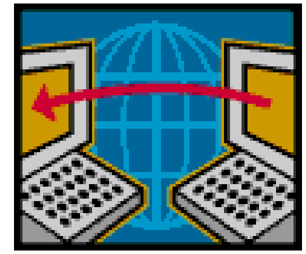
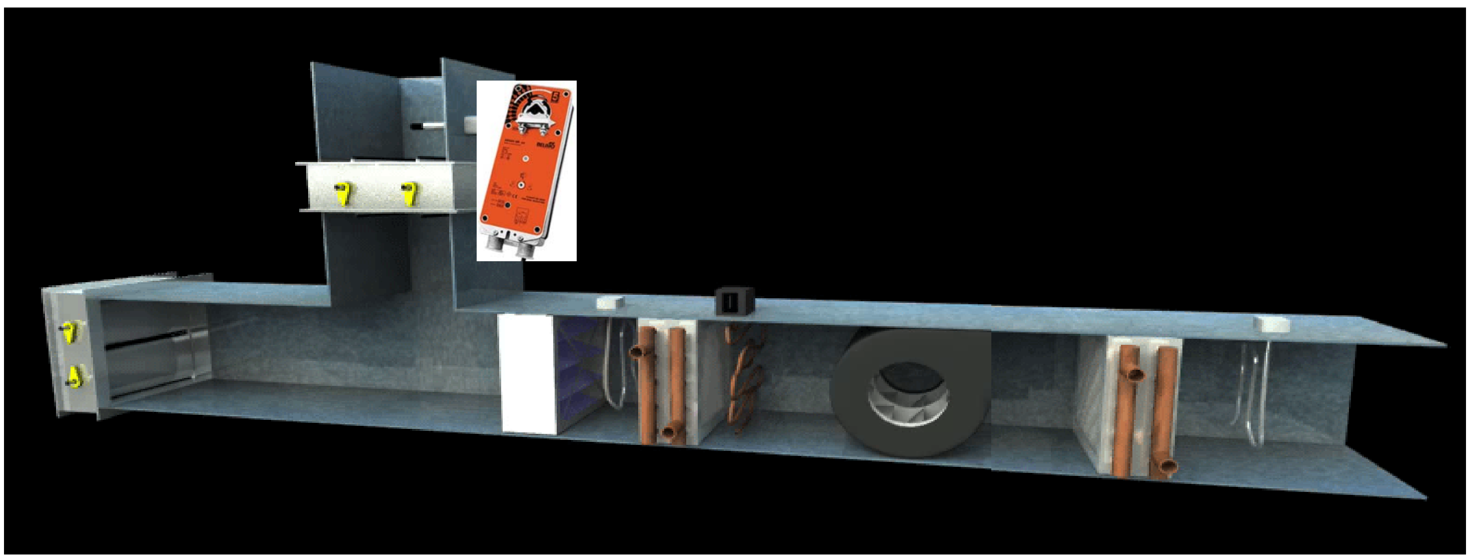
Battelle
The Business of Innovation

Automatic and DDC Control Fundamentals and Energy Conservation for HVAC Equipment-Part 1





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DDC Controls and Energy Conservation for HVAC Equipment - Agenda

1. Introduction of DDC Controls Project
2. HVAC Control Principles
3. Communication Standards and Networks
4. Vendor Examples of DDC Software Programming and Operator Interfacing
5. Typical Rooftop and Central AHU HVAC Control Systems and Applications
6. System Maintenance and Service of DDC Controls
7. Avoiding Common Control Problems and Fixing the Problems
8. Calibrating and Verifying Energy Savings of the DDC Controls

Part 1
HVAC Control Principles

1. Intent of Battelle Pacific NW Division involvement
2. Purpose of Controls
3. Key Components of Control Systems
4. Control Loops, Open vs. Closed Loops
5. Terminology
6. The Control Cycle and Control Actions
7. The Energy Sources for Control Systems
8. DDC Point Types

Part 2
Control Applications, Networks, Programming, Maintenance, and Energy Savings

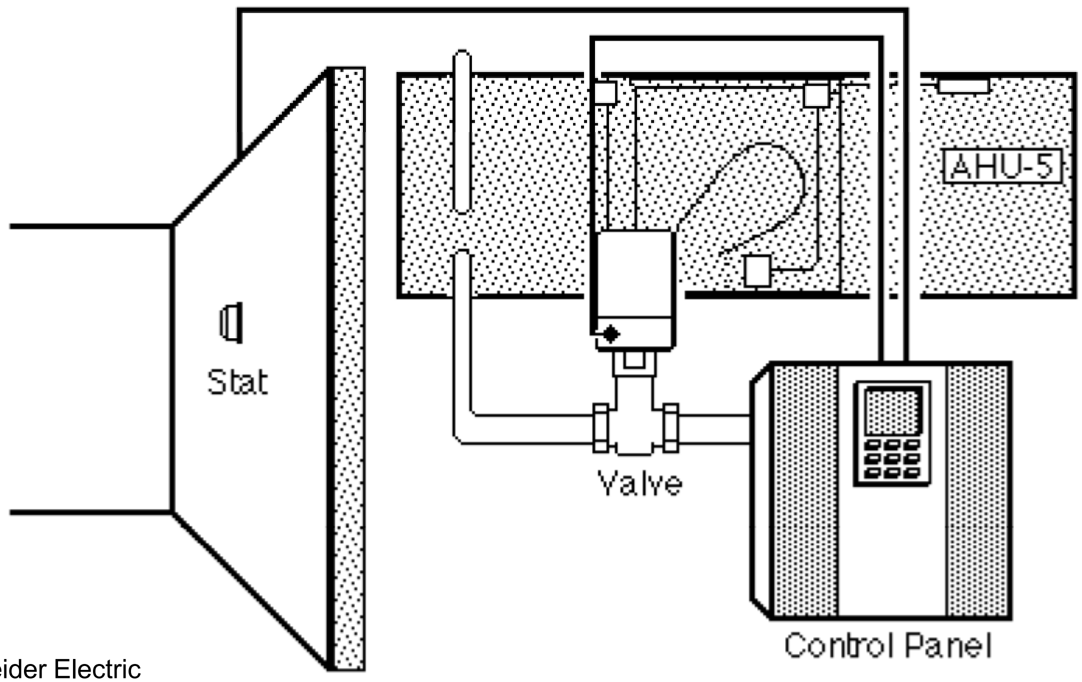
1. DDC Control Applications
2. DDC Networks and Architecture
3. Communication Standards and Networks
4. Vendor Examples of DDC Software Programming and Operator Interfacing
5. System maintenance and service of DDC controls
6. Using DDC controls to save energy

Section 1
Introduction of DDC Controls Project

- Purpose of this project is to provide HVAC educational materials to Washington State community colleges to educate students who have chosen or may chose career paths related to HVAC servicing and building energy management fields

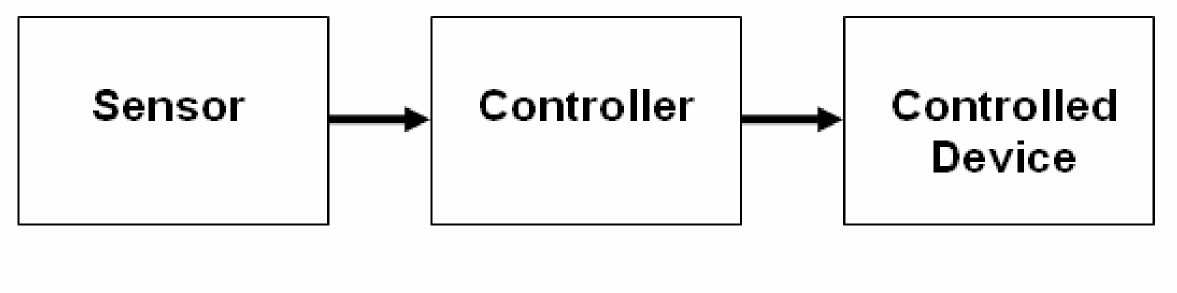
Section 2
HVAC Control Principles
The Purpose of Temperature Controls

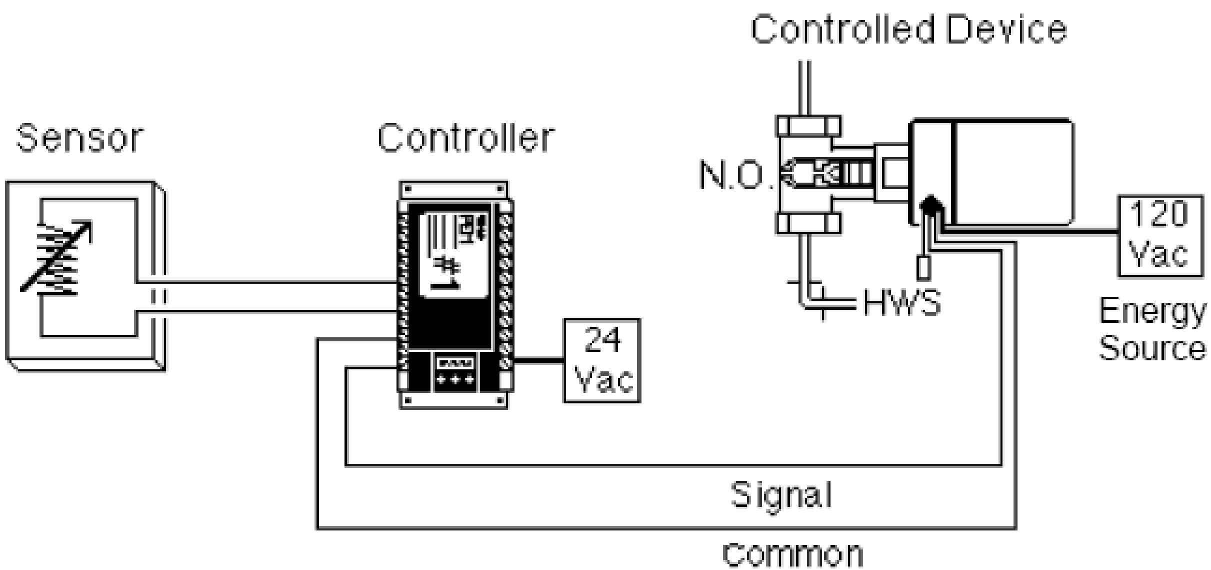
- Control systems are the "brains" of HVAC equipment to maintain human comfort. Pictured below is an AHU that serves only one zone. This type of AHU is called a *single zone AHU. In the example, a temperature sensor (stat) sends a signal to a control panel, which sends a signal to a valve.*



Courtesy TAC Controls/Schneider Electric

Section 3
Key Components of a Control System Include:



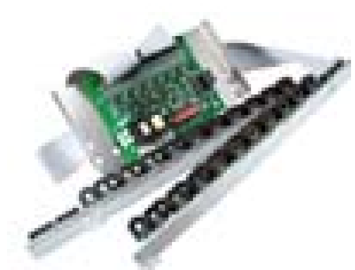


Courtesy TAC Controls/Schneider Electric

Sensors

Modern HVAC Sensors Include:

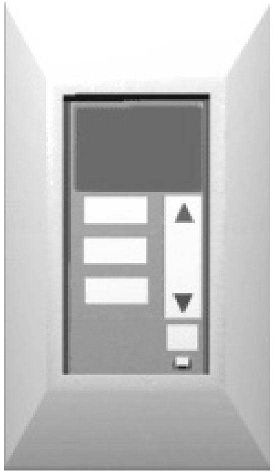
- Humidity and temperature transmitters
- CO_2 for indoor air quality (IAQ) utilizing demand control ventilation
- Power meters
- Branch circuit monitors
- Energy meters



Courtesy Veris Industries

Sensors

- A sensor monitors and measures a variable. The HVAC variables are temperature, humidity, flow, and pressure. Different types of signals are produced by different types of sensors. They include:
  - Electric sensors
  - Pneumatic sensors
  - Electronic sensors



An example of a sensor is shown here. While it may appear to be a thermostat, it is a remote sensor with a remote setpoint dial. The controller is in another location.

Courtesy TAC Controls/Schneider Electric

Pneumatic Sensors/Transmitters

- **Pneumatic controls sensors or transmitters sense the variable and produce a 3 psig to 15 psig (pound per square inch, gauge), [20 kPa (kiloPascals) -105 kPa] signal over a particular transmitter's *range.***

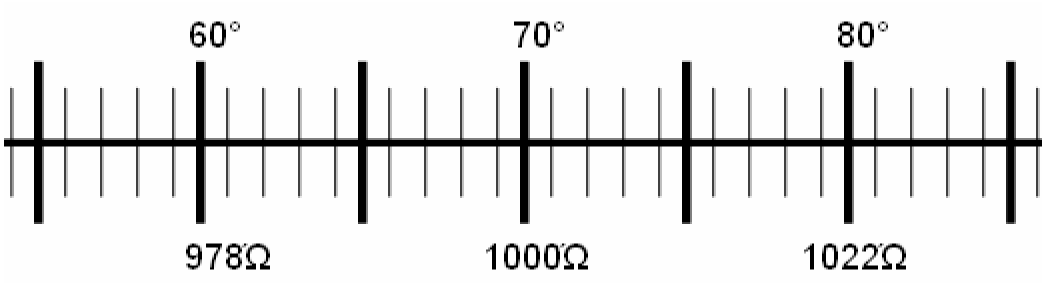
Courtesy Johnson Controls

Electronic Sensors Include:

- Resistance sensors are resistance temperature devices (RTDs), and are used in measuring temperature. Examples are Balco elements, copper platinum, 10K thermistors, and 30K thermistors.
- Voltage sensors could be used for temperature, humidity and pressure. Typical ranges are 0 to 5 Vdc (Volts direct current), 1 to 11 Vdc, and 0 to 10 Vdc.
- Current sensors could be used for temperature, humidity, and pressure. The typical current range is 4 to 20 mA (milliamps).

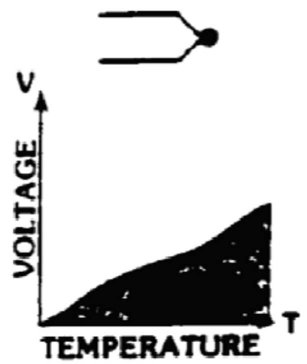
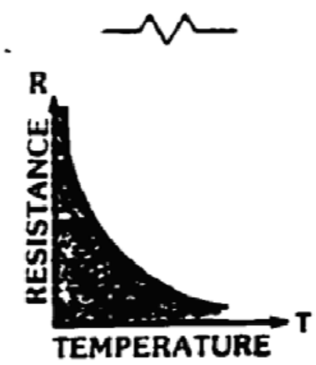
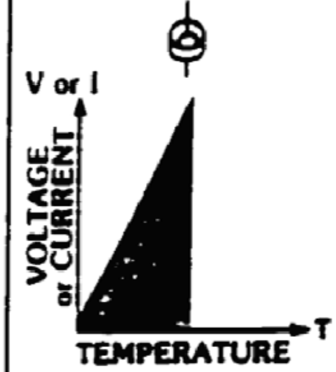
1000Ω (Ohms) Balco PTC Electronic Temperature Sensors

- The resistance outputs of a electronic Balco temperature sensor follow the diagrams below:



- When 1000 ohms is measured across the Balco element, the temperature is approximately 70°F (21°C). As the temperature increases, the resistance changes 2.2 ohms per 1°F (3.96 ohms per 1°C). In a Balco temperature sensor, as the temperature increases, the resistance increases proportionally in a positive direction. This is known as a positive temperature coefficient (PTC) sensor. However, many temperature sensors are considered thermistors, and perform as Negative temperature coefficients (NTC).

Comparison of Common Temp Sensors

	Thermocouple	RTD	Thermistor	I.C. Sensor
				
Advantages	☐ Self-powered ☐ Simple ☐ Rugged ☐ Inexpensive ☐ Wide variety ☐ Wide temperature range	☐ Most stable ☐ Most accurate ☐ More linear than thermocouple	☐ High output ☐ Fast ☐ Two-wire ohms measurement	☐ Most linear ☐ Highest output ☐ Inexpensive
Disadvantages	☐ Non-linear ☐ Low voltage ☐ Reference required ☐ Least stable ☐ Least sensitive	☐ Expensive ☐ Current source required ☐ Small ΔR ☐ Low absolute resistance ☐ Self-heating	☐ Non-linear ☐ Limited temperature range ☐ Fragile ☐ Current source required ☐ Self-heating	☐ T <200°C ☐ Power supply required ☐ Slow ☐ Self-heating ☐ Limited configurations

Courtesy Omega Controls

Controllers Can Include:

Electric Controls

Pneumatic Controls

Electronic Controls

DDC Controls

Courtesy Johnson, Honeywell, and Alerton Controls

Controllers basic principles the controller receives the input And processes an output

Sensors

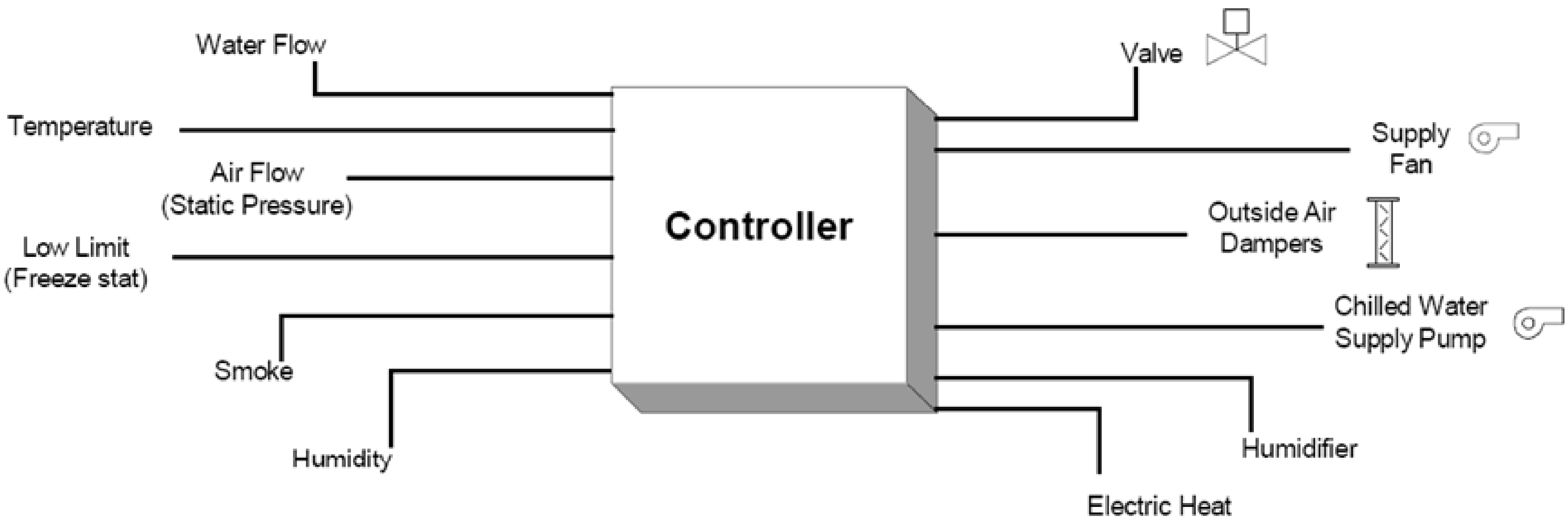
Input points

Analog (Variable) or Digital (2 State)

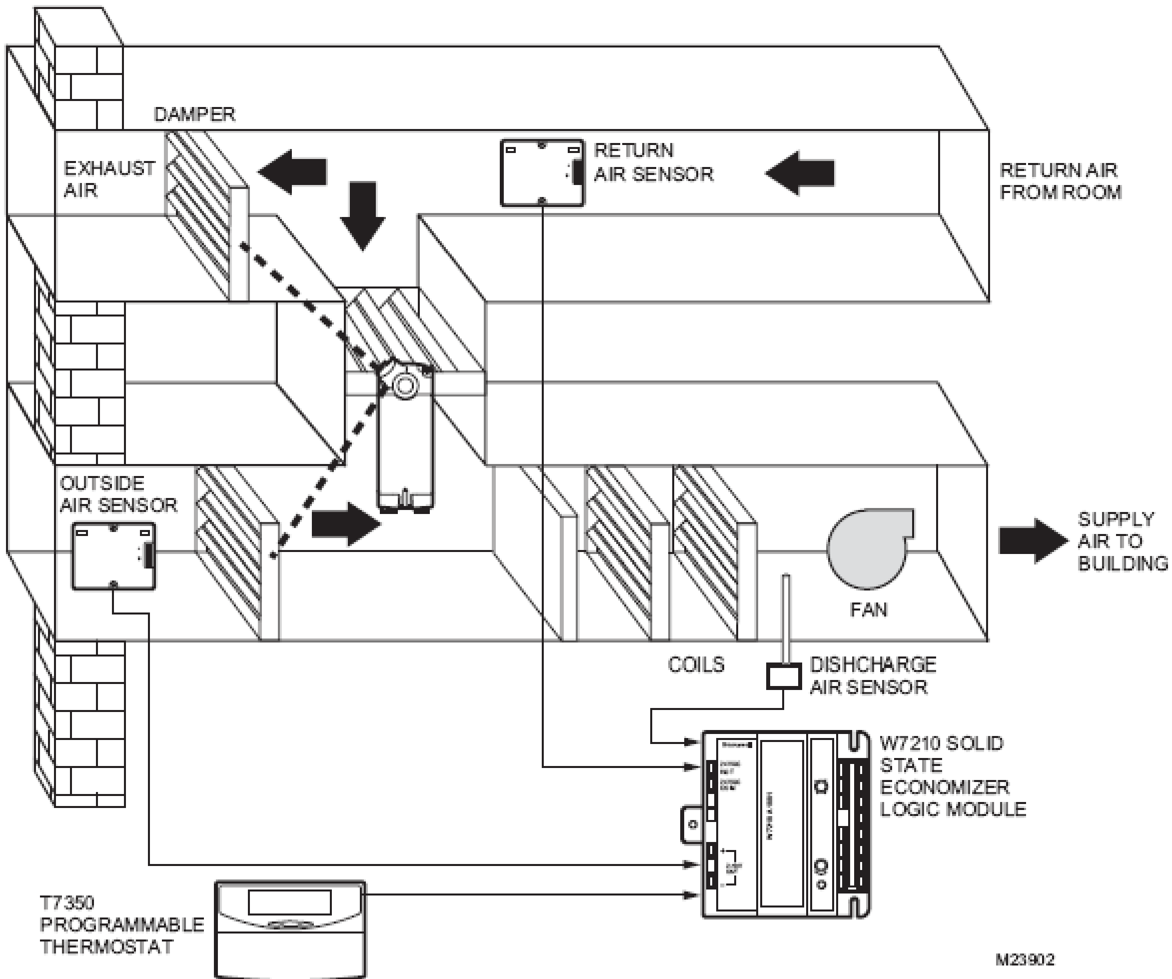
Controlled Devices

Output points

Analog (Variable) or Digital (2 State)

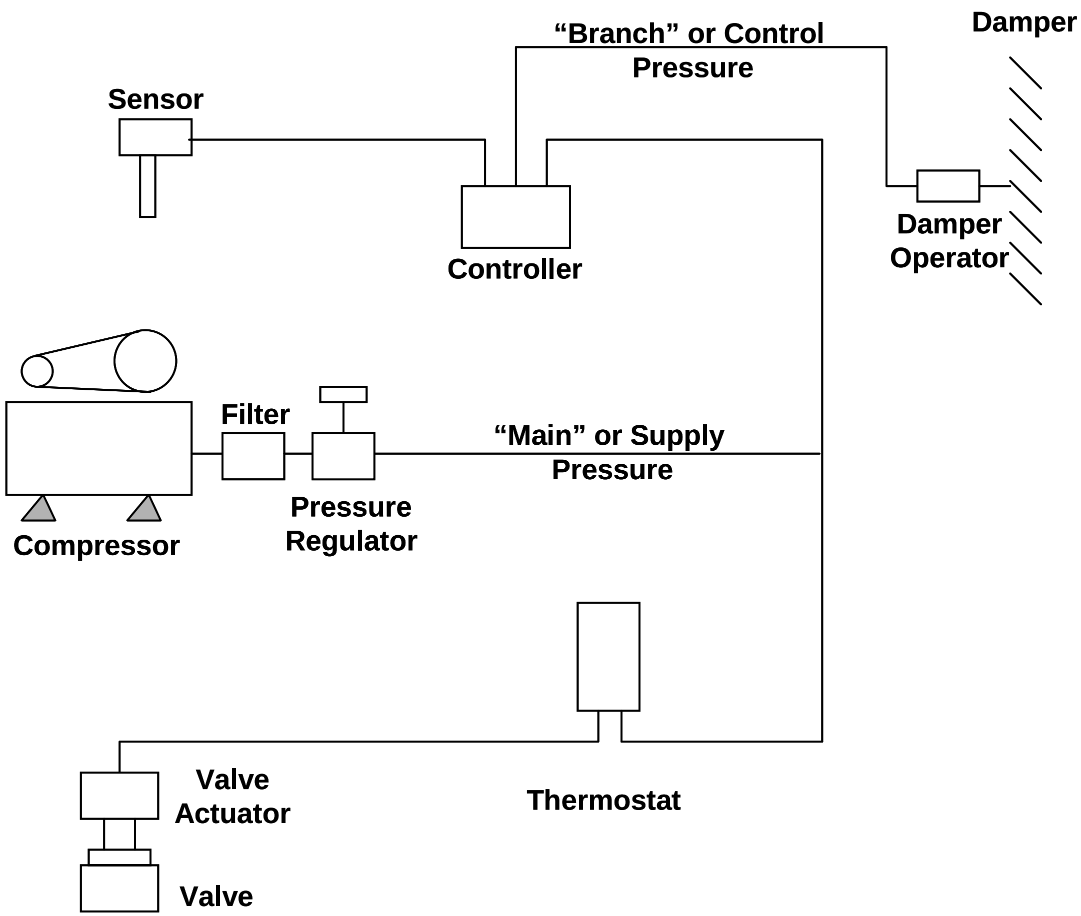


Electronic Control System



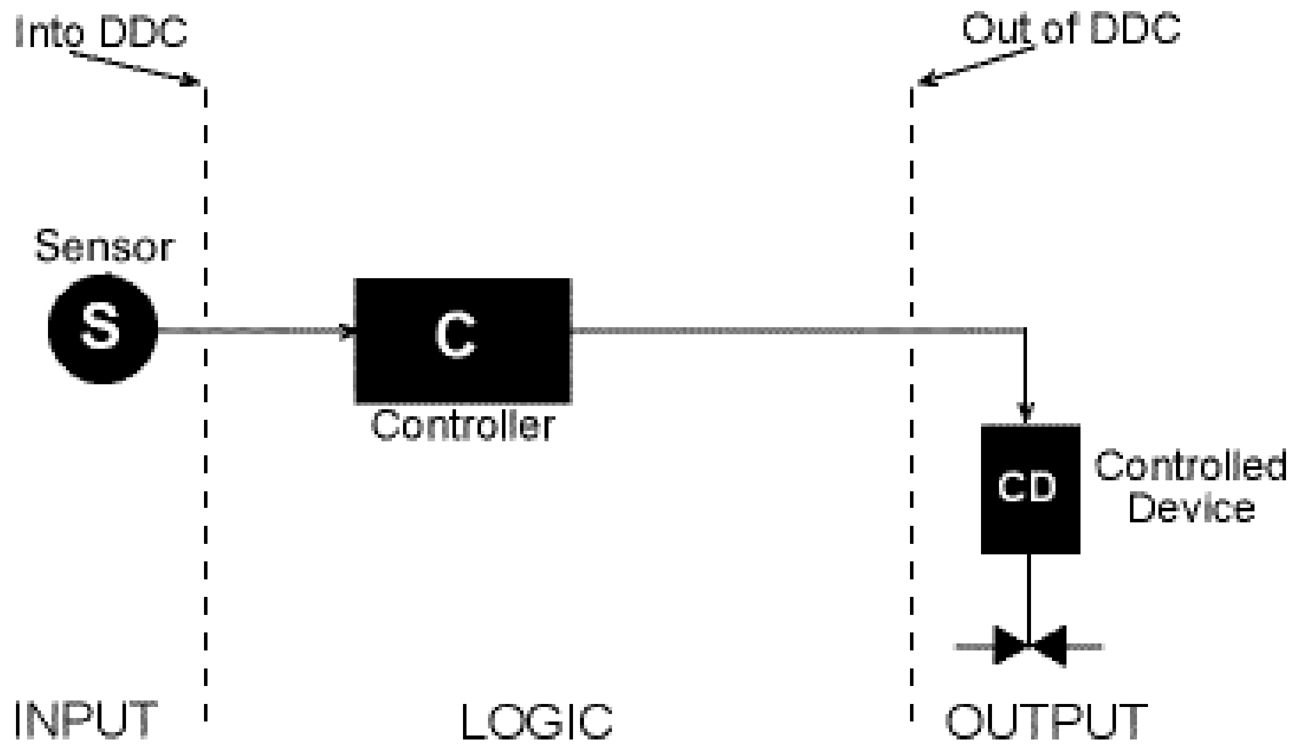
Courtesy Honeywell Controls

Pneumatic Controller System



Courtesy Northwest Energy Efficiency Council

The DDC controller receives the input from the sensor, performs a logic function, and processes an output



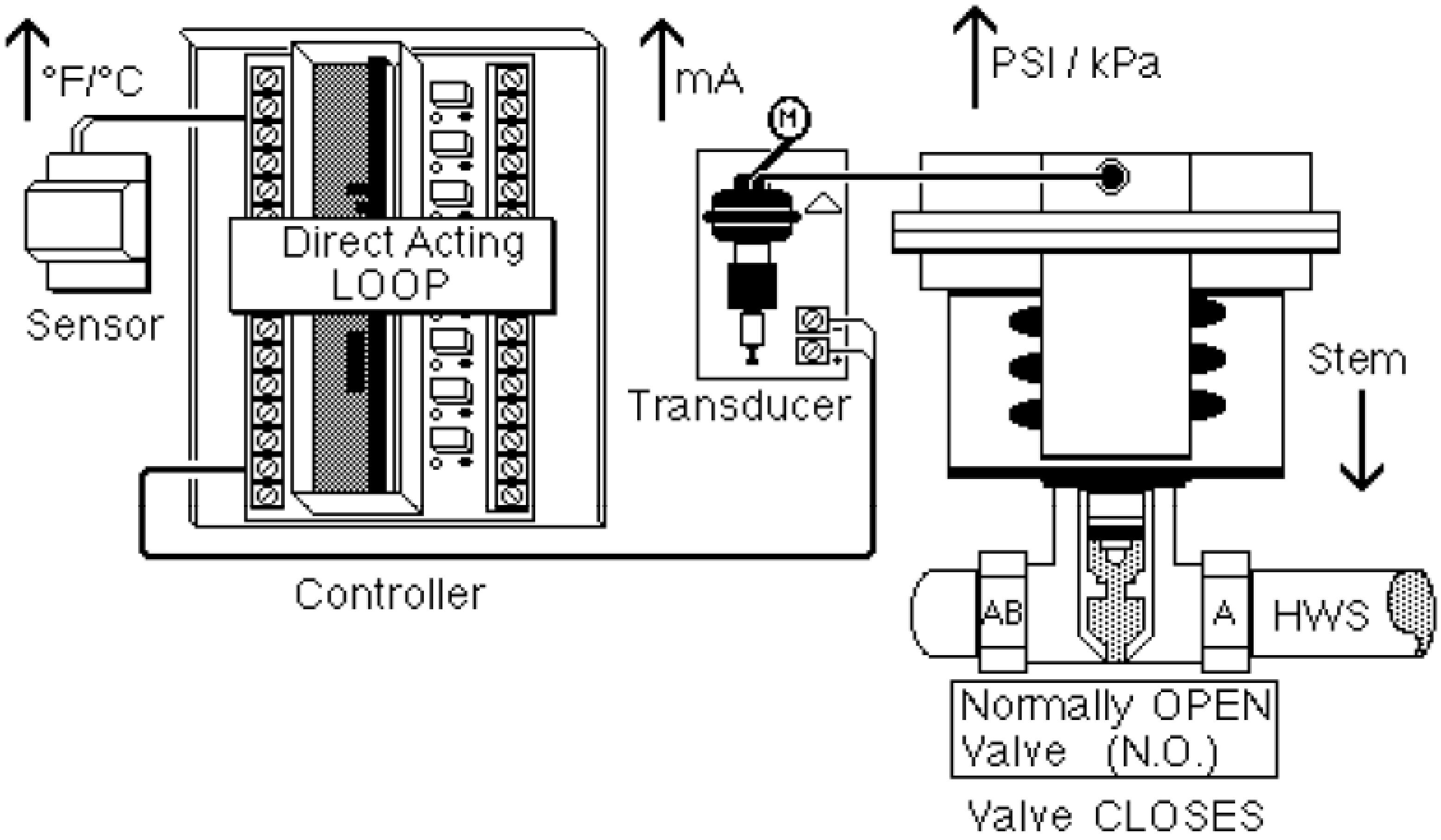
Courtesy DDC Online Org

Controller Action-Direct or Reverse Illustration

TEMPERATURE	BRANCH LINE PRESSURE	ACTION
↓ (Fall)	↓ (Fall)	Direct Acting
↑ (Rise)	↑ (Rise)	Direct Acting
↓ (Fall)	↑ (Rise)	Reverse Acting
↑ (Rise)	↓ (Fall)	Reverse Acting

Courtesy Honeywell Controls

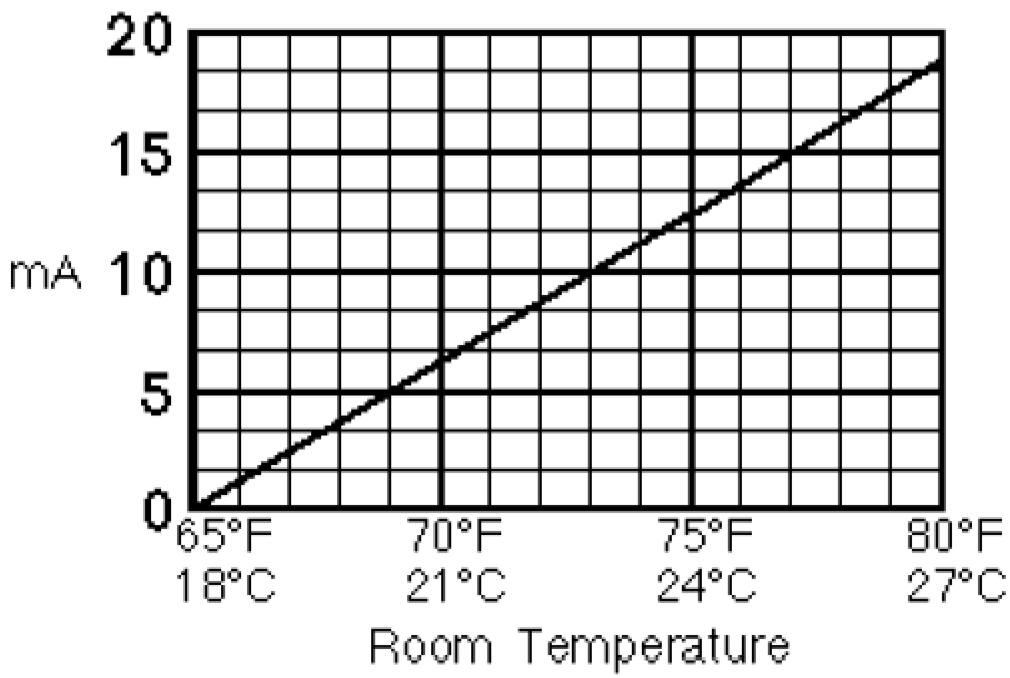
Controller Direct Action-Illustration



Courtesy TAC Controls/Schneider Electric

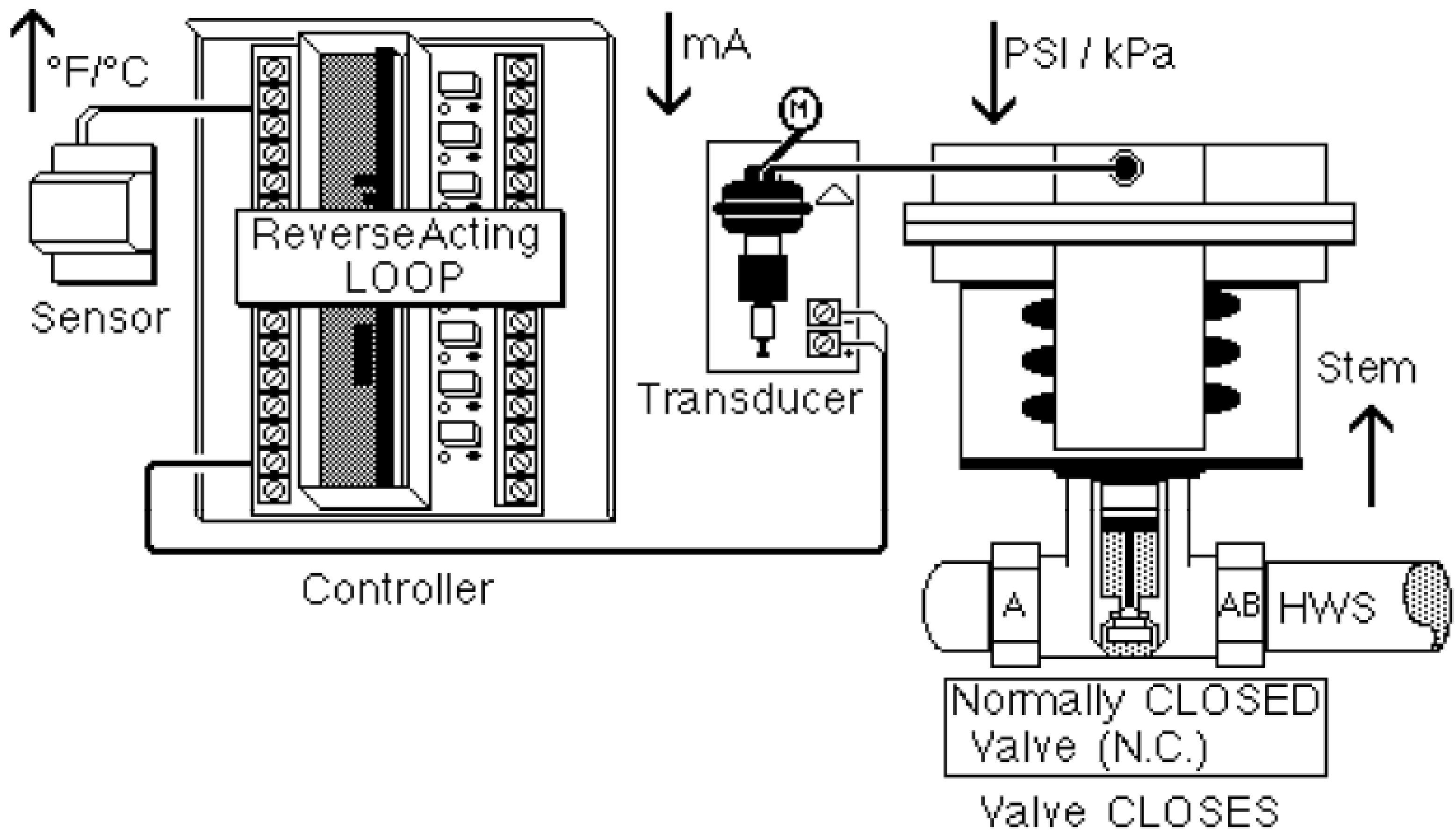
Controller Direct Action-Illustration

- This relationship between the input to a controller (temperature) and its output (current) can be displayed on a graph as follows:



Courtesy TAC Controls/Schneider Electric

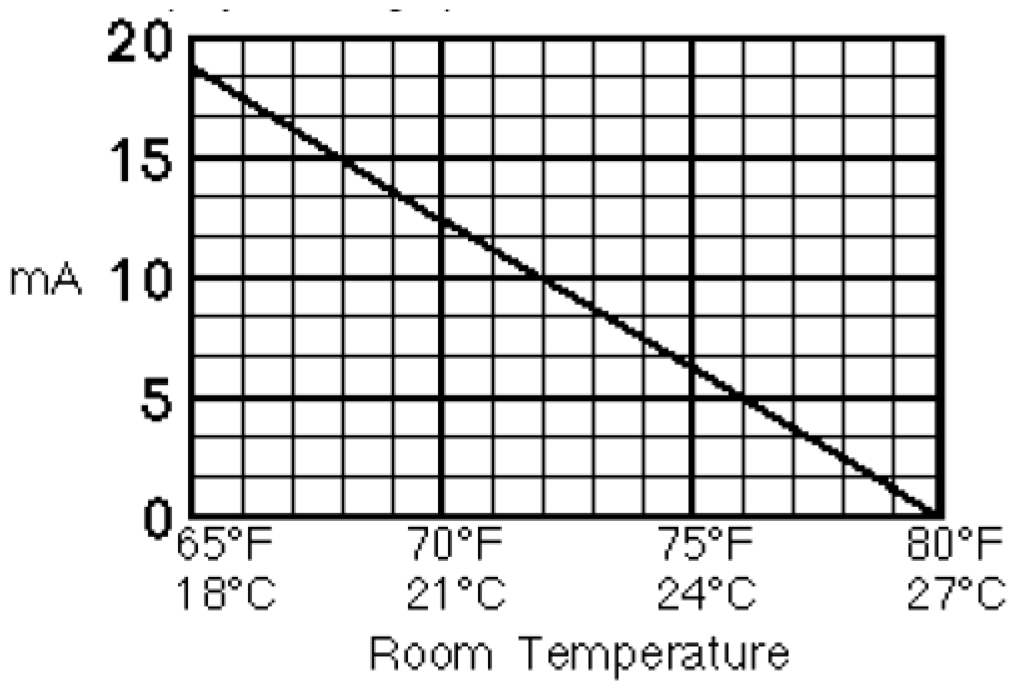
Controller Reverse Action-Illustration



Courtesy TAC Controls/Schneider Electric

Controller Reverse Action-Illustration

- This relationship can is displayed on a graph as follows:



Courtesy TAC Controls/Schneider Electric

Controlled Devices

Control Valves

– two-way Control Valves

Used with differential pressure (DP) sensors and VSD pump systems on primary and secondary loops

– three-way (mixing or diverting)

– Pressure independent control valves

Automatic dampers

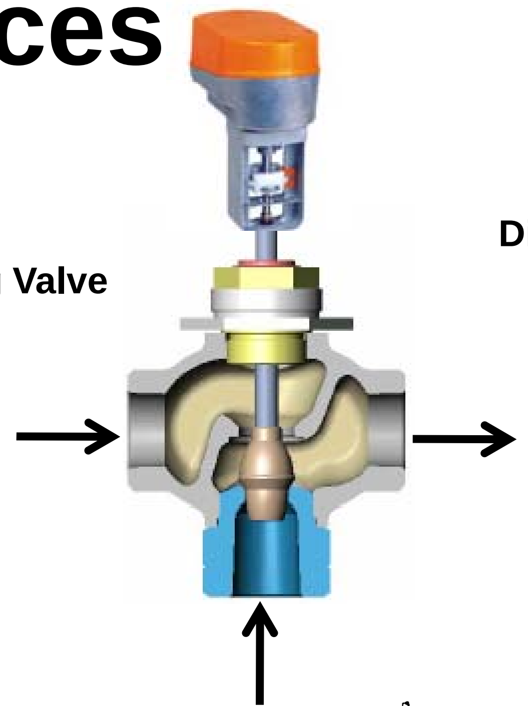
Damper operators

VSDs: variable speed drives

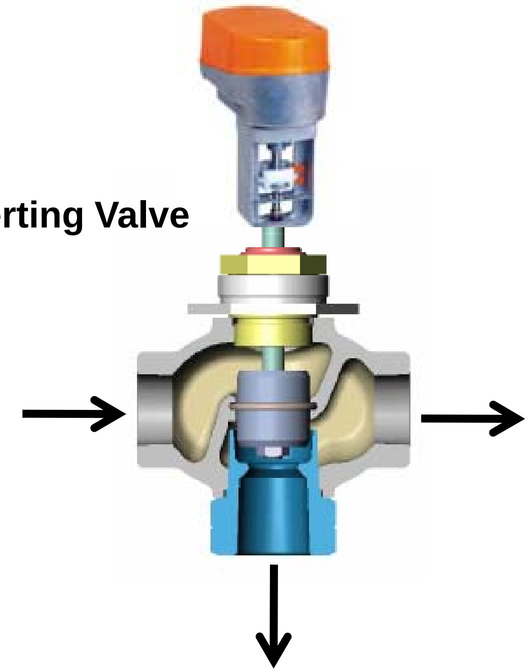
Courtesy Belimo

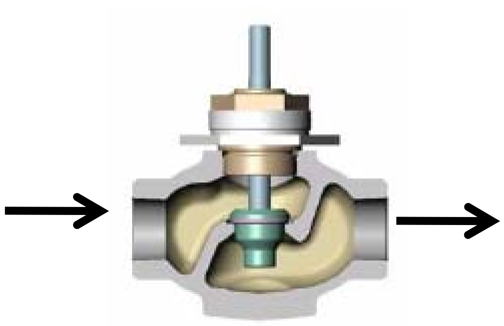
Controlled Devices
Valves

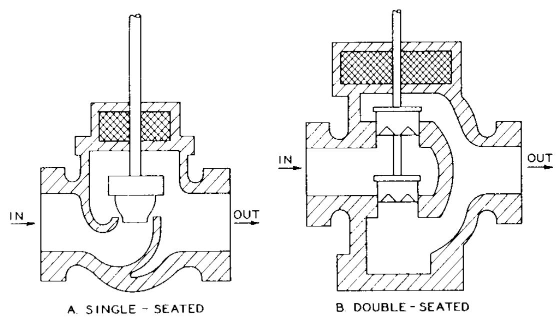
Mixing Valve



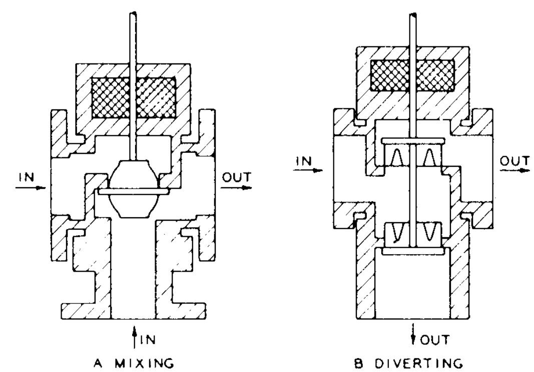
Diverting Valve







Typical Single - and Double-Seated Two-Way Valves



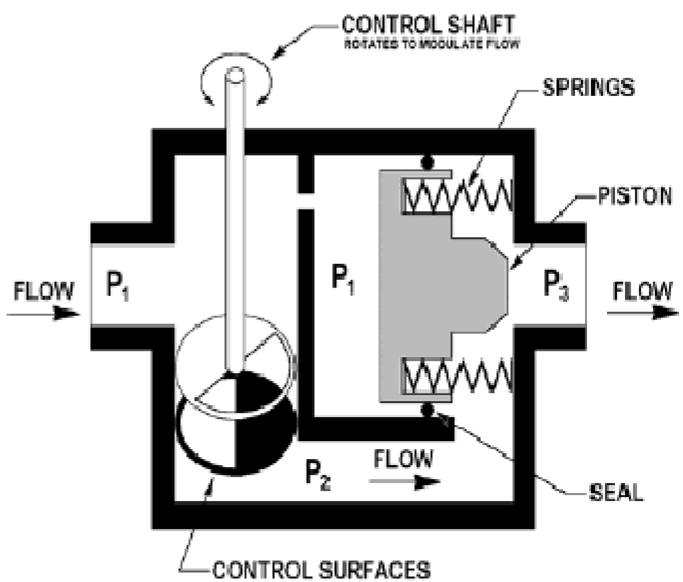
Typical Three-Way Mixing and Diverting Valves

Courtesy Belimo

The Present Control Systems

Use control valves that are:

- **Pressure independent control valves**
  - **No Cv required, reduced pumping costs, higher efficiency, easy to balance.**

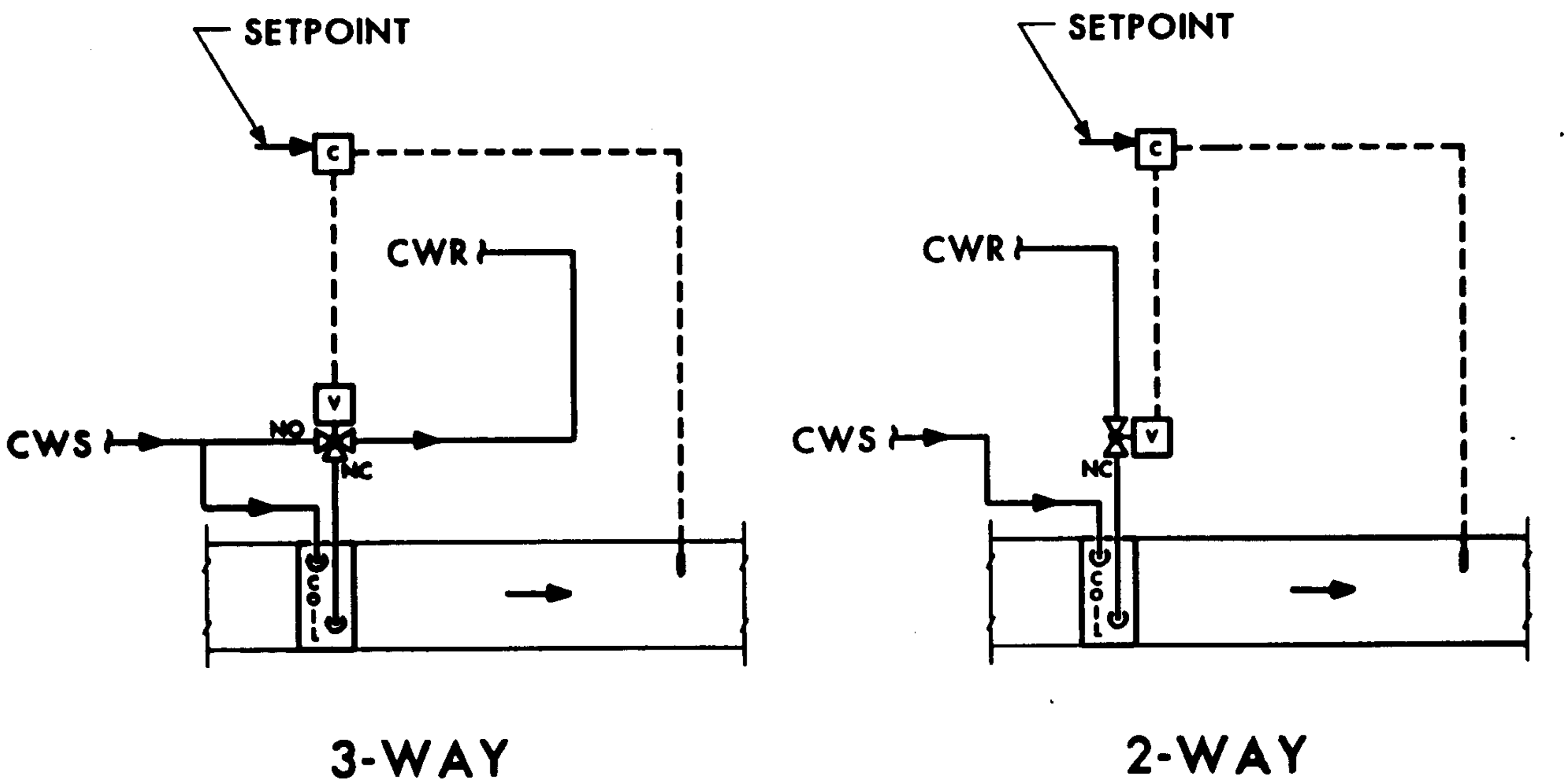


Note: Pressure across the control surface (P1-P2) remains constant. Steady flow improves heat transfer, minimizes flow, and raises delta T.

Schematic of Pressure Independent Modulating Control Valve

Courtesy Flow Control Valves

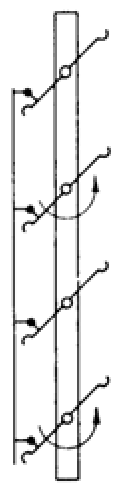
Examples of 2-Way and 3-Way Control Valves

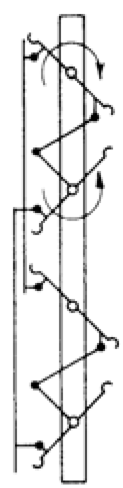


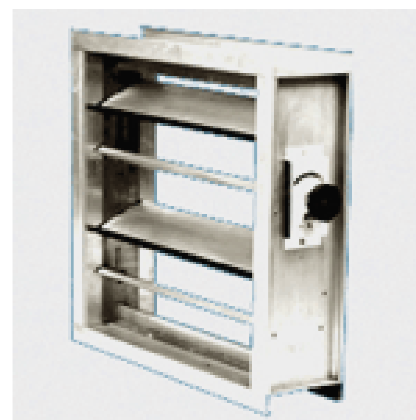
CHILLED WATER COIL CONTROL

Dampers: Types, Actuators, and Characteristics

- Economizers on many central AHUs are custom ordered for the job specific requirements
- Economizers on packaged RTUs are normally ordered as an option with the package
- <u>Control Dampers Can Be Either:</u>
  Parallel or opposed dampers







Parallel Blade

Opposed Blade

Economizer Damper Actuator Types

are either:

Pneumatic	Electric	Electronic

Economizer Damper Actuators

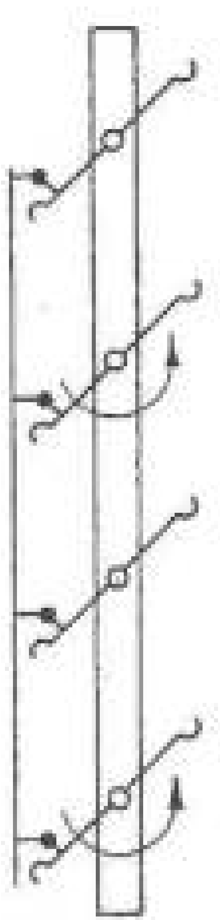
will have either direct connect actuators bolted directly to the damper or they will be installed with a shaft and linkage arrangement (more prone to fail)

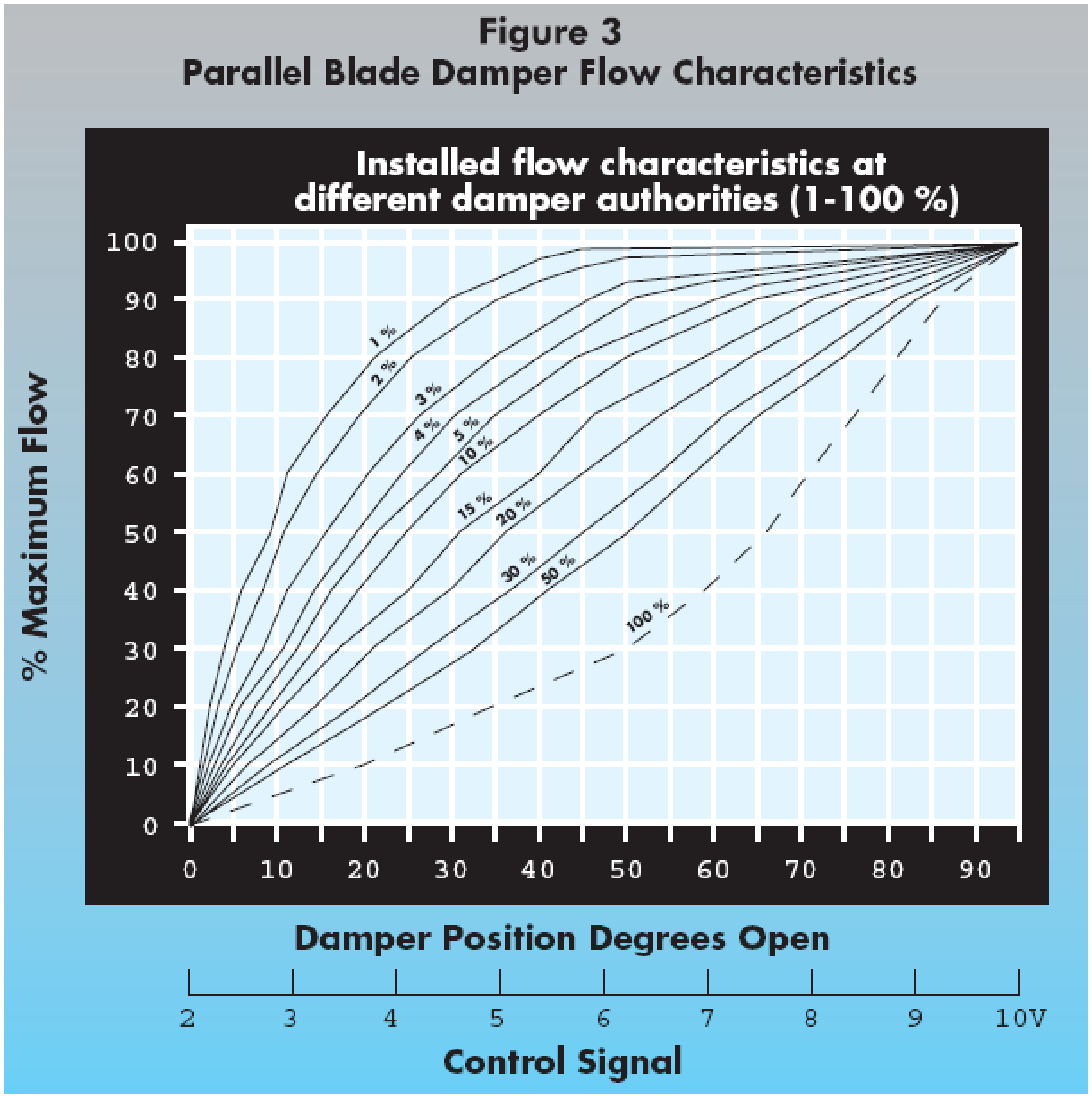
Direct Connect Actuator

Damper Connected to Actuator Via Shaft and Coupling

Parallel Blade Damper Characteristics

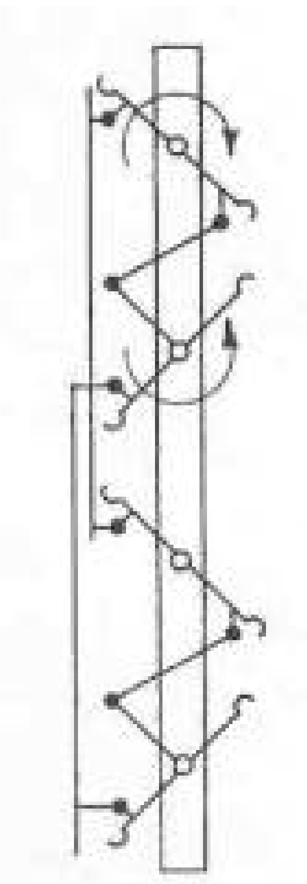
have poor linear control

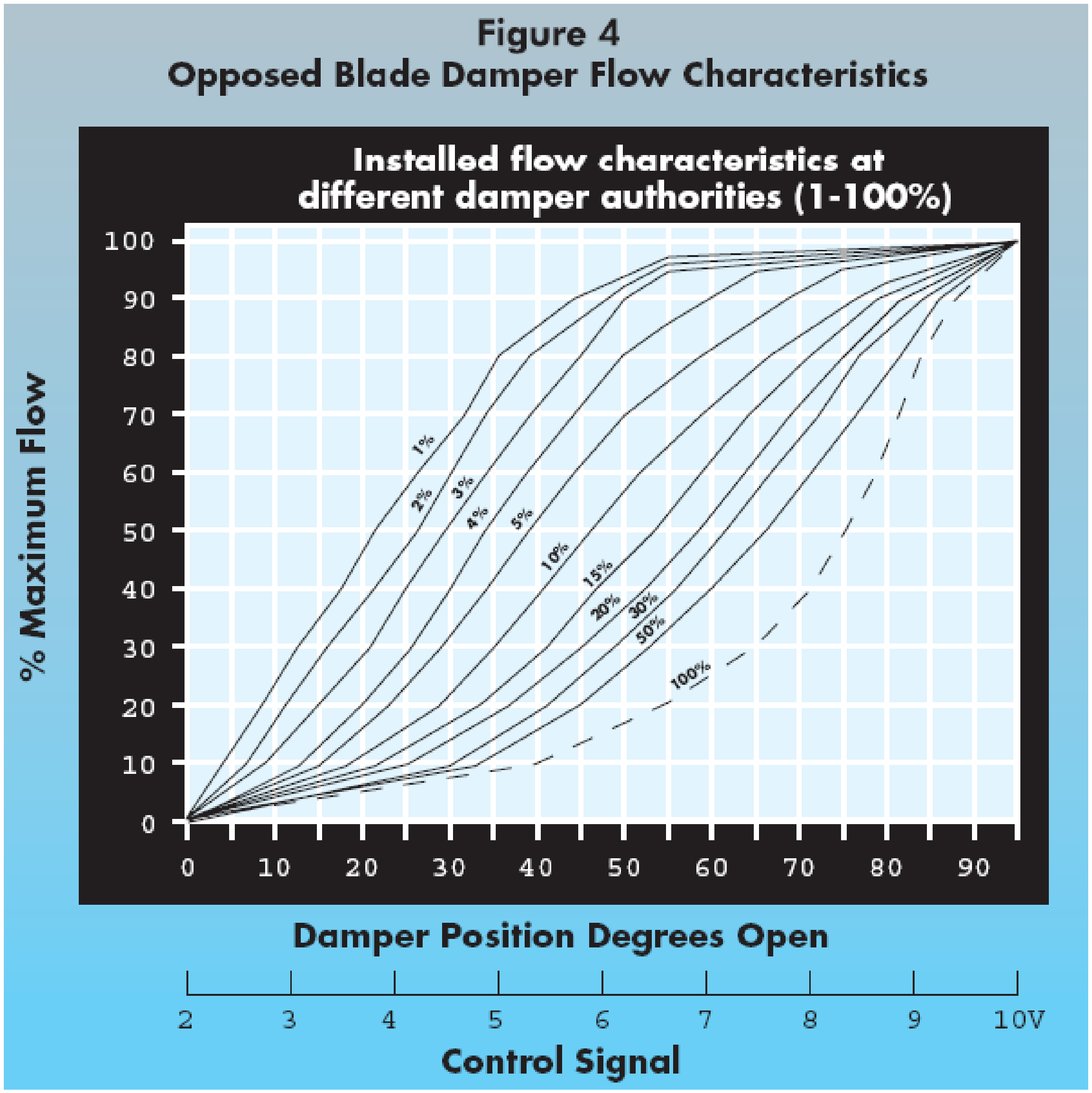




Courtesy T.A. & Co.

Opposed Damper Characteristics
have better linear control

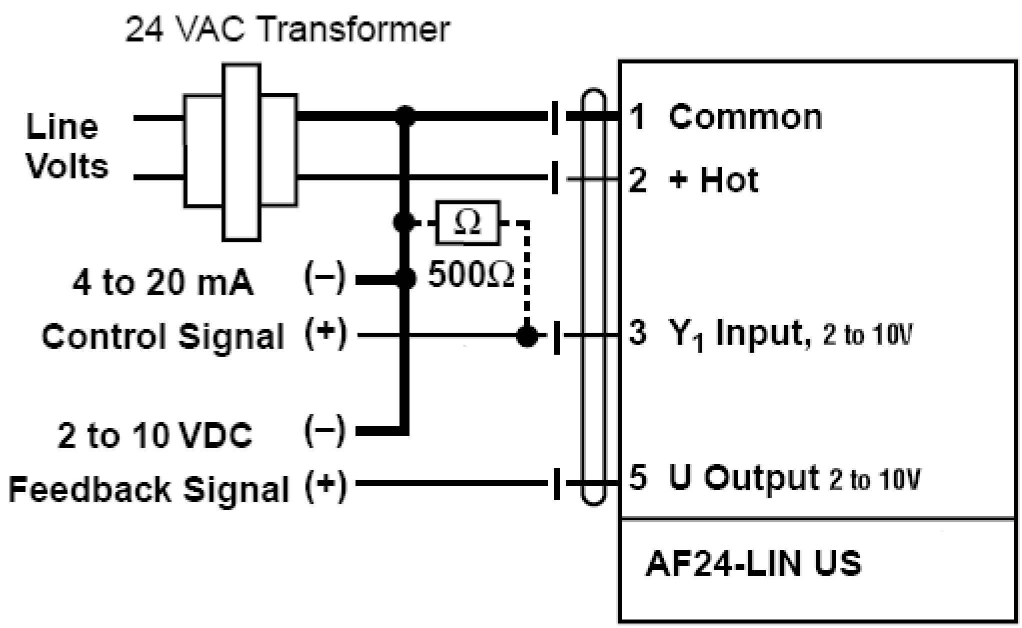




Courtesy T.A. & Co.

Damper Actuators can be Controlled by :

- Voltage (0-10Vdc or 2-10Vdc)
- Current (4-20mA)
- Floating point (binary pulse to open or close)
- PWM-pulse width modulated
- Resistance (0-135 ohms)



Example of analog control using 4-20mA or 2-10Vdc

Courtesy Belimo

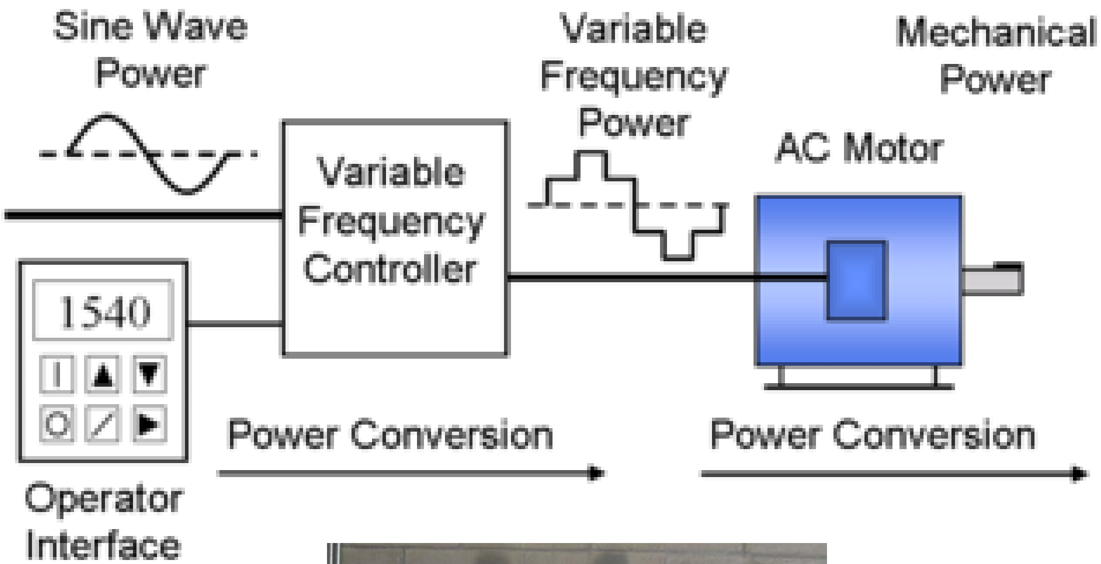
Electronic Variable Frequency Drives (VSDs)

- Vary frequency of motor to control speed
- Often called VSDs, VFDs, or ASDs

DDC control systems have variable frequency drives (VFDs) as standard equipment on:

- Cooling towers
- AHU's and VAV fans
- Pumps
- Chillers

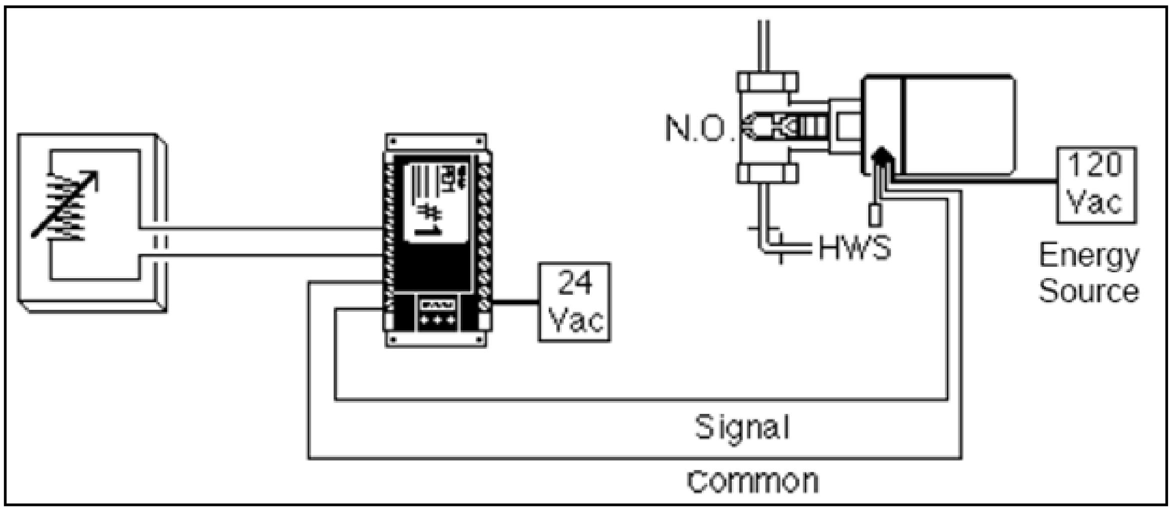
Variable Speed Drives

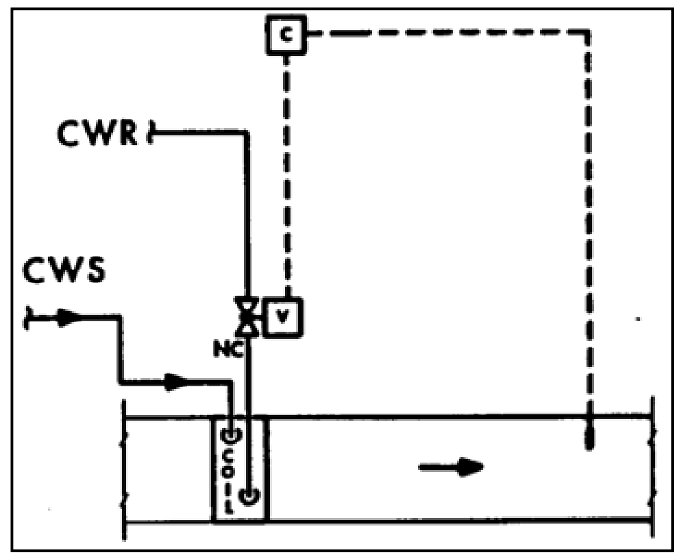


Courtesy ABB Controls

Review of the Key Control Components

Exercise-identify the sensors, controllers, and controlled devices

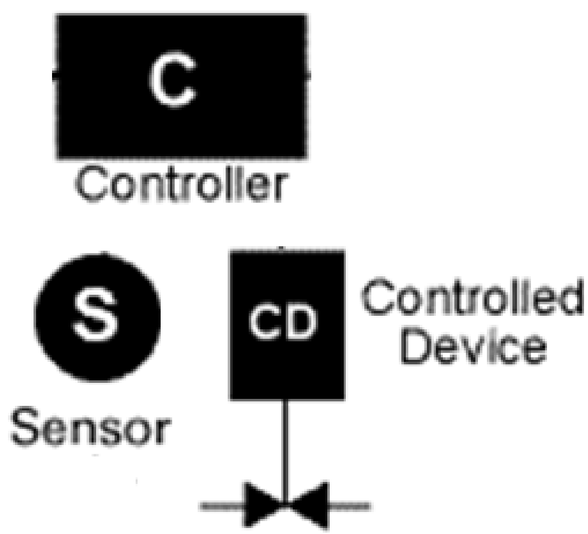




Courtesy TAC Controls/Schneider Electric

Review of the Key Control Components

Exercise-connect the sensor, controller, and controlled device in the proper order.



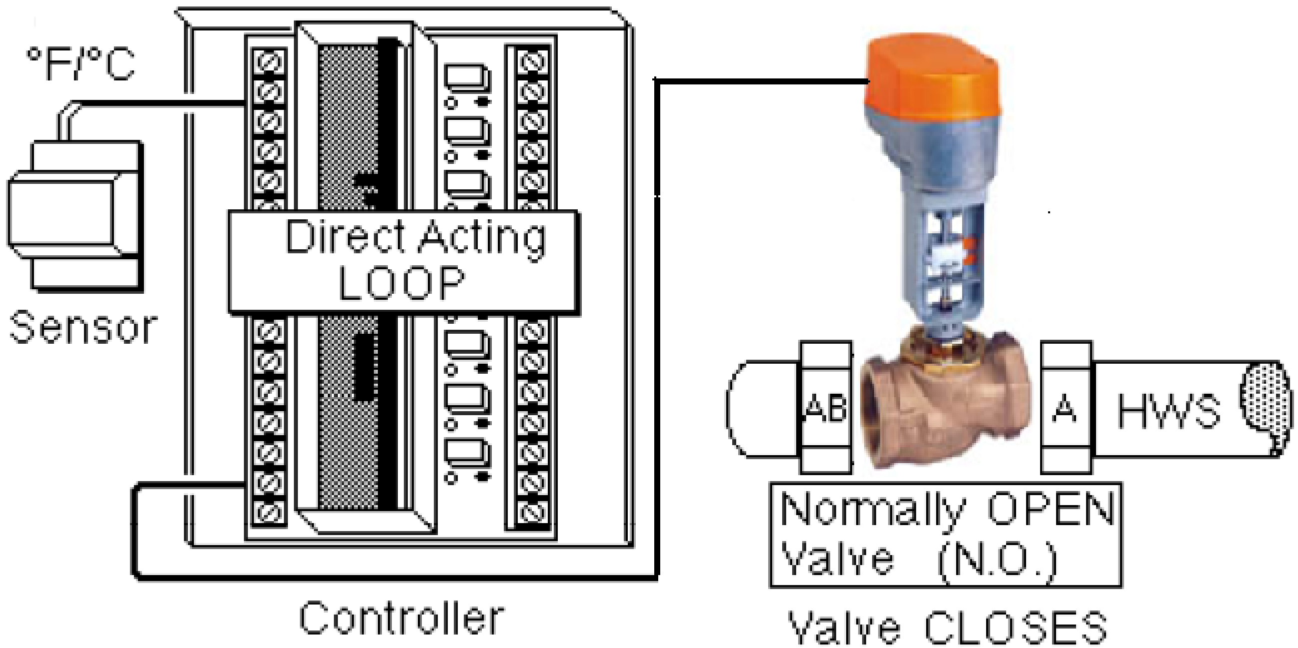
Courtesy Alerton and Belimo

Review of Control Action

Exercise-the control drawing below has a direct acting controller, with a NO valve. Show the correct action with arrows at each component when used for cooling mode.

↑

__________**Acting**



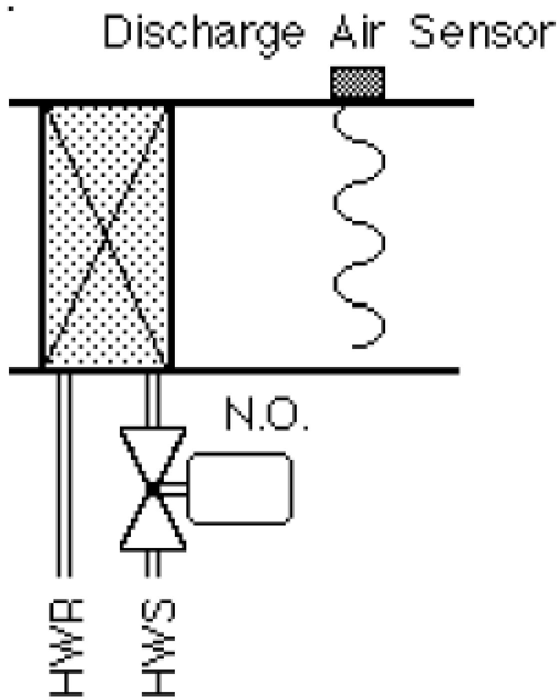
Courtesy TAC Controls/Schneider Electric and Belimo

Review of Control Action
Exercise-Circle the correct answer.

A discharge air sensor modulates a normally open hot water valve. What action is needed for the controller?

Circle the correct answer.

D.A. or R.A.

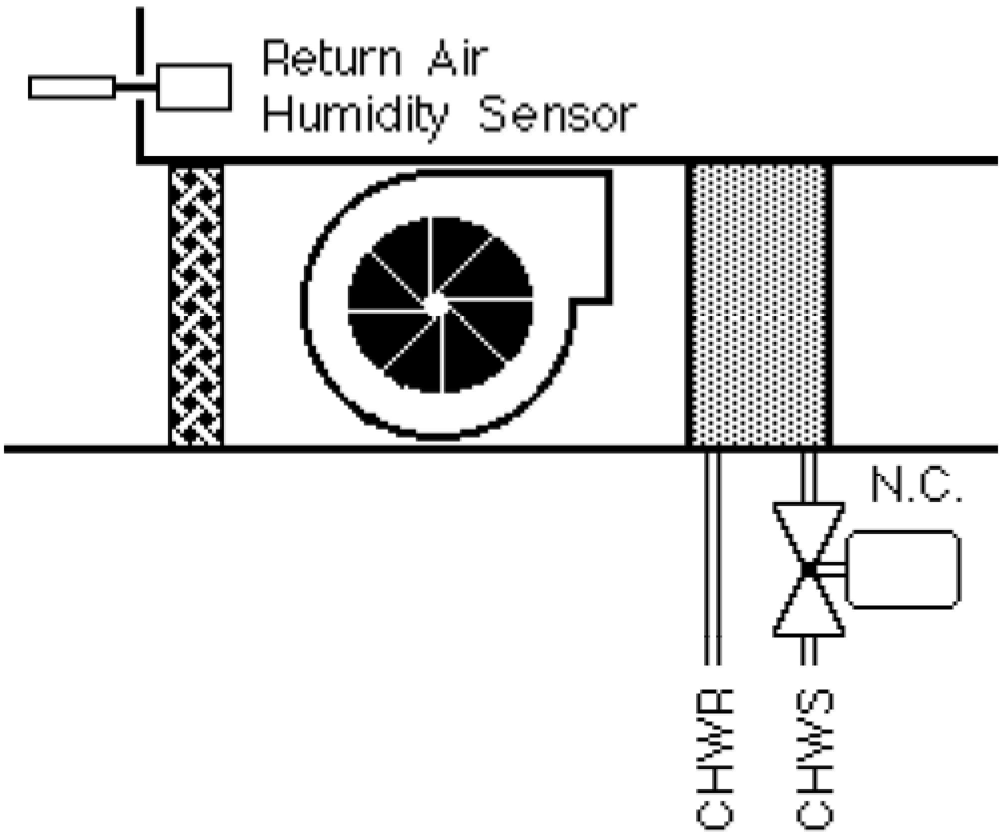


Courtesy TAC Controls/Schneider Electric

Review of Control Action
Exercise-Circle the correct answer.

A return air humidity sensor modulates a normally closed chilled water valve for dehumidification. What action is needed for the controller?

Circle the correct answer. D.A. or R.A.

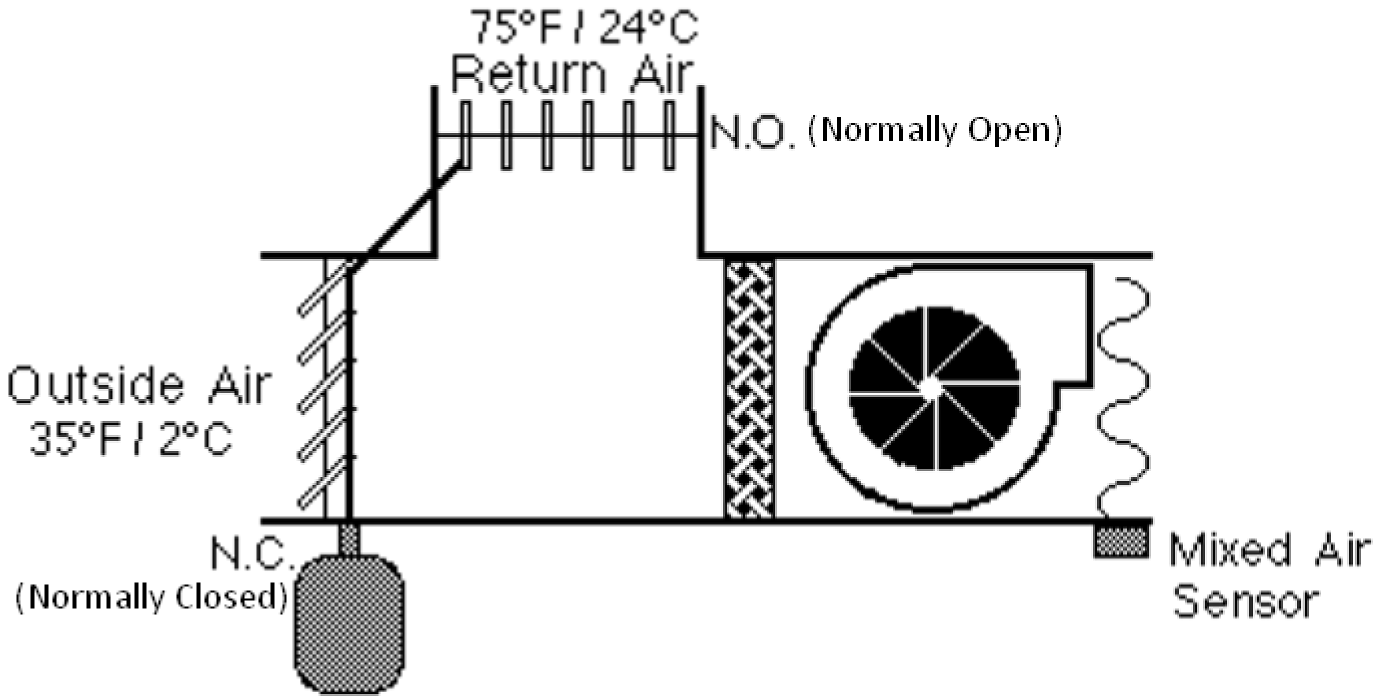


Courtesy TAC Controls/Schneider Electric

Review of Control Action
Exercise-Circle the correct answer.

The mixed air sensor modulates the normally closed outside air dampers and the normally open return air dampers to maintain a temperature of 55°F (13°C). What action is needed for the controller?

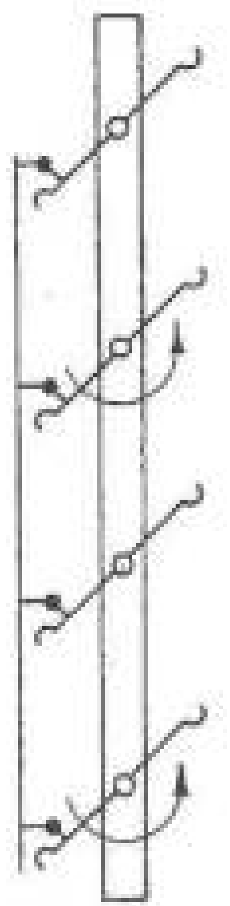
Circle the correct answer. D.A. or R.A.

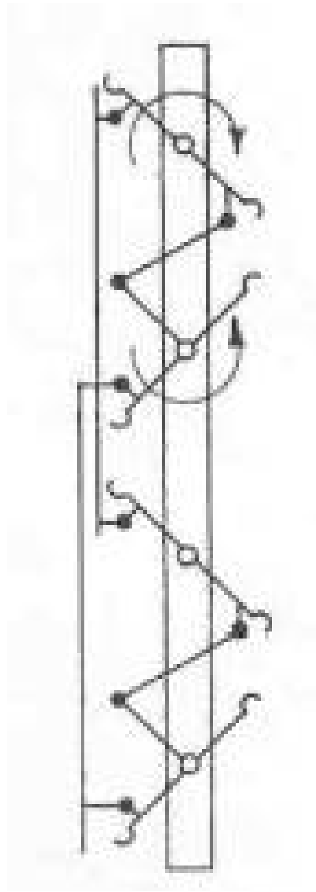


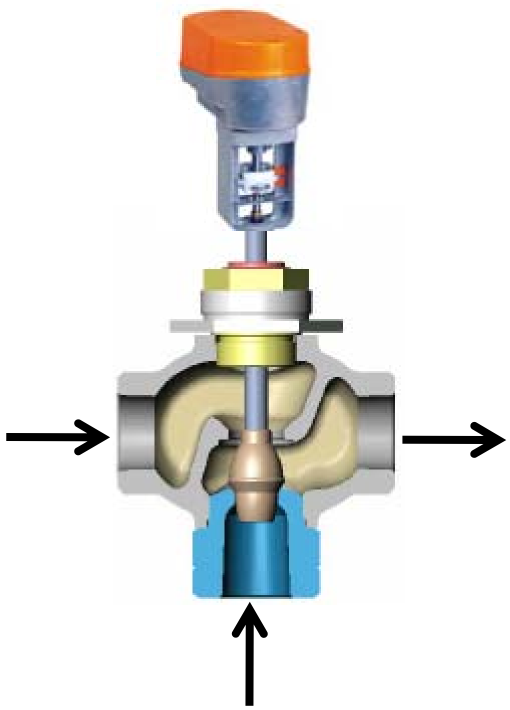
Courtesy TAC Controls/Schneider Electric

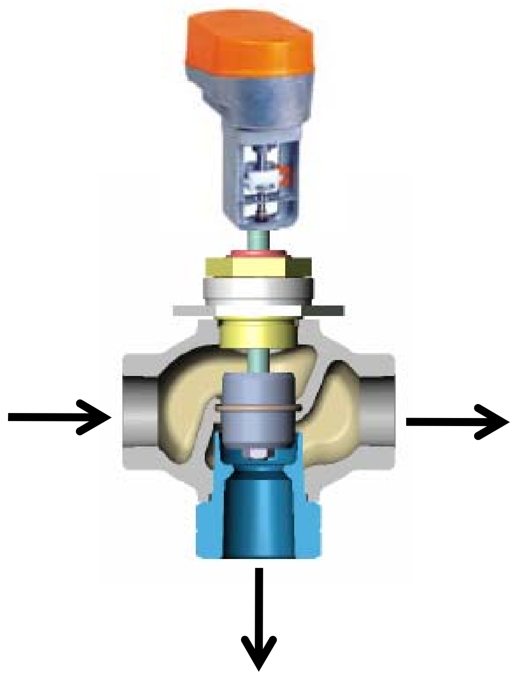
Review of the Key Control Components

Exercise-Identify the parallel vs. opposed blade dampers and the 3-way mixing vs. diverting









Courtesy Belimo

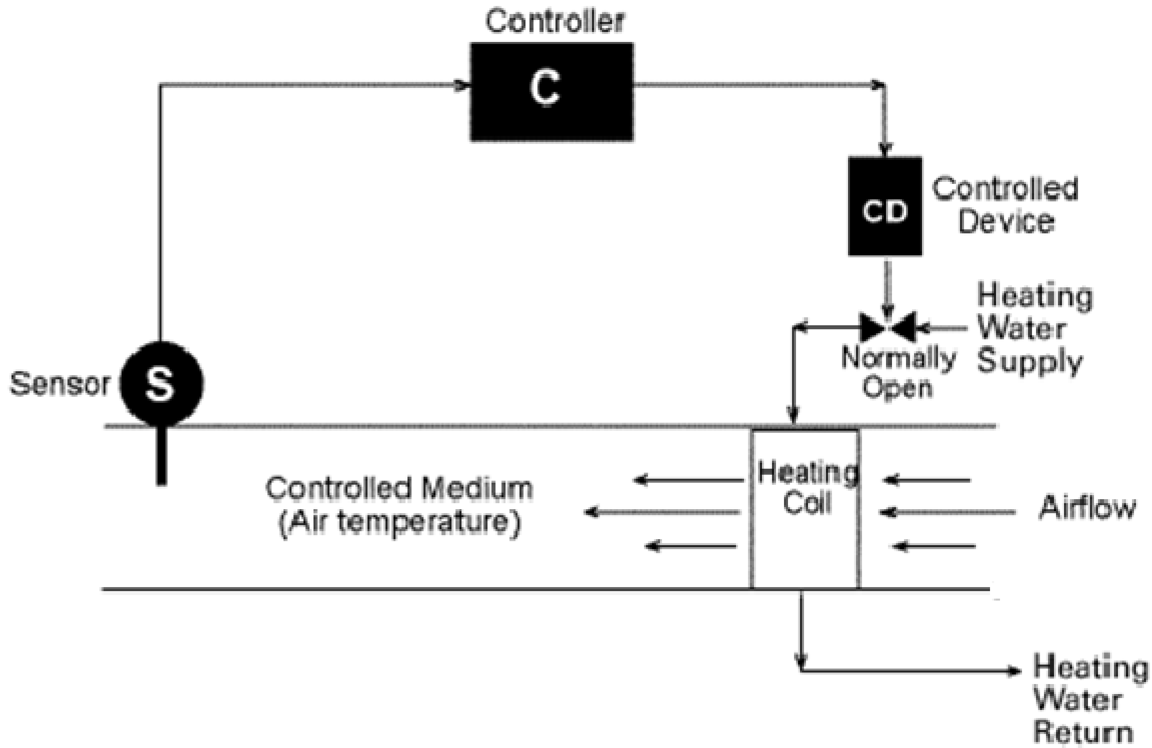
Section 4
Basic Control Loop Principles

Controllers can be either

“closed” or “open” Loop

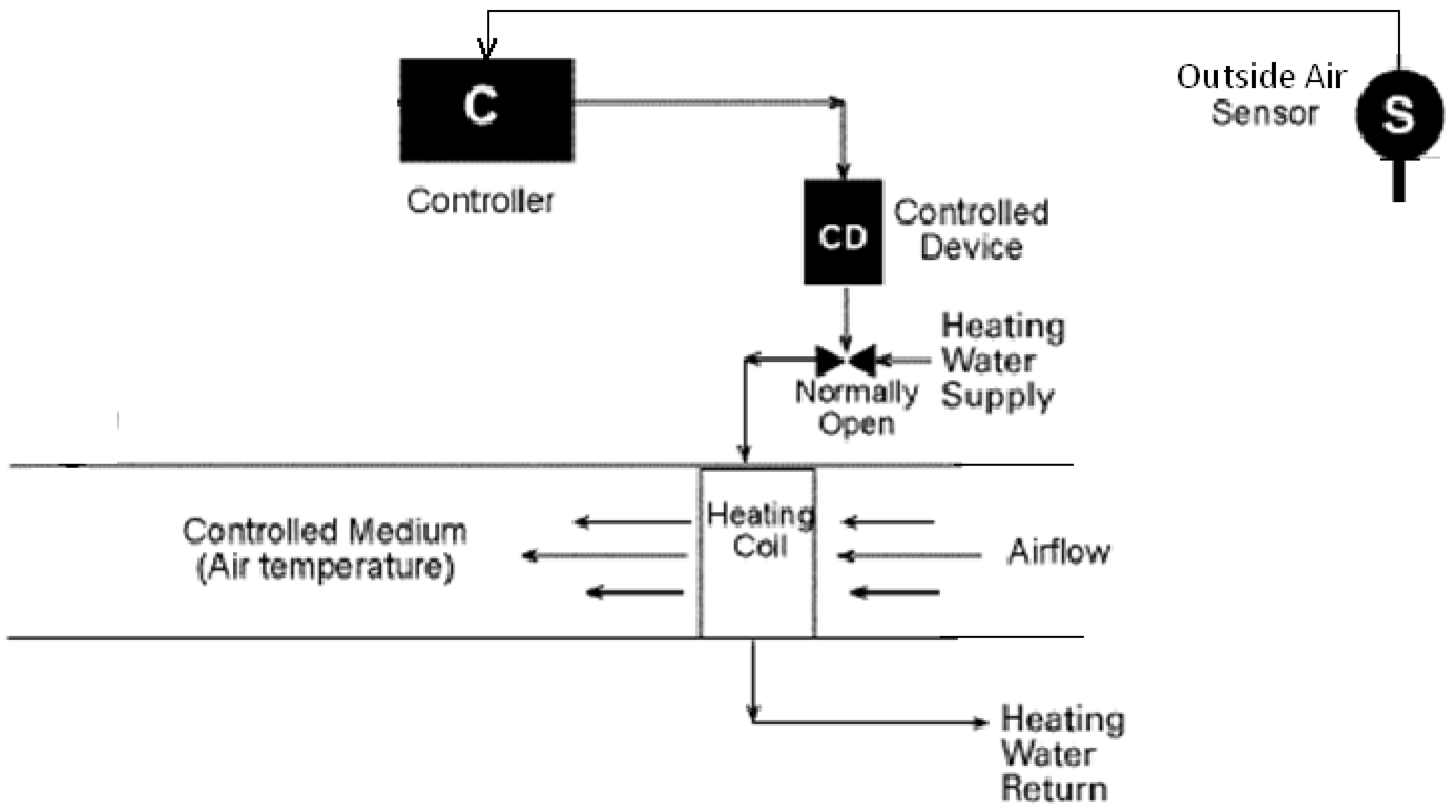
- Closes loops provide feedback-good control
- Open loops have no feedback-poor control

Basic Closed-Loop-Example
The sensor feeds back to the controller



Courtesy DDC Online Org

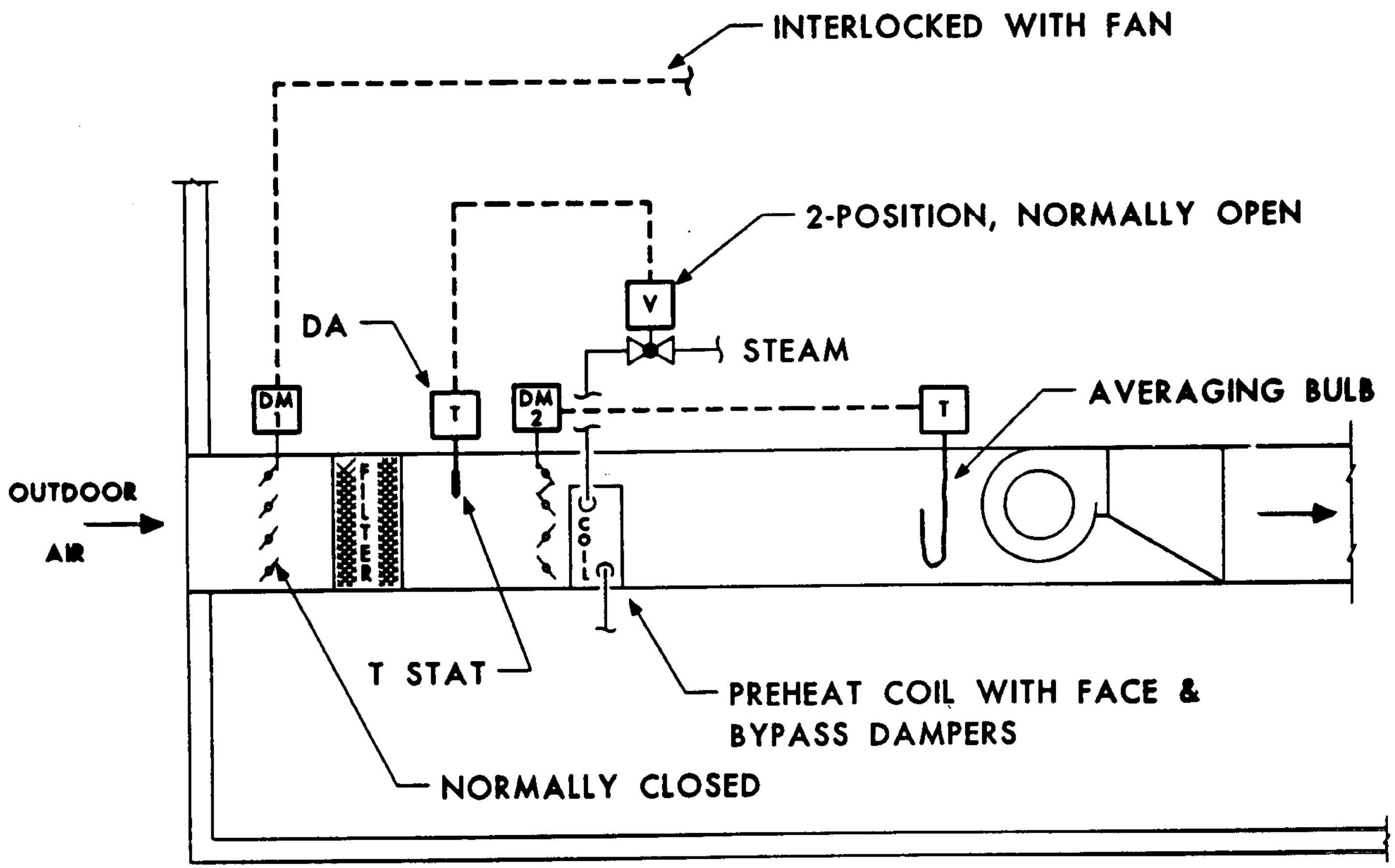
Open Loop Controls have no feedback to the controller



Courtesy DDC Online Org

Closed vs. Open Loop Control Illustration

Notice, averaging bulb is closed loop in supply air, but T-STAT between filter and coil is open loop.



PREHEAT FACE AND BYPASS DAMPERS

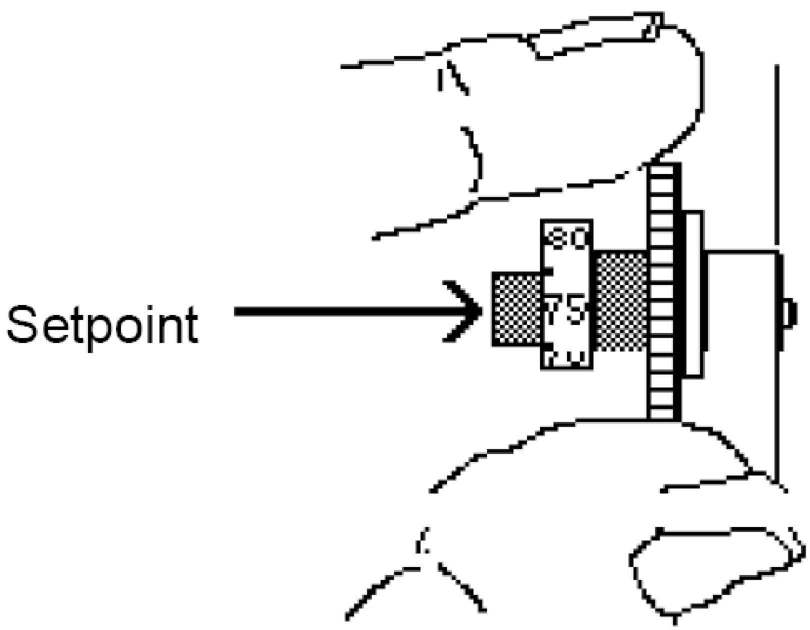
Courtesy Northwest Energy Efficiency Council

Section 5
Control Terminology

- Setpoint, offset, and control point
- Throttling range
- Span and range
- Authority
- Calibration
- Analog and digital
- Thermostat as sensor-controller

Setpoint

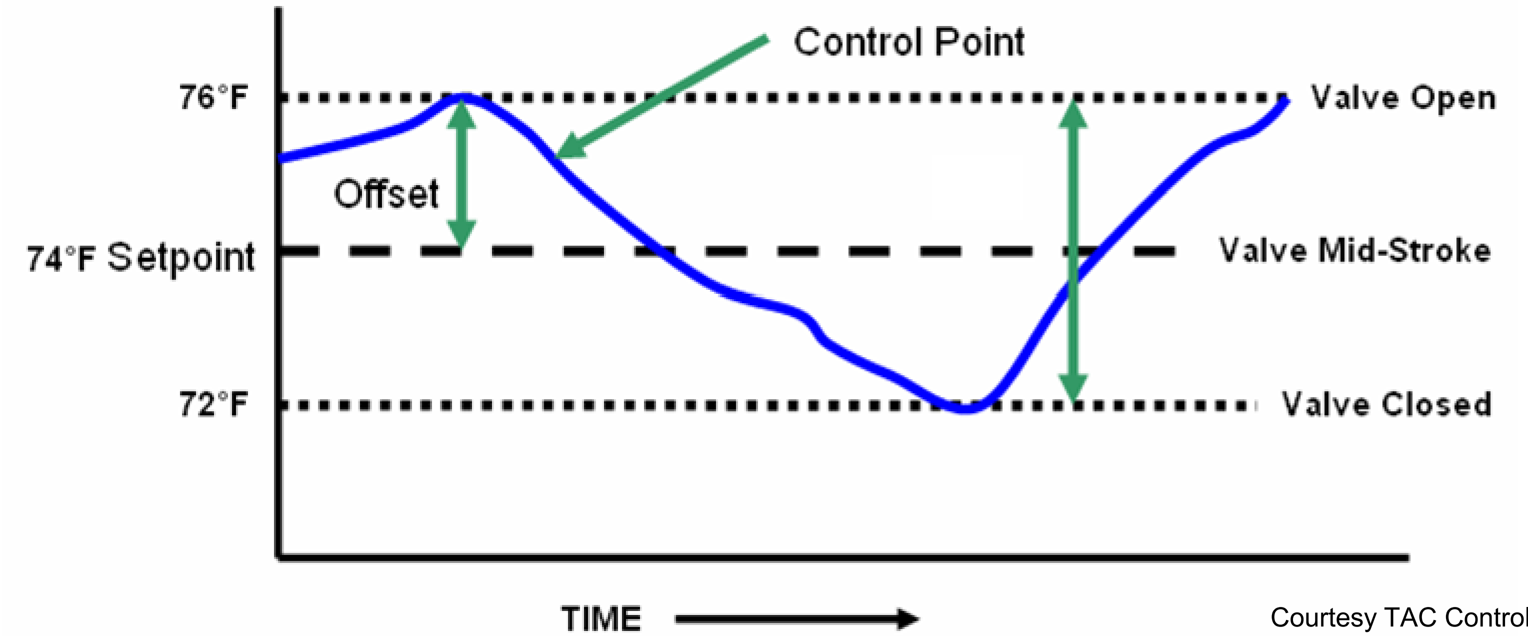
Setpoint is the desired condition of a variable that is to be maintained, such as temperature. In the example below, 75 degrees F. is the room temperature setpoint that the building occupant desires.



Courtesy TAC Controls/Schneider Electric

Control Point and Offset

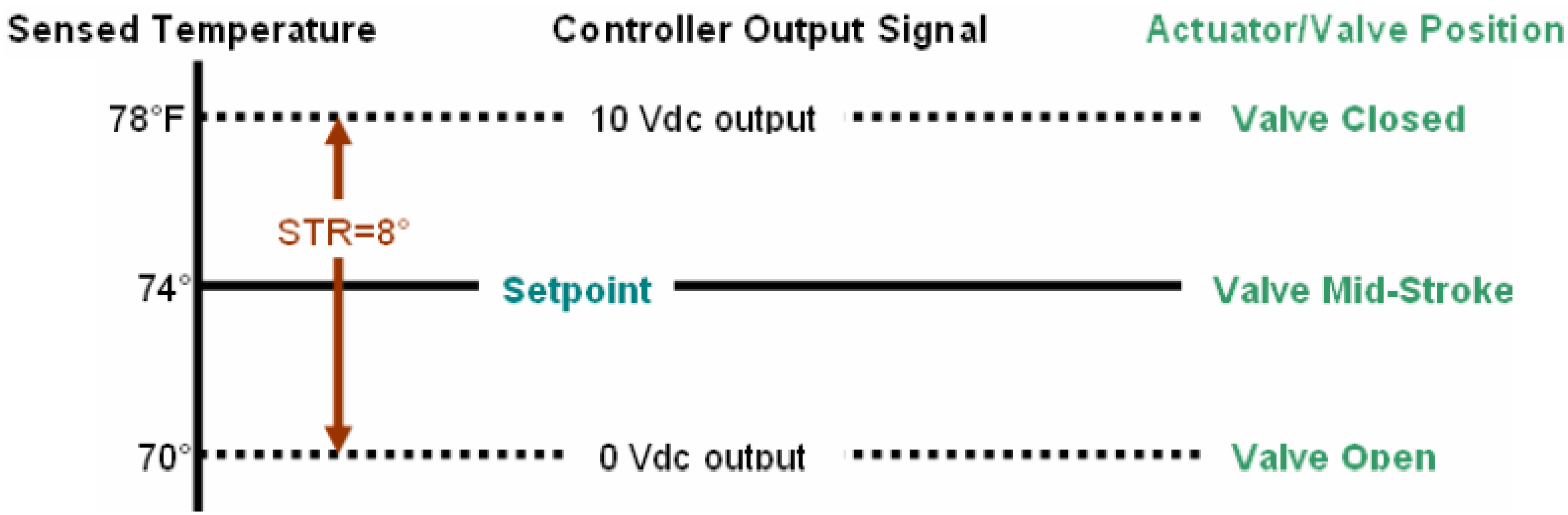
- The Control point is the actual temperature being sensed. The control point (temperature) may not be on the setpoint, but instead may be above or below it. Simply stated, setpoint is what you want, while control point is what you get. Offset is the amount of difference between control point and setpoint in a proportional control system. In the example below, the offset is approximately 4°F.



Courtesy TAC Controls/Schneider Electric

Throttling Range

- System throttling range (STR) is the *change in the measured variable (i.e., temperature) that causes the controlled device to travel from one end of its stroke to the other.*

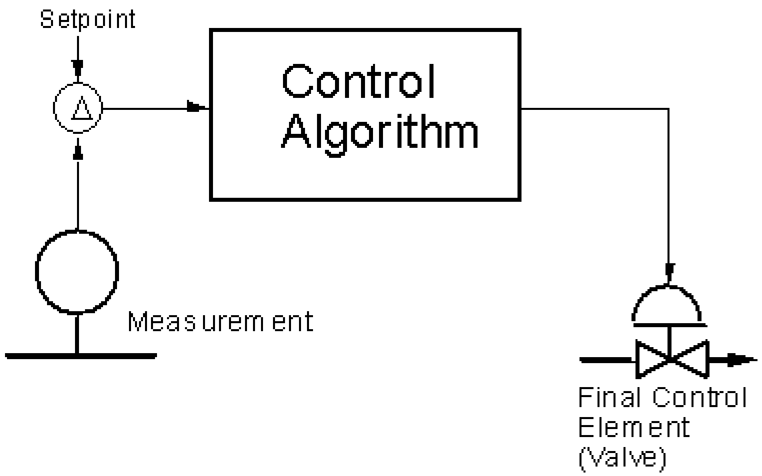


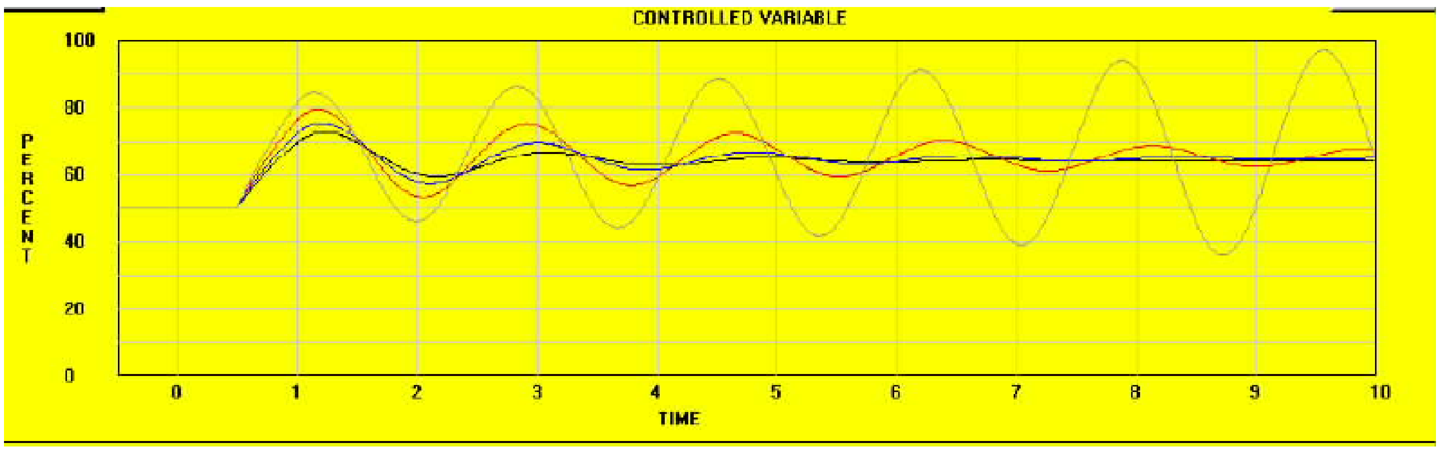
Courtesy TAC Controls/Schneider Electric

Section 6

The Control Cycle and Control Action

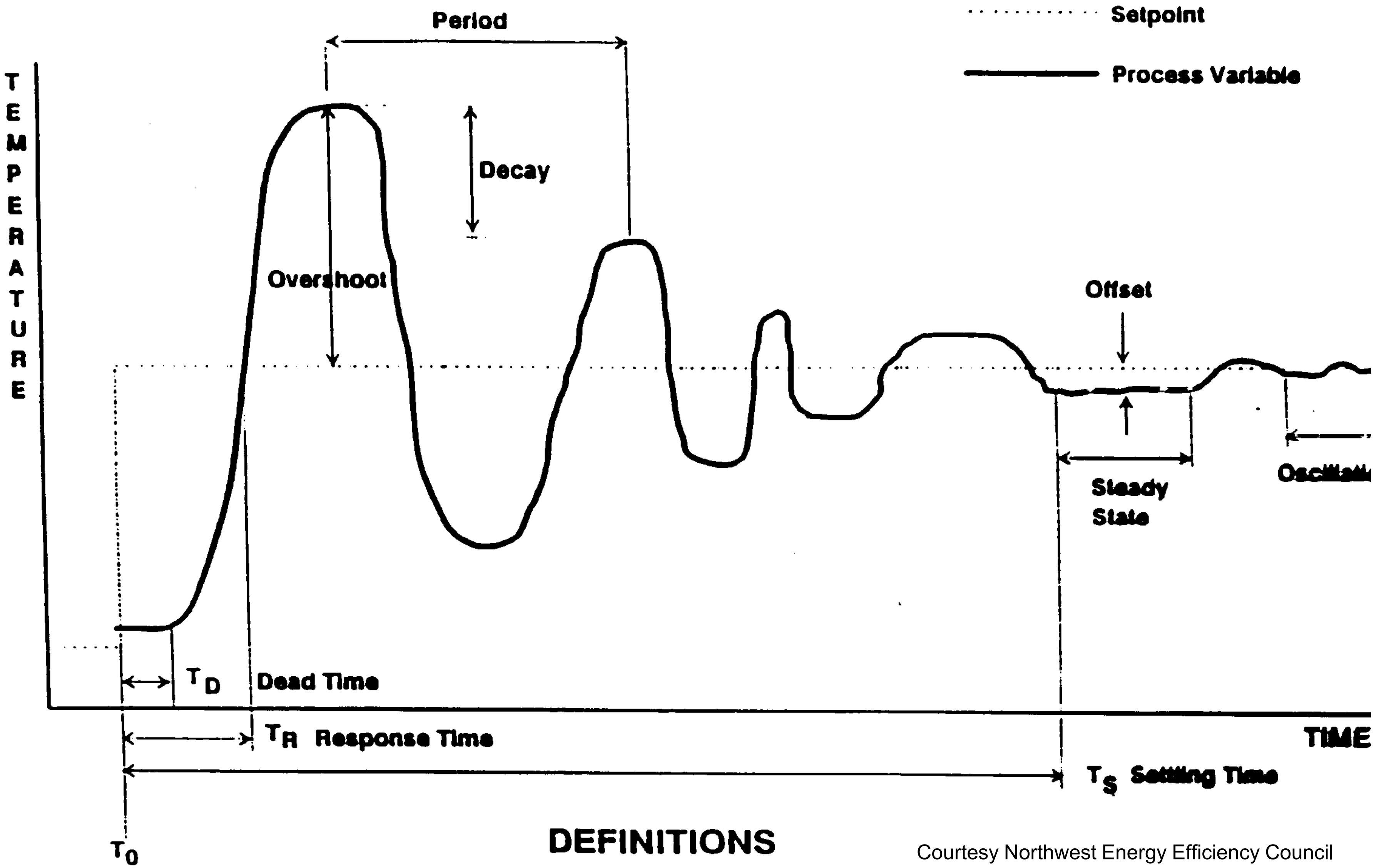
- •Two position
- •Floating action
- •Proportional action
- •PI
- •PID





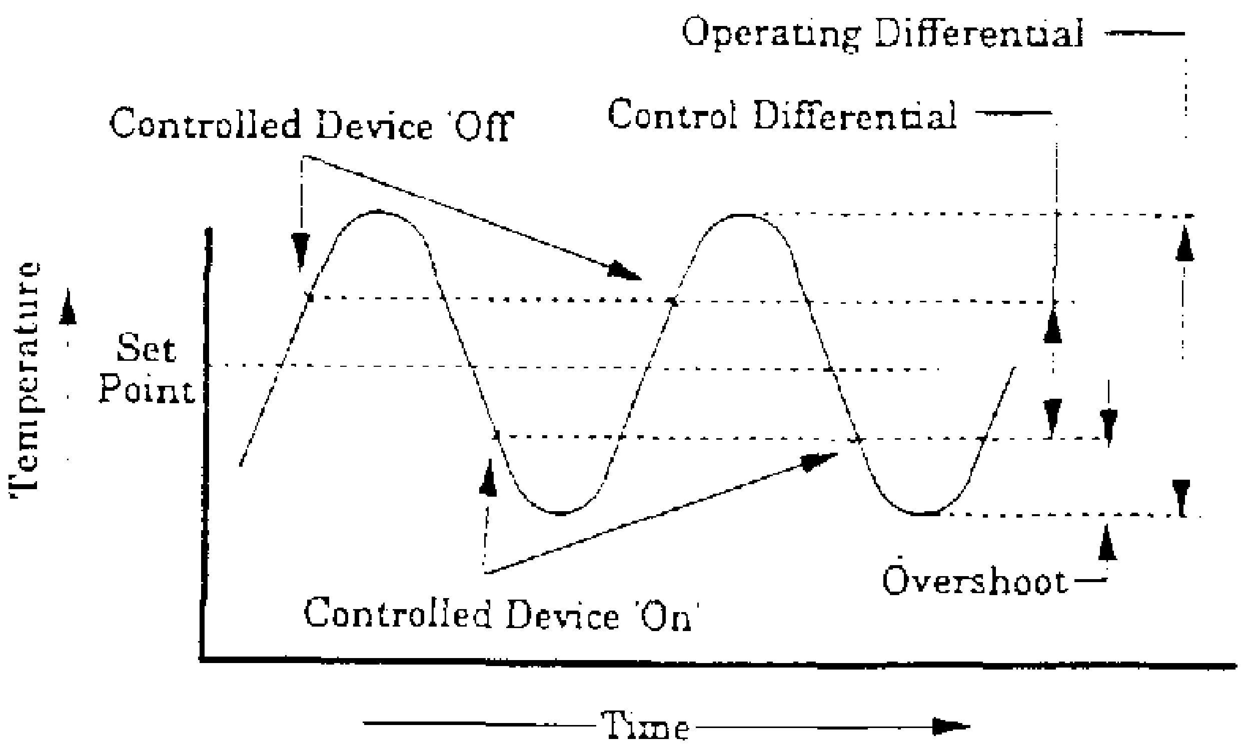
Courtesy PECI

Control Cycle Graph



Courtesy Northwest Energy Efficiency Council

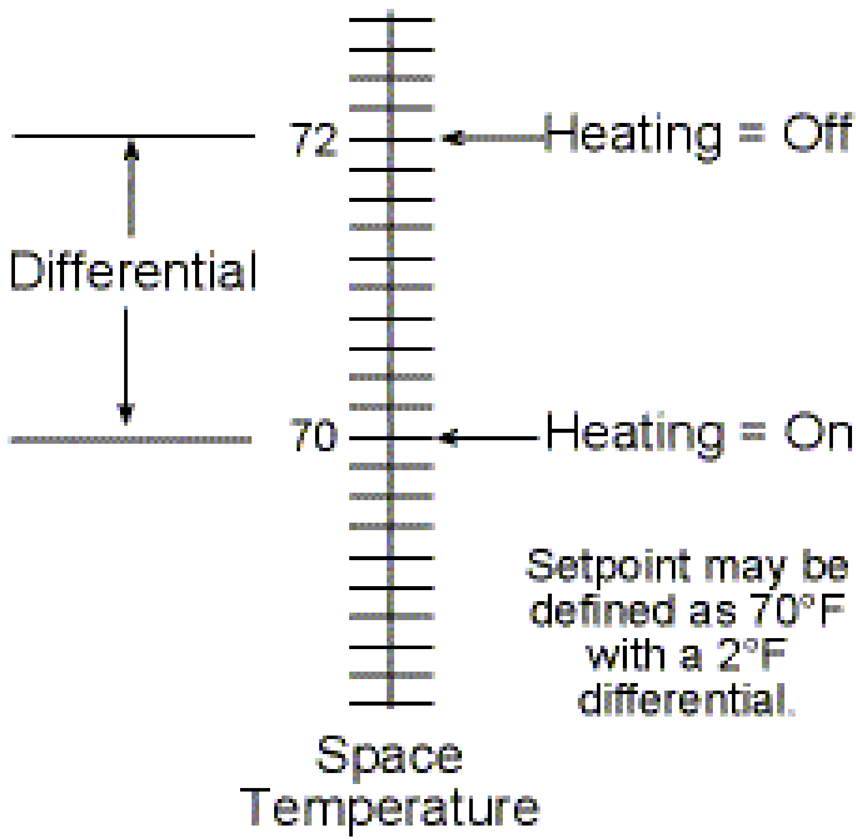
Two Position Control



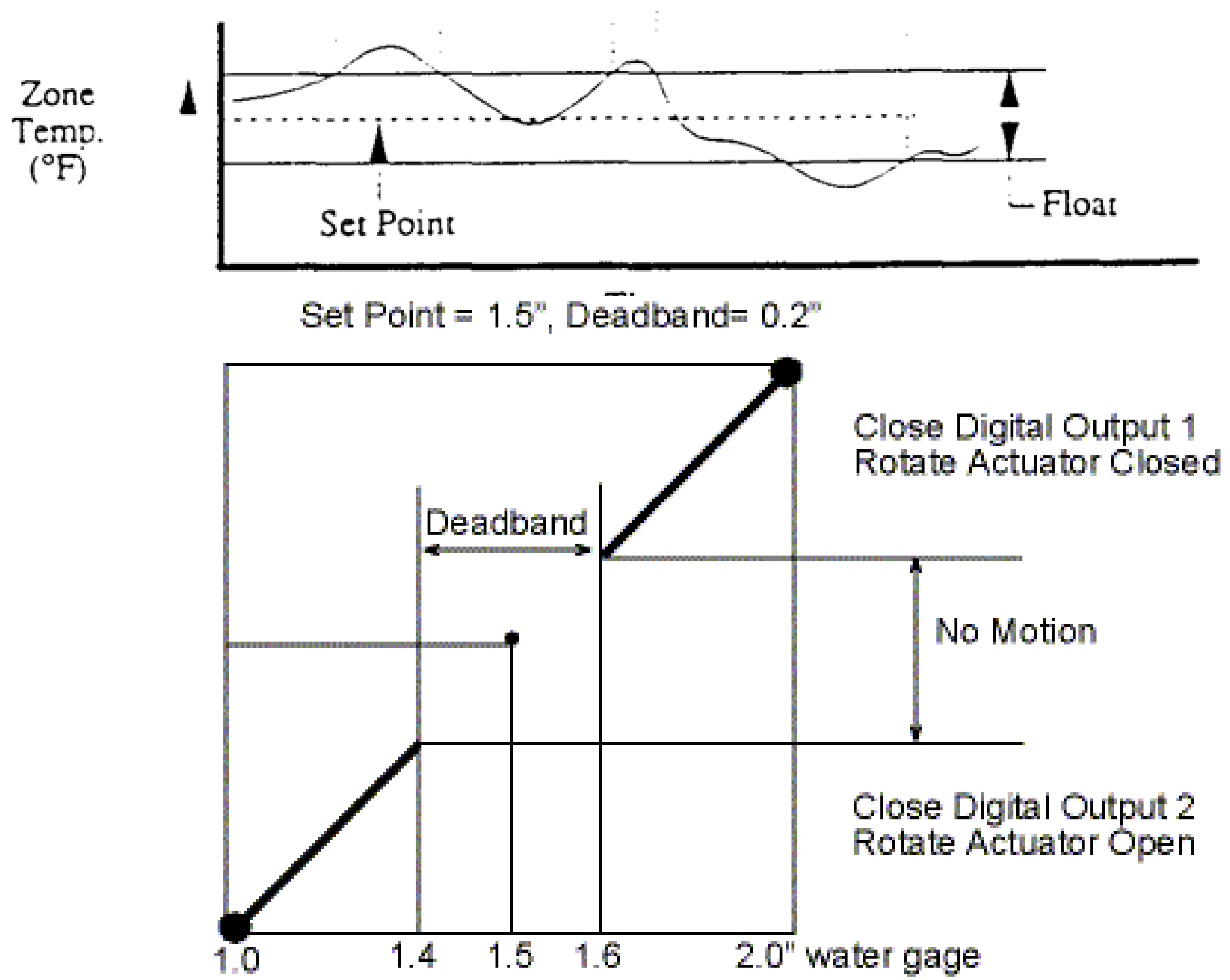
Two Position control action chart (heating action shown)

Courtesy Northwest Energy Efficiency Council

Two Position Control Response

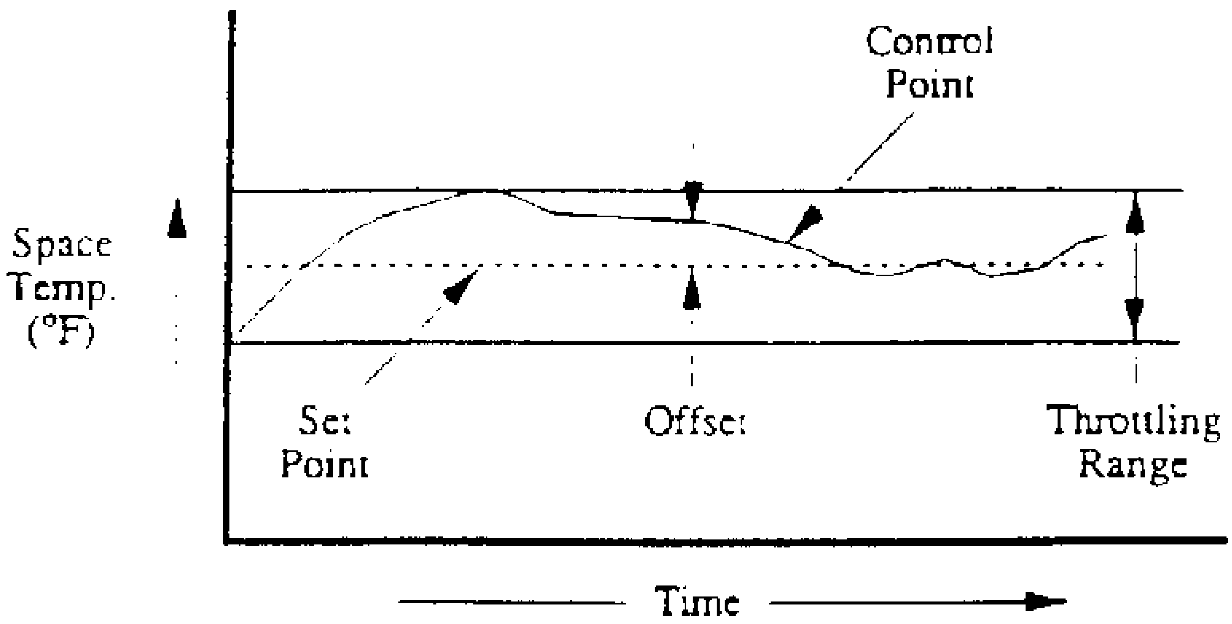


Floating Action Control



Courtesy Northwest Energy Efficiency Council

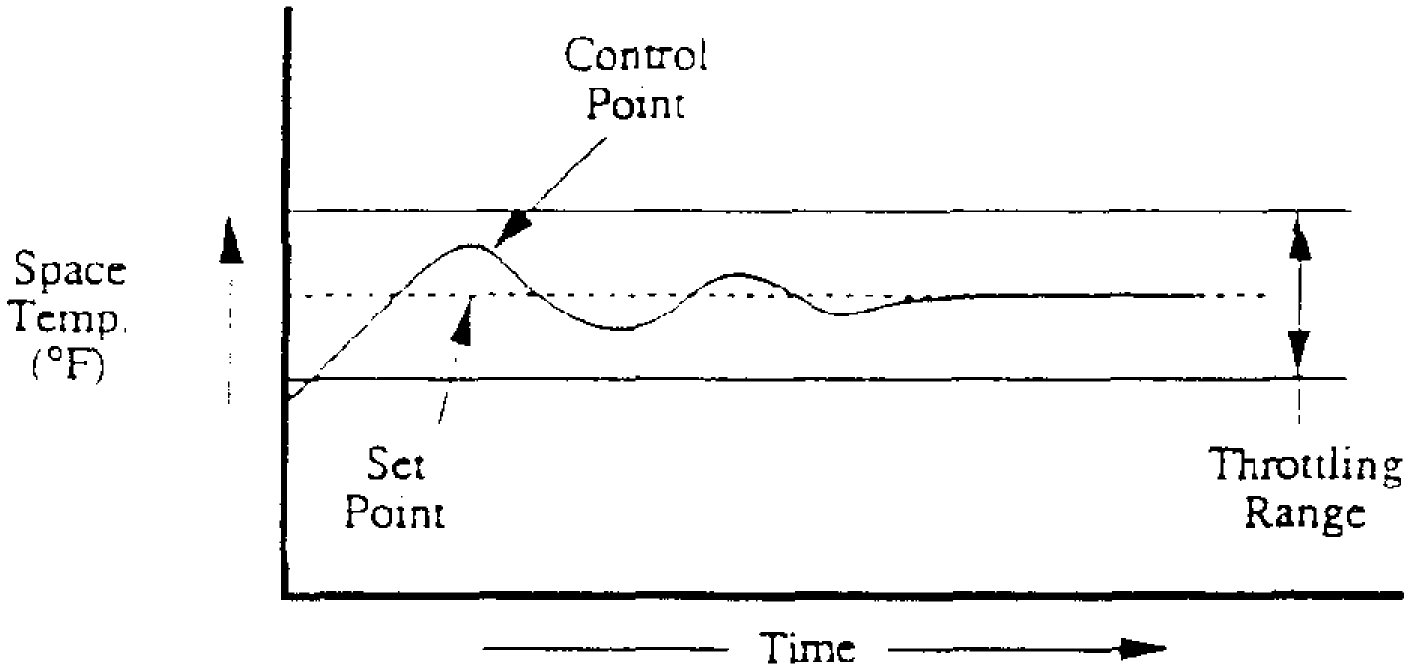
Proportional Control Action



Proportional Control Action

Courtesy Northwest Energy Efficiency Council

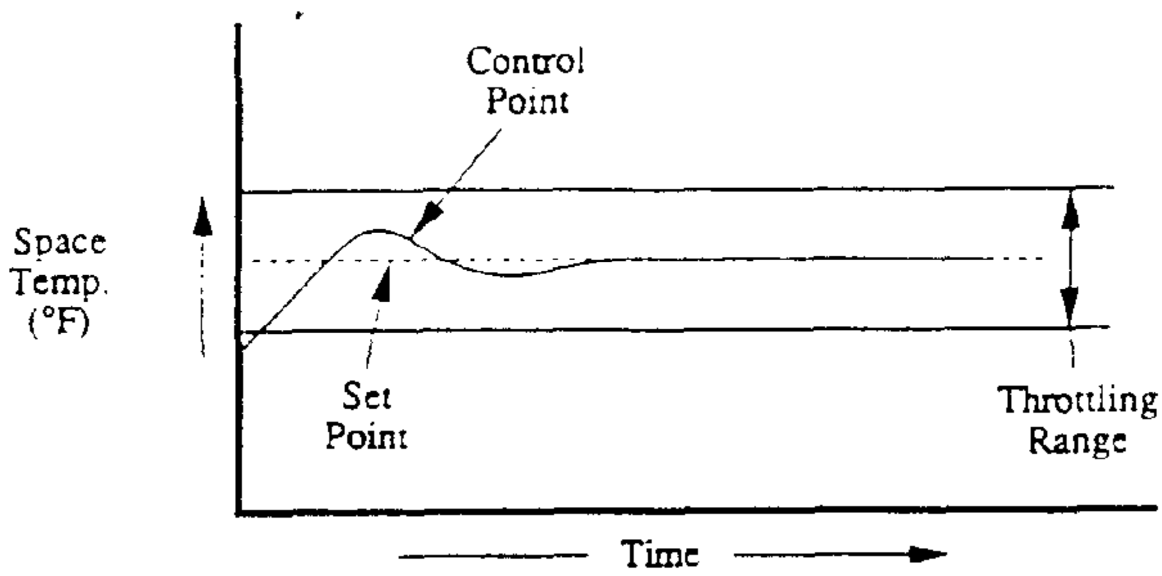
Proportional with Integral Control (PI)



Proportional Plus Integral (PI) Control Action

Courtesy Northwest Energy Efficiency Council

PID-Proportional Plus Integral & Derivative



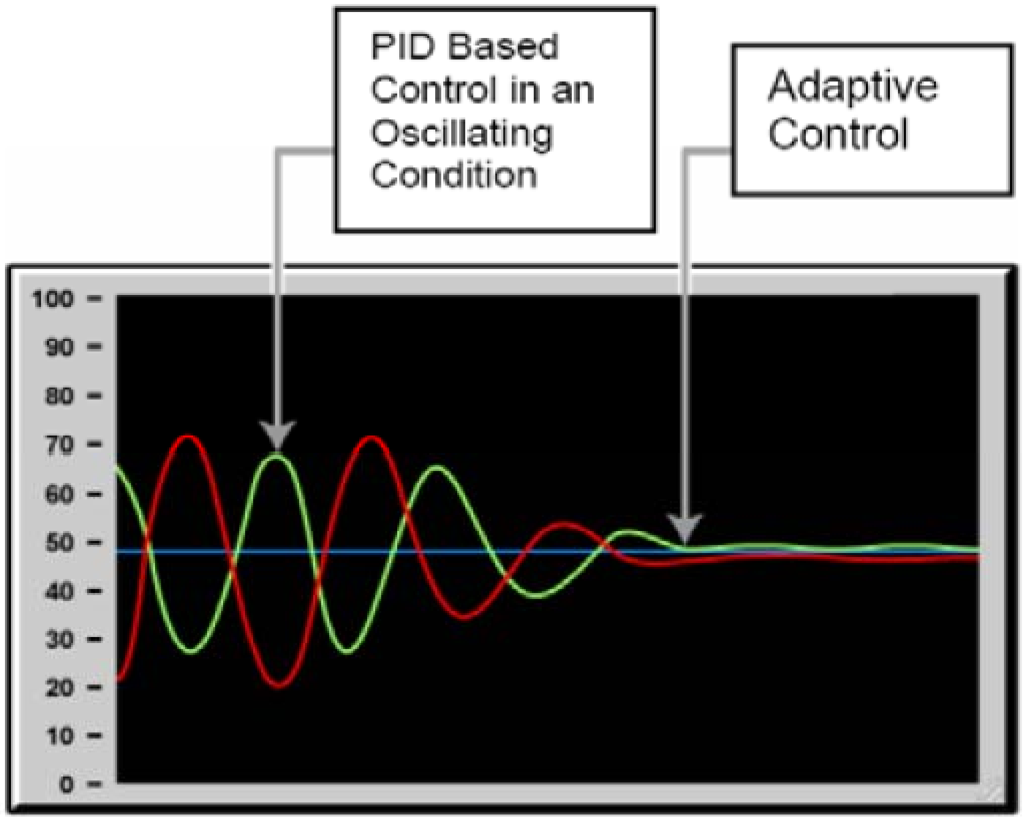
Proportional Plus Integral Plus Derivative (PID) control action

Courtesy Northwest Energy Efficiency Council

Adaptive Control

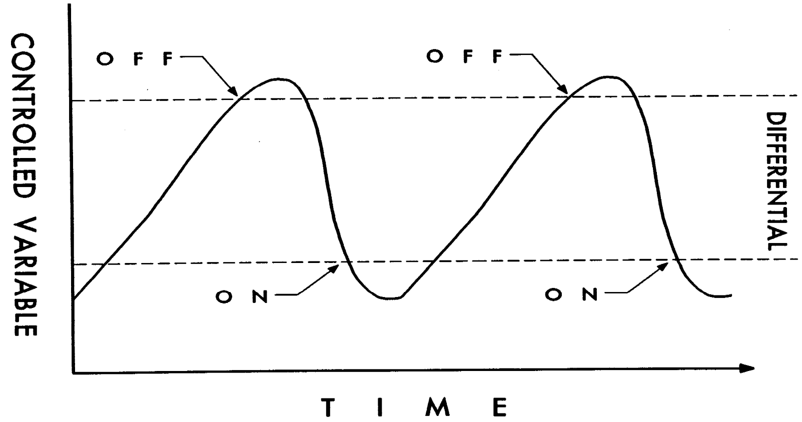
Adaptive loop tuning provides:

- Accurate, continuous loop control
- Faster tuning of loops for energy savings
- Less wear on valves, actuators, fans, pumps, dampers, VFDs, etc.



Review of Control Cycles

Exercise; study the drawings and identify the control loop types as either: 2-position, proportional, or PI Control



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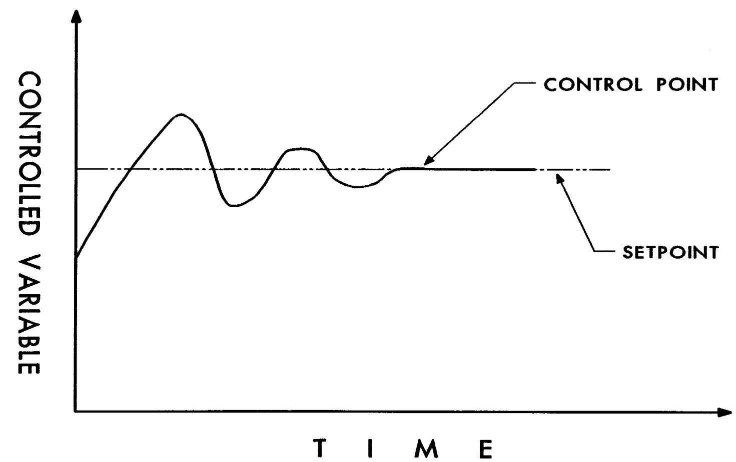

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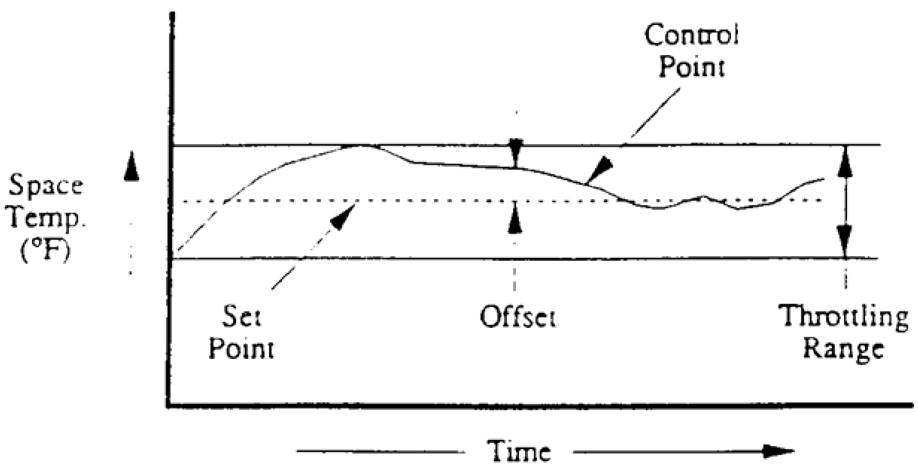

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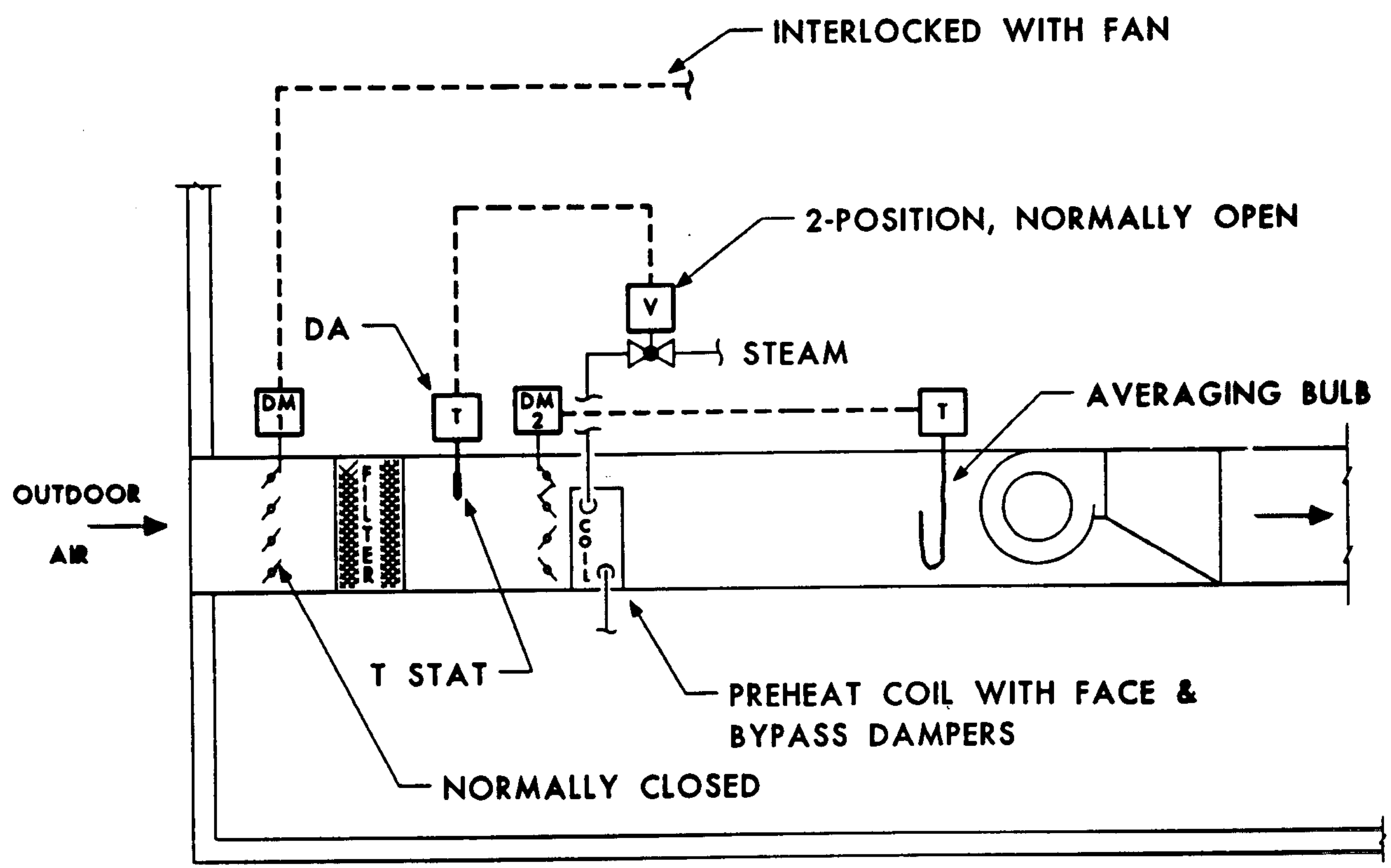
Courtesy Northwest Energy Efficiency Council

Review of Control Cycles

Exercise; identify and circle the closed loop vs. the open loop controls.

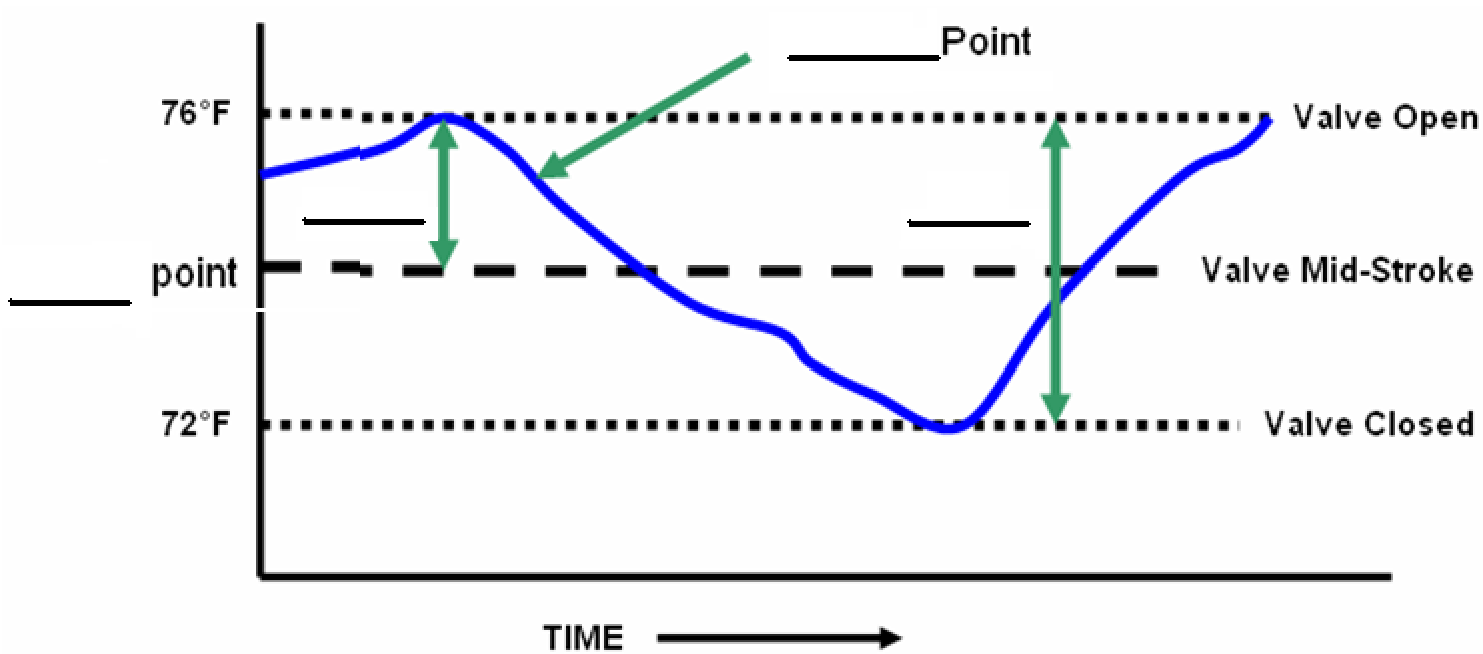


PREHEAT FACE AND BYPASS DAMPERS

Courtesy Northwest Energy Efficiency Council

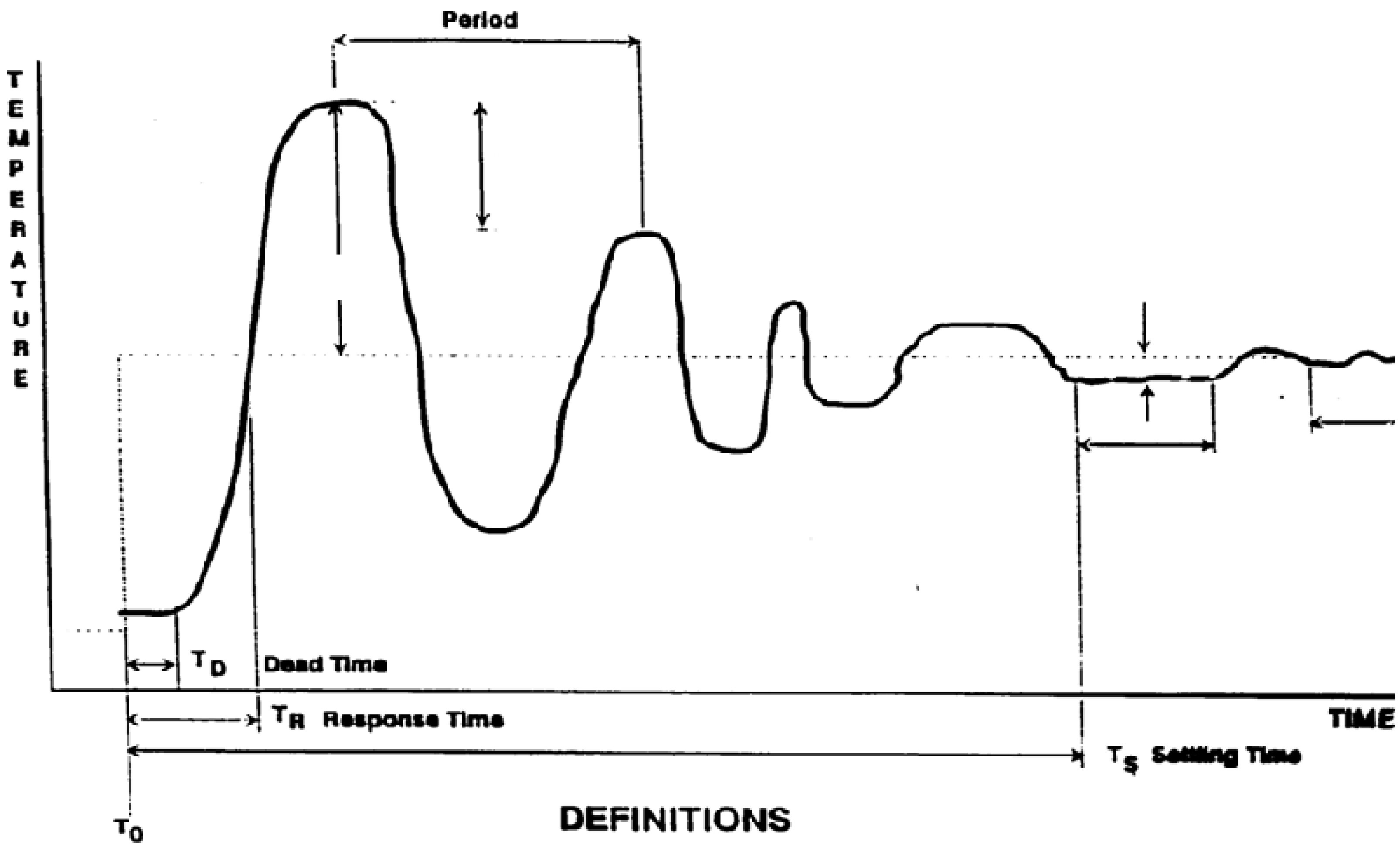
Review of Control Cycles

Exercise; review the drawing and identify setpoint, control point, TR, and offset.



Courtesy TAC Controls/Schneider Electric

Review of DDC Terminology Exercise; identify the missing terms



Courtesy Northwest Energy Efficiency Council

Section 7
Control Energy Sources

A power supply or source of energy is needed to power the control system. Control systems use either a pneumatic or electric power supply.

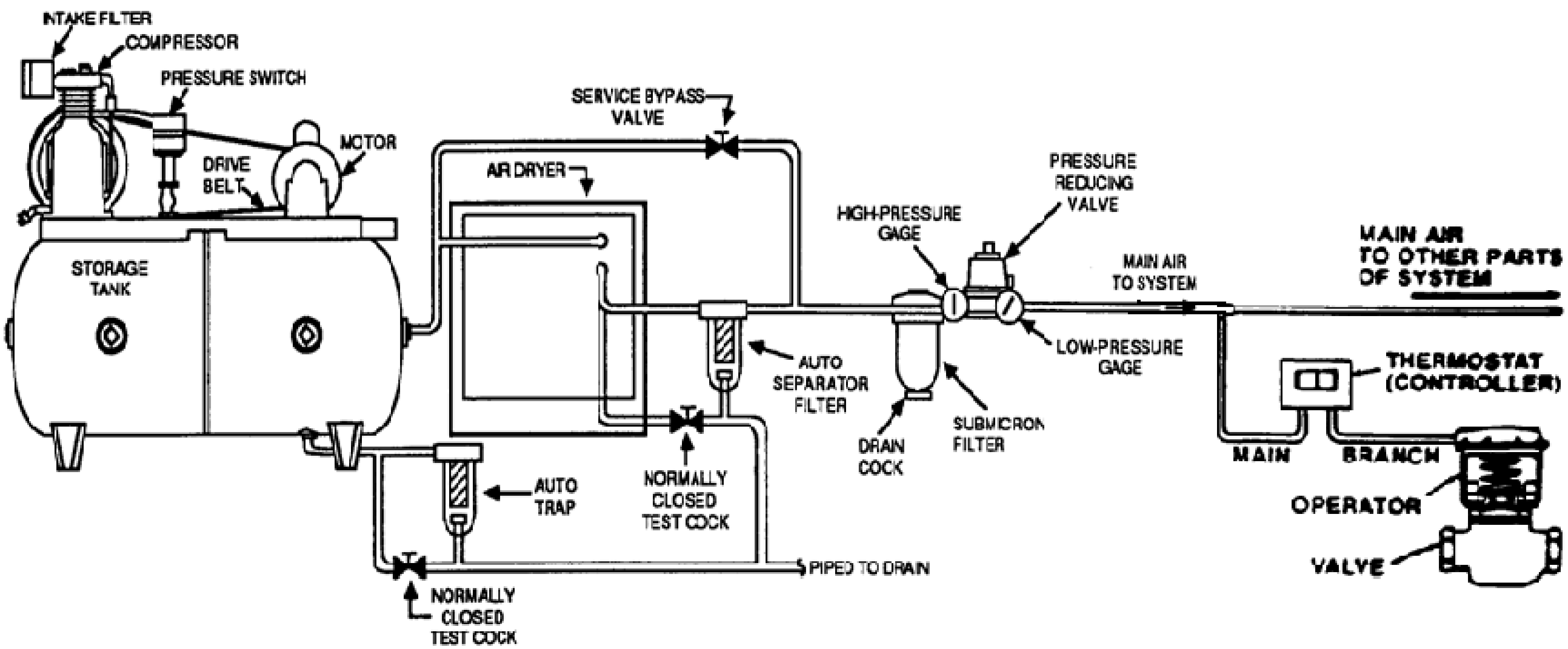
- **Pneumatic controls** use a compressed gas as a source of energy, typically compressed air.
- **Electric and electronic controls** could be powered by a variety of electrical power supplies of either alternating current (AC) or direct current (DC).
- **DDC-Direct digital controls** are considered electronically powered via a network of controls.

Comparing Advantages And Disadvantages

of pneumatics and DDC controls

- Pneumatic control systems
  - Low maintenance, ease of testing
  - Hard to integrate into DDC systems
  - Requires air compressor station
- DDC – Direct digital control
  - High accuracy
  - Flexible, easy to access
  - Programmable
- Energy management considerations
  - Easy to optimize, reduce kW peaks, schedule

Basic Pneumatic Control System
The Air Station Components



Courtesy Honeywell Controls

Basic Pneumatic Control System

Conventional Pneumatic Control Systems

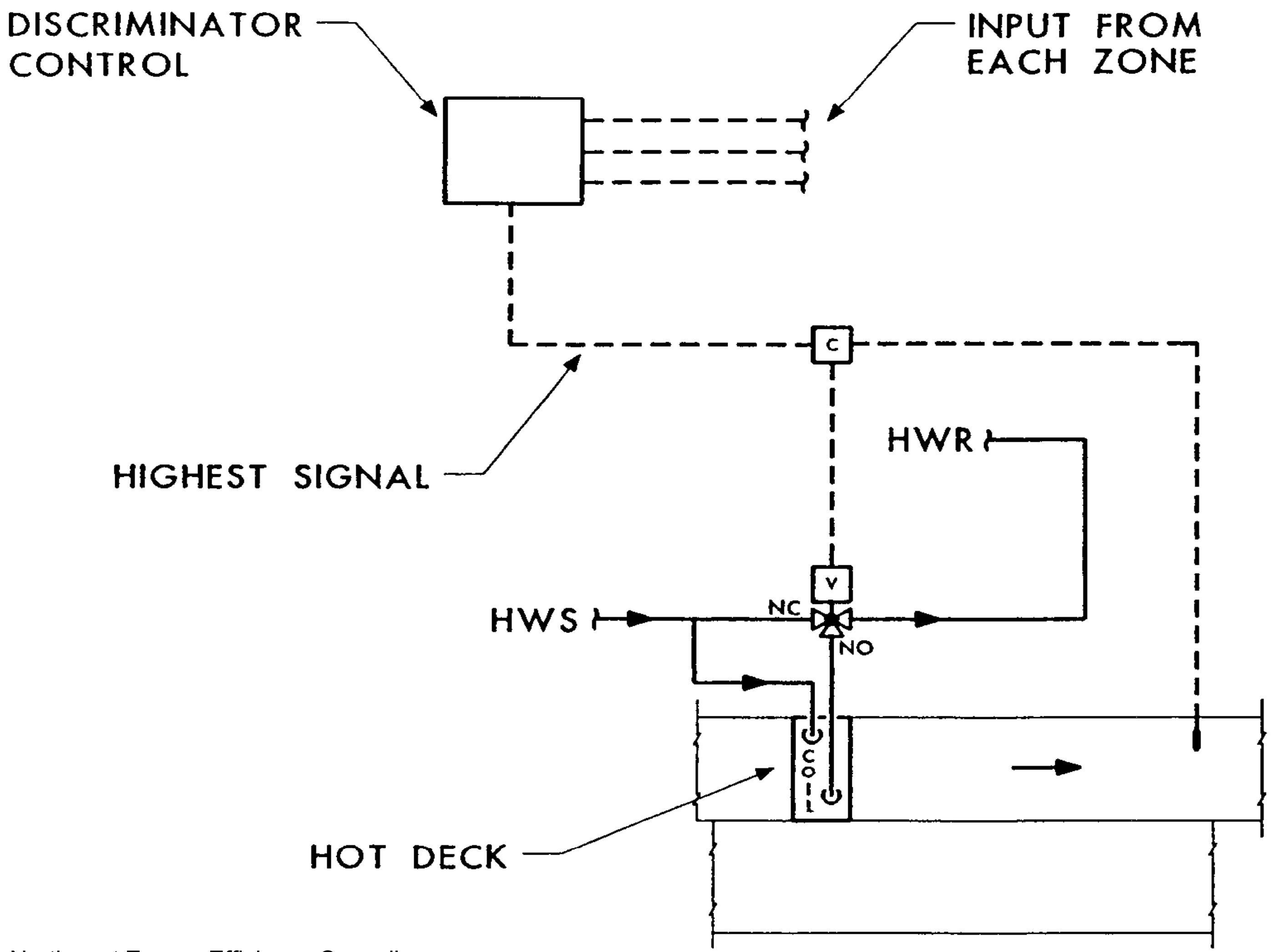
Requirements:

- Clean and dry air supply
- Pressure reducing valve
- Utilizes pneumatic controllers
- Pneumatic devices

Pneumatic Controls Include:

- Thermostats that can be either:
  - Room type
  - Dead band types
  - Dual pressure type
- Humidistats
- Receiver controllers
  - Combine 2 sensors into 1 receiver with reset setpoint options
  - Utilizes either one pipe or two pipes
  - Sensors

Pneumatic Control of Heating Coil Control with Reset



Courtesy Northwest Energy Efficiency Council

Pneumatic Control System Accessories

Pneumatic relays:

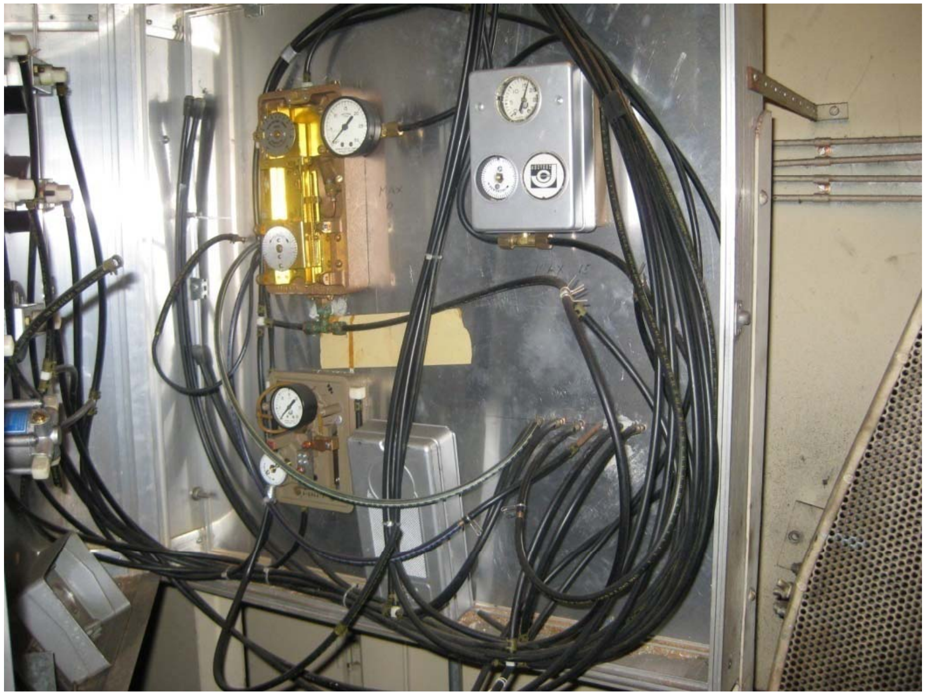
- Reversing relay
- High/low pressure selector
- Air motion
- Signal repeating
- Minimum position
- EPs and PEs

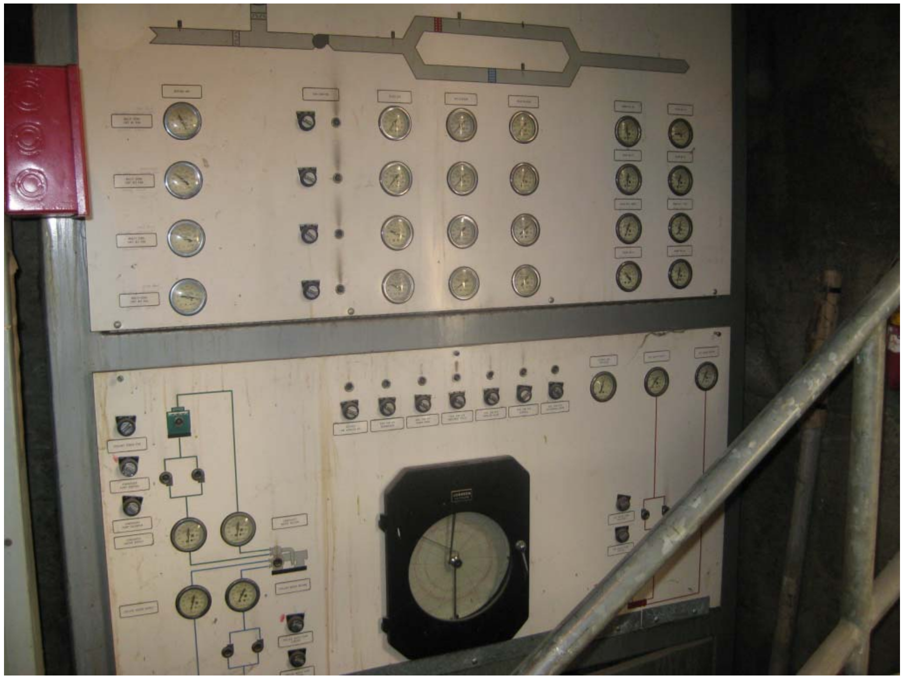
Pneumatic Switch

EP-Electric to Pressure Switch

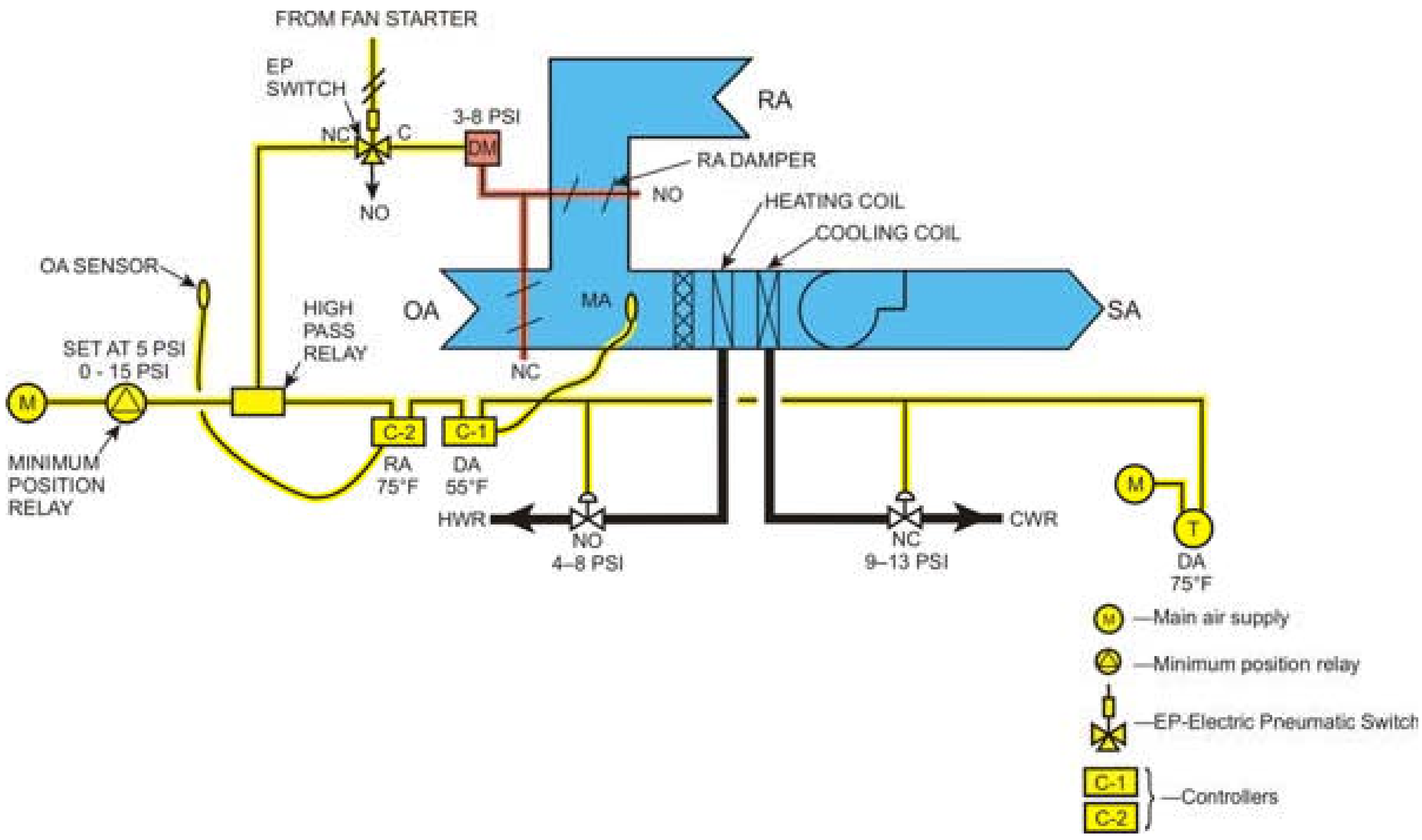
PE-Pressure to Electric Switch

Basic Pneumatic Control System



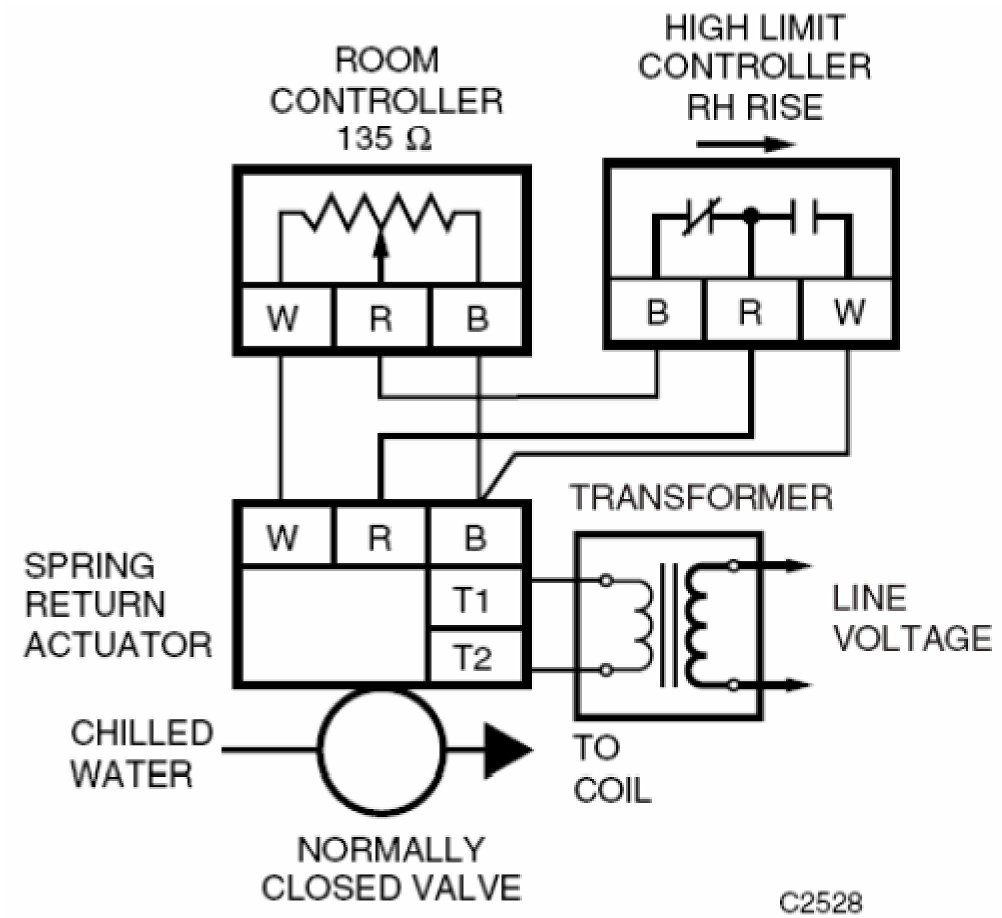


Example of Pneumatic Controls



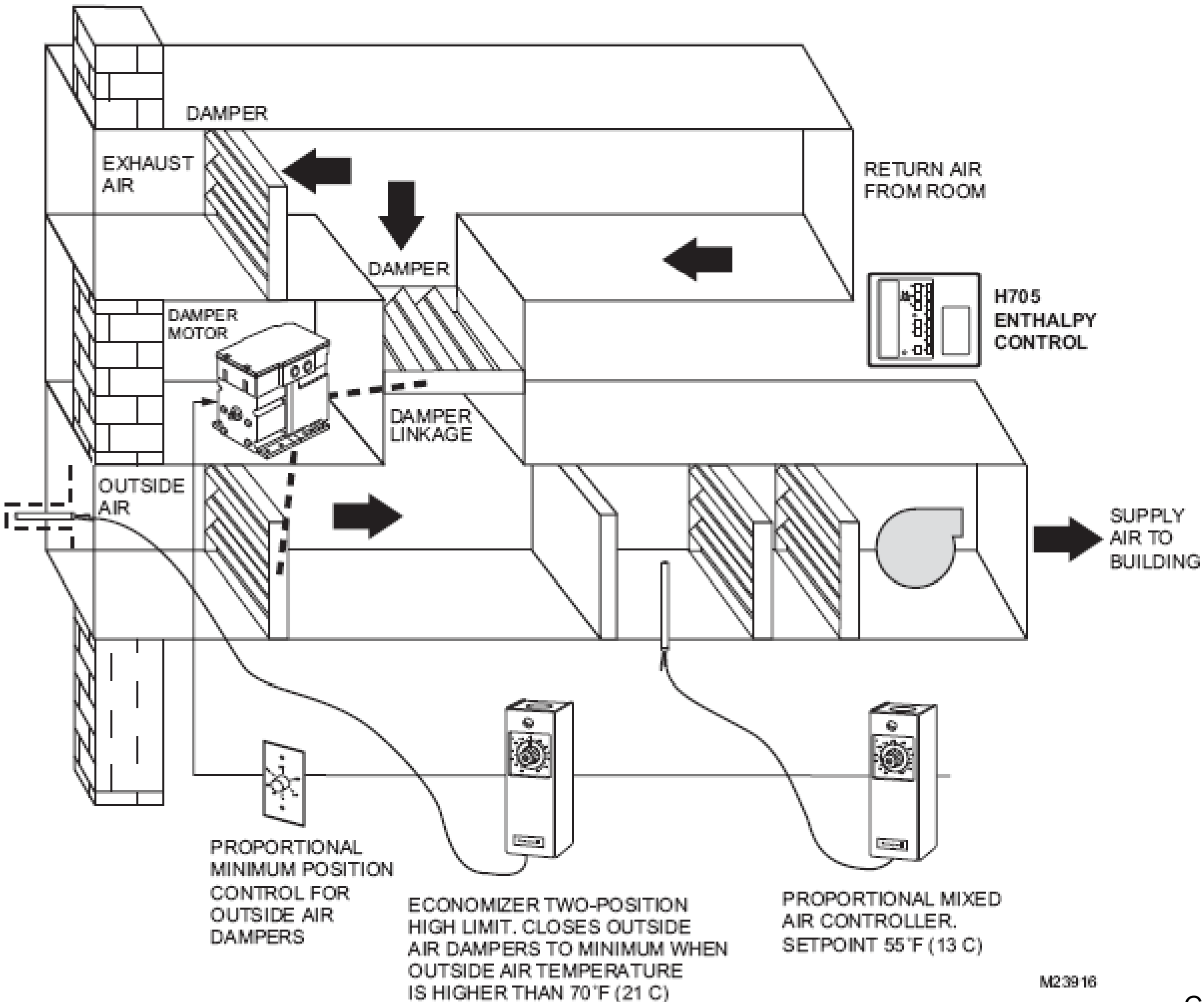
Courtesy LAMA Books

Basic Electric Control



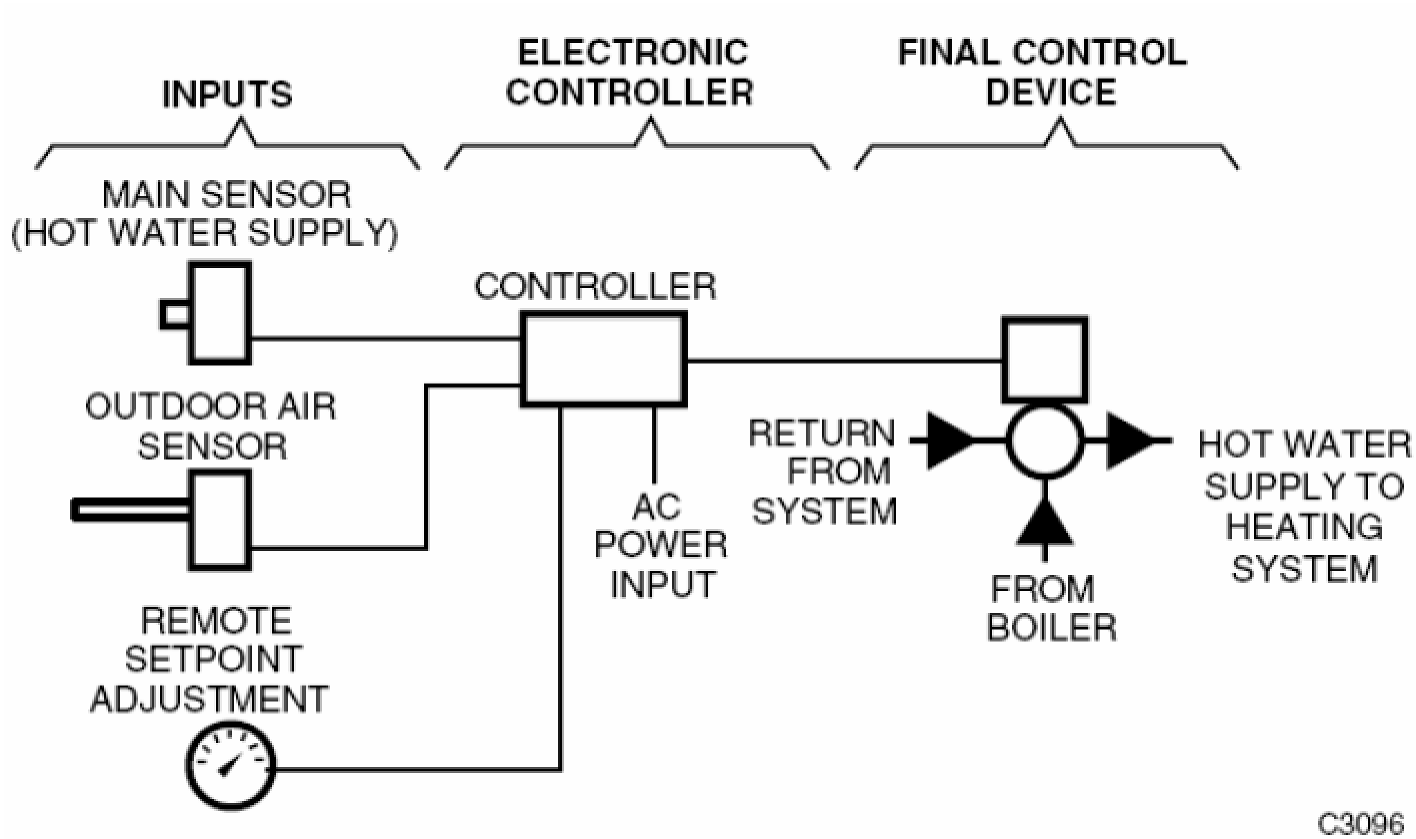
Courtesy Honeywell Controls

Example of Electric Controls for Economizers



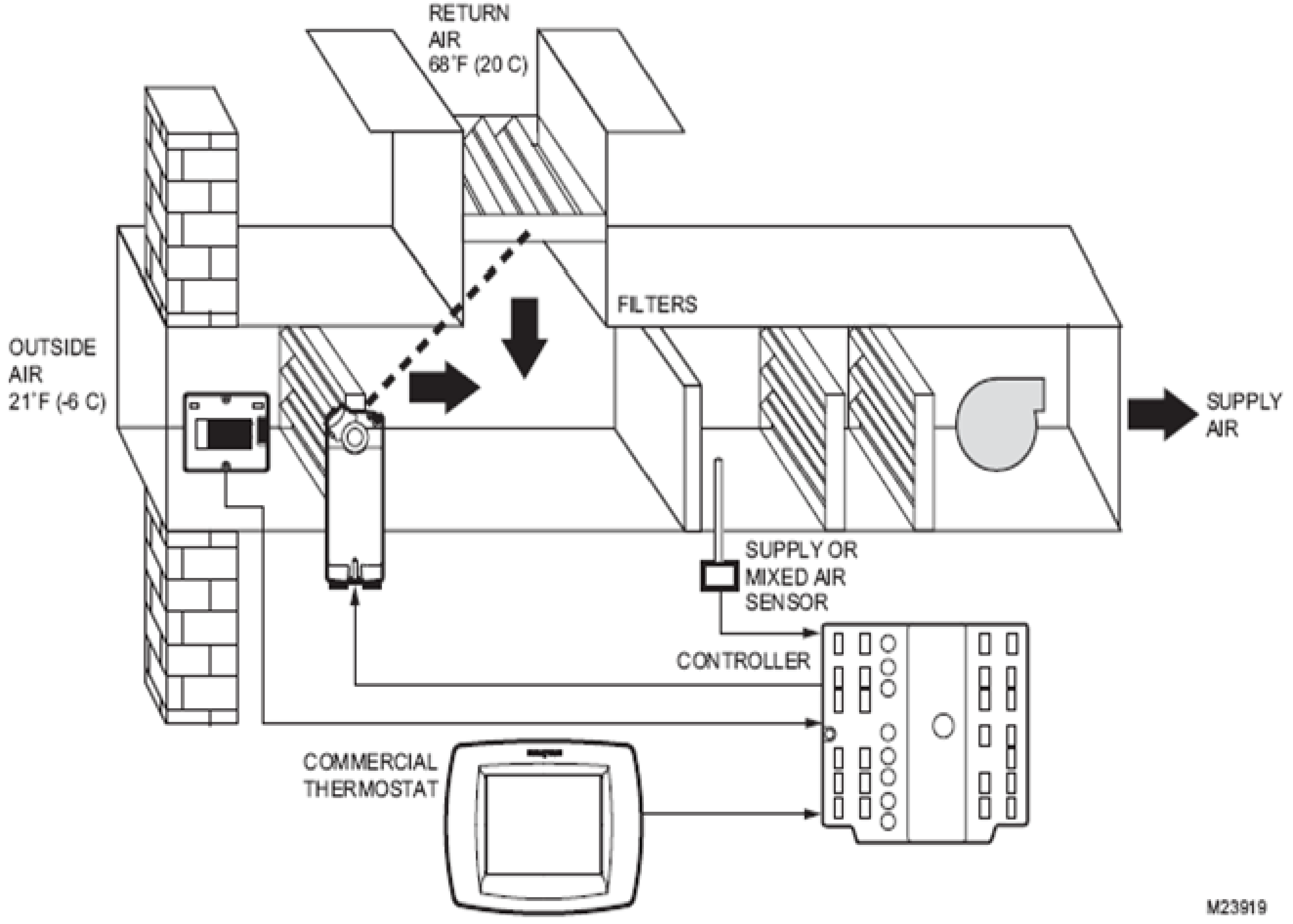
Courtesy Honeywell Controls

Simple Electronic Control System



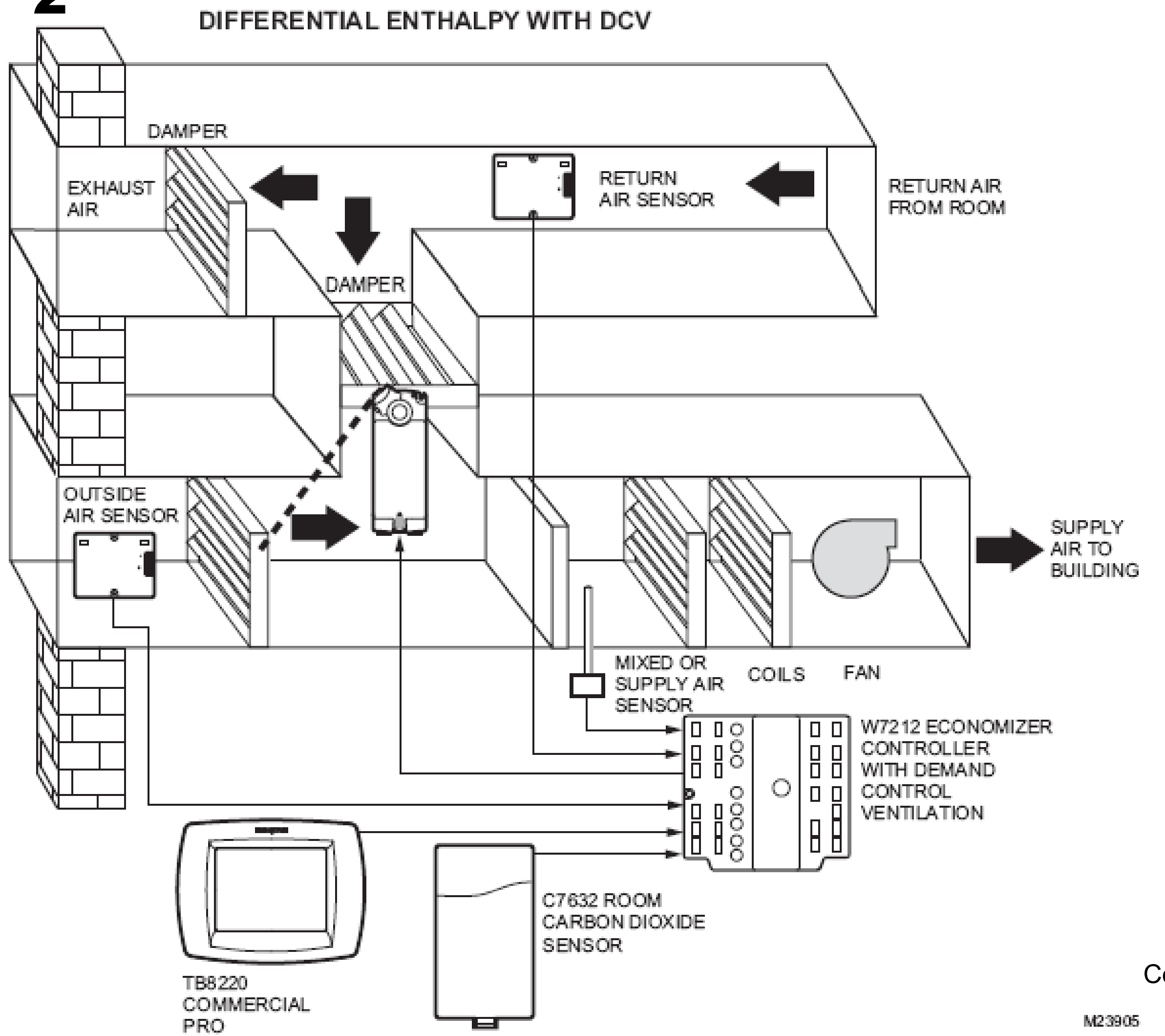
Courtesy Honeywell Controls

Example of Electronic Control for Basic AHU Economizer Control



Courtesy Honeywell Controls

Example of Electronic Control for Economizers with Differential Enthalpy and CO_2 Demand Ventilation Control



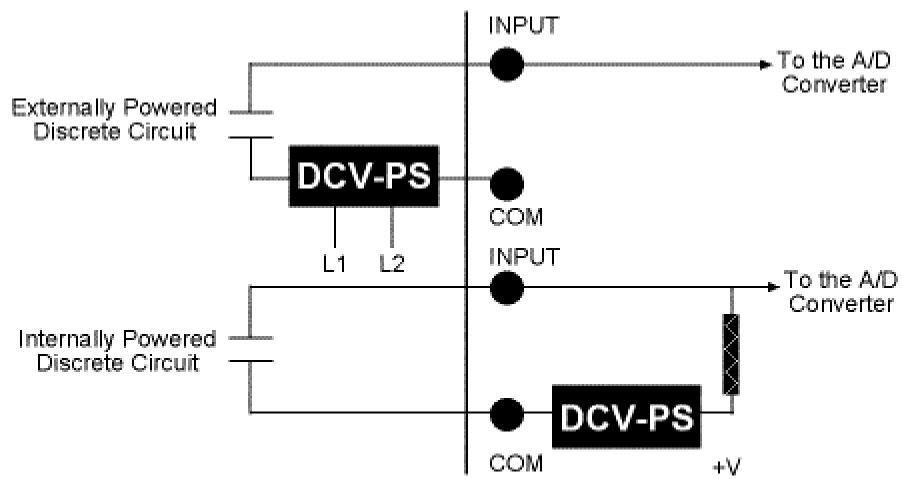
Courtesy Honeywell Controls

Section 8-DDC Point Types

Input and Output Point Types Chart

	Input	Output
Digital	Two state information from the building into the DDC field panel	Two state information from DDC field panel to the building
	Switches:	On/Off - fans, pumps, lights
	Differential press/proof	Open/Close, two position damper
	Smoke alarms	Control of two-speed motors
	Level alarm	Energize/de-energize valves for heat/cool changeovers
	High/low pressure alarm	
	Filter status	
Analog	Variable information from the building into the DDC control panel	Variable information from the DDC control panel out to the building
	Temperature-Room, duct, OSA	Modulate valves, dampers, actuators
	Humidities-Room, duct, OSA	Motor speed control – VSDs
	Pressure-Static, velocity, total	Modulate volume dampers
	Flow rates-Water and air systems	Adjust air pressure to pressure operated devices
	kWh power, volts, and amps	

DDC Control System Digital Input (DI) Illustration



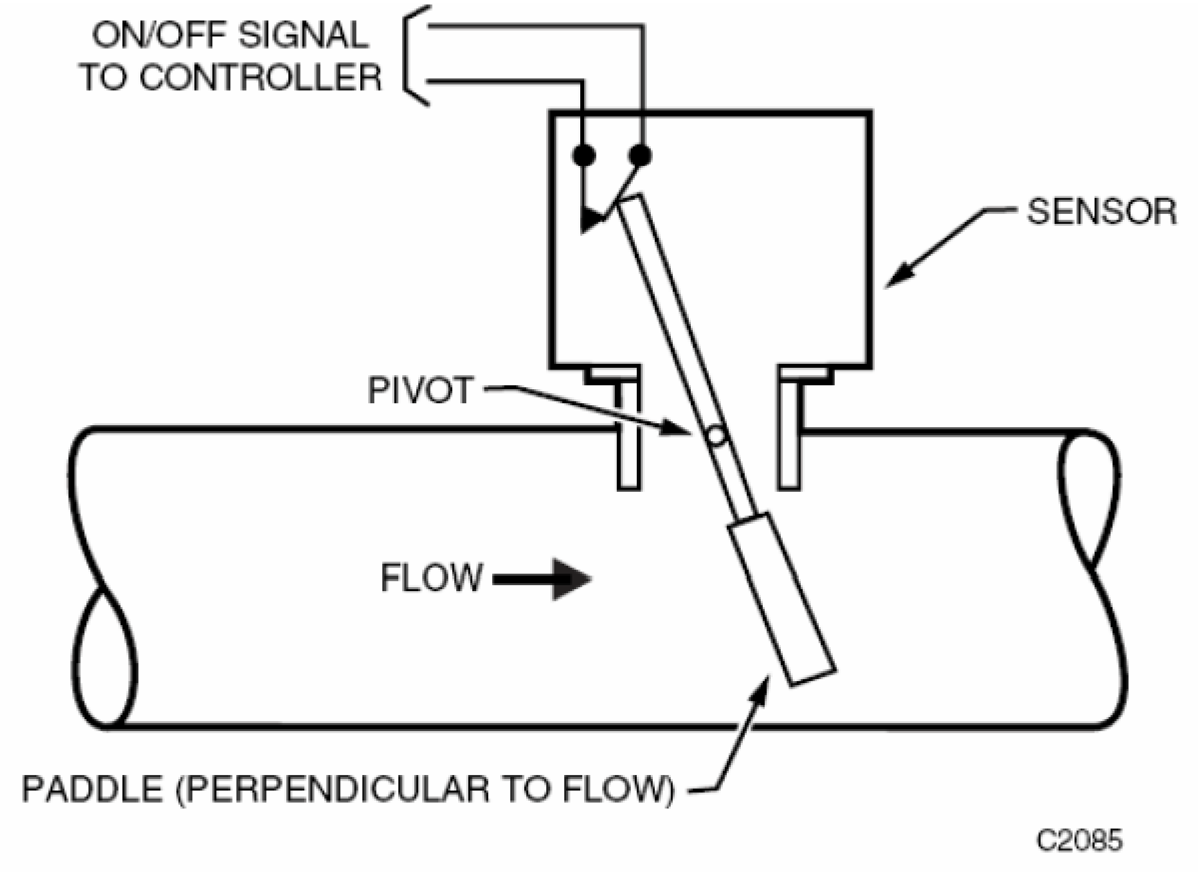
KEY

Figure 1: Digital Inputs

DCV-PS = Direct Current Voltage - Power Supply
COM = Common
L1 = Line 1
L2 = Line 2
+V = Positive Voltage

Courtesy DDC Online Org.

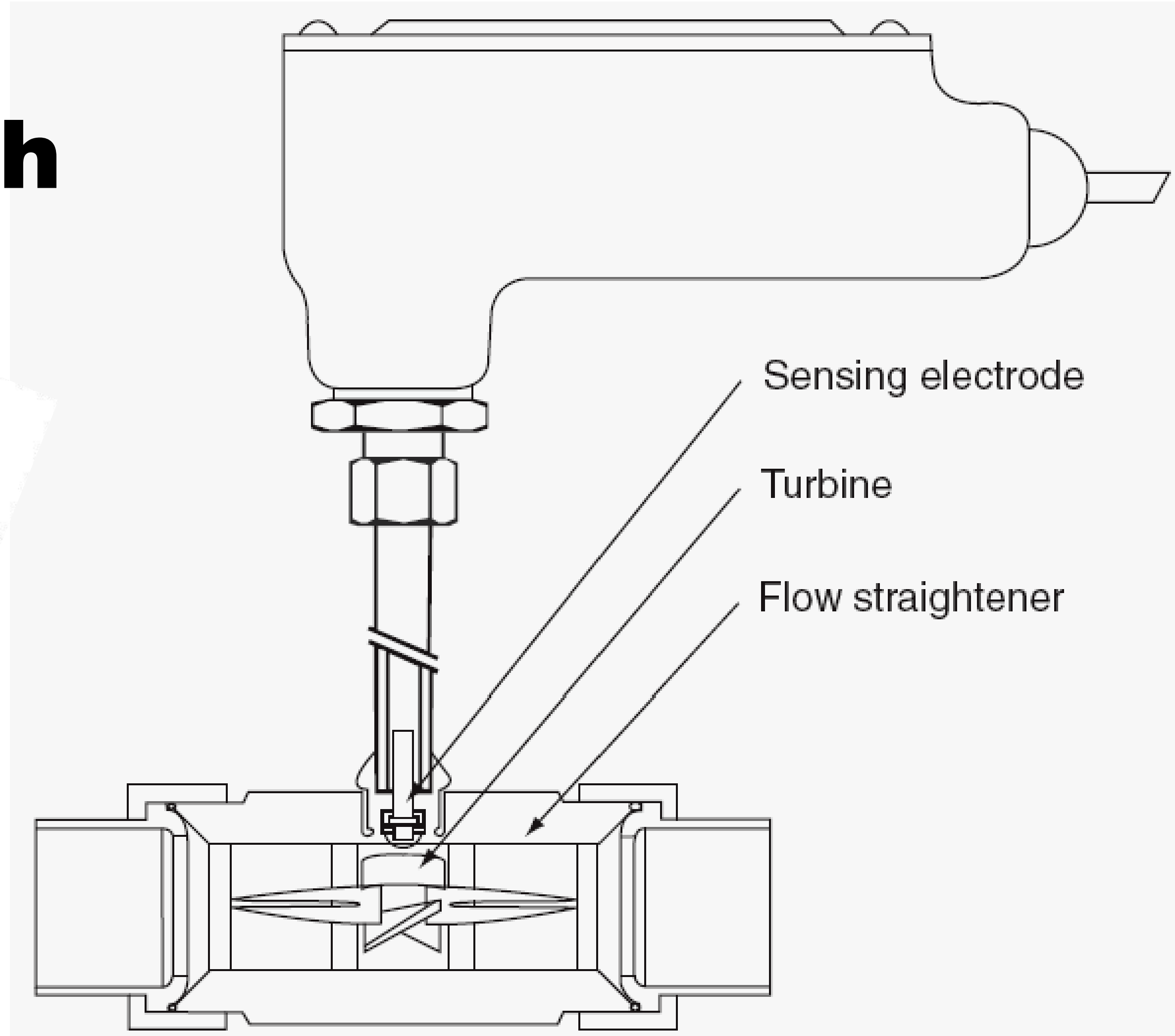
DDC Control System
Digital Input (DI) Illustration
Flow Switch



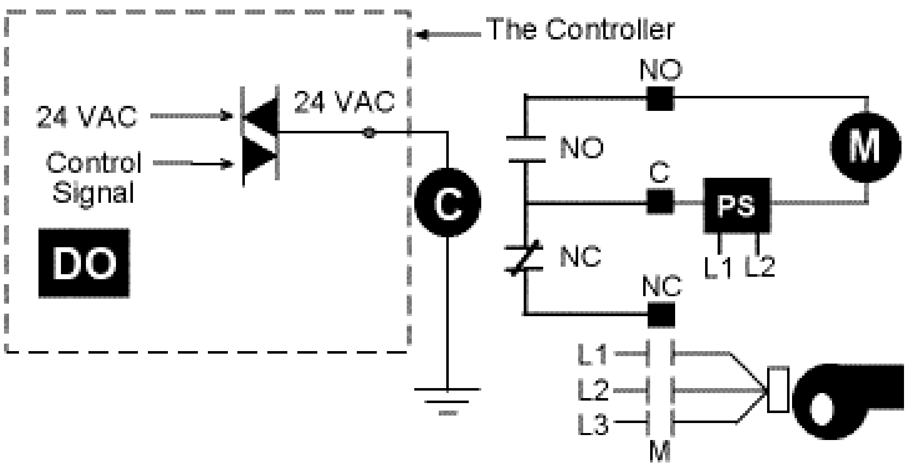
Courtesy Honeywell Controls

DDC Control System
Digital Input (DI) Pulsed Signal Illustration
Flow Switch

Courtesy Verris Industries



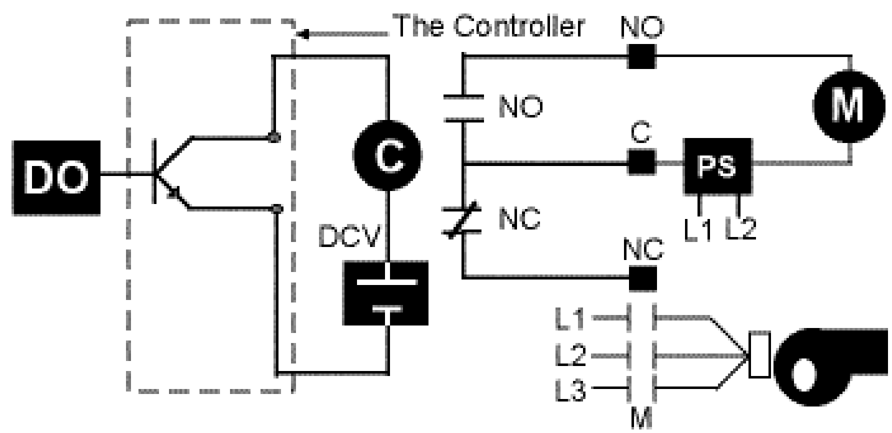
DDC Control System
Digital Output (DO) Illustration



Triac Type Digital Output with External Relay

KEY

C = Common Contact
DO = Digital Output
VAC = Voltage Alternating Current
NO = Normally Open
NC = Normally Closed
PS = Power Supply
M = Motor Starter
L1 = Line 1
L2 = Line 2
L3 = Line 3



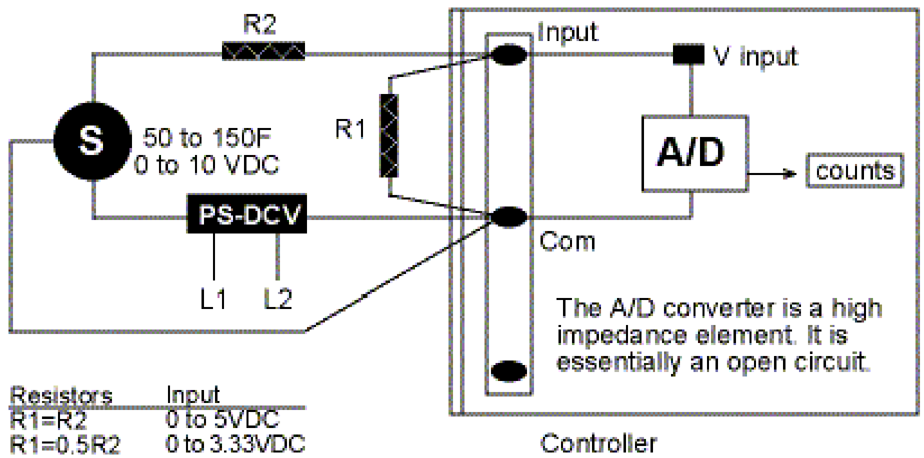
Transistor with Pilot Relay

KEY

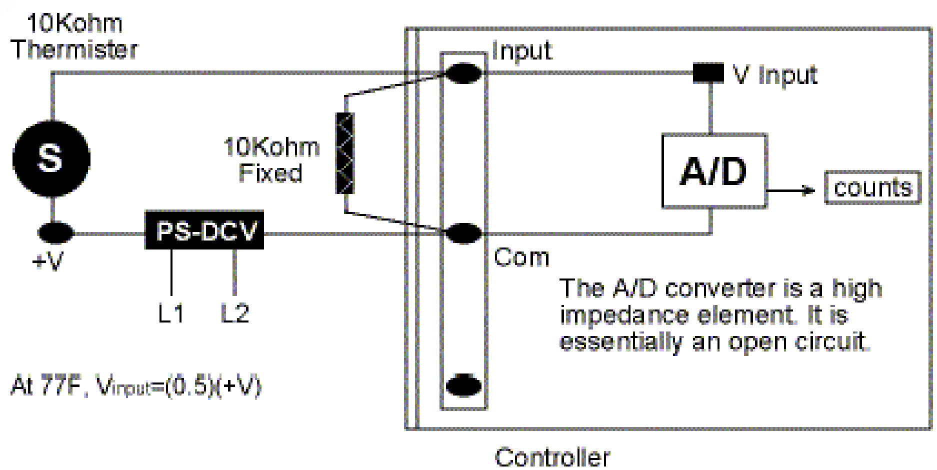
C = Common Contact
DO = Digital Output
DCV = Direct Current Voltage
NO = Normally Open
NC = Normally Closed
PS = Power Supply
M = Motor Starter
L1 = Line 1
L2 = Line 2
L3 = Line 3

Courtesy DDC Online Org.

DDC Control System
Analog Input (AI) Illustration



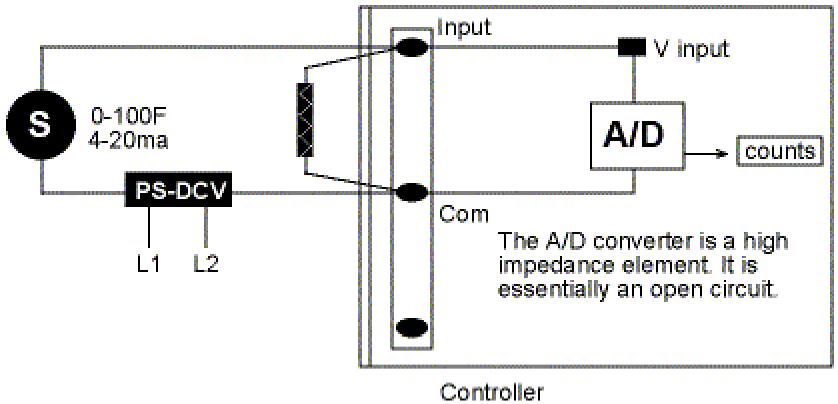
Externally Powered Voltage Input with Voltage Scaling Using Resistors



Resistance Input, Thermister

Courtesy DDC Online Org.

DDC Control System Analog Input (AI) Illustration For Measuring Air Flow in FPM

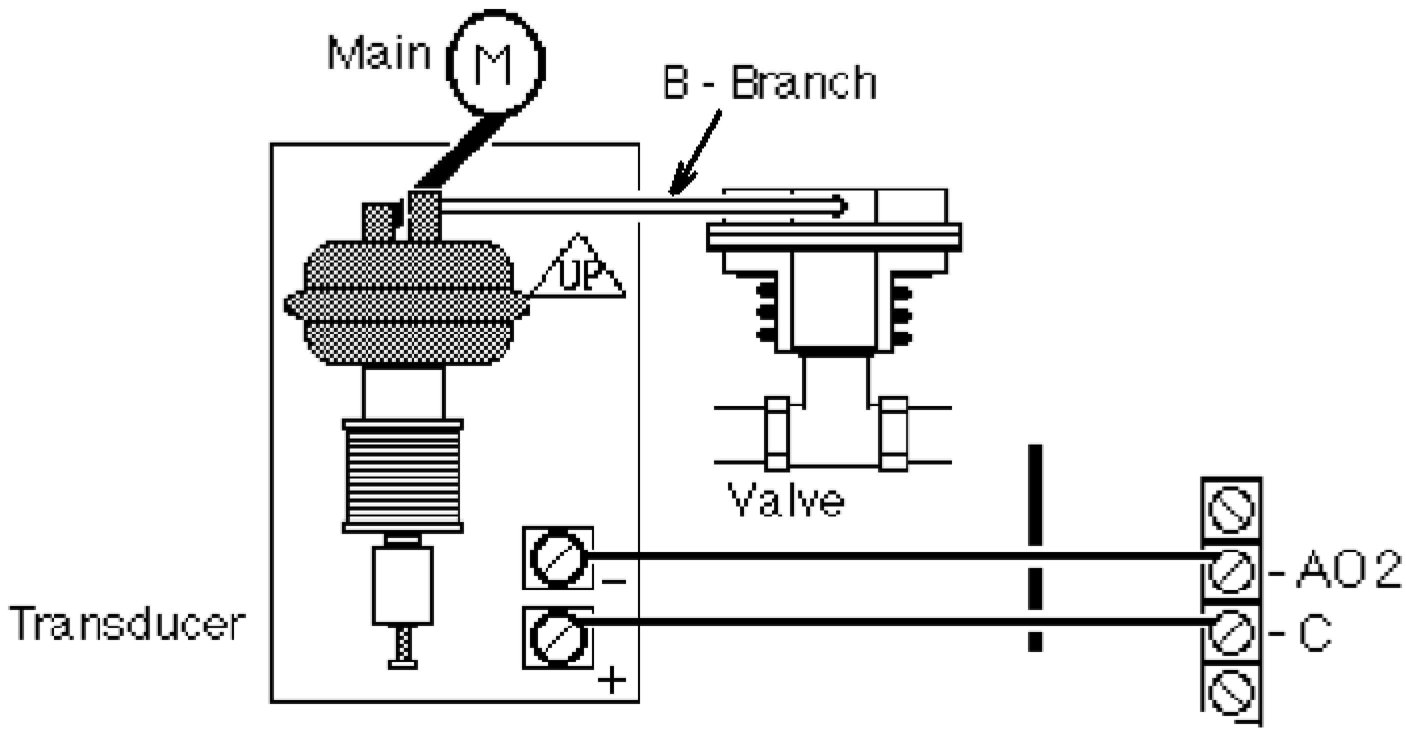


Externally Powered Analog Current Input

Courtesy Dwyer Instruments.

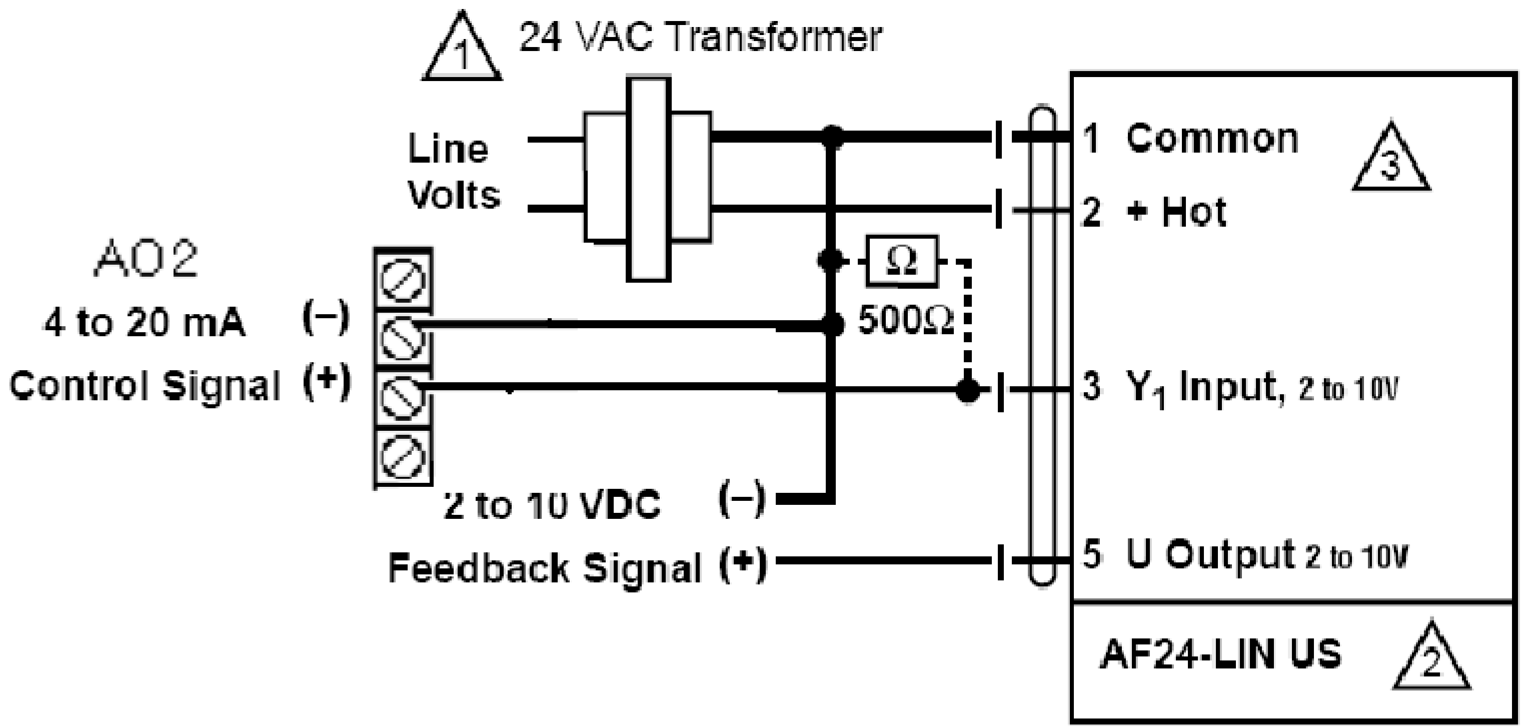
DDC Control System
Analog Output (AO) Illustration

For controlling a pneumatic valve



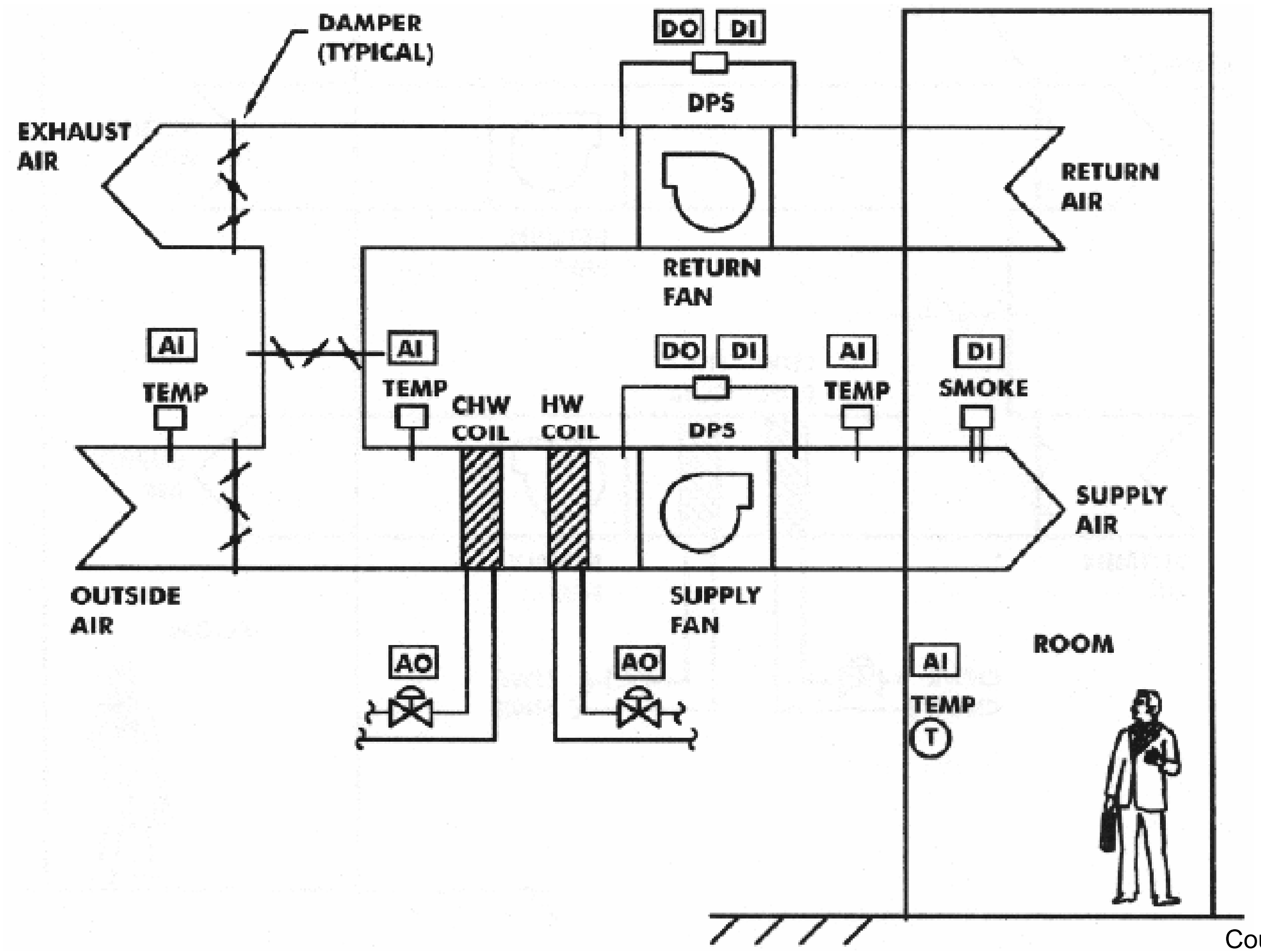
Courtesy TAC Controls/Schneider Electric

Analog Output (AO) Damper Actuators are controlled by either a voltage (2-10 Vdc) or current (4-20 mA) signal from the controller



Courtesy Belimo

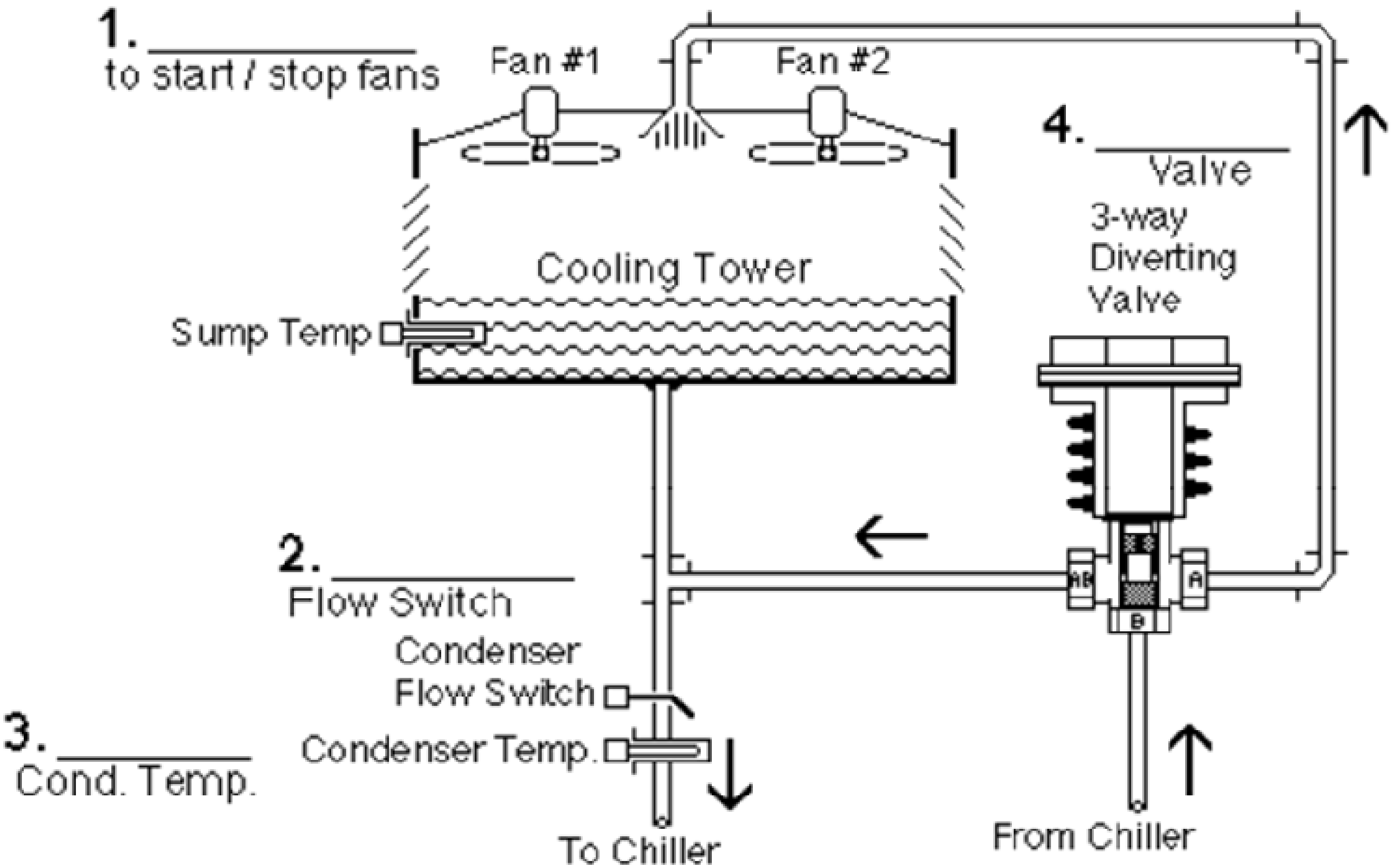
Example of DDC AHU Control Application with Point Types Identified



Courtesy Honeywell Controls.

Exercise
Review of DDC Terminology

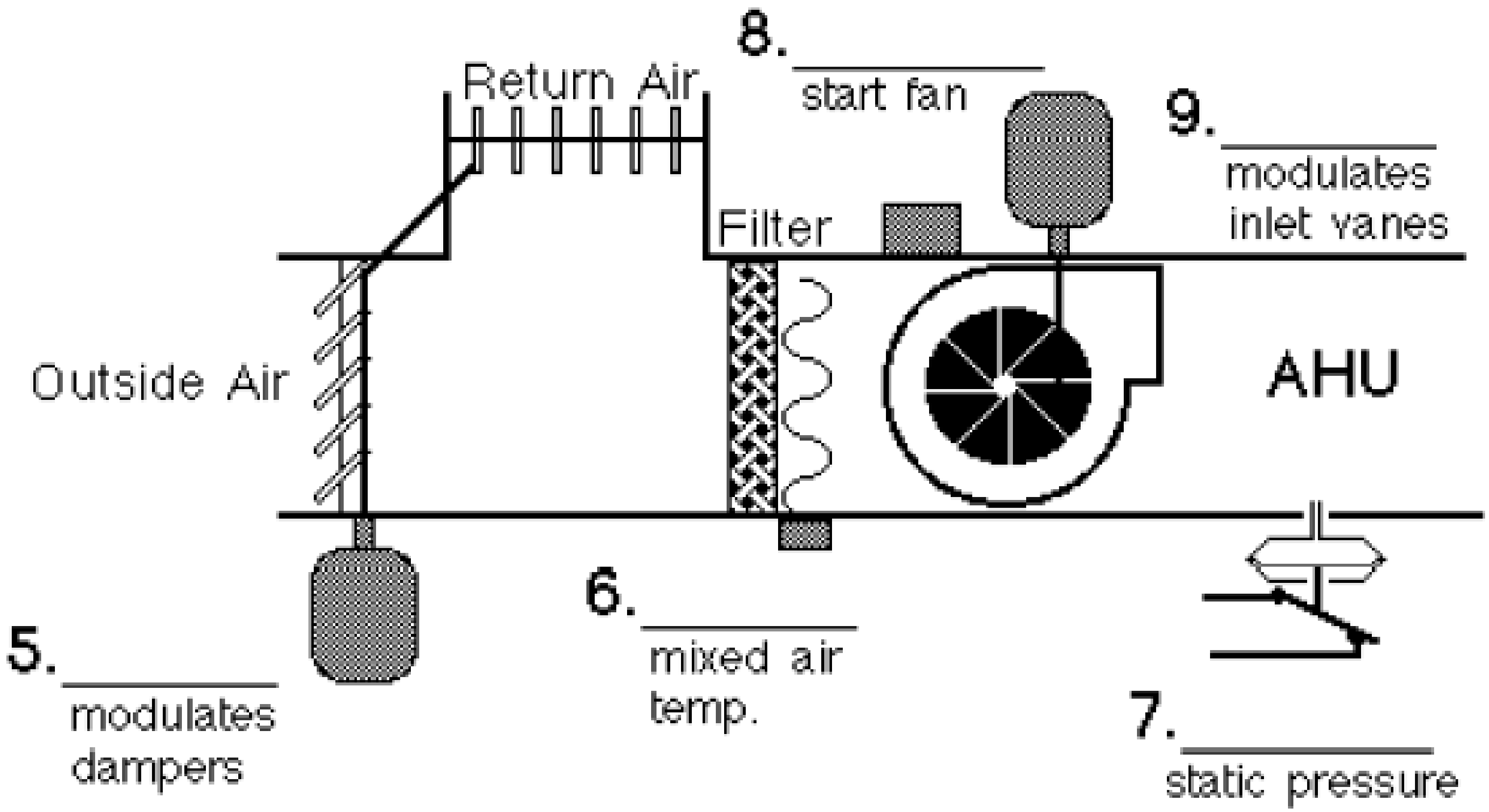
Study the drawing below and identify the numbered points as either: **AI**, **DI**, **AO**, or **DO**



Courtesy TAC Controls/Schneider Electric

Exercise
Review of DDC Terminology

Identify the numbered points in the following diagram as either: **AI**, **DI**, **AO**, or **DO**



Courtesy TAC Controls/Schneider Electric