CAE 438/538 Control of Building Environmental Systems

Fall 2021

August 24, 2021

Introduction to CAE 438/538

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Advancing energy, environmental, and sustainability research within the built environment

www.built-envi.com

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INTRODUCTION

About Me

- B.S.E., Mechanical Engineering
  - ❑ Sharif University of Technology Tehran, Iran, 2006
- M.S.E., Architectural Engineering
  - ❑ The Pennsylvania State University, 2011
- Ph.D., Mechanical Engineering
  - ❑ The Pennsylvania State University, 2014

- Experience relevant to this course
  - ❑ NSF, DOE, ASHRAE, HUD, Franklin Energy Projects
  - ❑ University of Maryland College Park
  - ❑ Licensed Professional Engineer
  - ❑ ASHRAE New Investigator
  - ❑ Taught and co-taught CAE 331/513, CAE 464/517, CAE 465/526, CAE 553, CAE 495, ENVE 576 at IIT

Introduce yourself

- Please introduce yourself
- Why did you choose this course?
- What do you expect from the course?
- How do you think the course will have impact on your career?
- What are the major aspect that you are primarily interested (e.g., mechanical systems, lighting fixtures, …)?
- How did you spend your summer?

Course Unique Numbers

- CAE 438 Section 01: (undergraduate) – In class
- CAE 438 Section 02: (undergraduate) - Online
- CAE 538 Section 01: (graduate) – In class
- CAE 538 Section 02: (graduate) - Online

Classroom and Meeting Time

- Classroom: SB Building 225
- Class Time: Tuesdays, 02:05 PM – 04:50 PM

Course Catalog Description

- Introduction to automatic control systems
- Control issues related to energy conservation, indoor air quality and thermal comfort in buildings
- Classification of HVAC control systems
- Control systems hardware: selection & sizing of sensors, actuators & controllers
- Practical HVAC control systems; elementary local loop and complete control systems. Case studies. Computer applications

Instructor's Course Objectives & Learning Outcomes

1. Prepare engineers to understand building controls (mostly HVAC systems)

2. Design control sequence for various building systems

3. Equip students to effectively communicate design intent

4. Select and size sensors, actuators, and controllers

Office Hours

- Office hours are by appointment only. Please email me to schedule an appointment. Or stop by when you see my office door open to see if I’m free. I have an open door policy.

- If you would like to schedule a virtual meeting, please email me to schedule a time for a virtual meeting.

Textbook (Not Required)

- 2017 American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Handbook of Fundamentals (IP unit version)
- The ASHRAE Handbook of Fundamentals isn't exactly a textbook, but rather is a deep and authoritative resource for many aspects of building engineering
- We reference it directly for almost every topic in this class, and you will also continue to use it in future required and elective courses, including CAE 463/524 Building Enclosure Design, CAE 495 Capstone Senior Design, and several others
- The ASHRAE Handbook of Fundamentals costs $209 to the general public, but costs only $49 to ASHRAE student members. And ASHRAE student membership is only $25 per year. You can purchase the handbook, as well as a student membership, directly through Dr. Brent Stephens, or online: https://www.ashrae.org/communities/student-zone/membership-and-meetings/student-membership-benefits.

Course Grading

Grading	Quantity	% of Total for Each	% of Total
Assignments	6	5	30
Exam	1	30	30
Group Project (Interim Reports)	2	7	14
Group Project (Final Report)	1	10	10
Group Project (Final Presentation)	1	6	6
Individual Project (Final Report)	1	5	5
Individual Project (Final Presentation)	1	5	5

Grading scale	A	B	C	D	F
UG and G	90% and up	80.0-89.9%	70.0-79.9%	60.0-69.9%	<60.0%

Homework Assignments

- Homework sets will be assigned based on lecture coverages. The homework will involve hand calculations, development of spreadsheets, and/or learning the fundamentals and data analysis. You must work on the homework assignments individually.

- Homework assignments and project reports are due at the midnight on the day that it is due. Homework assignments and project reports will receive an ***absolute 5-point deduction*** for every day that it is late.

Project and Presentation

- The course project focuses on designing the control of building systems.
- The project has three deliverables described in the project assignment document.
- Each student is responsible for working on the first two deliverable course project individually. The third deliverable will be a group project submission.
- Students are required to present their report at the end of the semester during the assigned university exam week.

Exam

- There will be one take home class exam during the semester of the fundamental concepts learned in the course. Each student is responsible for working on exam individually.

Course Topics

Week	Date	Topics	Assignment Due
1	08/24/21	Introduction and overview Control theory and terminology	
2	08/31/21	Instrumentation and sensors: Overview Instrumentation and sensors: Input and output	
3	09/7/21	Instrumentation and sensors: Temp., flow/pressure, RH, CO_2 sensors Control devices: Dampers	**Assignment #1**
4	09/14/21	Control devices: Dampers, valves, actuators Control devices: Actuators and motors, starters	**Assignment #2**
5	09/21/21	Controllers: Intro Controllers: Control Modes	**Assignment #3**
6	09/28/21	Control Modes and Sequences of Operation ASHRAE Guideline 36 **Project Overview**	**Assignment #4**

Course Topics

Week	Date	Topics	Assignment Due
7	10/05/21	ASHRAE Guideline 13: Intro ASHRAE Guideline 13: BAS Device Network Design	**Assignment #5**
8	10/12/21	Control of Building Systems: HVAC, Lighting, Fire Protection	**Assignment #6**
9	10/19/21	Building Automation Communication Systems: Intro	**Project Deliverable #1**
10	10/26/21	**Building Tour**	
11	11/02/21	**Exam (Take Home)**	
12	11/09/21	Building Automation Communication Systems: Data Communication	
13	11/16/21	Building Automation Communication Systems: BACnet Objects	**Project Deliverable #2**

Course Topics

Week	Date	Topics	Assignment Due
14	11/23/21	Building Automation Communication Systems: BACnet Objects and Services	
15	11/30/21	Building Automation Communication Systems: BACnet Services	
16	TBD	**Student Project Presentations (During the Final Exam)**	**Final Presentation**
17	TBD	**Final Project Report**	**Project Deliverable #1**

Academic Honesty

- It is your responsibility to be familiar with IIT's Code of Academic Honesty. The Code of Academic Honesty can be found online:
- https://web.iit.edu/student-affairs/handbook/fine-print/code-academic-honesty
- You must submit your own work for homework. You are encouraged to discuss and even work with other students on homework (unless explicitly told otherwise), but material that is submitted must be your own work. For group project assignments, each group is to submit their own work.
- For a first violation of the IIT Code of Academic Honesty for a homework or project, the homework will receive a grade of zero for all involved students and the students will be reported to the Designated Dean for Academic Discipline (DDAD).
- For a first violation of the Code of Academic Honesty for a major project or an examination, the student will receive a failing grade for the course and the student will be reported to the DDAD. For a second violation, the student will receive also failing grade for the course and be reported to the DDAD

Personal Problems

- If you have illness or personal problems that will affect your performance during the course of the semester, please let me know as soon as possible. “After the fact” provides little protection unless there are extreme circumstances. Contact the instructors by phone or e-mail at any time.

Students with Disabilities

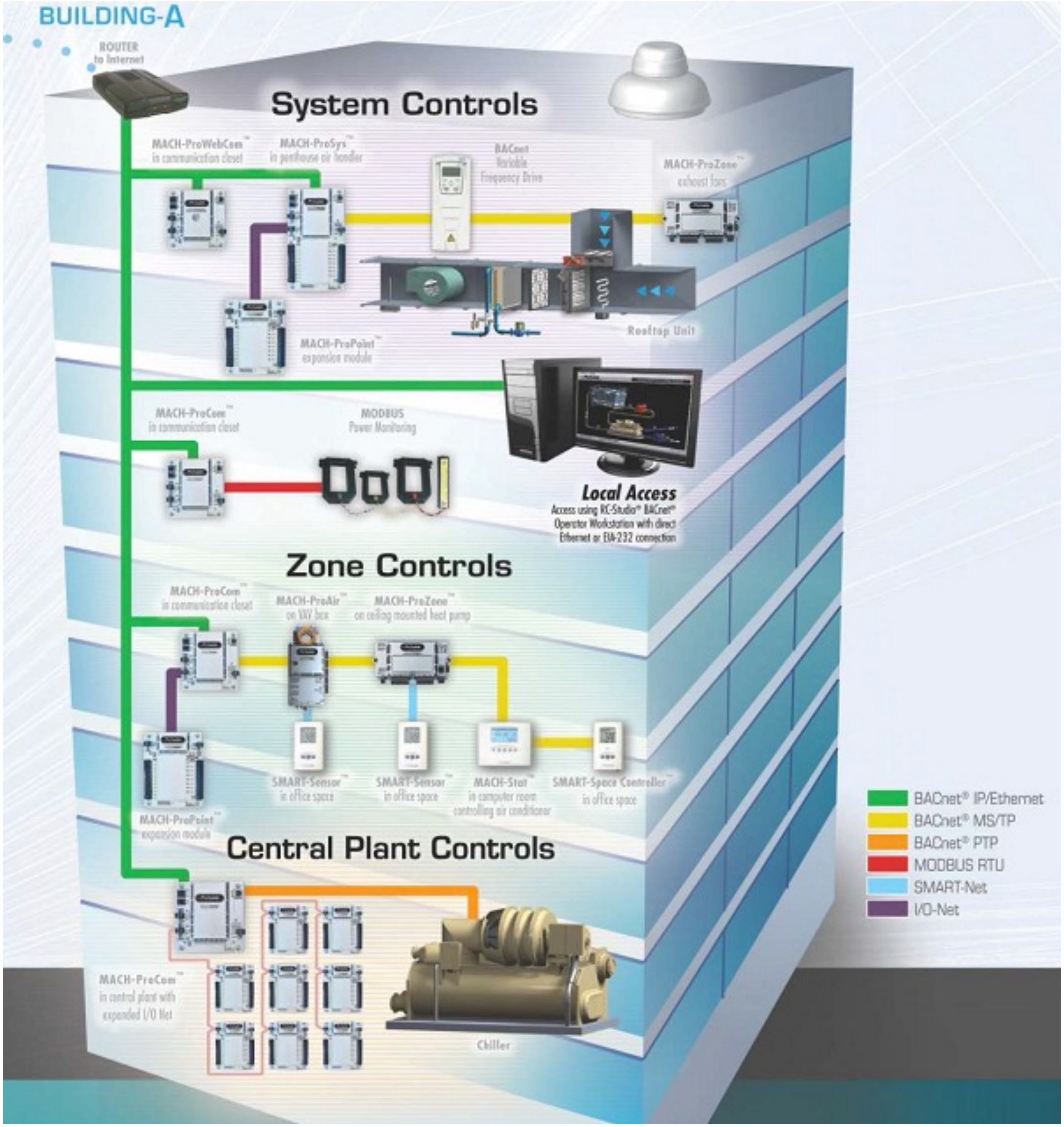
- Reasonable accommodations will be made for students with documented disabilities. In order to receive accommodations, students must obtain a letter of accommodation from the Center for Disability Resources. The Center for Disability Resources (CDR) is located in Life Sciences Room 218, telephone (312) 567-5744 or email: disabilities@iit.edu.

IIT's Sexual Harassment and Discrimination Information

- Sexual harassment, sexual misconduct, and gender discrimination by any member of the Illinois Tech community is prohibited. This includes harassment among students, staff, or faculty. Sexual harassment by a faculty member or teaching assistant of a student over whom they have authority or by a supervisor of a member of the faculty or staff is particularly serious. Such conduct may easily create an intimidating, hostile, or offensive environment.
- Illinois Tech encourages anyone experiencing sexual harassment or sexual misconduct to speak with the Title IX Office for information on the resolution process and support options.
- You can file a complaint electronically at iit.edu/incidentreport, which may be completed anonymously. You may also file a complaint in-person by contacting the Title IX Coordinator, Virginia Foster at 312.567.5725/ foster@iit.edu or the Deputy Title IX Coordinator 312. 567.5726/ eespeland@iit.edu.
- If you are not ready to file a formal complaint but wish to learn about your rights and options, you may contact Illinois Tech's Confidential Advisor service at 773.907.1062. You can also contact a licensed practitioner in Illinois Tech's Student Health and Wellness Center at 312.567.7550.
- For a comprehensive list of resources regarding counseling services, medical assistance, legal assistance and visa and immigration services, you can visit the Title IX Office's website at https://web.iit.edu/hea/resources.

How does building equipment make decisions?

How does the building equipment and systems interact?



majorheating

TERMINOLOGY

Overview

- Automatic HVAC control systems:
  - Designed to maintain temperature, humidity, pressure, energy use, power, lighting levels, and safe levels of indoor contaminants
  - Primarily modulates, stages, or sequences mechanical and electrical equipment to satisfy load requirements, provide safe equipment operation
  - Can use digital, pneumatic, mechanical, electrical, and electric control devices

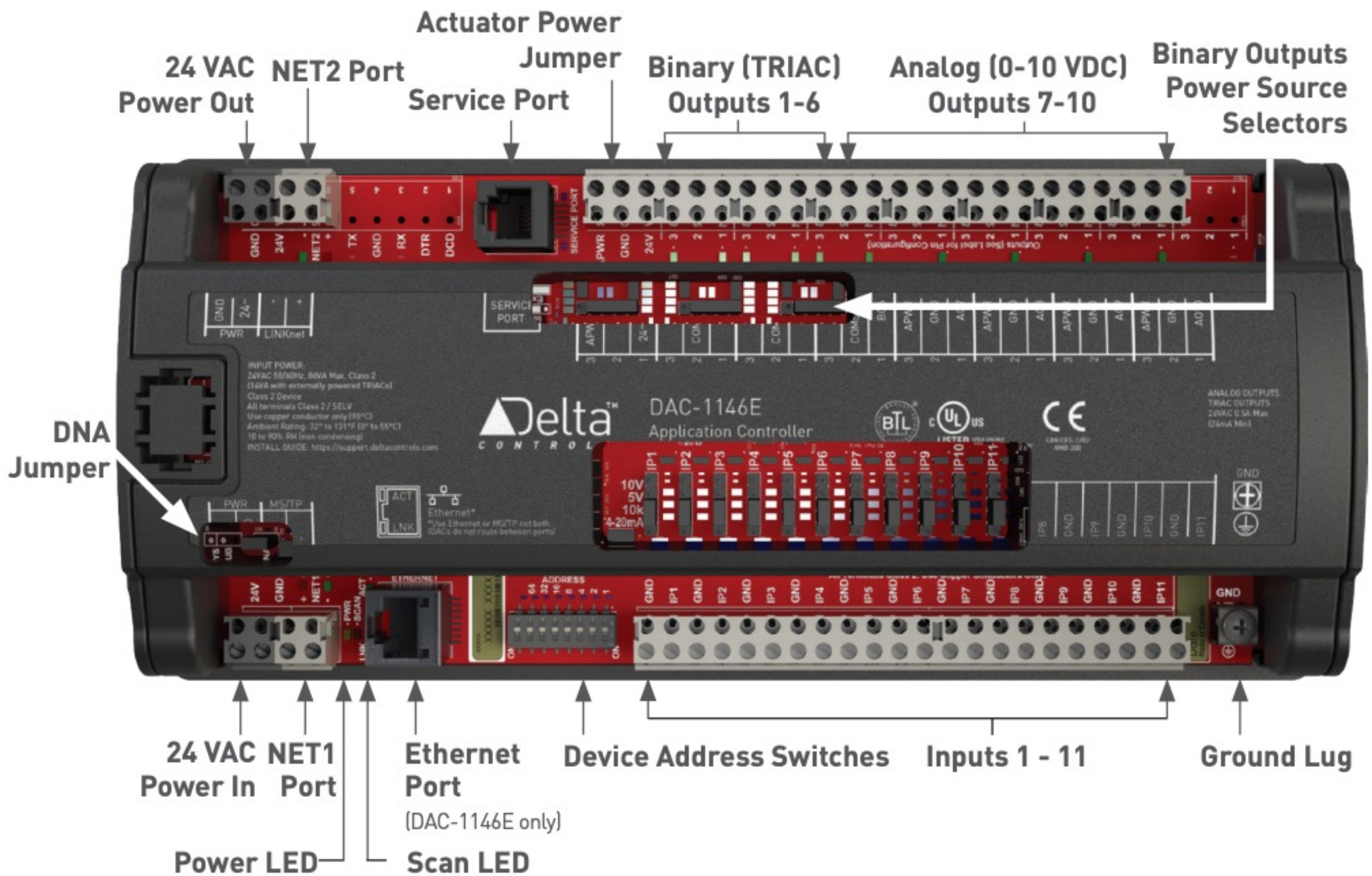
- Human intervention
  - Is not limited to scheduling equipment operation and adjusting control set points
  - Can include tracking trends and programming control logic algorithms to fulfill building needs

Terminology

- Closed Loop or Feedback:
  - **Sensor:** measures the controlled variable and transmits to the controller a signal (pneumatic, electric, or electronic)
  - **Controller:** compares this value with the set point and signals to the controlled device for corrective action
    - A controller can be hardware or software
    - A hardware controller is an analog device (e.g., thermostat, humidistat, pressure control) that continuously receives and acts on data
    - A software controller is a digital device (e.g., digital algorithm) that receives and acts on data on a sample-rate basis
  - **Controlled device:** is typically a valve, damper, heating element, or variable-speed drive

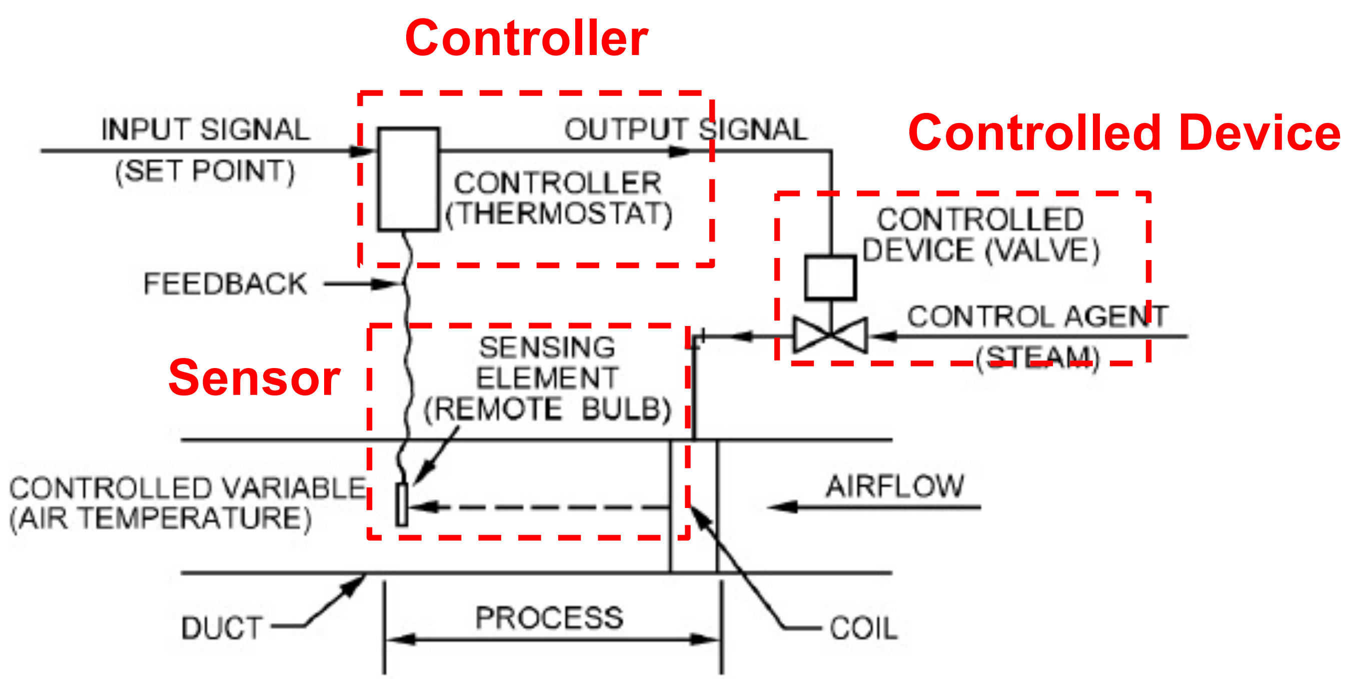
Terminology

- Controller:



Terminology

- Closed Loop or Feedback
  - ❑ A closed loop measures actual changes in the controlled variable and actuates the controlled device to bring about a change
  - ❑ This arrangement of having the controller sense the value of the controlled variable is known as feedback



Any Example?

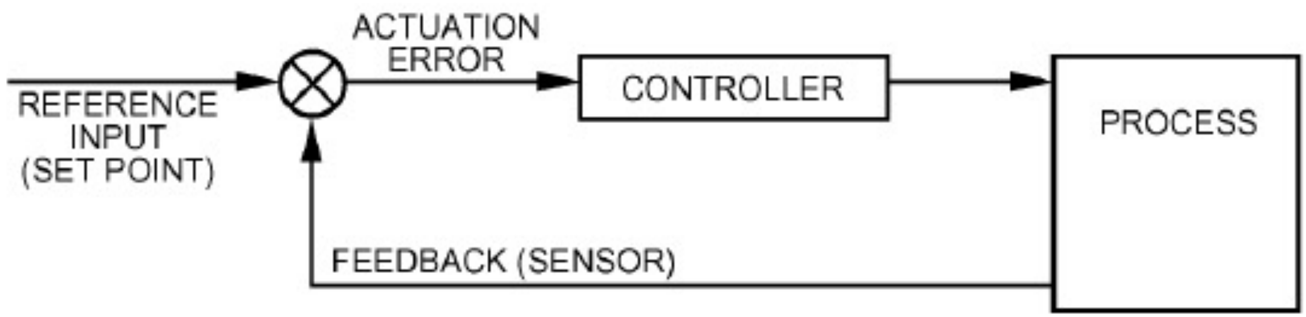
Terminology

- Open Loop Control
  - ❑ Does not have a direct link between the value of the controlled variable and the controller
  - ❑ Anticipates the effect of an external variable on the system and adjusts the set point to avoid excessive offset
  - ❑ An example is an outdoor thermostat arranged to control heat to a building in proportion to the calculated load caused by changes in outdoor temperature

Any Example?

Terminology

- We typically represent the controlled loop with a block diagram:



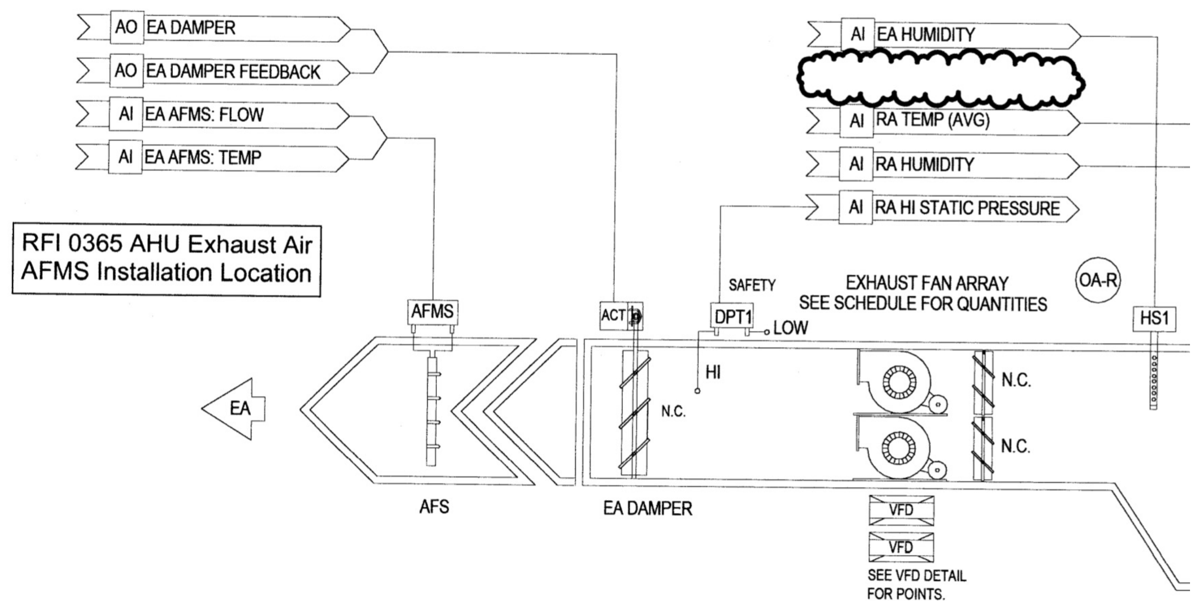
- Set point is being compared to the controlled variable

- The difference is the error. If the error persists, it may be called offset drift, deviation, droop, or steady-state error. The error is fed into the controller, which sends a control signal to the controlled device.

TYPE OF INPUT AND OUTPUTS

Type of Input and Outputs

- Signal Types:
  - Analog (mostly current or voltage)
    - Analog Input (AI)
    - Analog Output (AO)
  - Digital (discrete signals)
    - Digital Input (DI)
    - Digital Output (DO)



Type of Input and Outputs

- Voltage inputs are:
  - Most common types are:
    - 12 VAC
    - 12 VDC
    - 24 VAC
    - 24 VDC
    - 120 VAC

V: Volts

AC: Alternating Current

DC: Direct Current

Type of Input and Outputs

- Analog output:
  - ❑ Can be used to read a variable measurement
  - ❑ Examples are temperature, humidity and pressure sensor (e.g., 4-20 mA, 0-10 volt)

TYPE OF CONTROL ACTIONS

Type of Control Actions

- There are control action strategies:

  - **<u>Two position (e.g. on / off)</u>**
    - Simple and inexpensive
    - Example: Home thermostat

  - **<u>Modulating a continuous range (e.g., 0 to 100% open)</u>**
    - There is a set of parameters that quantifies the controller's response. The values of these parameters affect the control loop's speed, stability, and accuracy
    - In every case, control loop performance depends on matching (or tuning) the parameter values to the characteristics of the system under control

Type of Control Actions

- Proportional Control (P)

  - ❑ The controlled device is positioned proportionally in response to changes in the controlled variable

$$V_p = K_p e + V_o \qquad (1)$$

where

V_p = controller output
K_p = proportional gain (inversely proportional to throttling range)
e = error signal or offset
V_o = offset adjustment parameter

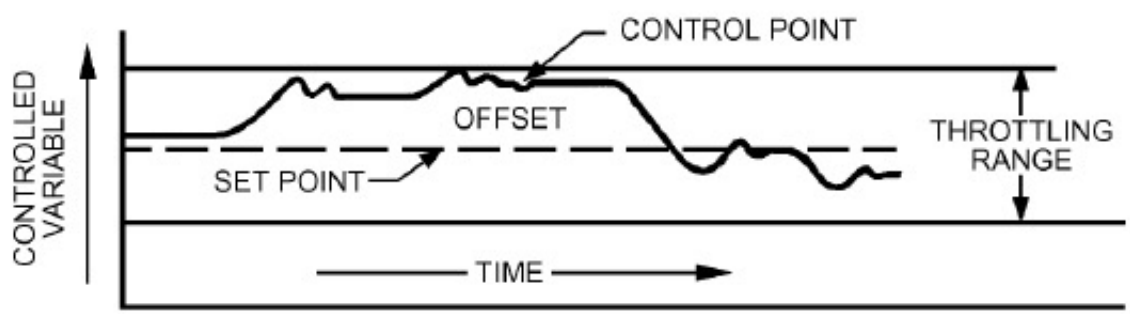


Fig. 5 Proportional Control Showing Variations in Controlled Variable as Load Changes

Type of Control Actions

- Proportional Plus Integral Control (PI)
  - PI control improves on simple proportional control by adding another component to the control action that eliminates the offset typical of proportional control

$$V_p = K_p e + K_i \int e d\theta + V_o$$

where

K_i = integral gain

θ = time

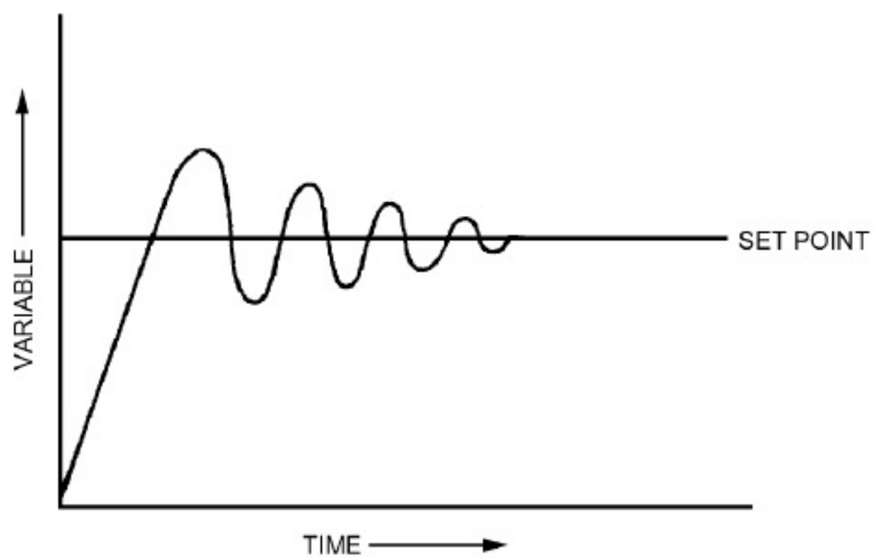


Fig. 6 Proportional plus Integral (PI) Control

Type of Control Actions

- Proportional-Integral-Derivative Control (PID)
  - ❑ This is PI control with a derivative term added to the controller. It varies with the value of the derivative of the error.

$$V_p = K_p e + K_i \int e\,d\theta + K_a \frac{de}{d\theta} + V_o$$

where

K_a = derivative gain of controller
$de/d\theta$ = time derivative of error

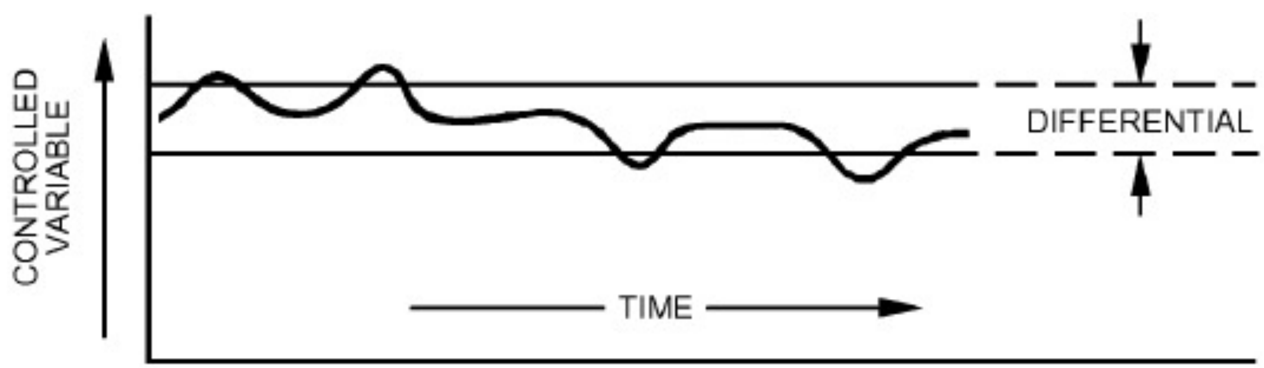


Fig. 7 Floating Control Showing Variations in Controlled Variable as Load Changes

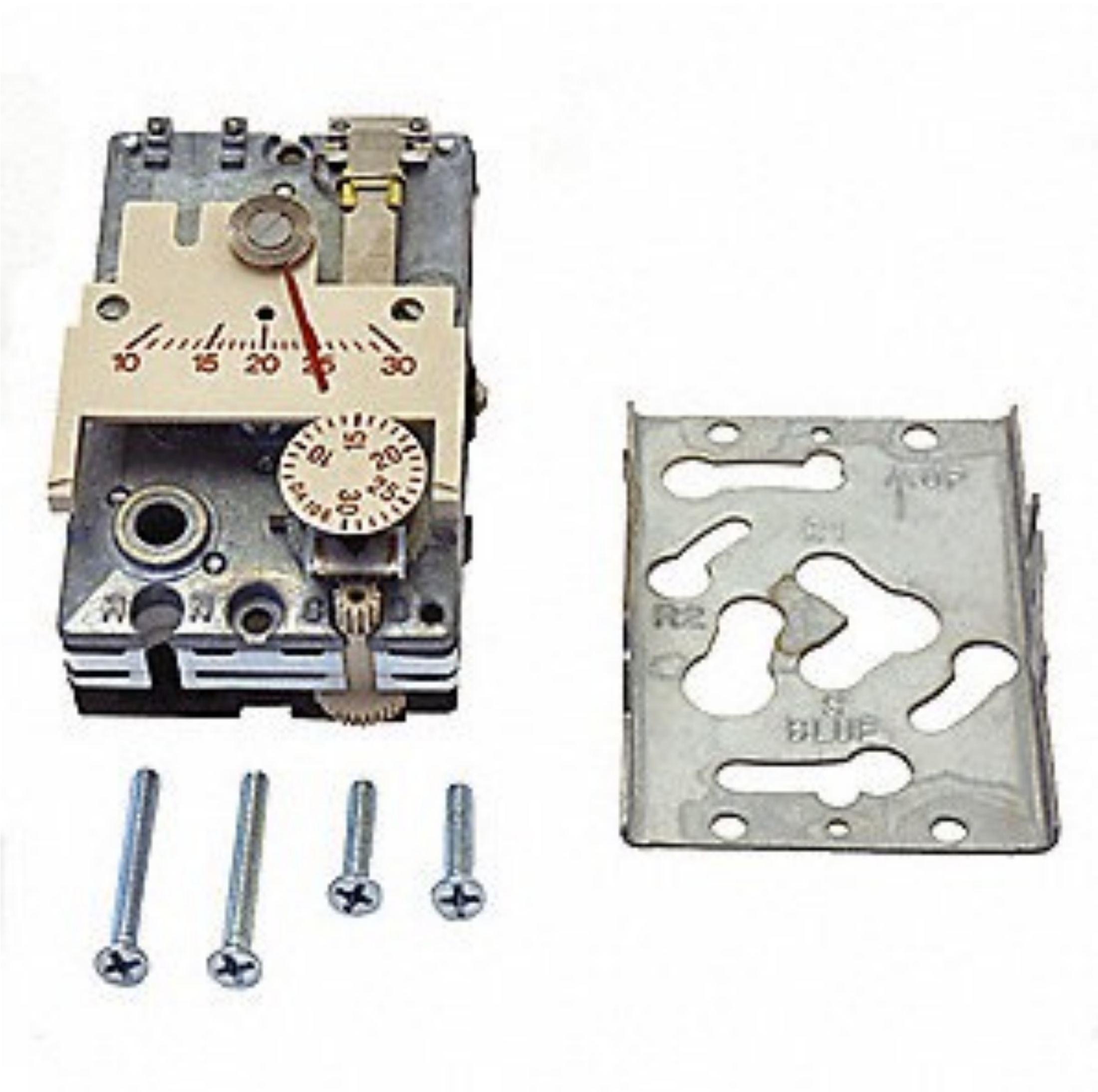
CONTROL COMPONENTS

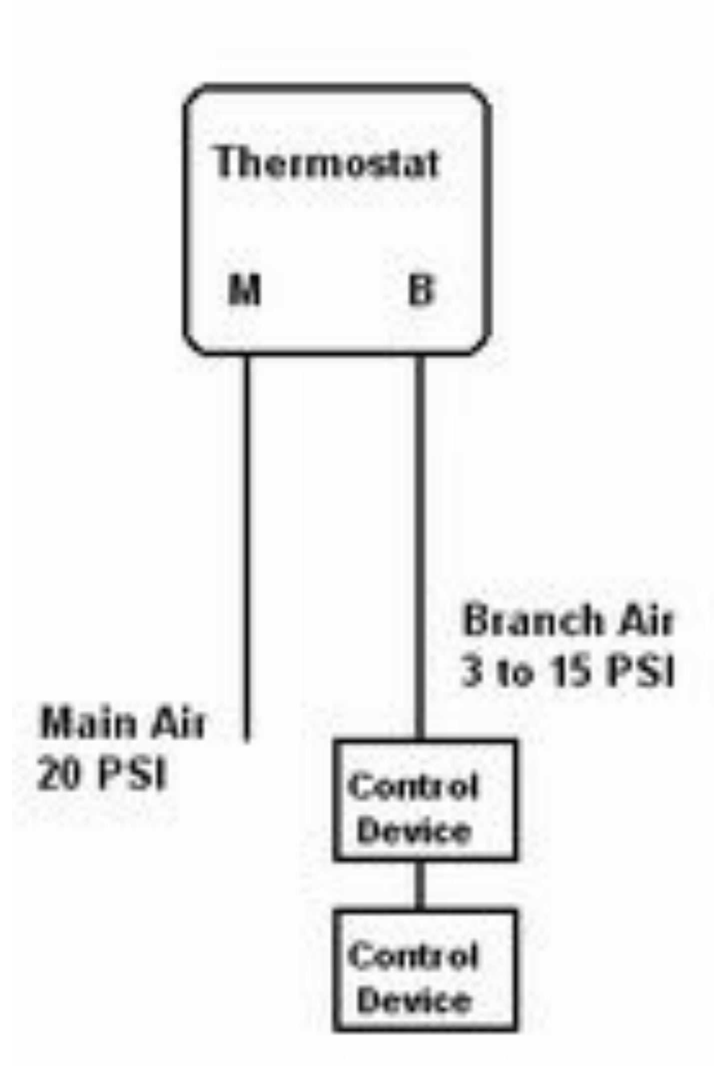
Control Components

- Classified by energy storage:
  - ❑ ***Pneumatic*** components use compressed air (15-20 psig)
  - ❑ ***Electric*** components use electrical energy (low- or line-voltage)
  - ❑ ***Electronic*** components include signal conditioning, modulation, and amplification in their operation
  - ❑ ***Self-powered*** components apply the power of the measured system to induce the necessary corrective action. The measuring system derives its energy from the process under control, without any auxiliary source of energy

Control Components

- Pneumatic control component





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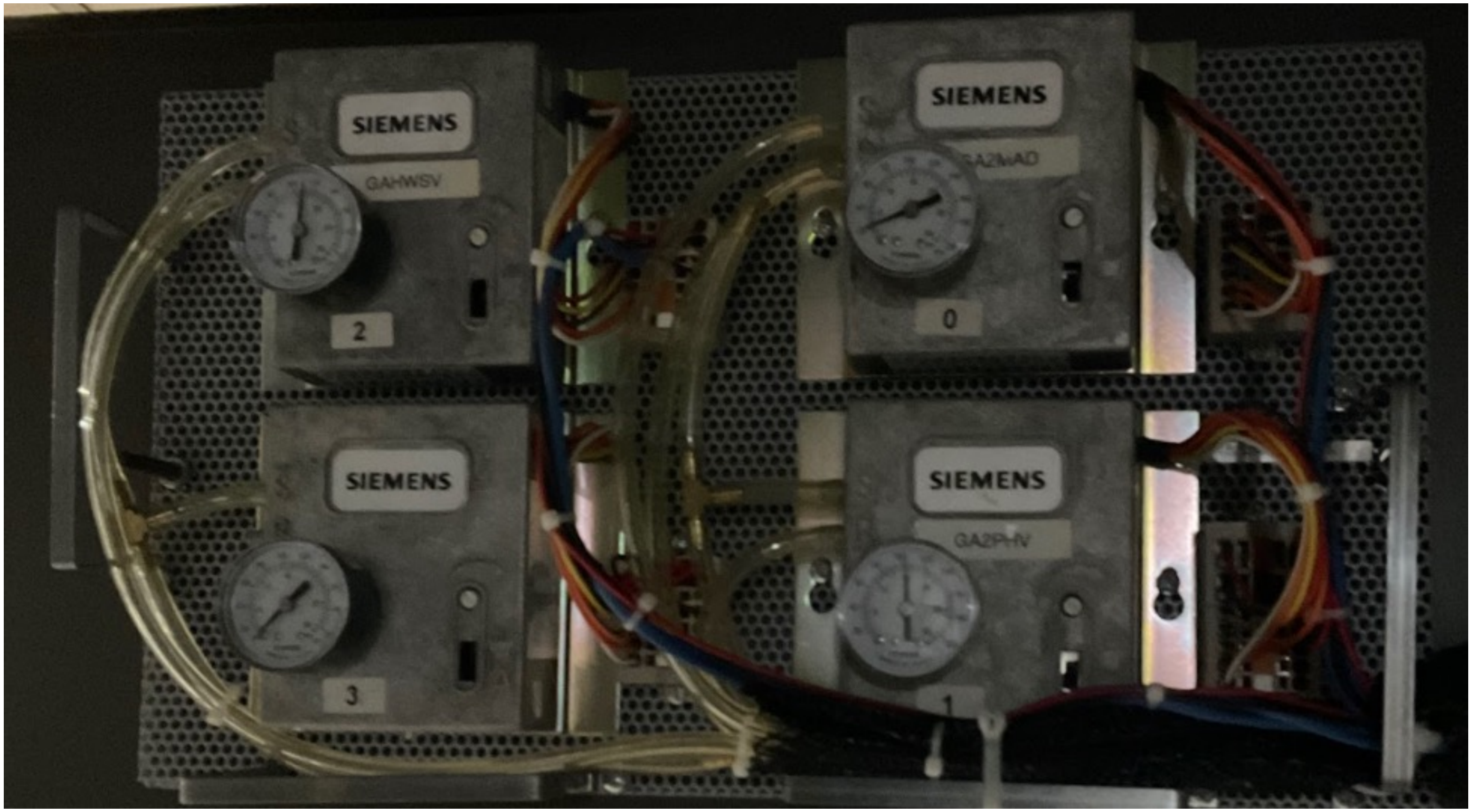
Control Components

- Pneumatic control component



Control Components

- Pneumatic control component
  - ❑ Advantages:
    - Can get higher torque on actuators
  - ❑ Disadvantages:
    - Use more energy energy
    - More components involved (What’s the setback?)
    - More maintenance
    - Require on-site adjustments (Why?)

Control Components

- Electronics control component
  - Uses electronic signals – more precise
  - Flexible programming
  - Remote monitoring & adjustment of settings
  - Trending, alarming, & reporting
  - Sharing of information between systems

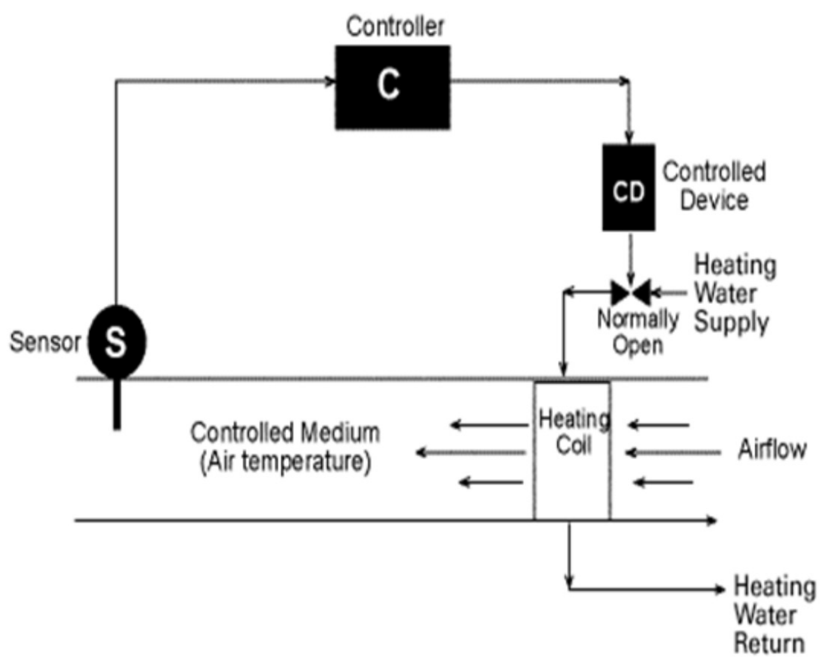


Diagram from DDC-Online.org

Control Components

- A control device is the component of a control loop used to vary the input (controlled variable):
  - Both valves and dampers perform essentially the same function and must be properly sized and selected for the particular application
  - The control link to the valve or damper is called an actuator or operator, and uses electricity, compressed air, hydraulic fluid, or some other means to power the motion of the valve stem or damper linkage through its operating range

Control Components

- Variable-Flow Chilled Water System:

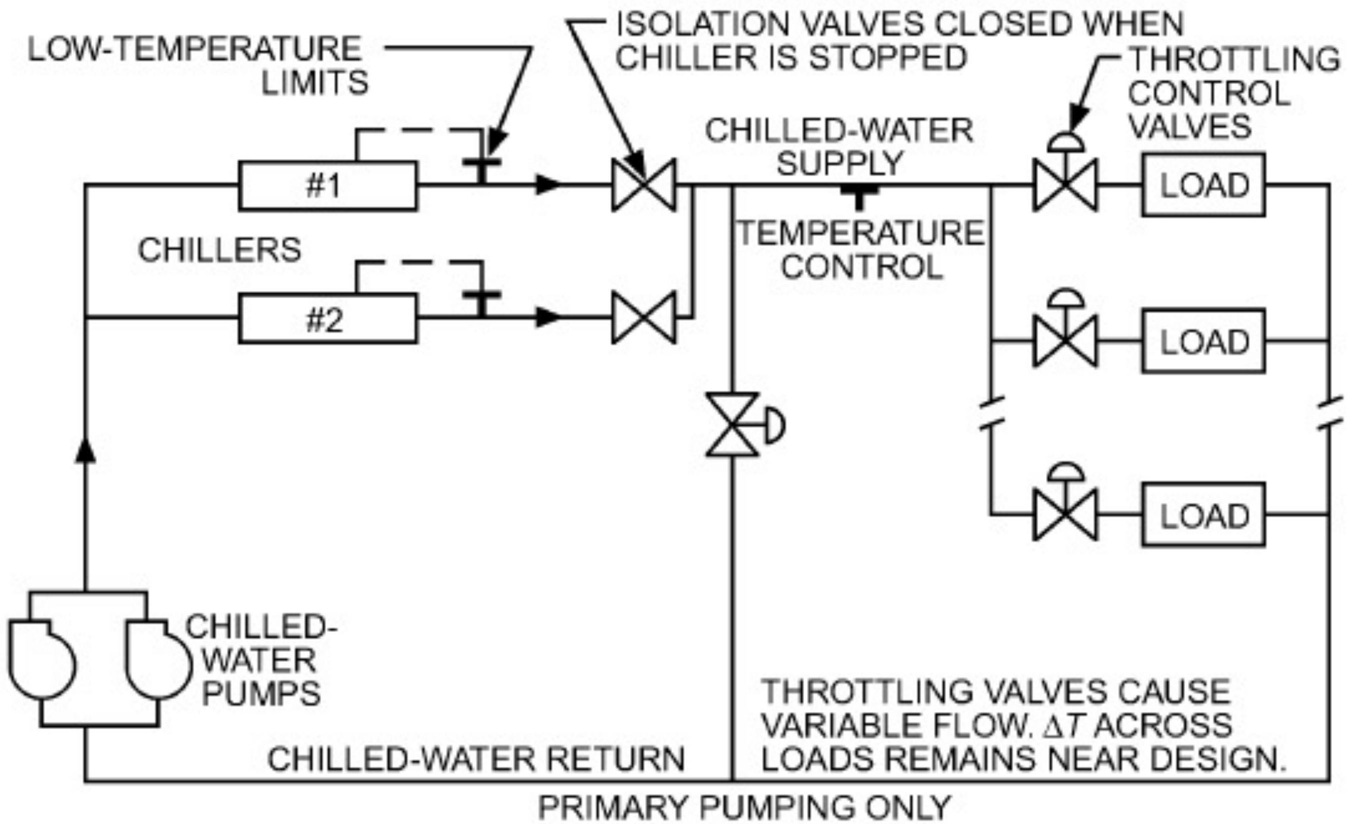
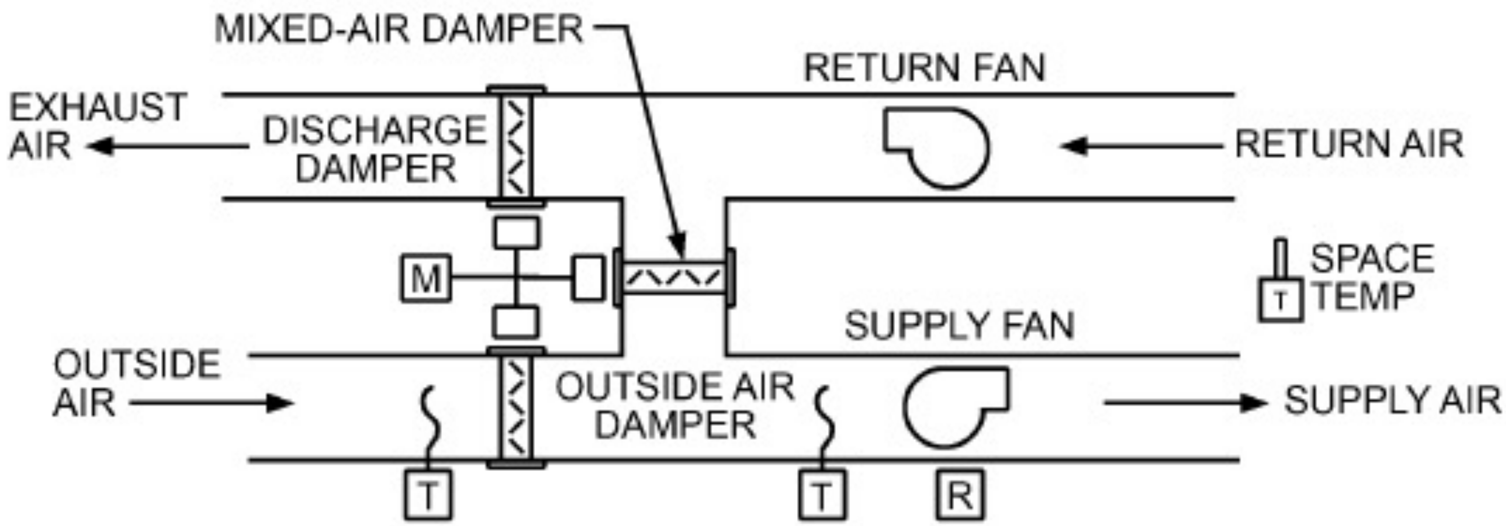


Fig. 9 Variable-Flow Chilled-Water System (Primary Only)

Control Components

- Airflow control:



OPERATION TABLE

UNIT	EA	MA	OA
Warm-up	MIN	OPN	MIN
Economizer	NC	NO	Control
Night Cooldown	OPN	CLO	OPN

Fig. 24 Economizer Cycle Control

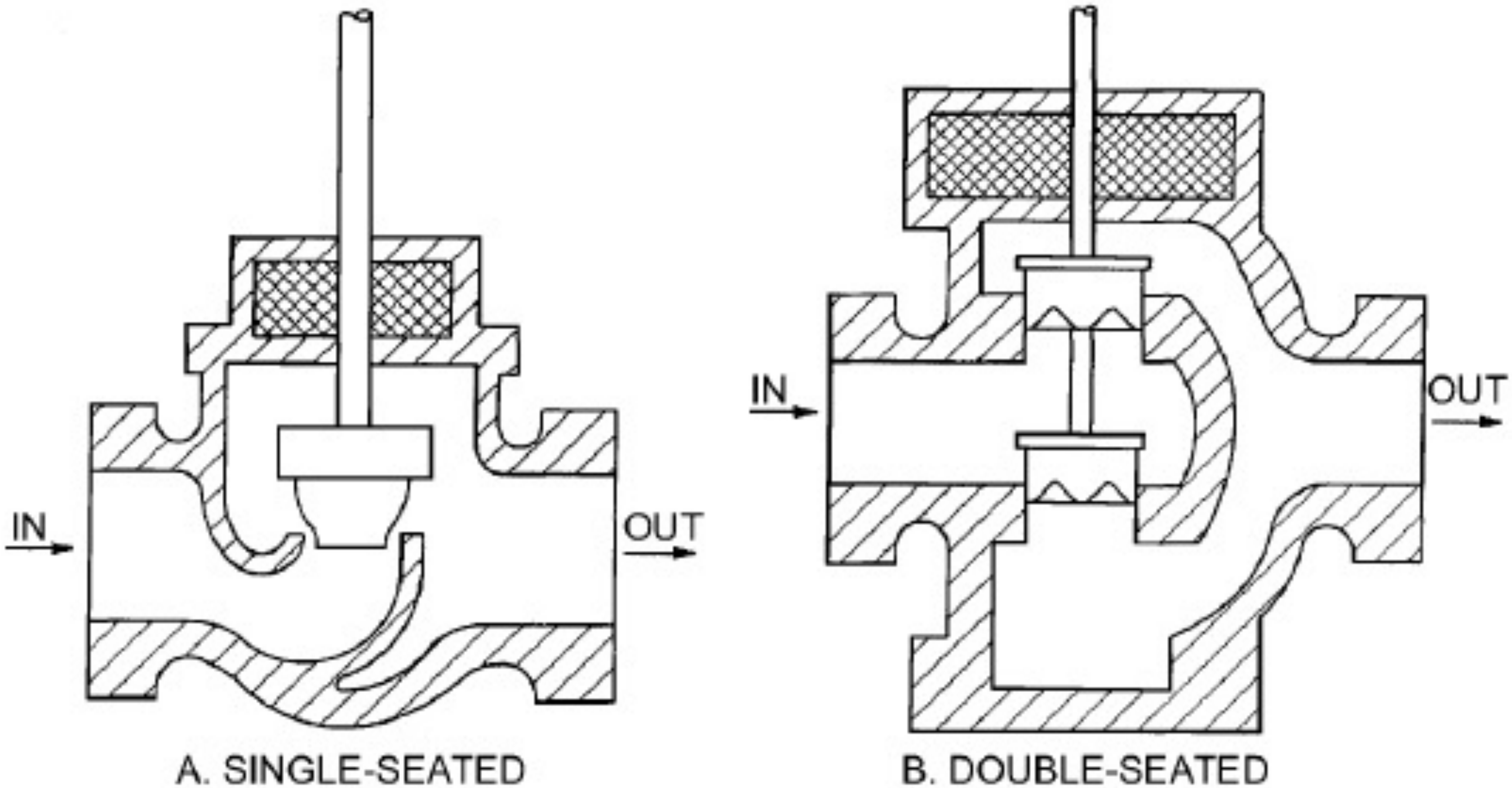
ACTUATORS & DAMPERS & SENSORS & VALVES

Valves

- An automatic valve is designed to control the flow of steam, water, gas, or other fluids. There are different types of valves:
  - ❑ Single-seated valve
  - ❑ Double-seated or balanced valve
  - ❑ Three-way mixing valve
  - ❑ Three-way diverting valve
  - ❑ Butterfly valve

Valves

- Single-seated valve and double-seated or balanced valve



https://www.youtube.com/watch?v=pTzx2ecA7Dc

Flow Characteristics

- Valve performance is expressed in terms of its flow characteristics. Common characteristics are:
  - ❑ **Quick Opening:** Maximum flow is approached as valve begins to open
  - ❑ **Linear:** Opening and flow are related in direct proportion
  - ❑ **Equal Percentage:** Each equal increment of opening increases flow by an equal percentage over the previous value

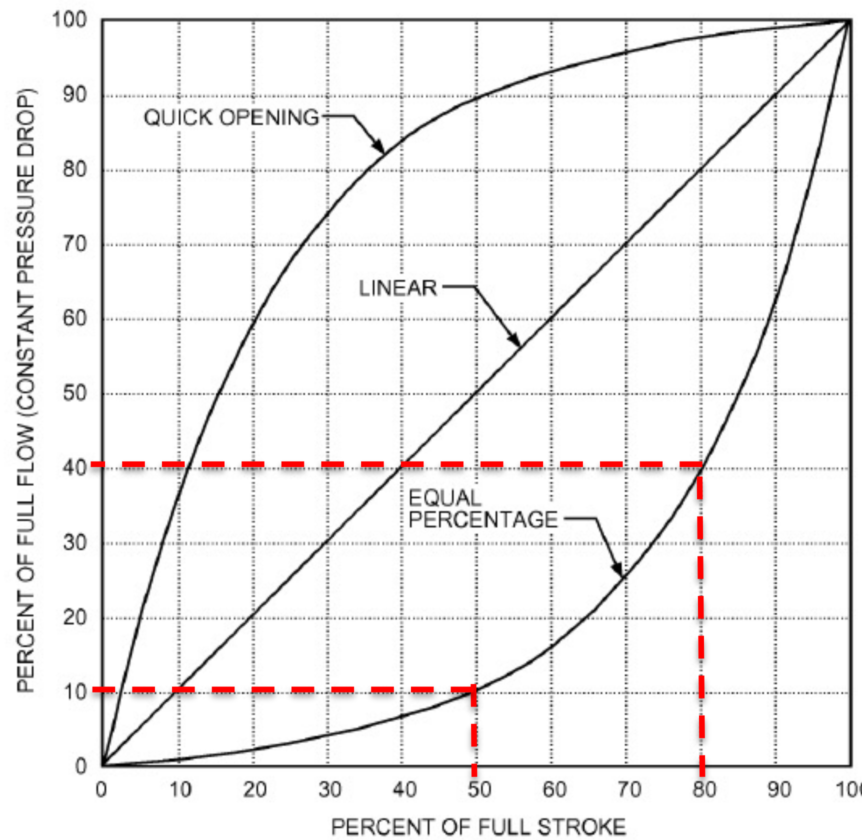


Fig. 10 Typical Flow Characteristics of Valves

Dampers

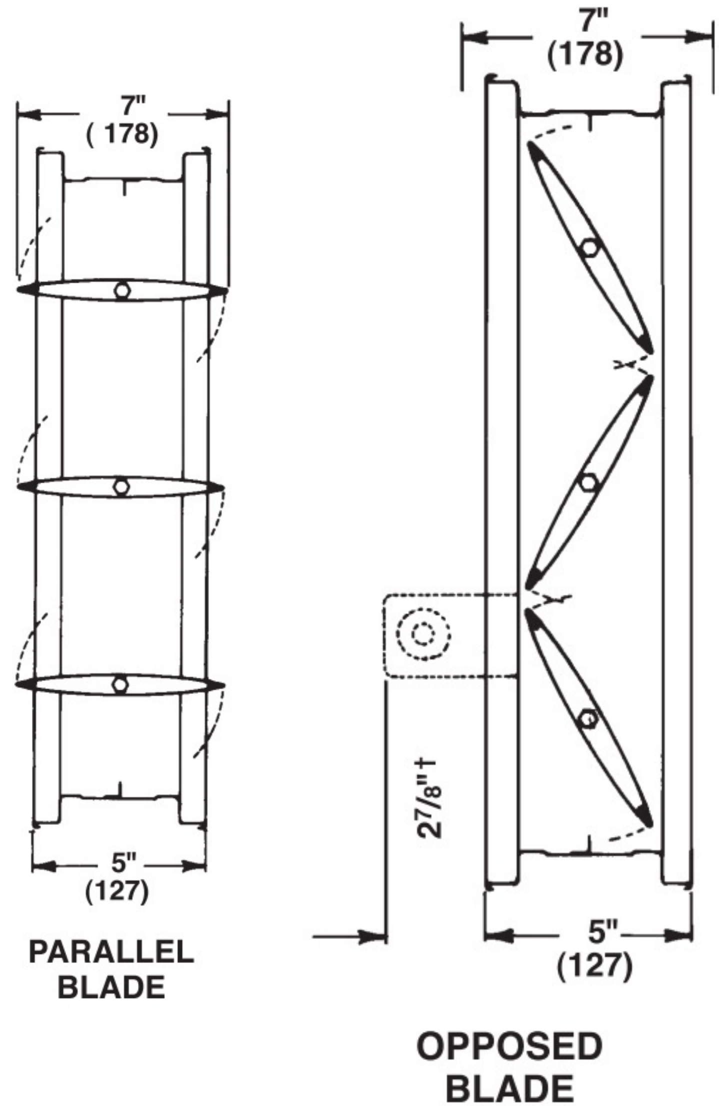
- Automatic dampers are used in air conditioning and ventilation to control airflow. They may be used:
  - To modulate control to maintain a controlled variable, such as mixed air temperature or supply air duct static pressure
  - For two-position control to initiate operation, such as opening minimum
  - outside air dampers when a fan is started

Dampers

- Multiblade dampers are typically available in two arrangements

  - **Parallel-blade:** Used when the pressure drop of the damper is about 25% or more of the pressure in a subsystem (mostly for two position of open or closed)

  - **Opposed-blade:** Used when the pressure drop of the damper is less than 15% of the pressure in a subsystem



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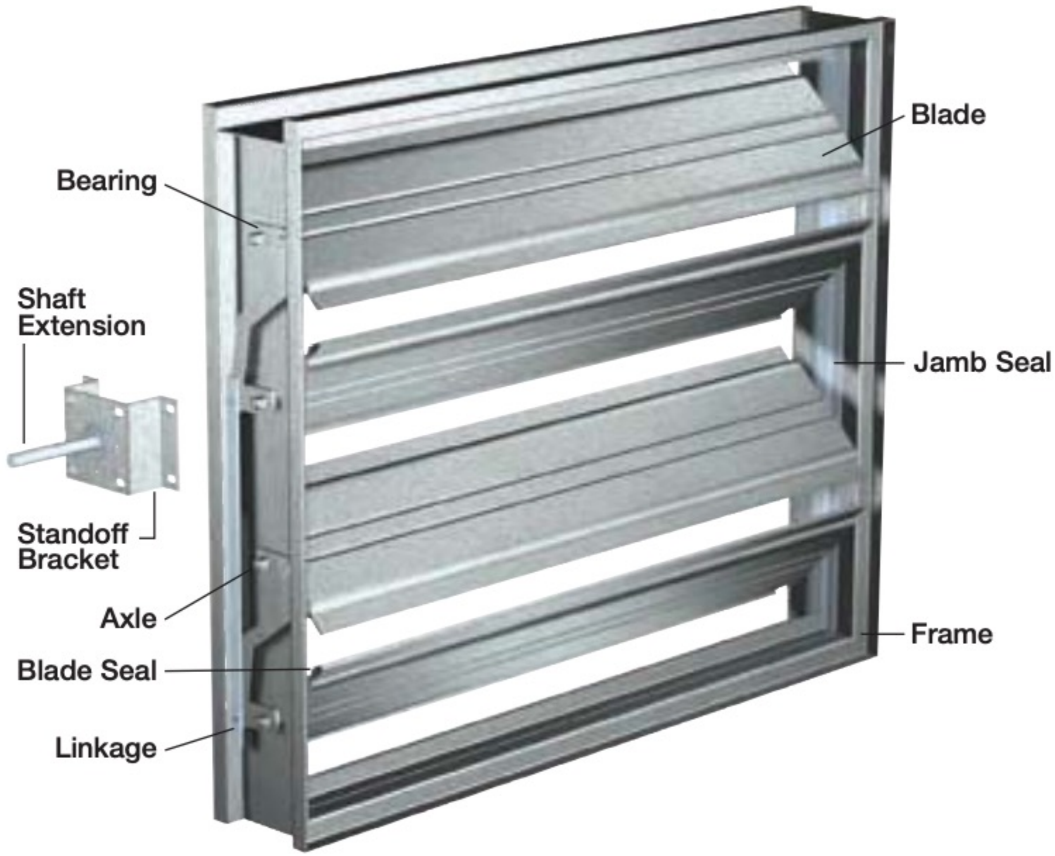
Dampers



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Dampers

- How to calculate the pressure drop:

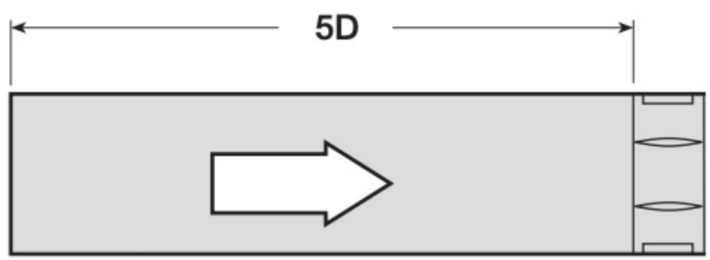


Figure 5.2

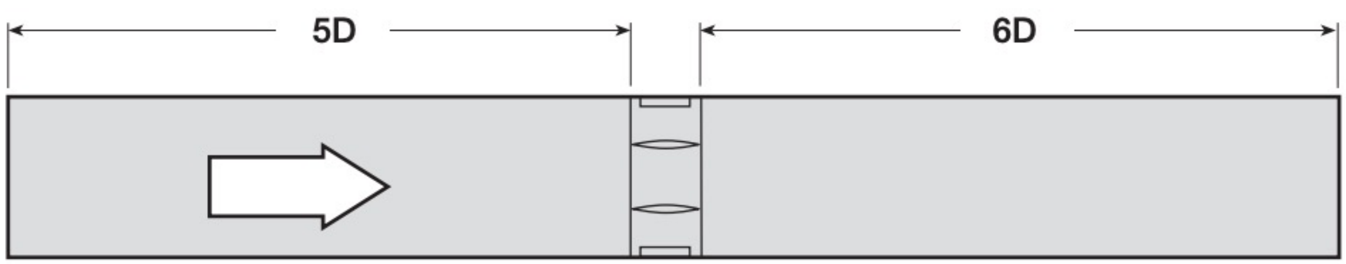


Figure 5.3

https://content.greenheck.com/public/DAMProd/Original/10002/ControlDampers_catalog.pdf

Dampers

- How to calculate the pressure drop:

ICD-44 and ICD-45

- Extruded aluminum airfoil blades with thermal breaks and insulated with polyurethane foam
- Extruded Frame (ICD-44) with thermal breaks (ICD-45)

Dimension inches	12x12			24x24			36x36			12x48			48x12		
AMCA figure	5.2	5.3	5.5	5.2	5.3	5.5	5.2	5.3	5.5	5.2	5.3	5.5	5.2	5.3	5.5
Velocity (ft/min.)	Pressure Drop in. wg														
500	.03	.01	.05	.02	.01	.05	.01	.01	.04	.01	.01	.04	.03	.01	.05
1000	.11	.04	.23	.08	.03	.21	.05	.02	.14	.06	.02	.18	.14	.06	.22
1500	.25	.09	.52	.19	.08	.47	.11	.04	.33	.14	.06	.42	.32	.14	.51
2000	.45	.17	.93	.34	.14	.84	.21	.08	.58	.25	.10	.74	.57	.25	.90
2500	.71	.26	1.44	.53	.22	1.32	.33	.12	.91	.40	.17	1.16	.89	.40	1.41
3000	1.03	.38	2.08	.77	.32	1.90	.47	.18	1.31	.57	.24	1.68	1.29	.58	2.04
3500	1.40	.52	2.83	1.05	.43	2.59	.64	.24	1.79	.78	.33	2.28	1.76	.79	2.78
4000	1.83	.67	3.70	1.37	.57	3.39	.84	.32	2.34	1.02	.43	2.98	2.30	1.03	3.70

VCDR-50 and 53

- Insert type round single blade
- Blade seals VCDR-53

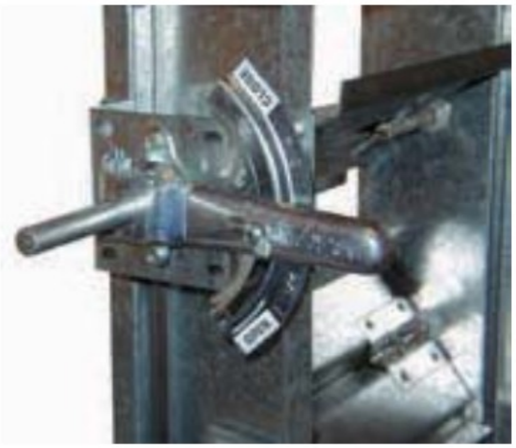
Dimension inches	12			24		
AMCA figure	5.2	5.3	5.5	5.2	5.3	5.5
Velocity (ft/min.)	Pressure Drop in. wg					
500	.01	.01	.02	.01	.01	.02
1000	.06	.02	.10	.04	.01	.09
1500	.13	.05	.22	.08	.03	.20
2000	.23	.08	.38	.15	.06	.36
2500	.37	.13	.60	.23	.09	.56
3000	.53	.19	.86	.33	.13	.81

https://content.greenheck.com/public/DAMProd/Original/10002/ControlDampers_catalog.pdf

Actuators

- Valve actuators include the following general types:
  - **A pneumatic** valve actuator consists of a spring-opposed, flexible diaphragm or bellows attached to the valve stem
  - An **electric-hydraulic valve actuator** is similar to a pneumatic one, except that it uses an incompressible fluid circulated by an internal electric pump
  - A **solenoid** consists of a magnetic coil operating a movable plunger
  - An **electric motor** actuates the valve stem through a gear train and linkage
  - **Unidirectional**, for two-position operation. The valve opens during one half-revolution of the output shaft and closes during the other half-revolution
  - **Spring-return**, energy drives the valve and spring returns back (e.g. two position vs modulating operation)

Actuators



Manual
Quadrant

Electric
External Mount

Electric
Internal Mount

Pneumatic

https://content.greenheck.com/public/DAMProd/Original/10002/ControlDampers_catalog.pdf

Sensors

- A sensor responds to a change in the controlled variable
- The response, which is a change in some physical or electrical property of the primary sensing element, is available for translation or amplification by mechanical or electrical signal. This signal is sent to the controller. The selection of sensors should consider:
    - ❑ Operating range of controlled variable
    - ❑ Compatibility of controller input
    - ❑ Accuracy and repeatability
    - ❑ Sensor response time
    - ❑ Control agent properties and characteristics
    - ❑ Ambient environment characteristics

Temperature Sensors

- Temperature-sensing elements generally detect changes in either
  - ❑ Relative dimension (caused by differences in thermal expansion)
  - ❑ The state of a vapor or liquid
  - ❑ Some electrical property
- Within each category, there are a variety of sensing elements to measure room, duct, water, and surface temperatures

Thermostats

- Thermostats combine sensing and control functions in a single device:
  - **Occupied/unoccupied** or **dual-temperature room thermostat**
  - **Pneumatic day/night thermostat** uses a two-pressure air supply system (often 13 and 17 psig, or 15 and 20 psig)
  - **Heating/cooling** or **summer/winter thermostat**
  - **Multistage thermostat** operates two or more successive steps in sequence
  - **Submaster thermostat** has its set point raised or lowered over a predetermined range in accordance with variations in output from a master controller
  - **Dead-band thermostat** has a wide differential over which the thermostat remains neutral

Thermostats

- A few example of thermostats are:

SEQUENCE OF OPERATION (SOO)

Sequence of Operation

- A recent ASHRAE Guideline aims to determine high-performance sequences of operation for HVAC systems

ASHRAE®

GUIDELINE

ASHRAE Guideline 36-2021
(Supersedes ASHRAE Guideline 36-2018)
Includes ASHRAE addenda listed in Appendix C

High-Performance Sequences of Operation for HVAC Systems

See Informative Appendix C for approval dates.

This Guideline is under continuous maintenance by a Standing Guideline Project Committee (SGPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Guideline. Instructions for how to submit a change can be found on the ASHRAE® website (https://www.ashrae.org/continuous-maintenance).

The latest edition of an ASHRAE Guideline may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 180 Technology Parkway NW, Peachtree Corners, GA 30092. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

Sequence of Operation

- Examples of SOO for a radiant cooling design and control:

Example Sequence of Operation:

In the cooling mode floor slab temperature set points shall be set as follows:

1. As AHU-1 and AHU-2 operating cooling capacity decreases from 100% to 50% BMCS shall reset floor slab temperature set points from 68°F to 74°F.
2. BMCS shall calculate current indoor dew-point and reset slab temperature set points to prevent condensation.
3. When AHU-1 and AHU-2 operating cooling capacity decreases from below 45% BMCS shall deactivate radiant floor system.

Paliaga et al. (2017)

Sequence of Operation

- Examples of SOO for a radiant cooling design and control:

Sequence of Operation:

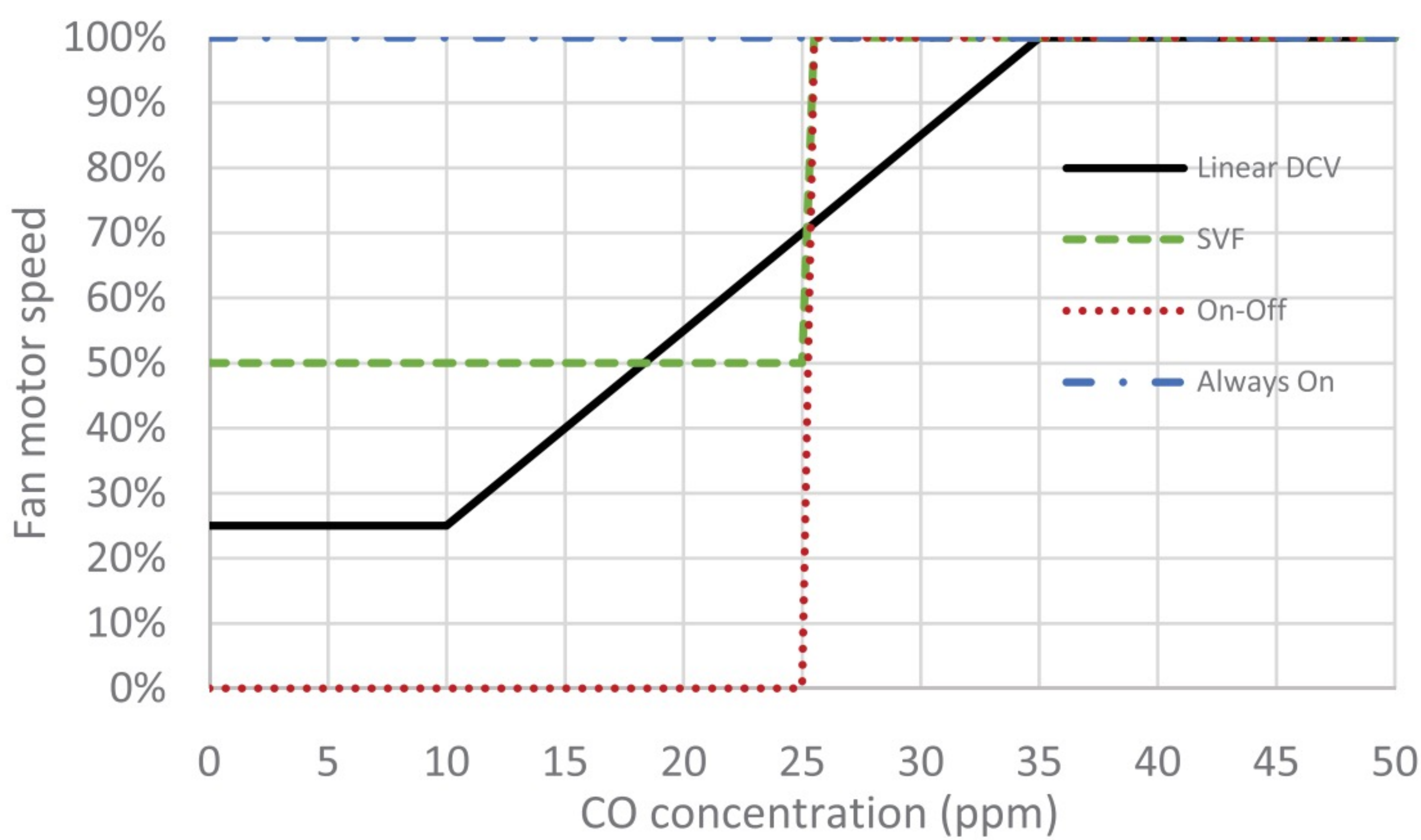
Radiant floor control: The radiant floor is intended to provide a base level of heating or cooling while minimizing change-overs from slab heating to slab cooling on a particular day. Airside equipment is intended to fine tune the space temperature. Temperature and time delay settings shall be adjusted during initial and seasonal commissioning.

a. Radiant floor heating shall be enabled for occupied hours when OAT < [50]°F and the zone is in heating ($T_Z < T_{ZH}$) and the space was not in cooling mode ($T_Z > T_{ZC}$) during the previous [24] hours.
b. Radiant floor heating shall be enabled for unoccupied hours when OAT < [40]°F and the zone temp is [2]°F below the occupied hours space temperature, TZ, and the space was not in cooling mode ($T_Z > T_{ZC}$) during the previous [16] hours, and it is less than [3] hours before occupancy.
c. Radiant floor heating shall be disabled if OA > [55]°F or ($T_Z > T_{ZH}$+[2]°F.
d. Radiant floor cooling shall be enabled for occupied hours when OAT > [80]°F for more than [2] hours, the zone is in cooling ($T_Z > T_{ZC}$) and the radiant floor was not enabled in heating mode during the previous [12] hours.
e. Radiant floor cooling shall be disabled if OA < [80]°F for [2] hours or ($T_Z < T_{ZC}$ - [5]°F).
f. Once enabled, a radiant floor zone shall remain enabled for a minimum of [20] minutes. Once disabled, a radiant floor zone shall remain disabled for a minimum of [10] minutes.
g. When enabled, the radiant manifold control valve(s) shall open.
h. Each radiant floor zone shall have separately adjustable settings.
i. Floor Slab temperature shall be trended to fine tune operation.

Paliaga et al. (2017)

Sequence of Operation

- Developing SOO to optimize energy efficiency and maintain indoor air quality requirements in parking garages:



Faramarzi et. al (2020)

COMMUNICATION PROTOCOLS

Communication Networks

- A building automation system (BAS) is a centralized control and/or monitoring system for many or all building systems (e.g., HVAC, electrical, life safety, security).

  - ❑ A BAS may link information from control systems actuated by different technologies
  - ❑ One important characteristic of direct digital control (DDC) is the ability to share information. Information is transferred between
    - ❖ Controllers to coordinate their action
    - ❖ Controllers and building operator interfaces to monitor and command systems
    - ❖ Controllers and other computers for off-line calculation
  - ❑ This information is typically shared over communication networks
  - ❑ DDC systems nearly always involve at least one network; often, two or more networks are interconnected to form an internetwork

Communication Protocols

- Many approaches to interoperability have been proposed and applied, each with varying degrees of success under various circumstances.

- Typically, an interoperable system uses one of two approaches:

  - ❑ **Standard Protocols:** The supplier is responsible for compliance with the standard; the system specifier or integrator is responsible for interoperation
  - ❑ **Special-purpose Gateways**: the supplier takes responsibility for interoperation

Communication Protocols

- Some applicable standard protocols used in BAS are:
  - BACnet
    - MS/TP
    - IP
  - LonTalk
  - Konnex
  - MODBUS
  - PROFIBUS FMS

Communication Protocols

- MODBUS were designed for low-cost industrial process control
- LonTalk defines a LAN technology but not messages that are to be exchanged for BAS applications
- BACnet® or implementer's agreements, such as those made by members of LonMark
- Konnex evolved from the European Installation Bus (EIB) and several other European protocols developed for residential
- BACnet is the only standard protocol developed specifically for commercial BAS applications

Communication Protocols

ANSI/ASHRAE Standard 135-2010
(Supersedes ANSI/ASHRAE Standard 135-2008)
Includes ANSI/ASHRAE addenda listed in the History of Revisions

ASHRAE STANDARD

BACnet®

A Data Communication Protocol for Building Automation and Control Networks

See the History of Revisions at the end of this standard for approval dates by the ASHRAE Standards Committee, the ASHRAE Board of Directors, and the American National Standards Institute.

This standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE Web site (www.ashrae.org) or in paper form from the Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 404-321-5478. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

STANDARD

ASHRAE®

ANSI/ASHRAE Standard 135-2020
(Supersedes ANSI/ASHRAE Standard 135-2016)

ASHRAE BACnet™

A Data Communication Protocol for Building Automation and Control Networks

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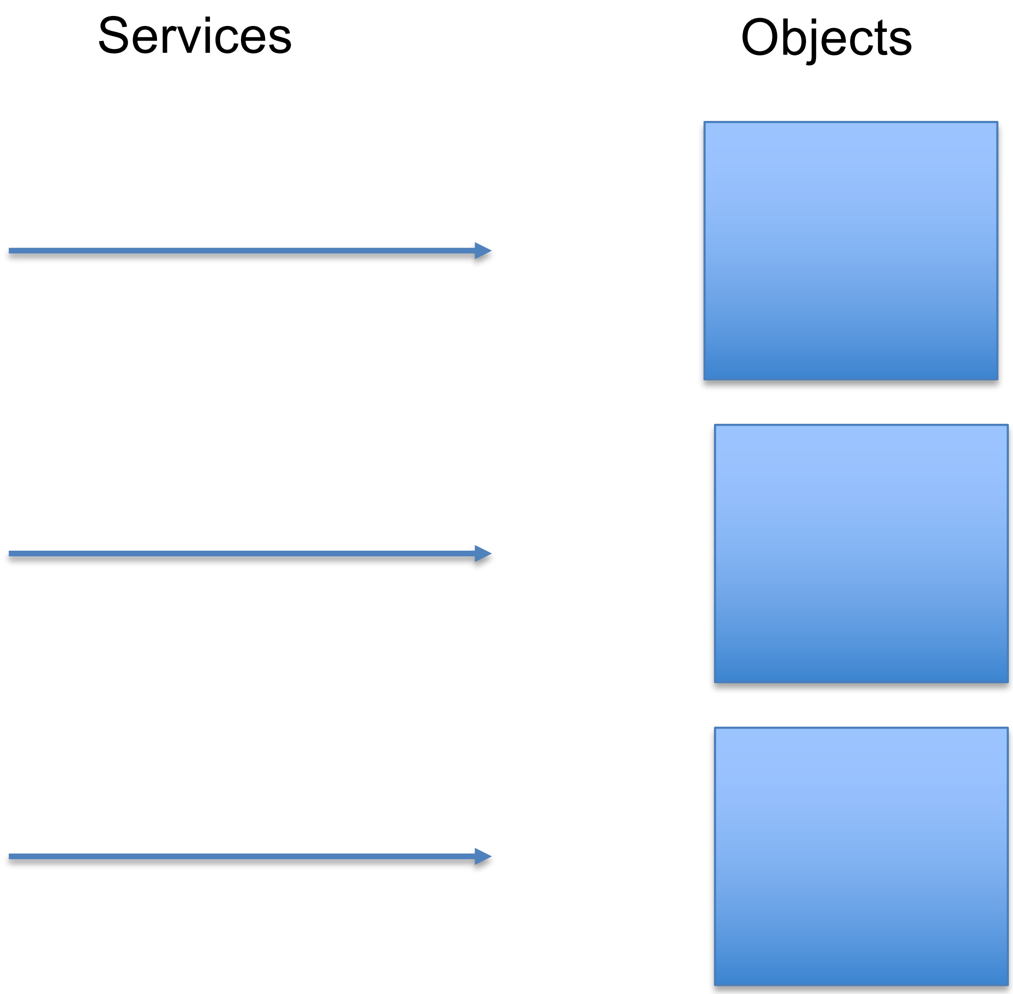
ISSN 1041-2336

Approved American National Standard
ANSI
www.ansi.org

INTRO TO BACNET

Intro to BACnet

- The standardized message in BACnet entails two concepts
  - ❑ Objects
  - ❑ Services

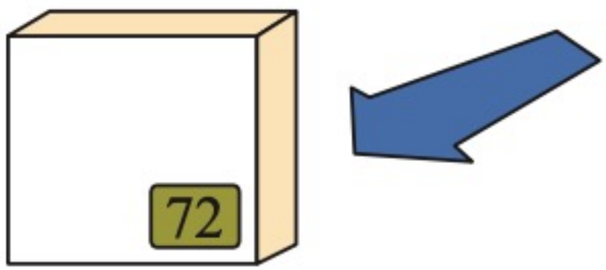


Intro to BACnet

- ***Services:***
  - Is a formal procedure for BACnet nodes
  - Enables making requests of other nodes (e.g., a node with attached temperature sensor)

BACnet

- A sample object is as follow:

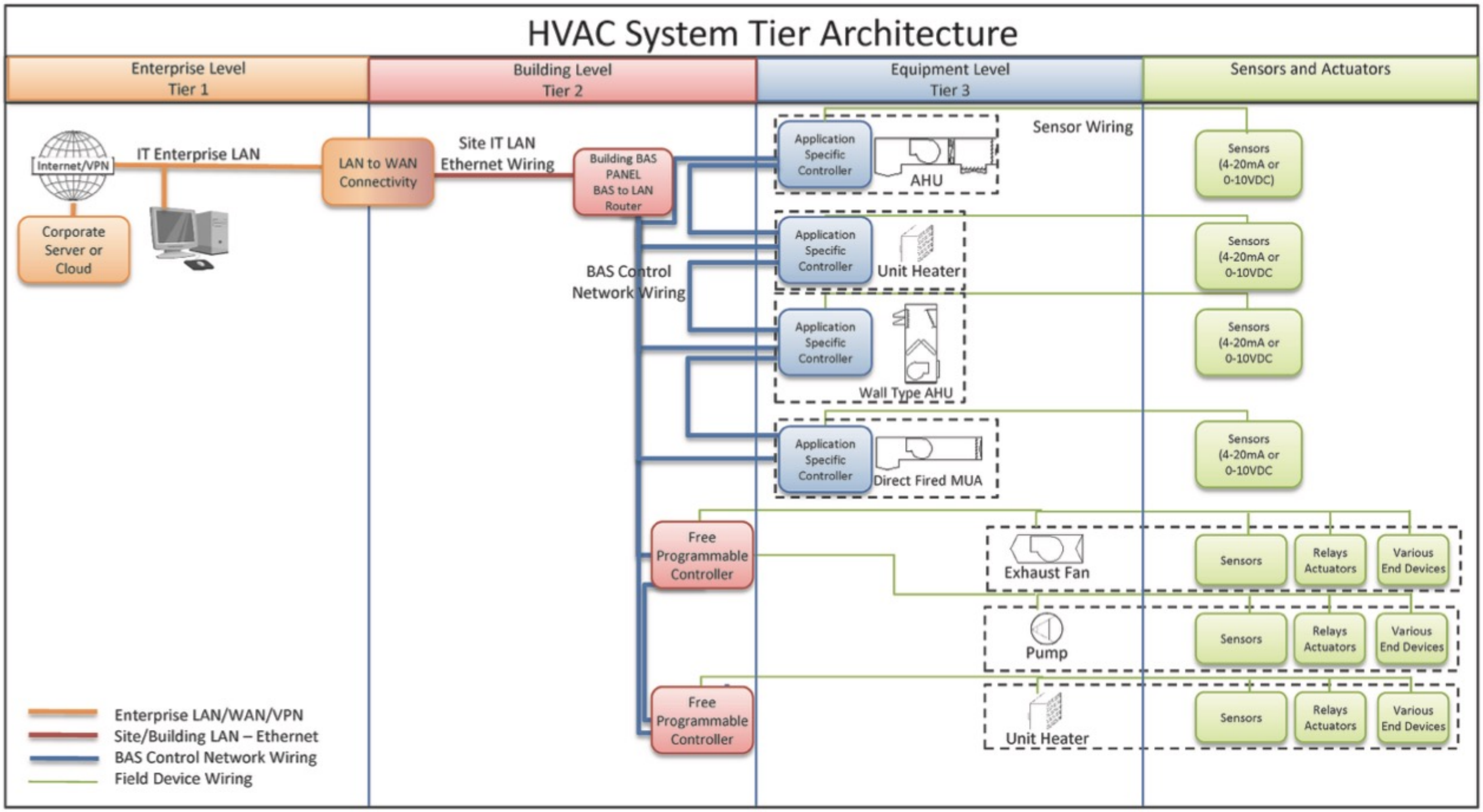


Object_Name	SPACE TEMP
Object_Type	ANALOG INPUT
Present_Value	72.3
Status_Flags	Normal, Out-of-Service
High_Limit	78.0
Low_Limit	68.0

CLOSING REMARK

Closing Remark

- Example multitier HVAC integration overview drawing



Closing Remark