooked, element in a control system is power. See Figure 27. For example, a bimetallic, electromechanical, room thermostat receives its 24 volts alternating current (vac) power from the furnace transformer. The thermostat uses that power in its switching action. The control itself is mechanical, initiated by the coiling or uncoiling of the thermostat's bimetallic element, so it needs no power for its basic functioning.

Pneumatic controls need a source of air pressure (usually 20 psig), so pneumatic tubing must be run to all control devices in the system. A constant supply of clean, dry, pressurized air must be maintained for proper control action because of the air bleed characteristic of pneumatic control systems.

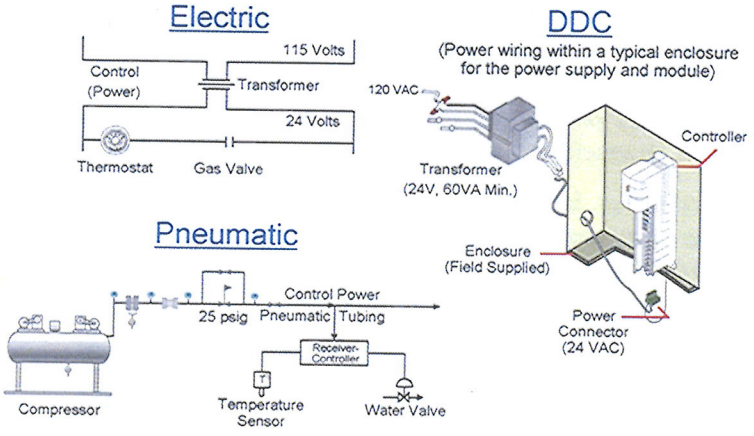


Figure 27

Control System Power

DDC controls need a constant source of electric power to operate properly. They also need some internal provision for retaining memory of their control set points, function, and timing in the event of power outages. Usually non-volatile memory, and/or a capacitor, is used for this purpose. Typical power requirements for DDC controllers are 24 vac, 50/60 Hz, which can usually be easily obtained from building power by using a common control transformer.

User Interface

Another key element in a control system as shown in Figure 28 is human interface. Although a controller is an automated device that does not require human intervention for normal functioning, there are times when a person needs to know what the control is doing, to make set point adjustments, or to modify the control sequence.

With a room thermostat, there is usually a thermometer, which indicates room temperature, and a knob to change the control set point. The room temperature set point is controlled by the adjustment knob. The thermometer gives feedback data to the human observer about the room temperature but it does not send output to the system.

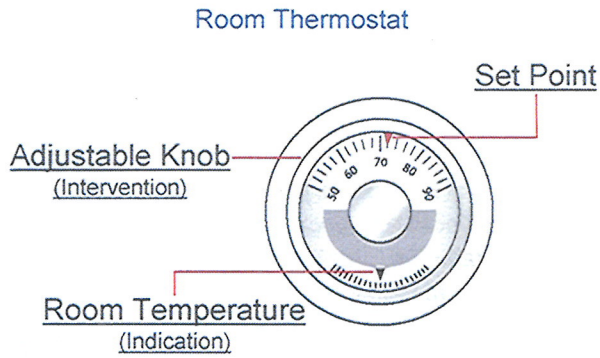


Figure 28

Human Interface Device (Room Thermostat)

User Interface

Some form of indication (data output) and interventional (data input) are what constitutes use interface.

For this example, the thermometer built into the face of the thermostat is the indication, or output, of the controlled variable (the actual room temperature), while the set point knob is the intervention, where data is input (desired room temperature).

Typical indicators include gauges, lights, audible beeps, digital displays, or even computer screens as shown in Figure 29. Means of intervention include manual switches, knobs, pushbuttons, or a keypad built into a control panel.

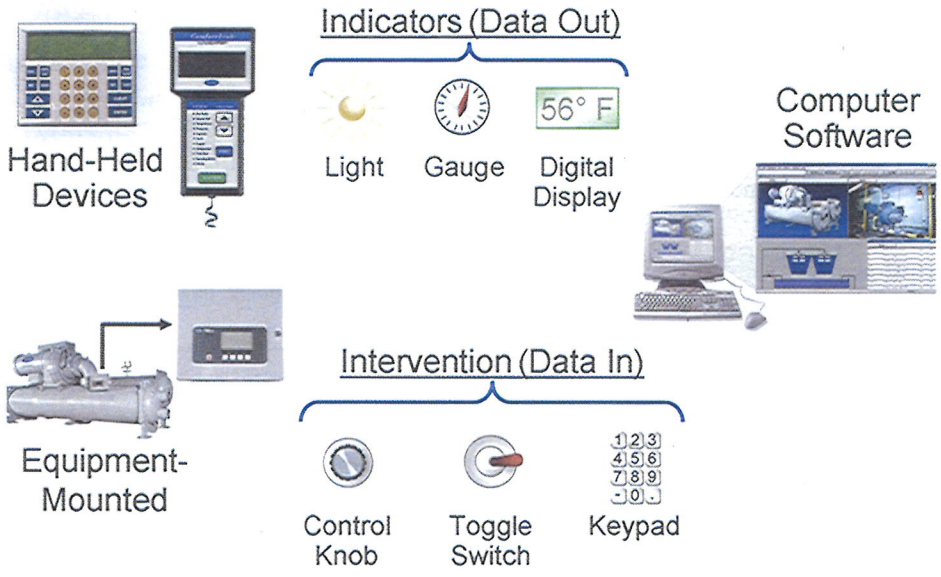


Figure 29

Typical User Interface Devices

The controller must be accessed for configuring or resetting. See Figure 30. While it is usually possible to access a general purpose DDC controller with a PC (personal computer) or laptop computer which incorporates compatible supervisory software, a popular method is to use a portable user interface. The interface is a handheld module with alphanumeric data display and a keypad with functional and numeric keys for data entry. The portable user interface is connected to the DDC controller via a phone-type plug which provides power as well as communications. If desired, the interface can be permanently mounted on the door of the enclosure housing the controller.

The advantages to using such a user interface are cost and portability. The building operator or service technician can take the interface with them as they move from panel to panel. The disadvantage is they usually can only communicate with one panel at a time, so, for example, if the user wanted to see all of the space temperatures on one screen at one time, they would need to have a PC or laptop computer.

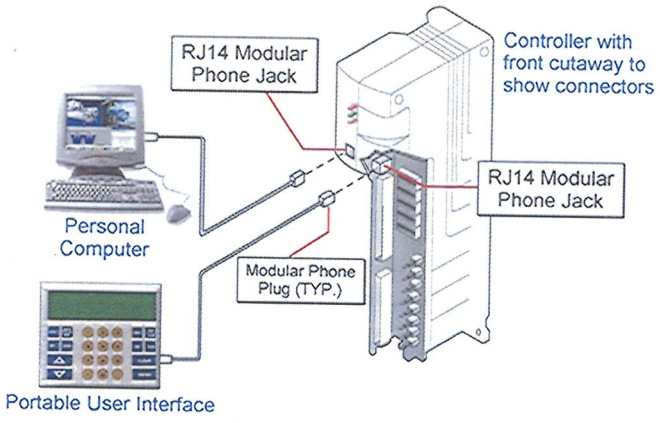


Figure 30

Configuration Devices or Methods

Software

A general purpose DDC controller contains a software library and a blank database as shown in Figure 31. The user selects the algorithms, set points, schedules, alarms and system functions required for the application from the library. The controller stores in its database the selected items. The size of the database is relative to the amount of space the selected items occupy. The user can select items from the library until the available area in the database is filled. Once the database has been established following installation, it can be configured to meet the needs of the site's applications.

As mentioned before, a DDC controller is a microprocessor assimilating input information, manipulating the data in some way to produce a desired result, and then driving output actuators to carry out the mechanical tasks involved.

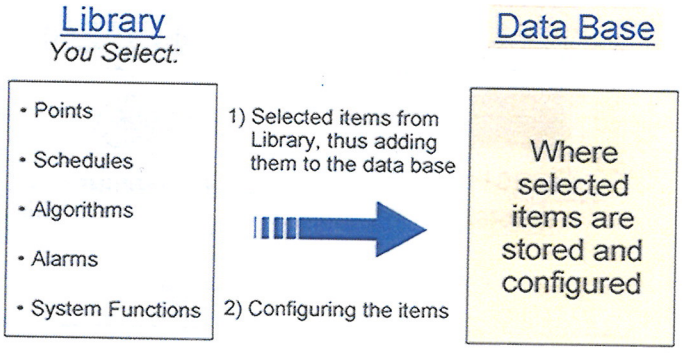


Figure 31

DDC Controller Software

With HVAC general purpose DDC controllers, the processing inside the controller is determined by selected algorithms, which are software programs designed for specific and related HVAC applications. Each algorithm is a pre-engineered group of processes that provides the user with the capability to control and monitor HVAC devices in a safe, energy-efficient manner.

An algorithm can consist of one or more HVAC control routines, schedules, input and output points, alarms, and system functions.

Figure 32 lists some of the algorithms available for general purpose DDC controllers.

- Cooling and Heating Control
- Space Temperature Comfort Zone
- Humidification and Dehumidification
- Mixed Air Damper Optimization
- VAV Fan Control
- VAV Supply and Return Fan Tracking
- Indoor Air Quality
- Generic PID Control
- Time Scheduling with/without Override
- Analog Temperature Control
- Discrete Interlock
- Staged Thermostat
- Proportional Thermostat
- Primary/Secondary Pump Control
- Staged Discrete Control
- Permissive Interlock
- Nighttime Free Cooling
- Morning Warm-up
- Adaptive Optimal Start/Stop
- Control Point Reset

Figure 32

Typical HVAC Control Algorithms

Control System Networks

In the stand-alone mode, general purpose DDC controllers are a very powerful way to ensure that comfort and energy management strategies are successfully employed at the unit control level. In many small building applications, this is sufficient.

When several controllers are connected together in a communications network, however, many additional benefits result. See Figure 33. This level of the control system network is referred to as the primary bus.

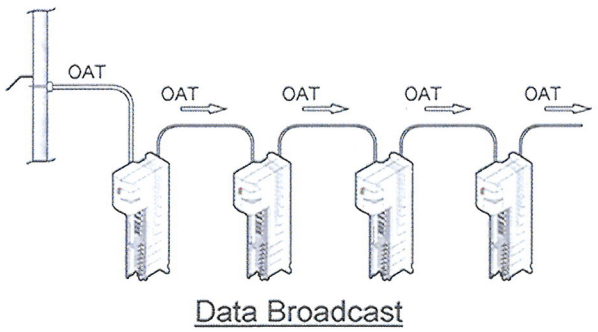


Figure 33

Primary Bus Broadcasting

The Primary Bus

The *primary bus* is the first level of a communication architecture where controllers can connect to each other and share data. Many control systems have a secondary bus which can isolate controller to controller communication, keeping the primary bus free to send important information to user interfaces, alarm printers, and other upper level components.

Two examples of networking benefits include:

- Information can be shared with another controller or broadcast to all controllers on the network. For example, many controllers in a building may need to know the outside air temperature (OAT) to run their control algorithms, but only one OAT sensor needs to be physically connected to a controller in the system. Others can "share" this sensor reading and use it when running their algorithms. This saves sensor and wiring expense as well as simplifying the systems.
- System coordination can be achieved by "linkages" between waterside systems (made up of chillers, boilers, pumps, valves, etc.) and airside systems (made up of air handlers, terminals, dampers, etc.). *Linkage* can best be described as the sharing of consolidated information and modes of operation between system components over a network. Consolidated information can include highest, lowest or average set point values, highest CO_2 sensor reading, valve positions, etc. Modes can include heating, cooling, morning warm-up, stand-by, unoccupied, etc. Linkages ensure, for example, that energy optimization at the chiller does not result in energy waste at the supply fans. Without such coordination, the water temperature may be reset to save chiller or boiler operating expense, but the increased air volume required to compensate may cost more in fan energy than what was saved at the chiller or boiler.

Although all system control functions are contained within individual controllers, the information the system can generate is most useful to maintenance and facility management personnel. With the use of a networked building computer, usually a PC with supervisory programs installed, it becomes easy to monitor and interact with the HVAC system as shown in Figure 34.

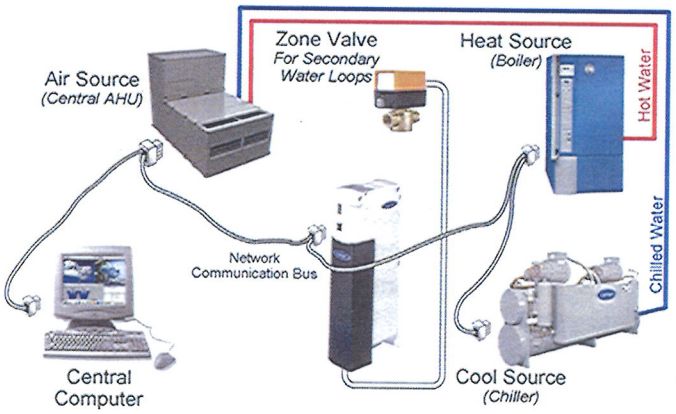


Figure 34

Networked Building Computer

A remote computer with appropriate supervisory software and a telephone modem will perform the following functions (Figure 35):

- Permit remote control, programming, and monitoring of any control point in any system on the network. This means that every control point can be adjusted remotely, from a control room in the same building, without interfering with the occupants or struggling to gain access to equipment.
- Provide maintenance and management information, such as:
  - Consumable reports, which show energy usage patterns
  - Runtime reports
  - Alarm history
  - Tenant billing
- Make remote communication with a stand-alone system or the systems on a network possible through the use of a modem. This includes automatic dial-out to on-call technicians for critical alarms or equipment failure situations. Remote networking permits monitoring, control, or programming of any point in any system on the network from any location with a phone line.

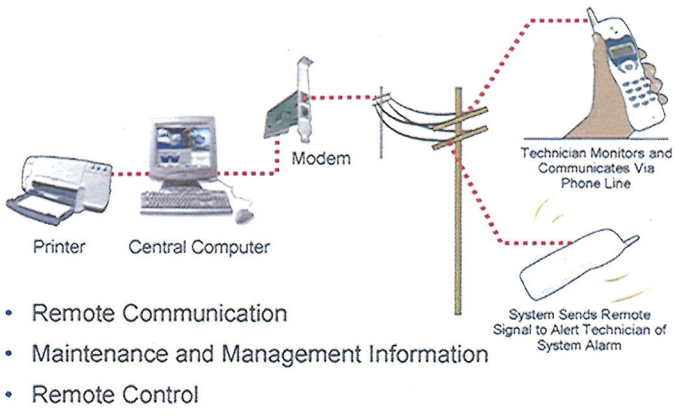


Figure 35

Remote Networking Benefits

Today's computer technology also affords the facility manager with dynamic and interactive high-resolution graphic representations of the HVAC system, making access to the needed information logical and timely. With multi-tasking capabilities, dedicated PCs are unnecessary, and the use of the graphical user interface format makes consistent and intuitive operation a reality.

High-Speed Networks

In addition to the primary bus, many control systems today use a high speed data network (10 megabit or higher). These networks are used to share information among multiple-user PCs, communicate with other building systems, or transmit data long distances. The most popular high speed network is Ethernet. The most popular transport mechanism is the Internet Protocol or IP.

High-Speed Networks

Using existing building Ethernet infrastructure and Internet Protocol offers the greatest advantage amongst network choices.

DDC systems take advantage of modern building infrastructure where an Ethernet network already exists. This allows several advantages:

- With protocol converters such as the CCN to Ethernet converter, wiring costs can be greatly reduced. A multi-building campus is a perfect example where it would be much more cost effective to utilize the Ethernet between buildings rather than digging a trench between them and running dedicated communication wiring for the controls.

- Any desktop or laptop computer can be a potential portal into the control system. Many control systems today have network-compatible versions of their human interface software and can utilize a standard web browser for access into the control system. This frees up the facility manager to work throughout the building or campus, knowing that the control system is as close as the nearest desktop computer.
- Interoperability with other building systems is typically done at this level. Most building systems usually have connectivity to Ethernet and IP, making it much easier to share information with the controls system.

Figure 36 illustrates a typical control system network.

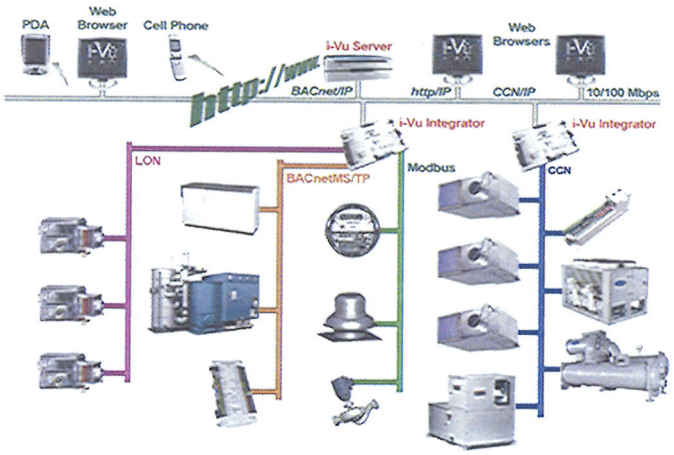


Figure 36

High-Speed Network

DDC Management Systems

At one time, the control of HVAC systems was simply called *ATC*, or *automatic temperature control*, since its primary function was temperature regulation of the conditioned space. As controls technology and hardware have progressed from electromechanical, pneumatic, electronic, and finally to DDC, the power, intelligence, and flexibility of the microprocessor has been tapped to provide a host of benefits and capabilities in addition to the primary task of temperature control. The use of DDC allows the employment of four key management systems as shown in Figure 37.

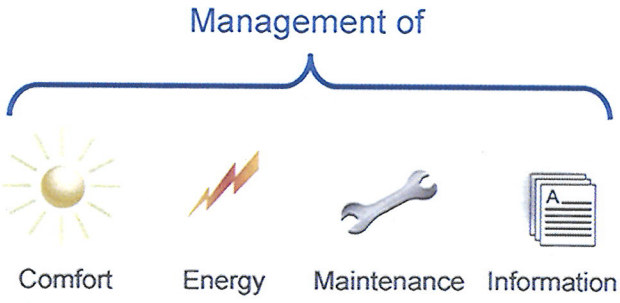


Figure 37

Four Key Management Systems

Comfort Management

Comfort management is still the main goal of DDC, but now temperature control of the conditioned space can be accomplished more precisely, with less hunting and drifting of the room temperature set point. In addition, functions such as humidity control, ventilation, filtering, and air volume or circulation control can be coordinated and more readily accomplished with DDC techniques.

Some comfort methods now possible with DDC are:

- Temperature set point control without offset via PI loops
- Precise and stable temperature set point control via PID loops (e.g., to 1/10° F accuracy)
- Pre-occupancy cool-down or warm-up
- Automatic system restart after power failure
- Demand controlled ventilation and air purification based on contaminant concentration

Energy Management

Energy management was the main focus of DDC as it developed in the late 1970s, a time in which energy supply limitations made the HVAC industry acutely aware of the need for energy conservation and operating cost control in air conditioning plants. Because of this awareness and focus, most microprocessor-based control devices were called ***EMS***, or ***energy management systems.*** Some were specialty controls for chillers, boilers, lighting, air terminals, and other HVAC components. Others were large monitoring and/or loadshed systems.

As technology improved and capabilities became more generalized, EMS gave way to such terms as *BMS (building management systems)*, *BAS* ***(building automation systems)***, and *FMS (facilities management systems).*

Some of the energy management and operating cost control methods which can be employed with DDC include:

- Time clock functions (turning equipment off or altering set points during unoccupied periods) which are flexible and sophisticated. Multiple schedules can be set on a daily and weekly basis, with holidays and vacation periods entered, and daylight savings time switchover done automatically.
- Start-up and setback routines that automatically reset their times based on a historical record of how long it took the system to achieve its set point in the previous days/weeks (adaptive optimal start/stop [AOSS]).
- Optimization routines which allow equipment to unload or shut off during periods of mild weather or diminished use, without compromising comfort conditions.
- Coordination of air distribution volume and temperature for energy effectiveness.
- Electrical demand programs which limit utility "ratchet" charges by reducing electrical load or shifting energy sources on a priority basis during periods of peak demand as shown in Figure 38.

Demand Limiting to Reduce Ratchet Charges

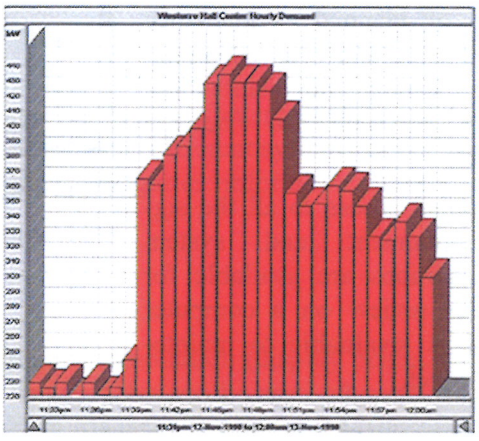


Figure 38

Energy Management

Maintenance Management

Maintenance management is a key feature of DDC. Since microprocessors inherently produce huge quantities of data, it is only natural to tap into this source for maintenance purposes. Initially, the limitation was in sorting all the data out. Today, DDC makes managing maintenance easier.

Alarm and alert reporting is shown in Figure 39. Out-of-range and failure conditions can generate immediate attention via local interface devices (LIDs), screen messages on central computers, or, with auto dial out features, can even initiate phone calls to on-call technicians. Alarm priority levels can be assigned so that non-critical alarm conditions will not generate nuisance calls. Time-stamped alarm history messages can be made available in the controller's memory, and printed on demand or automatically with a local or remote printer.

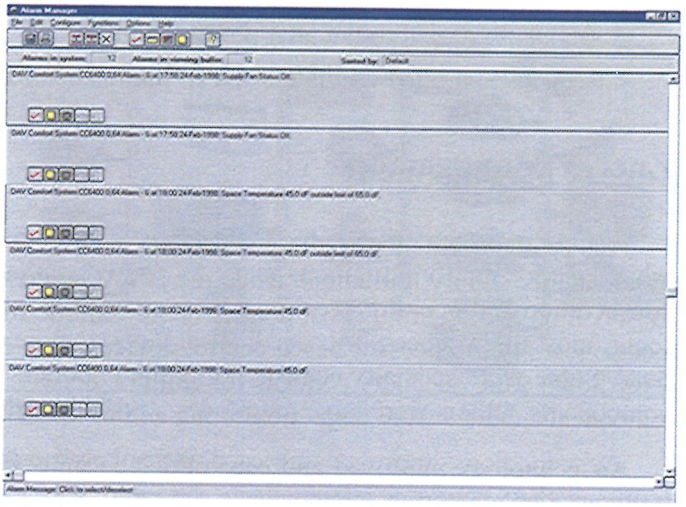


Figure 39

Maintenance Management – Alarm and Alert Reporting

Trending reports, as shown in Figure 40, can be made available which will allow the technician to review equipment operating conditions which occurred for a period of time prior to a failure.

Run time and operational reports can be generated which aid in the scheduling of planned maintenance events such as oil and filter changing, air system cleaning and disinfection, equipment overhaul, or bearing replacement.

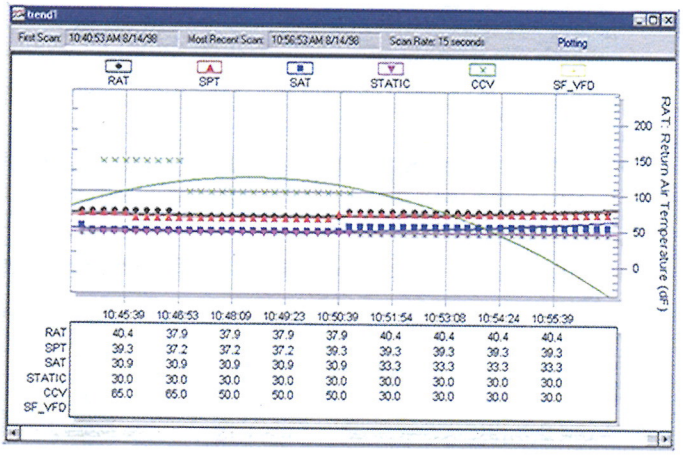


Figure 40

Maintenance Management – Trending Reports

Operational access to all the significant equipment and system running conditions are available for simultaneous review on a computer screen and is invaluable to maintenance personnel.

Information Management

From the viewpoint of the facility manager or owner, significant and timely information about the HVAC system is highly beneficial.

Some available tools are:

- Consumable reports, which look at energy usage of various pieces of equipment over time with an eye toward identifying equipment or application "energy hogs."
- Tenant billing programs which monitor usage patterns in a multi-tenant facility so that operational costs can be equitably allocated.
- User-friendly computer graphics (see Figure 41) which can display real-time operating information on easily accessible screens of anything from facility overview to the smallest element in the HVAC system.

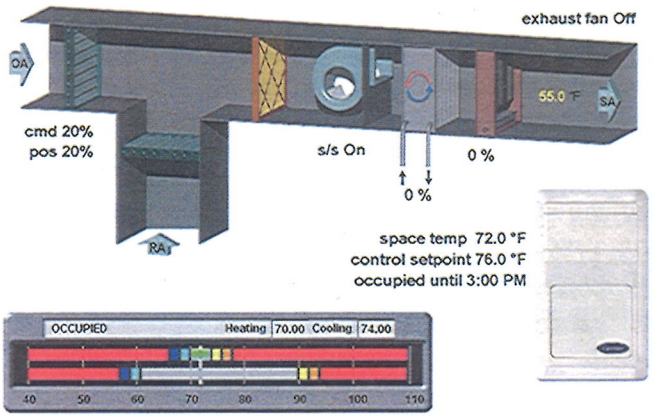


Figure 41

Information Management

Interoperability

Modern DDC controllers can do more than control HVAC equipment. With the advent of open communication protocols, it is now possible to integrate the HVAC DDC system with other building systems such as lighting, card access, and fire/life safety.

Levels of Interoperability

It is important to understand that there are several levels of interoperability and that, depending on the open protocol being used, the effort to integrate different systems can be large or small. Interoperability can be broken down into two major categories: information transfer and connectivity.

Information Transfer

Information transfer is defined as the sharing of information (display points, set points, and time schedules) with another HVAC controls vendor. This can be used when an owner needs to add new HVAC equipment to an existing Building Management System. Maybe a new chiller or rooftop has been purchased but the factory supplied controls are different than the existing

controls already in the facility. See Figure 42. There needs to be a way for the existing control system to get information from this new piece of equipment as well as control it. In years past, this was done by "overlaying" a controller from the existing controls vendor onto the new piece of equipment. In essence, the equipment would now have two controllers, one from the factory and one from the existing controls vendor. Now this task is done through open protocols. The equipment manufacturer and the controls vendor must first agree on one of the open protocols that are available. Then the equipment manufacturer supplies a protocol converter to the agreed to open protocol and the controls vendor incorporates the new equipment into the existing building management system.



Figure 42

Interoperability – Information Transfer

Connectivity

Connectivity takes information transfer to a higher level. Connectivity goes beyond simply integrating HVAC equipment to include any controllable items in the facility as shown in Figure 43. This could include:

- Lighting
- HVAC
- Security
- Fire/Life Safety

At the highest connectivity level, called the Enterprise Level of Integration, connectivity shares information and control decisions with systems such as:

- Utilities
- Finance
- Maintenance Management

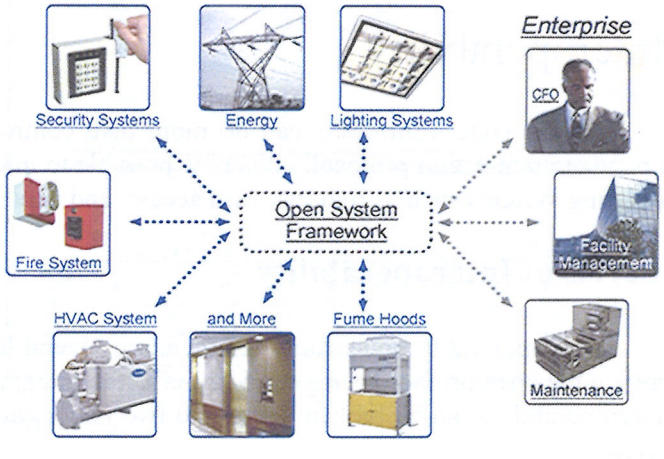


Figure 43

Interoperability – Connectivity

Controls Integration

Connectivity can result in energy savings, productivity increases, and even tenant retention/satisfaction.

What is gained by connecting the HVAC system to other building systems? There are many reasons, but the driving factor is usually cost savings. This savings can show up in energy savings, productivity increases, or intangibles such as tenant retention and satisfaction.

The following are some connectivity examples:

The building owner does not want to waste air conditioning or lights when employees are not in the building. A connectivity solution can send card access information to the HVAC and lighting control systems to turn on the lights and set the HVAC controls to occupied mode when an employee's card is scanned upon entering the building (see Figure 44).

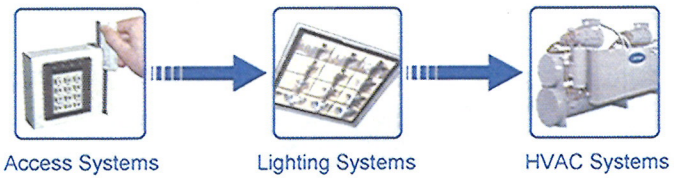


Figure 44

Connectivity Example – Occupancy Determination

The utility company serving a facility offers to provide a daily rate structure via the Internet (see Figure 45). This rate information is sent to the chiller plant through a connectivity open protocol standard. Depending on the cost of power, the chiller plant HVAC controllers decide the proper amount of demand limit for each chiller. This creates efficiency by matching the production of chilled water to the cost of electricity.

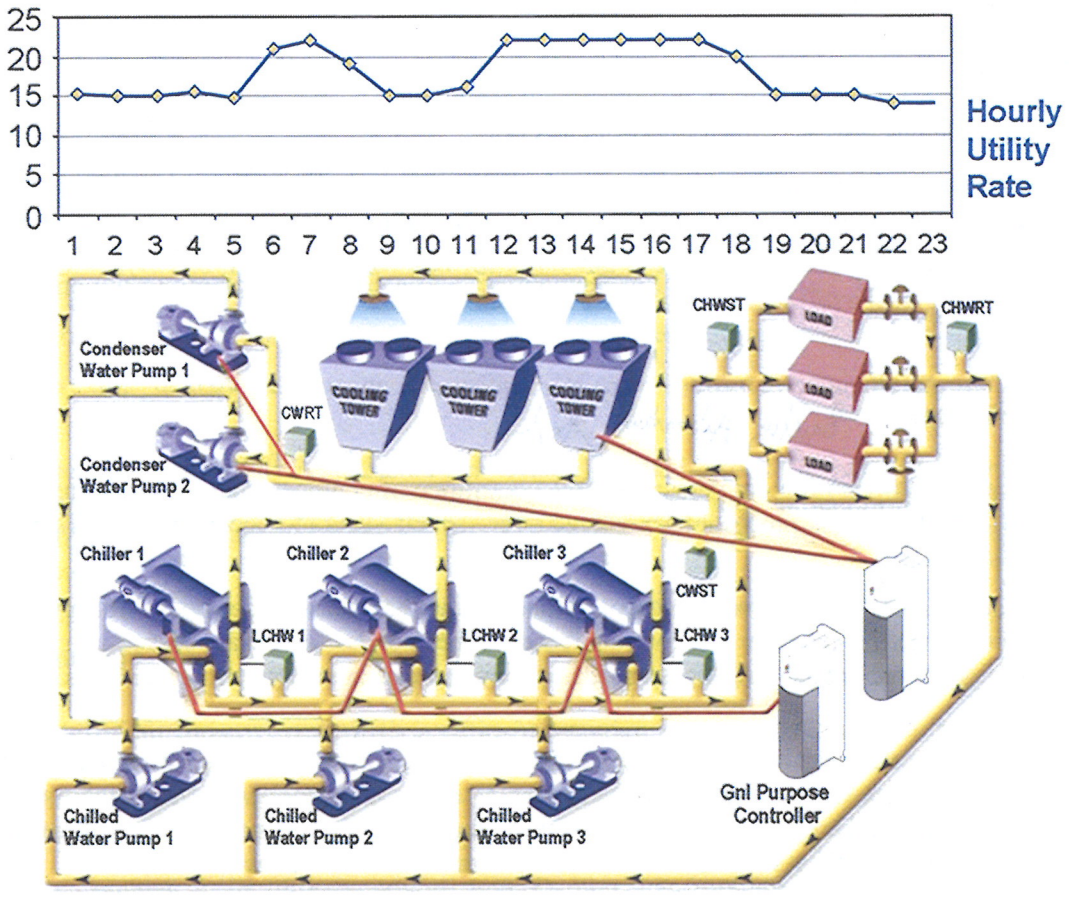


Figure 45

Connectivity Example – Interactive Demand Limiting

Open Protocols

Open protocols, as shown in Figure 46, are defined standards that allow different control systems from different manufacturers to communicate and share information. Different open protocols have various rules to try to ensure that good communication takes place. However, problems arise when manufacturers use a subset of a protocol, making it hard or impossible for other manufacturers to understand their controllers.

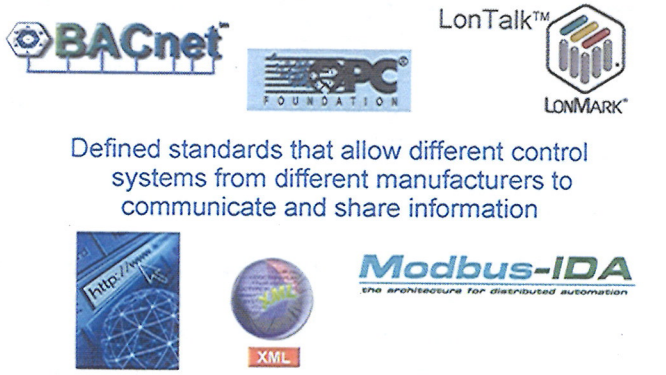


Figure 46

Open Protocols

Building owners have targeted open protocols as the way to provide controls in their facility without getting "locked in" to any specific vendor. As we examine the most popular open protocols, keep in mind that none are perfect. Just because two different manufacturers say they communicate via a certain protocol, only minimal information may be shared. Also, some protocols can work on different electrical media, such as BACnet for example. One manufacturer may talk BACnet over an Ethernet connection and another manufacturer may talk BACnet over a 3-wire communication bus (this is typically BACnet MSTP).

Following are the most popular open protocols to date. This list is not exhaustive and does not cover protocols outside of the building industry such as those used in automotive and factory floor industries. Note that there is no one protocol that has come to the forefront and would be considered the "best." Each protocol has supporters and each has detractors in the commercial HVAC industry.

BACnet Protocol

Building Automation Control

BACnet is an open protocol developed by a committee of engineers and manufacturers affiliated with ASHRAE. This protocol has evolved over several years to become a very flexible and powerful standard.

BACnet is a defined software protocol, which means that the standard does not regulate the electrical transport mechanism of communication. There are no hardware restrictions. BACnet protocol is only concerned with the standards of communication where two controllers can share data.

BACnet is a relatively complex standard. The standard defines protocol implementation conformance statements (PICS) that describe different levels of compliance. Manufacturers have implemented various levels of compliance, so that, even though two manufacturers can claim to be BACnet compliant, they still may not be able to communicate with each other.

If a vendor states their product is native BACnet, they are using the BACnet protocol in lieu of a proprietary protocol on their LAN.

1) Proprietary exclusive. 2) Open open to public domain & sucked any vendor 3) Standard. formalized by Gov. eg BACnet

Modbus Protocol

Modbus is a control system protocol standard introduced by Modicon in 1979. The Modbus protocol then became a trademark of Schneider Electric. Schneider Electric has made the protocol specification and its implementation available for free and submitted the Modbus TCP/IP protocol specification to the Internet Engineering Task Force (IETF) to make Modbus TCP/IP the Industrial Internet protocol owned by the Industrial Internet community.

The Modbus standard defines both hardware and software standards. Currently there is a Modbus standard that communicates serially over EIA-RS232 and EIA-RS485 connectors (Electrical Industry of America defined communication electrical connections). This standard is called Modbus RTU (Remote Terminal Unit). Another version of Modbus communicates over an Ethernet connection. This standard is called Modbus TCP (Transmission Control Protocol).

Modbus is popular in the industrial, electrical equipment, metering, and power generation markets. Modbus is generally used as an intermediate protocol between two proprietary systems. Modbus is characterized by its use of registers (a holding place in computer memory) to store raw data values and coils to represent discrete states (the coil can only be on or off). This means, for example, when a temperature sensor reads 75.0° F, this may be transmitted from one system to another as register 1 = 0 and register 2 = 75. It is up to the application reading the data to know that this is a temperature and that the units are in degrees Fahrenheit, and that the data is being sent in a low byte/high byte format.

LON Protocol

The Echelon Corporation has created an open protocol that uses a standard processor and a set of standard transceivers, which allows components from different manufacturers to co-exist on the same LAN. The protocol is licensed for a fee and is called LonTalk. A unique chip is required for any device that uses LON. Standard network variable formats have been established to allow the transfer of data from one device to another regardless of origin.

Because this standard requires the use of the LON chip, it ensures compatibility on the same wire.

LonMark Interoperability Association has created standard profiles for standard applications such as a rooftop controller or a chiller controller. Fully programmable controllers may or may not use profiles and or standard network variables, making it a challenge to share data with this type of device.

OPC Protocol

OPC (OLE for process control) is a series of standard specifications created by Microsoft. The OPC protocol follows the progression of the earlier DDE (Dynamic Data Exchange) standard but is much less processor intensive. OPC uses Microsoft's OLE (Object Linking and Embedding) technology.

OPC is popular in the process control industry and, like Modbus protocol, it is sometimes used as an intermediate protocol between two proprietary systems.

OPC uses the architecture of servers (serving up data) and clients (requesting data) to implement the protocol. While the OPC standard does not define the physical transport mechanism of the protocol, it is almost exclusively implemented over an Ethernet connection.

OPC is found mainly in factory process machinery. Since OPC is a Microsoft standard, it will typically only be found on devices that can run a Microsoft Operating System such as Windows XP.

http Protocol

Hypertext transfer protocol (http) is the underlying protocol used by the World Wide Web. http defines how messages are formatted and transmitted, and what actions Web servers and browsers and network area controllers should take in response to various commands.

This standard is published, updated, and maintained by The World Wide Web Consortium (*W3C*). Using TCP/IP as the transport of the information over the internet, http presents the data to the end user through a web browser.

Control systems can take advantage of this well defined protocol to share data with end users as well as other controllers. Since this standard goes well beyond the HVAC industry, control systems that implement it can share data with other non-HVAC systems such as energy companies, corporate financial data, and maintenance management systems.

XML Protocol

In the same way that html describes information for a web browser, eXtensible Markup Language (XML) is a relatively new protocol that describes information transferred from one machine to another (M2M). XML describes the meaning of data in a manner that two devices on a TCP/IP network can understand. XML holds the best promise of using the Internet and other TCP/IP networks for building controls. XML is also the technology being used by many other industries to carry its data across TCP/IP networks such as the Internet.

Before XML can be useful in carrying HVAC and other building relevant data, the building systems industry must first agree on the description and meaning of the data that is being carried using XML. Without such agreement, XML will be used by different companies in different 'proprietary' manners with little or no possibility for multi-vendor systems to work together. Efforts in this area are currently underway through such industry forums as the BuilConn Forum, the Continental Automated Buildings Association (CABA), and the Open Building Information eXchange (oBIX). Along with the participation of engineers from the LonWorks and BACnet communities, these groups are driven by a need to define the use of XML in buildings.

Strategies for Interoperability

The confusing array of open protocols and differing standards can make it very challenging for a building owner or consulting engineer to decide on the correct approach. The best way to look at open protocols is to determine the end user's needs and wants.

If a single piece of equipment is being added to a project, all that may be required is to transfer the information from the new piece of equipment to an existing building management system by the most economical means possible. This would mean specifying that any new equipment must have the ability to communicate with the existing control system.

Sometimes providing an open protocol solution is overkill when the end user simply wants to be able to view and control their building through a standard web browser. Many manufacturers

provide a web based connection to their control systems and this may be the lowest cost solution. In that way, the end user will be able to see and control multiple building systems on one screen.

If the building owner is looking for a full connectivity solution in order to control and bring in information from several different systems, there will be a need to weigh the pros and cons of each open protocol. Their goals may include connecting lights, HVAC, security, factory floor equipment, and integrating with enterprise applications such as energy management or maintenance management systems. Many times it ends up that one protocol is not sufficient to meet all requirements and it becomes necessary to specify the functional requirements of the connected system rather than the protocol being used. For example, many HVAC controls are BACnet compatible, but most factory floor controllers use Modbus. Rather than specify that a BACnet system needs to communicate with a Modbus system, it would be better to specify that the factory floor controllers must share specific point data with the HVAC controllers as part of an energy saving control algorithm. Table 1 lists advantages and disadvantages of the open protocols that have just been discussed.

Table 1
Open Protocol Comparison

Protocol	Advantages	Disadvantages
BACnet	Designed and supported by ASHRAE Very flexible No licenses or fees	Complex set of standards Manufacturers are not held to strict implementation standards Communications media (electrical communication bus) can vary from one vendor to the next
Modbus	Widely accepted in industrial as well as HVAC marketplace Very simple protocol using registers and coils Works well as an intermediary protocol to translate 2 different protocols	Does not support text Does not support alarms Requires well defined documentation for each vendor to understand the raw data stored in the registers
LonTalk	Strict wiring standard allows for same wire communication between different manufacturers Standard profiles provide definitions of minimum functionality Good market acceptance in all building control areas, not just HVAC	Requires the use of Echelon's Neuron chip for communication Requires licensing of the technology Works well in small applications, but because every device talks to each other, a lot of devices on the bus can bog down communication
OPC	Works well as an intermediary protocol between two protocols Uses Microsoft's standards Well supported in the Process Control industry	Subject to change when Microsoft updates to a newer technology Requires a PC or some type of controller that uses a Microsoft operating system Can be limited in the amount of points and data that can be shared
http	A well-defined standard for Web based communication Anyone familiar with Web programming can set up communications and share data	Designed for displaying content in a Web browser – adds a lot of overhead to the communication just for displaying data Manufacturers have not created standards for sharing data
XML	Very concise structure allows for data to be shared efficiently Designed for Machine to Machine communication	No standards have emerged yet, still in the works Even though it's based on an open standard, manufacturers can opt to create a proprietary communication protocol

Specifying DDC Control Systems

Specifying a DDC control system is usually an iterative process which is typically done at the same time as selecting the HVAC equipment for the project.

Specification Process

For comfort conditioning, the process starts with knowledge of how the space will be used and the needs of the occupants. Sometimes this is just temperature and ventilation control. Sometimes this includes humidity control, building pressurization control, zoning, and many other factors.

After initial HVAC selections and high level control design, it is best to consult with the HVAC and controls vendor to verify that systems exist that can meet the design requirements. Every control system has logical limits in capacity and capabilities. These limits can show up in the number of zones the control system can have on one HVAC unit. The limits can also show up in the level of sensitivity or controllability available for selected price points or in the total amount of controllers that can reside on a communication bus. This may require the engineer to go back to the drawing board to change the number of zones, which in turn changes the sizes of the HVAC units.

Specifications

Controls specifications have typically shown up somewhere in the section 15900 series of the division 15 mechanical specifications (see Figure 47). Sometimes control specifications show up in other parts of the mechanical specification and sometimes they have a division all to themselves, typically division 17. With the 2004 version of the CSI MasterFormat™ (Construction Specification Institute), control systems have their own division - Division 25 Integrated Automation.

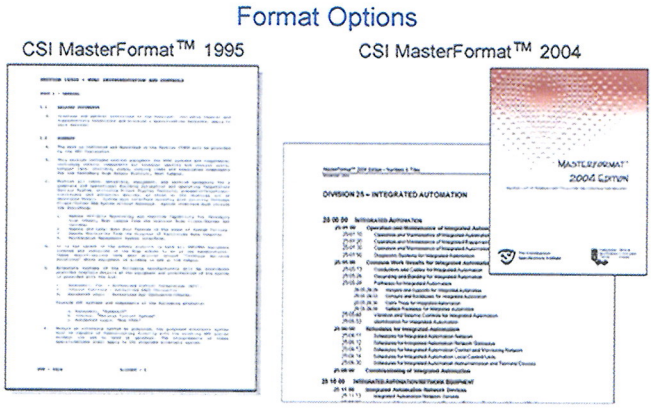


Figure 47

DDC Specification

While there are ASHRAE guidelines for controls specifications, most controls specifications have evolved to adopt some form of the CSI SectionFormat™ and PageFormat™ set of components. Some are job specific and some are boilerplate. These sections are:

- Part 1 - General
- Part 2 - Products
- Part 3 - Execution (including the Sequences of Operation)

Along with the specification text, the project mechanical drawings should include control information such as sensor locations, thermostat locations, point I/O lists, control diagrams, power requirements and any other information that would clarify the controls requirements for the project.

Part 1 - General

The general conditions part of the specification defines the scope of work for the controls project, along with general administrative and technical requirements of the section. A key item in this part of the specification is the Related Work section. This must be coordinated with all other engineers working on the project to make sure all trades know their scope, that no work is left out, and that work is not duplicated in different trades. The more details included in this section and on the project drawings will equate to a better bid price and less extras on the project.

This section also defines how the controls vendor is to coordinate with other trades, how controls vendors are qualified to bid and install the work, and how they are to submit shop drawings for approval.

Part 2 - Products

This section details the qualifications for products used in the control system. Everything from the DDC controllers to the space temperature sensors are defined by their characteristic specifications. While some of this can be boilerplate information, care must be taken to verify that a device specified will actually work with the type of DDC controllers specified. Instructions should be given on whether substitutes for certain materials are acceptable and the procedure for securing approvals.

The Products section can become very vendor-specific. Sometimes this is necessary to ensure that certain functions are provided. It is important to check that vendor-specific data from different controls manufacturers is not mixed into the same specification. This can create a situation where no one can bid the specification. For example, several controls vendors may provide products that can implement a common ventilation control strategy called demand controlled ventilation (DCV). If the products section lists a CO_2 sensor (necessary for DCV) that communicates via an open protocol such as LonTalk™, but the project is being designed using BACnet, there may be no BACnet controls vendors that have the ability to communicate LonTalk™ to a CO_2 sensor. It is best to ask several controls vendors to review the specification before it is released to make sure they can bid the work.

Part 3 - Execution

The execution section provides the direction to the controls contractor on how the project will be installed, commissioned, and turned over to the owner. A key area of this section is where owner training is specified. This is usually stated as a certain amount of classroom training and/or a certain amount of on-site training. The amount of training hours specified here should be influenced by several factors:

- The type of control system being installed. If this is a small VVT system with thermostats as the human interface, 8 hours of training would be more than enough. If this is a multi-building facility, with a chiller plant and hundreds of HVAC control points, 40 hours or more may be necessary.
- The owner's experience with the system being installed. If the owner already has a similar system from the same controls vendor, all that may be required is an on-site training session to familiarize the owner with the new installation.
- If this is a multi-building bid and the same amount of training shows up in each building's specification, the controls contractor may unnecessarily specify too much training for the overall project.

This section will also address commissioning of the system. It must be determined how the controls contractor will prove that they have provided a complete and working system. This could consist of a spot check of points, a system level checkout, or a point-to-point checkout.

Sequences of Operation

Sequences of operation are, by far, the hardest part of the specification for the designer to write. To create a sequence of operation for a system in the building, the designer needs to understand the end user requirements, the limitations of the HVAC system, and the limitations of the control system. Writing sequences that multiple vendors can bid can sometimes be an art. This may take several iterations, confirming with several target controls vendors that the stated sequences can be accomplished with their control system. Several companies can provide help in this situation by having a library of sequences that match most typical system configurations. This greatly reduces the time spent on developing sequences of operation.

Sequences of operation are usually written on a system by system basis, so that it becomes obvious to the controls vendor how all of the controls within a system will interact with each other. A VAV system is a prime example of how a system sequence requires interaction between different HVAC components. The controller on the air handler must receive certain information (such as occupancy status, ventilation requirements, etc.) from the terminal boxes. The terminal boxes need information from the air handler (the mode of the unit, the temperature coming down the duct, etc.). A typical sequence of operation for a VAV air handler with terminal boxes is shown in Appendix A.

System Diagrams

System control diagrams are schematic drawings of the configurations of each type of HVAC unit or system and the points required for each system. These diagrams are often overlooked in bid documents but can prove invaluable in securing a valid controls bid price. Without them, controls vendors have to guess the designer's intentions on the control of some systems. For example, if the designer specified that there should be a fan status point, one controls vendor could interpret this as requiring a separate input point that monitors the actual status of the fan while another controls vendor could interpret this as being the commanded state to the fan start/stop control point from their DDC controller.

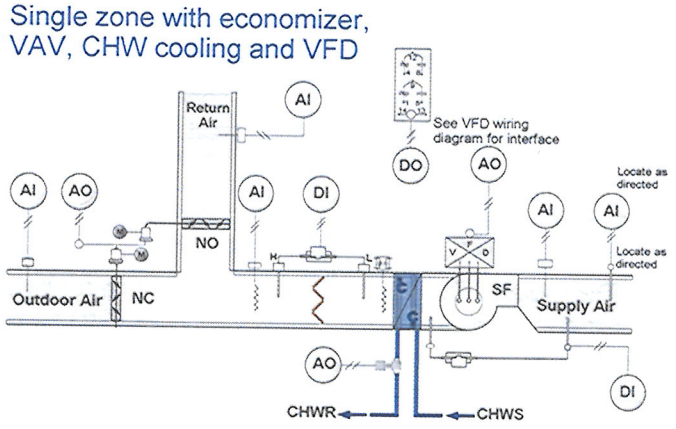


Figure 48

System Diagram

Figure 48 shows a system control diagram for a VAV air handler system. Note that the points are shown based upon their type (AI, AO, DI, DO). This is important for the controls vendor when bidding the project. As a rule, analog sensors are much more expensive than discrete sensors. If the designer calls for an AI filter differential pressure sensor rather than the more typical

and less costly DI differential pressure switch, the resulting bid price must reflect this higher cost in materials.

Points List

The points list complements the system diagrams by summarizing all the required points for each system and defining the functions each point serves. Functions such as alarm limits, graphical display criteria, and report criteria are selected for each point.

This is another item that is often overlooked in bid documents but is extremely important. Without a points list, controls vendors may estimate different functions for each point or may not provide the necessary points for each system. Figure 49 shows a typical points list for a packaged heating and cooling rooftop unit.

| Job Name: | Input/Output Point List Summary | | |

Installation

Because DDC systems have such widely distributed components, such as general purpose controllers, it is important that they are designed to be easily installed in a variety of field situations with such features as edge or flush-mounting capabilities, wiring harness pre-wiring, easy-access doors on the modules, and use of commonly available control transformers for power. See Figure 50. With a detailed wire list and installation instructions available, the installing contractor should have no trouble completing the job expediently. It is the design engineer's responsibility to require sufficient detail in the controls submittal to ensure that the installation goes smoothly and that the final documents (As-Builts) that are turned over to the owner at the end of the project include all details on how the project was installed. For example, the wire list should detail terminal connections and the wire type and location for each sensor and actuator. Communications and power connections, as well as interconnection between control modules should also be specified, if applicable. Once final-wired, the installation should be checked out to confirm proper connections and the operation of each element (module, sensors, actuators, etc.), in accordance with instructions.

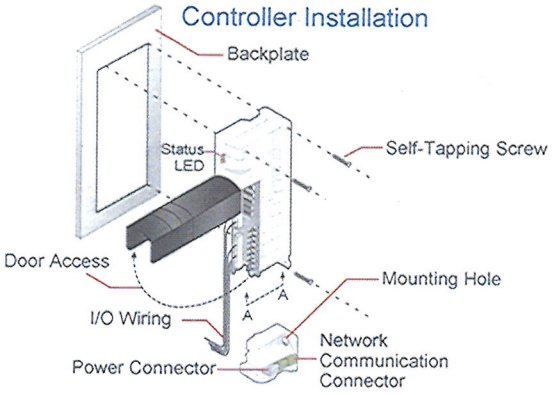


Figure 50

DDC System Installation

Start-Up

The final stage is for the controls technician to configure the controller in accordance with the configuration sheets. Algorithms and schedules are assigned and values selected for decisions and variables in the configuration tables which accompany each algorithm. Once these are entered, operations are confirmed and the system is ready for commissioning and then turnover to the owner/user.

Commissioning (Cx)

More and more building controls projects today are taking an extra step in completion. A commissioning agent or third-party contractor is hired to verify that all building systems, controls included, have been installed and are working per the specifications (see Figure 51). The need for a commissioning agent has risen because of the level of complexity of today's control systems and the fact that the controls are no longer stand-alone devices. Controls must now work and communicate with other systems.

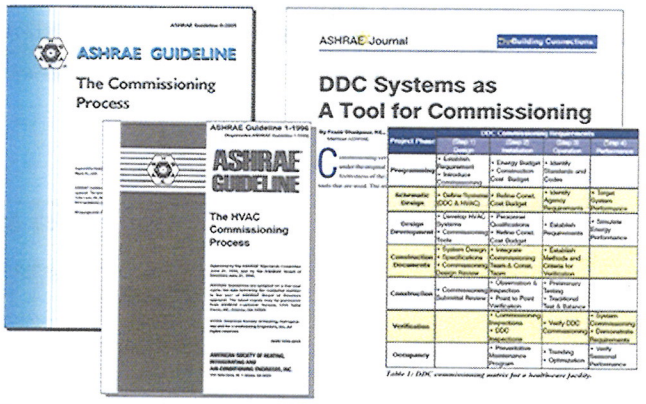


Figure 51

Commissioning (Cx)

Commissioning the control system on a project is a multi-step process. The process starts with checking all of the sensors and end devices with a volt-ohm meter for valid readings. Then, the control panels are energized and verified. Each end device is checked for calibration and proper operation through a user interface at the control panel or at a central computer. A punch list is made of any items that either could not be checked due to installation issues or that failed the calibration or operational test. Finally, after all control points are working correctly, the sequence of operation is verified for each system.

Verifying the sequence of operation usually requires developing a test plan which will mimic all modes of the equipment (occupied, unoccupied, fire shutdown, etc). The test plan must be coordinated with other trades, the general contractor and with the building occupants. Typically, commissioning comes at the worst possible time in building construction: when all trades are trying to complete their work. The general contractor wants to get the certificate of occupancy and the building owner wants to take possession of the building. This "time crunch" at the end of a project needs to be addressed by the designer in the execution portion of the specification.

Since commissioning work cannot be completed until the rest of the building is completed, provisions need to be made on how this will be dealt with. Some suggested means include exempting the controls contractor and commissioning agent from liquidated damages for being completed by the end of the project schedule, defining substantial completion of the controls system to exclude commissioning, or providing a commissioning schedule based upon the actual project completion rather that the scheduled project completion.

Commissioning has become a valuable tool for both design engineers and building owners. Not only will they get assurance that the controls system will operate as specified, they also will now have the groundwork for maintaining the facility. This approach to maintaining the integrity of the controls system is called continuous commissioning. Continuous commissioning helps the building owner maintain a well operating building by comparing current operating conditions to the baseline conditions established when the building was new. For example, if energy consumption starts to rise for the building, the facility manager can compare coil temperature readings, valve positions, and chilled water plant temperatures to see if they have changed from the baseline. This could point to unauthorized changes in set points, dirty coils, or malfunctioning equipment.

Summary

DDC controls have become easier to use, yet more complex. This paradox is created by the fact that owners want the simplicity of using a web browser to access their system from anywhere, yet they do not want to be locked into any specific vendor, making interoperability a challenge for today's controls manufacturers. Both general purpose and application specific controllers have evolved to where many can communicate with other building controls systems such as lighting, security, and fire/life safety. Specifying control systems and sequences within a building requires a good working knowledge of controls and systems intended functionality. Most specifying engineers rely on control specialists for guidance in laying out large controls projects.

Work Session

1. True or False? General purpose controllers usually come factory-mounted on specific pieces of equipment. _____

2. General purpose controllers are commonly applied to which of the following equipment or situation? (list all that apply.) _____

   a. Central Station Air Handlers
   b. Package Rooftop Units
   c. Cooling Towers
   d. Retrofit Applications, Including Systems Integration
   e. Unit Ventilators

3. Which of the following describes the function of an algorithm within a control system? (list all that apply.) _____

   a. An algorithm solves recurrent mathematical computations.
   b. Each control loop contains an algorithm that takes the input error signal and computes an output value used to adjust the controlled device.
   c. A library of algorithms is used by the controller to take input data and properly compute output values for controlled devices to implement control strategies.

4. True or False? Algorithms are used in all control system types. _____

5. Channel signals are either discrete or analog. Explain the difference between the two and name the classifications used in a control system.

   _____

   _____

   _____

   _____

   _____

6. Temperature sensors are the most common AI used in an HVAC system. Name 2 or 3 other common parameters which could be monitored by the DDC system.

   _____

   _____

   _____

7. Many different control actions and strategies exist, but from the following list, which three are the most commonly used in DDC? (list all that apply.) _____

    a. Two-position control
    b. Timed two-position
    c. Fast control
    d. Floating-point control
    e. Proportional control
    f. Integral control
    g. Proportional + integral control
    h. Proportional + integral + derivative control
    i. Derivative control

8. What is the primary function of a DDC network? List the two primary benefits of that networking.

    Function: _____
    Benefit: _____
    Benefit: _____

9. Name the four management methods available with DDC-networked controls, and briefly state their primary functions:

    _____ _____
    _____ _____
    _____ _____
    _____ _____

10. Name the two elements of interoperability.

    _____ _____

11. Name three types of information that might be shared on a networked control system.

    _____ _____ _____

12. List four building systems that might be interconnected by a networked control system.

    _____ _____ _____
    _____

13. What are three open protocols that can provide control systems interoperability?

    _____ _____ _____

14. True or False? Specifying a DDC control system should not be done until after all the equipment selections have been finalized. _____

15. For comfort conditioning, control functioning is often limited to just temperature and ventilation control. Name three other areas that a networked DDC control system could be expected to provide functionality.

    _____ _____ _____

Work Session Answers

1. False. That is the definition of a Product Integrated Control (PIC). General purpose controllers are field-installed microprocessor-based modules or devices (FIDs) that also include I/O terminals and communications ports. They are adaptable to a wide variety of control sequence requirements for all types of HVAC equipment, and system integration needs.
2. a., c., d.
3. a., b., c.
4. True. An algorithm is a mathematical procedure that solves recurrent computations. They are used for all control actions and control types.
5. Discrete, meaning discontinuous or individually distinct, indicates that there are only two states, or conditions that the signal can be in, open or closed, on or off, enabled or disabled. Inputs are classified as discrete inputs and outputs as discrete outputs.

   Analog, meaning continuously variable and measurable, indicates that there are theoretically an infinite number of states, or conditions that the signal can be in. Inputs are classified as analog inputs and outputs as analog outputs.
6. relative humidity, airflow, waterflow, pressure (air or water), current, air quality
7. e., f., i. (actions) or e, g, h (strategies)
8. Function: Communication between general purpose controllers (FIDs) and integrated controllers (PIC)

   Benefit: Information can be shared with another controller or broadcast to all controllers on the network.

   Benefit: System coordination between waterside and airside components. These linkages allow sharing of consolidated information and modes of operation between system components over a network.
9. Comfort Management: traditional HVAC systems control of temperature, and relative humidity, along with schedule-based reset of set points.

   Energy Management: this function birthed DDC control in the 1970's during the Arab oil embargo energy crisis. Energy usage by HVAC systems is minimized through load-following scheduling of both on-off functions and set points, along with equipment optimization routines, airflow and waterflow load tracking, and demand limiting to match energy tariffs.

   Maintenance Management: covers the gamut of operational-oriented activities like alerts and alarms, runtime totalizing, and data point trending, along with operational access to all significant equipment and system running conditions.

   Information Management: this area really helps the facility manager or owner by presenting information like consumable reports to identify "energy hogs", prepare tenant billing, and real time graphics to assist in trouble

10. information transfer and connectivity
11. display points, set points, time schedules, alarm conditions, trending data
12. lighting, HVAC, security, fire/life safety, utilities, finance, maintenance management
13. BACnet, Modbus, LonTalk, OPC, http, XML
14. False. Specifying a DDC control system is usually an iterative process which is typically done at the same time as selecting the HVAC equipment for the project.
15. zoning, building pressurization, energy demand limiting, smoke control, building security – hazmat response, occupancy initiated sequences

References

ASHRAE Handbook, 2005 Fundamentals. Chapter 15, Fundamentals of Control

Appendix A – Typical Guide Specification Sequences of Operation

The following sequence of operation is typical for a VAV air handler with terminal boxes:

A. AHU1 System Description:
The single duct VAV air terminal system, with modulating hot water heat, shall consist of a central VAV air source (rooftop unit or air handler), one VAV air terminal per zone, and a network communication bus that allows the air terminals and air source to communicate with each other.

B. Linkage
The VAV system shall utilize Linkage software to "link" the air terminals with their source of air to form a coordinated whole system. Linkage shall allow the air source to respond to changing conditions in the zones, and likewise allow the air terminals to respond to changes in the air source's mode of operation.

1. Master Zone Controller (ZC) Information to Air Source
   The "Linkage Master" ZC shall poll all the ZCs in a VAV system and "link" them all together into a single virtual load to the air source. In creating this virtual load, the "Linkage Master" ZC shall provide the air source with the following information about the VAV system:
   a. Weighted average temperature of all zones in the VAV system
   b. Weighted average occupied temperature of all occupied zones
   c. Weighted average of all zone set points (heat and cool) – (occupied and unoccupied)
   d. Earliest zone occupied mode and last zone unoccupied mode

   The information provided by the Master ZC to the air source shall be "weighted" proportionally by the maximum operating CFM of each control zone in the VAV system in order to provide larger zones more influence in what the air source will provide.

2. Air Source Information to Master Zone Controller
   The "Linkage Master" ZC shall poll the air source and read the supply air temperature and air source operating mode. Air source operating modes shall include:
   a. Off
   b. Morning Warm-up
   c. Cooling
   d. Heating
   e. Night Time Free Cooling
   f. Pressurization
   g. Evacuation
   h. Operator Initiated Start Time (Biased or Timed override)

C. Terminal Occupancy Schedule
Each Zone Controller (ZC) shall have its own Occupancy Schedule. This schedule shall be user configurable to show when selected days of the week will become occupied, and what to do on holidays. Each individual zone occupancy schedule shall also be configurable to respond to a timed override (adjustable from 1 minute to 24 hours) initiated by a pushbutton on the zone's room sensor.

Air terminal controllers shall have the capability of being established as the "Global" Occupancy schedule master or as a schedule slave. As such, other ZC occupancy schedules shall change automatically when the "Global" occupancy schedule master is changed.

Appendix A – Typical Guide Specification Sequences of Operation (cont)

D. Zone Set Point Schedule

Each ZC shall contain its own zone adjustable set point schedule consisting of Occupied High (72° F) and Low (68° F) values as well as Unoccupied High (85° F) and Low (65° F) values. The high set point shall be used for cooling and the low set point shall be used for heating. The cooling set point must always be at least 1° F higher than the heating set point and the software will ensure that it is done. In addition the room sensor slide-bar set point adjustment shall be configurable in the ZC to an offset value – adjustable from 0 to 15° F.

Each ZC shall have the capability of being established as the "Global" set point schedule master or as a schedule slave. Other ZC set point schedules shall be changed automatically when the "Global" set point schedule master is changed. Up to sixteen "Global" set points shall be available on each bus.

E. Air Terminal Operating Mode

1. Linkage Operation

   The air terminals, through Linkage, shall use the air source operating mode along with the zone needs to establish their individual operating mode and to determine which adjustable primary air minimum and maximum CFM settings to use.

   The air source start time bias shall be used by each ZC to adjust its occupancy schedule. If the operator forces the central time schedule into the occupied mode, all air terminals operating on that time schedule shall follow. Also, the ZC shall use the air source supply air temperature, with information from its own sensors, to calculate the cooling and heating Btuh consumed by each zone.

2. Central Unit in Cooling

   With the central source of air in the cooling mode, the Zone Controller shall modulate the damper airflow (CFM) between configurable minimum and maximum CFM limits to maintain the zone high set point. The damper will throttle down to the minimum cooling CFM setting – assuring minimum ventilation needs of the zone. If the zone requires heat, the damper will remain at the configurable minimum cooling or reheat CFM (whichever is greatest). The ZC shall then modulate the hot water valve to maintain the zone heating set point.

3. Central Unit In Heating

   With the ZC configured for VAV heating, and the central air source in the heating mode, the ZC shall modulate the damper airflow (CFM) between the minimum and maximum heating CFM limits to maintain the zone low set point. The damper will throttle down to the minimum heating CFM setting – assuring downstream diffuser heating performance is maintained.

   If the central units supply air temperature is not warm enough to satisfy the space heating needs, the ZC shall modulate the hot water valve to maintain the zone heating set point.

   Should the terminals not be configured to do VAV heating, with the central unit in the heating mode, all VAV terminal types shall set their dampers to the minimum heating CFM.

4. Dehumidification Control

   The ZC shall be capable of either dehumidification control or Demand Controlled Ventilation control – not both simultaneously. During dehumidification, the ZC will increase the drier primary airflow up to a maximum %RH CFM (adjustable) in order to prevent the space relative humidity from exceeding the maximum relative humidity set point (adjustable) during occupied periods when:

   a. The air terminal has been configured to enable dehumidification.
   b. A space relative humidity sensor has been wired to the ZC.
   c. If the increase in primary airflow causes the space to fall below the heating set point, the controller will suspend dehumidification, and modulate the hot water reheat to bring the space back to the heating set point.

5. Demand Controlled Ventilation
The ZC will increase the primary airflow up to a maximum IAQ CFM (adjustable) in order to prevent the space CO_2 level from exceeding the maximum CO_2 set point during occupied periods when:
   a. The software has been configured to enable IAQ control.
   b. The air source outside air damper is actively providing ventilation.
   c. A space CO_2 sensor has been wired to the ZC.

   The ZC in conjunction with the air source shall fulfill the requirements of ASHRAE standard 62-1999 "Ventilation for Acceptable Indoor Air Quality"
   If the increase in primary airflow causes the space to fall below the heating set point, the controller will suspend IAQ control, and modulate the hot water reheat to bring the space back to the heating set point.

6. Morning Warm-up
The "Linkage Master" ZC shall scan all zones and transmit the earliest occupied zone to the air source controller through "Linkage." Once per day the air source controller shall initiate morning warm-up – using its source of heat to bring the VAV system zones up to temperature prior to occupancy. When the central air source goes into morning warm-up, the "Linkage Master" ZC shall alert all zones scheduled for occupancy that day.

   The occupied scheduled air terminals shall open their dampers to their maximum heating CFM setting (adjustable) until the zone reaches the configured morning warm-up set point. Then, the air terminals shall close their dampers to their minimum heating CFM setting (adjustable).

7. Night Time Free Cooling
Between 3 AM and 7 AM in the morning, the air source controller shall initiate the NightTime Free Cooling Routine (NTFC) if conditions are right. When initiated, The Master ZC shall be alerted through "Linkage," and the Master ZC then will alert all other ZCs in the VAV system to go into their NTFC mode.

   During NTFC, air terminals shall open their dampers to their full maximum cooling CFM setting (adjustable) until the zone reaches the configured NTFC set point. Then, the air terminals shall close their dampers to their minimum cooling CFM setting (adjustable).

8. Pressurization
When the fire marshal forces the central air source into the pressurization mode by activating control relays in a fire panel, the air handler shall start its fan, open the outside air dampers and close the exhaust dampers. The pressurization mode shall then be transmitted to all VAV zones by the "Linkage Master" ZC. At each zone the individual ZC shall position its damper to the maximum nominal air terminal CFM. This CFM will be maintained until the central air source releases it.

9. Evacuation
The fire marshal shall force the central air source into the evacuation mode through activation of control relays in a fire panel. In this mode the air handler shall start its fan, close the outside air dampers and open the exhaust dampers. The evacuation mode shall then be transmitted to all VAV zones by the "Linkage Master" ZC. At each zone the individual ZC shall position its damper to its fully closed position. This position will be maintained until the central air source releases it.

Appendix A – Typical Guide Specification Sequences of Operation (cont)

10. Pressure Independent Control
    A velocity probe located in the terminal inlet shall be used to measure the CFM of primary air delivered by the terminal. Thus, any variation in inlet CFM caused by varying inlet duct pressure shall be automatically adjusted back to the original calculated CFM value by the PID algorithm controlling the damper.

F. Non-Linkage Operation

When used with a non-linkage air source, the "Linkage Master" ZC shall use its own airflow (velocity) sensor to determine if the air source is running or not. The Master ZC shall establish the operating mode of the air source (cool or heat) by using its primary air temperature sensor (mounted in the main supply duct upstream of the air terminal) to measure the air temperature supplied by the air source

If the supply air temperature is 5° F greater than the actual or average zone temperature, then the mode shall be heating. If the supply air temperature is 2° F less than the actual or average zone temperature, then the mode shall be cooling (default mode = cooling). Otherwise, the unit shall remain in its last selected mode.

G. Alarm Processing

Refer to the input/output point summary for alarm conditions.

Glossary

algorithm	a mathematical procedure that solves recurrent computations. They are used for all control actions and control types.
binary	characteristic or property involving a selection, choice, or condition in which there are two possibilities; as binary numbers in a computer, on-off, or opened-closed switch positions.
building automation system (BAS)	a programmed, computerized, "intelligent" network of electronic devices that monitor and control the mechanical and electrical systems in a building to reduce energy and maintenance costs.
control action	the nature of the change of the output produced by the input.
control loop	a control loop establishes relationships between the various data points (inputs and outputs.) The number of points required depends on the type of control strategy employed.
control strategy	a plan using algorithms and control actions to achieve an end result, usually expressed as a sequence of operation.
cooling coil	a component, often in the air-handling unit or room fan coil unit, that absorbs the heat and condenses the moisture to be removed from the space.
digital	of, pertaining to, or using data in the form of numerical digits.
direct digital control (DDC)	controller technology components that handle inputs and outputs electronically with software providing the logic.
discrete	a type of input or output point whose value is binary, or one that exhibits only one of two possible states, usually expressed internally as one (1) or zero (0), or externally as ON or OFF.
energy management system (EMS)	a system of computer-aided tools used to monitor and control building energy-using system functions to ensure a continual improvement in energy efficiency.
facility management system (FMS)	an automation system for a building or complex of buildings, encompassing basic BAS functions, plus additional equipment/maintenance data bases for extended functionality.
field-installed device (FID)	field-mounted and connected generic control device constructed from the same commercial standard modules as PICs, but intended for connection to and control/monitoring of non-manufacturer HVAC equipment. Differentiated from a PIC by being configured and installed in the field as opposed to the factory. Compare *product-integrated control*.
negative temperature coefficient (NTC) sensor	a sensing element in which the resistance decreases as the temperature increases.

network	an organized set of circuits and nodes that interconnect control components and allows them to communicate with each other.
primary bus	that portion of the network that interconnects field devices and controllers.
product-integrated control (PIC)	factory-mounted and connected control device, able to monitor, control, and diagnose the significant functions of the equipment of which it is a part. Compare *field-installed device*.
self-tuning loop	control loop that monitors output performance and adjusts algorithms to improve output accuracy and stability.

Prerequisites:

An understanding of air conditioning equipment and systems, along with the basics of automatic HVAC control systems. This knowledge can be gained from: TDP-103, Concepts of Air Conditioning, and TDP-801 Controls, Level 1: Fundamentals.

Learning Objectives:

After reading this module, participants will be able to:

- Understand the differences between product integrated controls and general purpose DDC controllers.
- Understand the function of an algorithm in DDC controls.
- Explain the differences between analog and discrete signals and how they work in control systems.
- Identify and describe the three basic strategies for operating DDC control loops.
- Identify common applications for general purpose DDC controllers.
- Understand the workings of networks in controls systems.
- Define and explain the four key management methods available with DDC controls.
- Define and explain interoperability and its role in DDC Controls.
- Specify DDC network configuration and functionality.

Supplemental Material:

Selecting and Specifying a Web-Accessible Controls System (WACS) by Steve Tom, Director of Technical Information, Automated Logic Corp.
http://automatedlogic.com/alcinternet.nsf/webview/Specifying_and_Selecting_a_WACS?OpenDocument

Instructor Information

Each TDP topic is supported with a number of different items to meet the specific needs of the user. Instructor materials consist of a CD-ROM disk that includes a PowerPoint™ presentation with convenient links to all required support materials required for the topic. This always includes: slides, presenter notes, text file including work sessions and work session solutions, quiz and quiz answers. Depending upon the topic, the instructor CD may also include sound, video, spreadsheets, forms, or other material required to present a complete class. Self-study or student material consists of a text including work sessions and work session answers, and may also include forms, worksheets, calculators, etc.



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