CAE 553 Measurements and Instrumentation in Architectural Engineering

Fall 2018

November 6, 2018

HVAC: Building automation systems and controls

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Civil, Architectural and Environmental Engineering
Illinois Institute of Technology

Dr. Brent Stephens, Ph.D. (brent@iit.edu)
Civil, Architectural and Environmental Engineering
Illinois Institute of Technology

ASHRAE lunch & learn w/ Baumann Consulting

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Illinois Institute of Technology
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AJIT NAIK
PE, BEMP, Commissioning & Energy Engineer

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Professional Lunch & Learn Event

Thursday, November 8th | 1:00 PM
Perlstein Hall Auditorium
Lunch will be provided

Membership Inquiries
ashrae_iit@iit.edu

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"This seminar provides a roadmap to an integrated design process for achieving high performance buildings."

LEARNING OBJECTIVES

- Understand what building simulation is and the types of analyses available
- Understand how integrating simulation in design can aid high-performance building
- Understand data visualization and client communication techniques

Green building panel discussion

What is the Future of the Global Green Building Industry?

Discussion panel featuring:

Chris Pyke
U.S. Green Building Council

Jorge Chapa
Green Building Council of Australia

Roxana Isaiu
GRESB

Eric Corey Freed
Morrison Hershfield

RSVP
Required

LOCATION
Illinois Institute of Technology

Kaplan Institute Building, Steelcase Commons Area (2nd Floor)

DATE
Thursday Nov. 15 2018 @ 12:45 PM

CONTACT
Department of Civil, Architectural, and Environmental Engineering, IIT

Phone: 312.567.3540
www.iit.edu/~ce

REFRESHMENTS
Lunch will be provided

RSVP REQUIRED
https://tinyurl.com/y83zznz3

Abstract

A panel of international experts will discuss and debate the future of the global green building movement. They will share their perspectives on the history of high performance buildings in the U.S. and the around the world. They will reflect on the circumstances that have led to a profound moment of transition and change for the movement. This moment is defined by the success of the last 20+ years of green building – tens of thousands of certified projects around the world recognized by dozens of major rating systems. This success is juxtaposed against new expectations, new challenges, and new capabilities. These circumstances have created demand for change, including a push to recognize buildings, communities, and entire cities based on objective measures of operational performance. Simultaneously, concerns about climate change, health, resilience, and biodiversity have intensified, and buildings are being asked to do more than ever to demonstrably address these challenges. The panel will provide their perspectives on these dynamic and the state-of-the-market and their hopes and aspirations for the future of the industry.

Speaker Bios

Chris Pyke is the Research Officer for the USGBC and Green Business Certification, Inc. Dr. Pyke has experience in the private sector, nonprofits, and government, including service as Chief Operating Officer for GRESB, B.V., Chief Strategy Officer for Aclima, Inc., and a physical scientist with EPA. Dr. Pyke is on the faculty of the Urban and Regional Planning Program at Georgetown University.

As Head of Market Transformation, Jorge ensures that GBCA's strategic priorities, partnerships, product/services, including Green Star, accelerate the transformation of Australia's built environment, delivering healthy and resilient places for people and natural environment. He has an architecture degree from University of Monterrey and a Masters in Design Science from University of Sydney.

Roxana Isaiu is Director Real Estate for GRESB, with responsibility for the development and execution of the firm's ESG data benchmarking methodology for the real estate sector. Isaiu focuses on the promotion of transparency in the real estate sector through systematic reporting on ESG indicators of performance. Isaiu holds a master's of science in corporate finance.

Eric Corey Freed is an award-winning architect, author of 11 books, and global speaker. He is Sustainability Disruptor for Morrison Hershfield, and a visionary design leader in biophilic and regenerative design. In 2012, he was named one of the 25 "Best Green Architecture Firms" in the US, and one of the "Top 10 Most Influential Green Architects." In 2017, he was named one of Build's American Architecture Top 25.

ILLINOIS INSTITUTE OF TECHNOLOGY
Armour College of Engineering

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[WANGER INSTITUTE FOR SUSTAINABLE ENERGY RESEARCH AT ILLINOIS INSTITUTE OF TECHNOLOGY]

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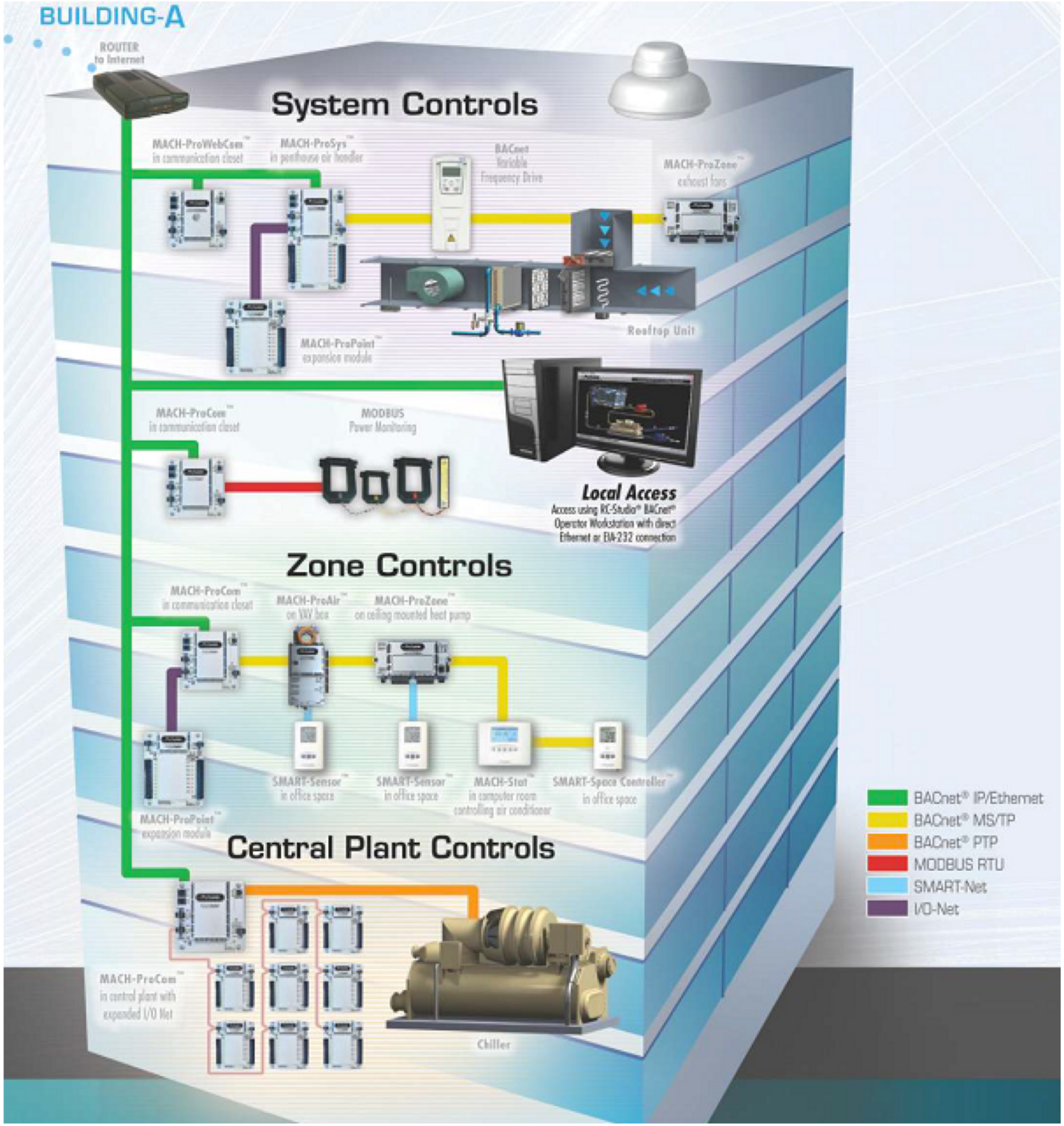
Department of Civil, Architectural, and Environmental Engineering

How does building equipment make decisions?

How does the building equipment and systems interact?


BUILDING-A
ROUTER to Internet
System Controls
MACH-ProWebCom™ in communication closet
MACH-ProSys™ in penthouse air handler
BACnet Variable Frequency Drive
MACH-ProZone™ exhaust fans
Rooftop Unit
MACH-ProPoint™ expansion module
MACH-ProCom™ in communication closet
MODBUS Power Monitoring
Local Access
Access using RC-Studio® BACnet® Operator Workstation with direct Ethernet or EIA-232 connection
Zone Controls
MACH-ProCom™ in communication closet
MACH-ProAir™ on VAV box
MACH-ProZone™ on ceiling mounted heat pump
SMART-Sensor™ in office space
SMART-Sensor™ in office space
MACH-Stat™ in computer room controlling air conditioner
SMART-Space Controller™ in office space
MACH-ProPoint™ expansion module
Central Plant Controls
MACH-ProCom™ in central plant with expanded I/O Net
Chiller
BACnet® IP/Ethernet
BACnet® MS/TP
BACnet® PTP
MODBUS RTU
SMART-Net
I/O-Net

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

- 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

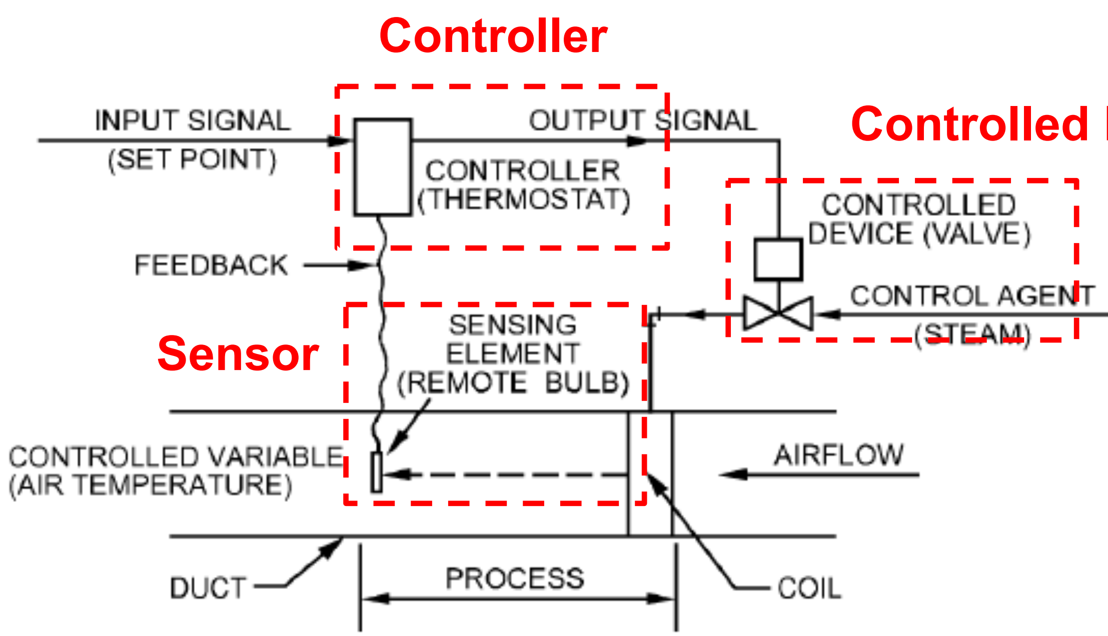


Fig. 1 Example of Feedback Control: Discharge Air Temperature Control

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:

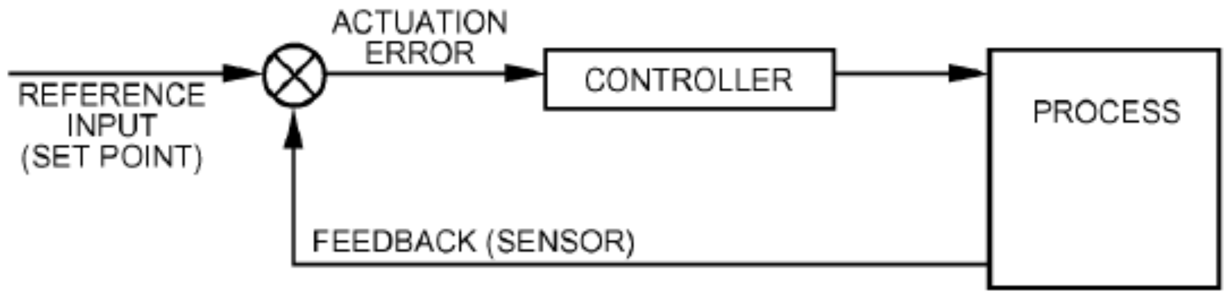


Fig. 2 Block Diagram of Discharge Air Temperature Control

- 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.

Terminology

- Changes in the process are shown below:

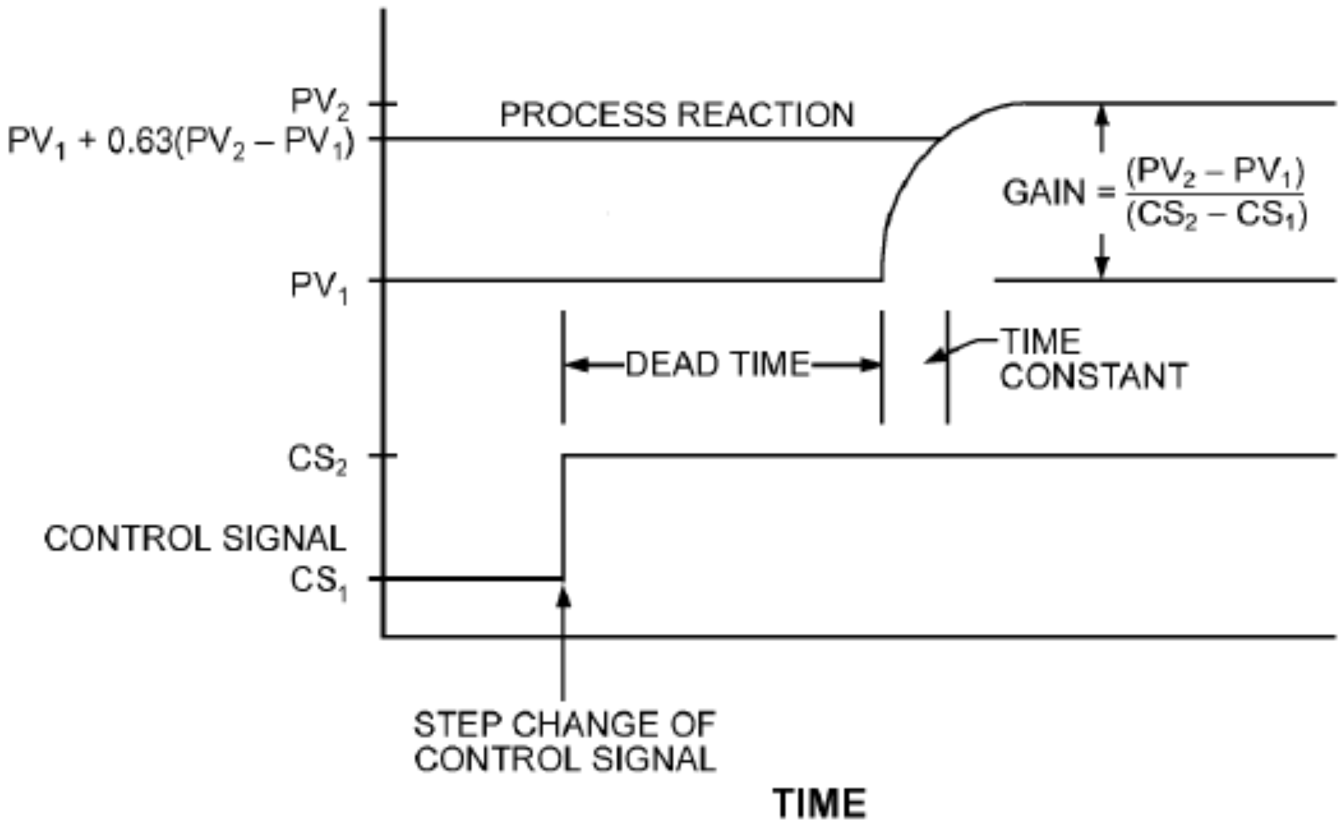


Fig. 3 Process Subjected to Step Input

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

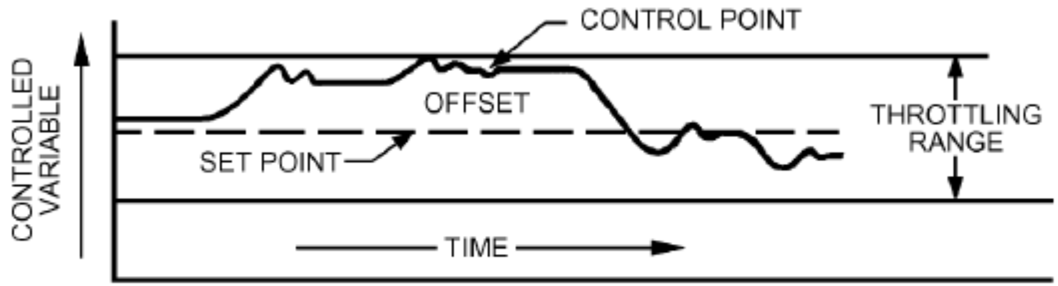


Fig. 5 Proportional Control Showing Variations in Controlled Variable as Load Changes

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

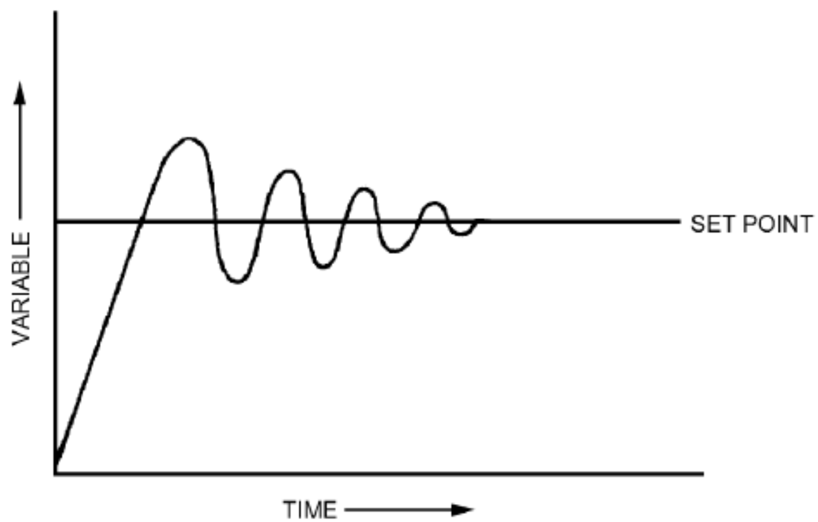


Fig. 6 Proportional plus Integral (PI) Control

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

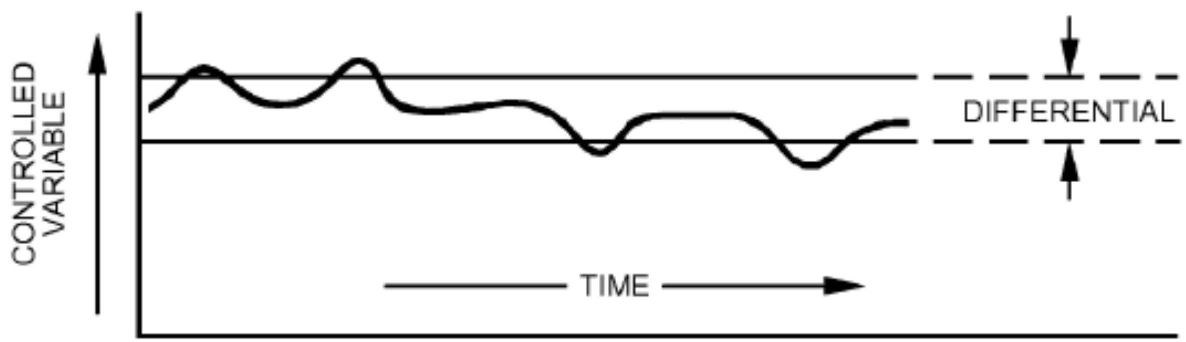


Fig. 7 Floating Control Showing Variations in Controlled Variable as Load Changes

Type of Control Actions

- P, PI, PID Controllers

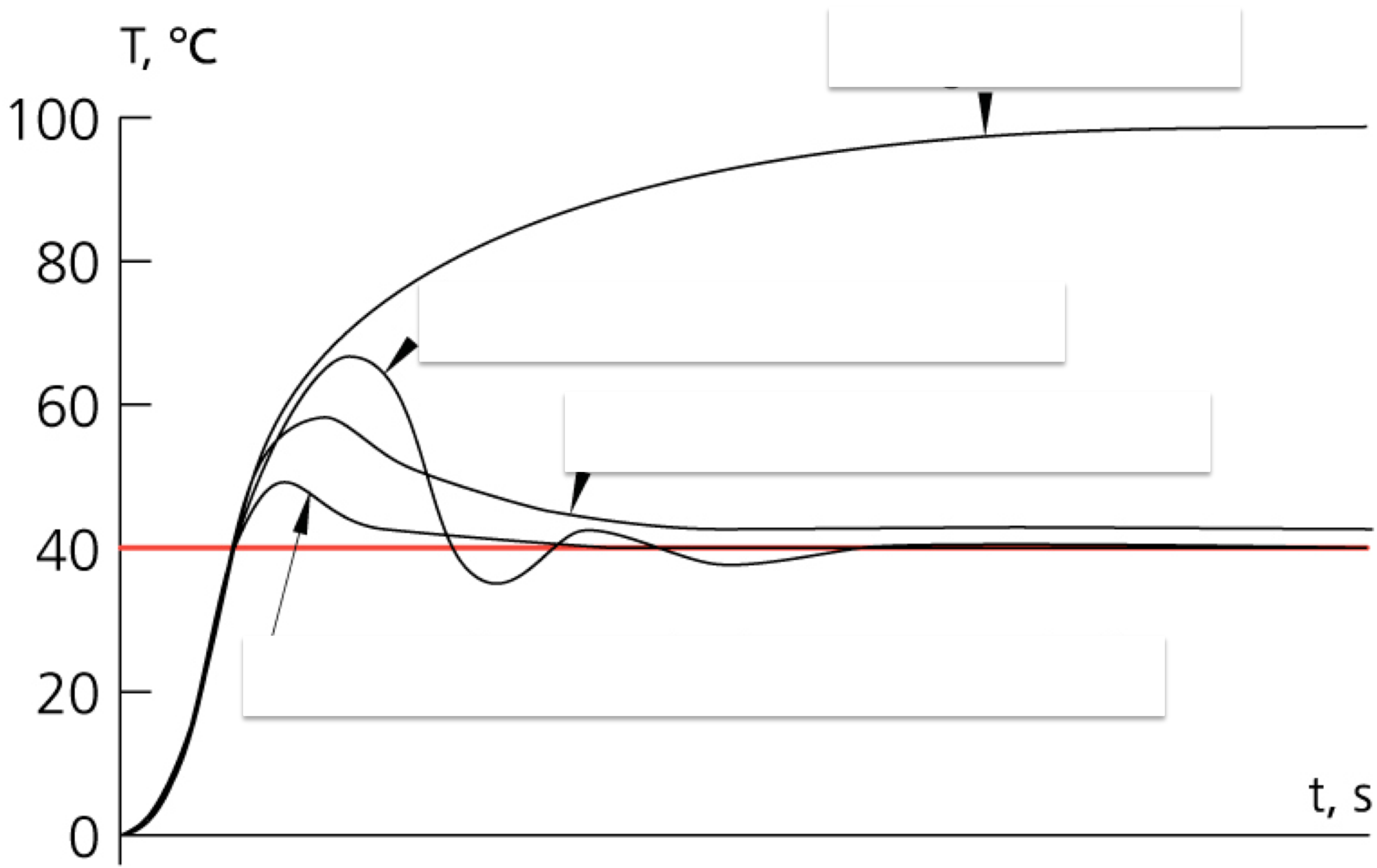
Parameter	Response Time	Stability	Accuracy
P	Increase	Deteriorates	Improves
I	Decrease	Deteriorates	Improves
D	Increase	Improves	No Impact

Type of Control Actions

- P, PI, PID Controllers

Controller	Estimates	When To Use	Examples
P	Present	• Systems with slow response • Systems tolerant to offset	Float valves Thermostats
I	Back	• Not often used alone (very slow)	Used for very noisy systems
D	Forward	• Not used alone (too sensitive to noise)	None
PI	Present & Back	• Often used	Thermostats, flow control, pressure control
PID	All time	• Often used • Most robust (but can be sensitive to noise)	Cases where the system has inertia that get out of hand

Type of Control Actions



skytech

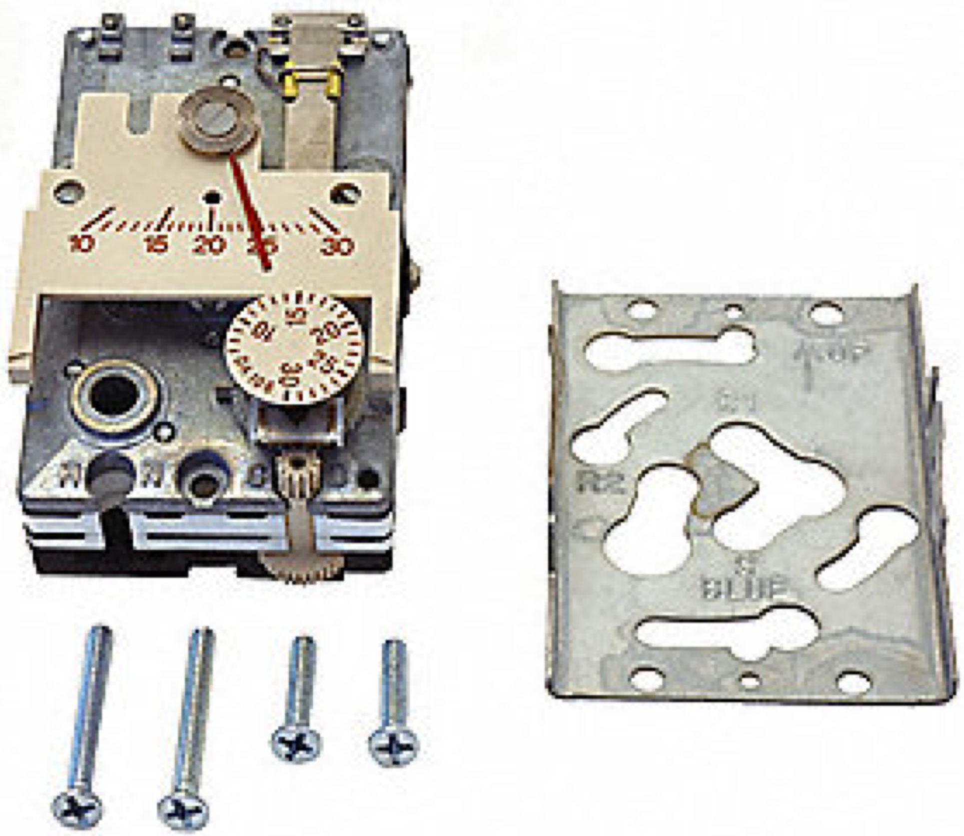
CONTROL COMPONENTS

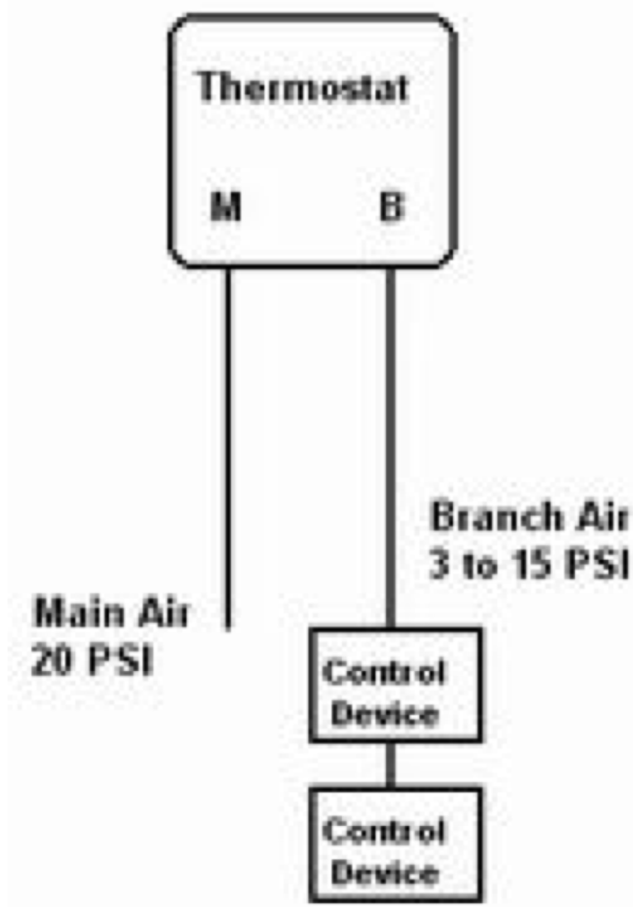
Control Components

- 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





Grainger. Com

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

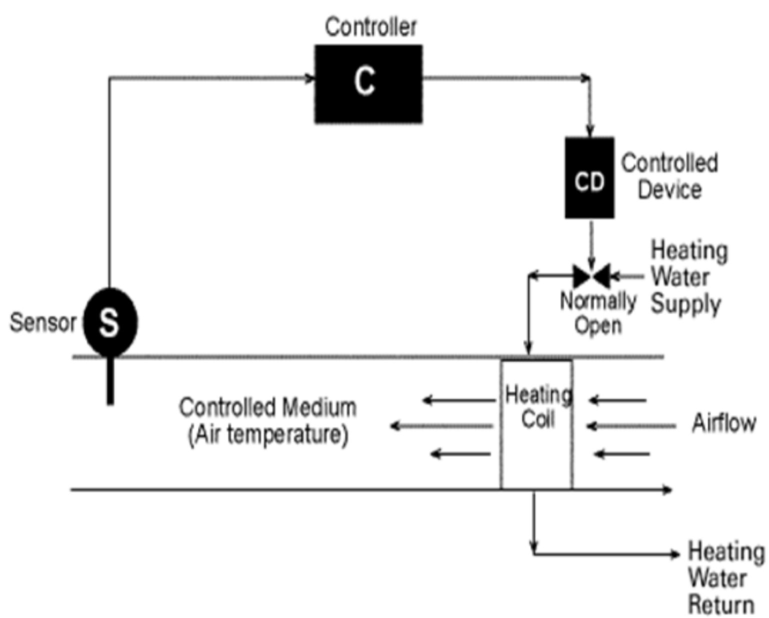
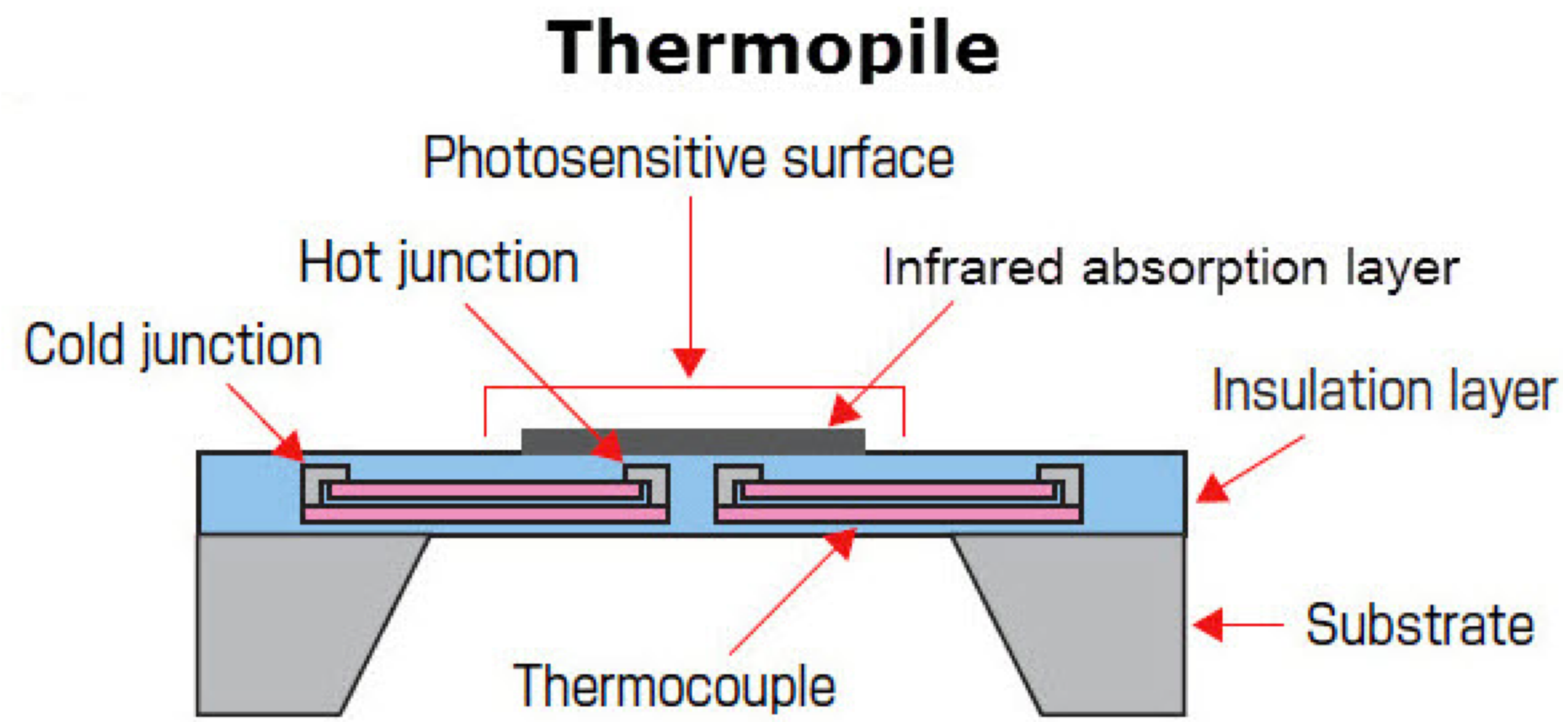


Diagram from DDC-Online.org

Control Components

- Self powered control component



Hamamatsu Photonics

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:

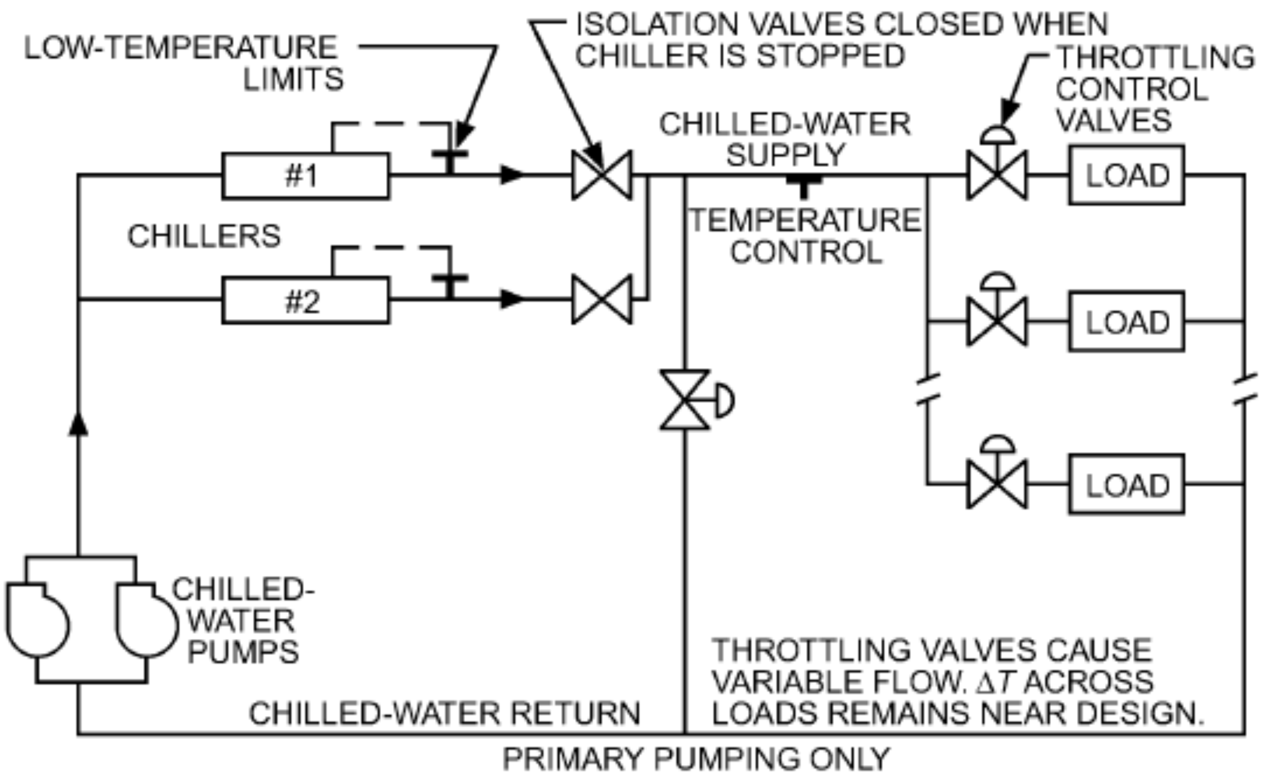
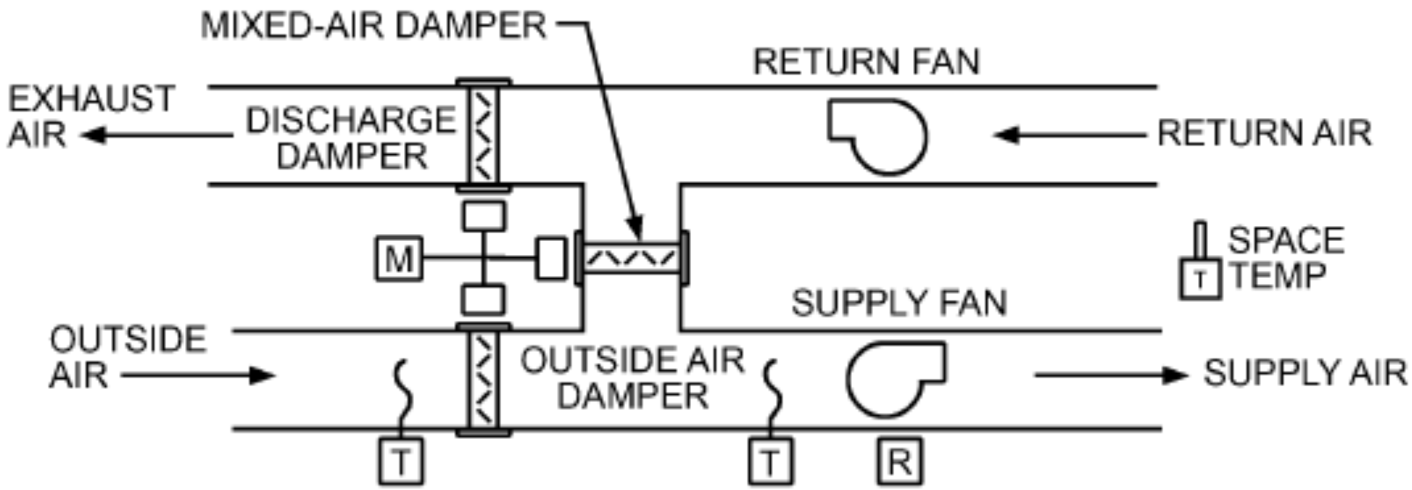


Fig. 9 Variable-Flow Chilled-Water System (Primary Only)

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

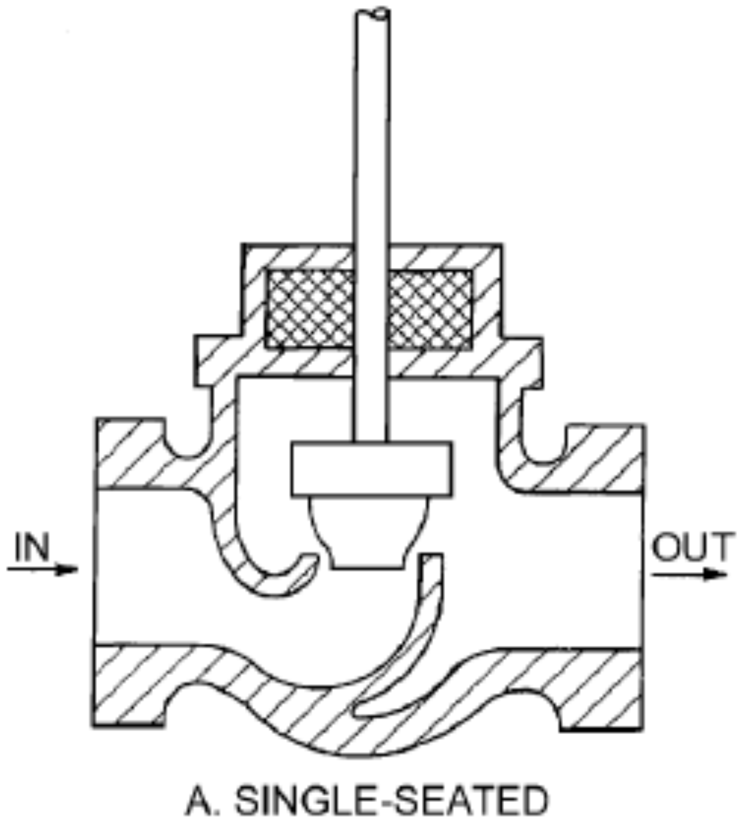
Valves

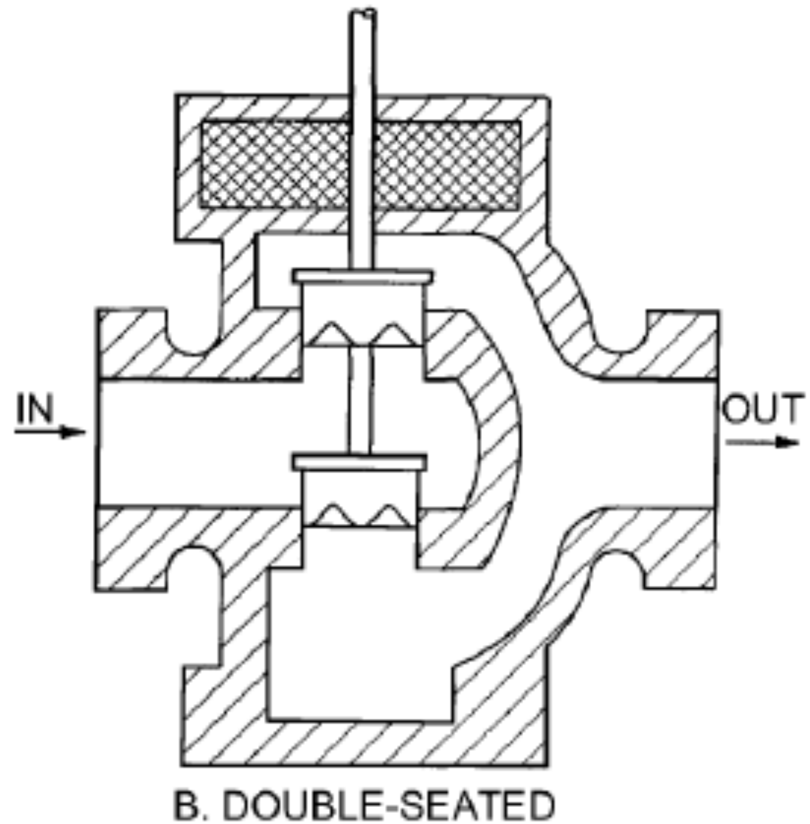
- An automatic valve is designed to control the flow of steam, water, gas, or other fluids. There are different types of valves:

  - 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

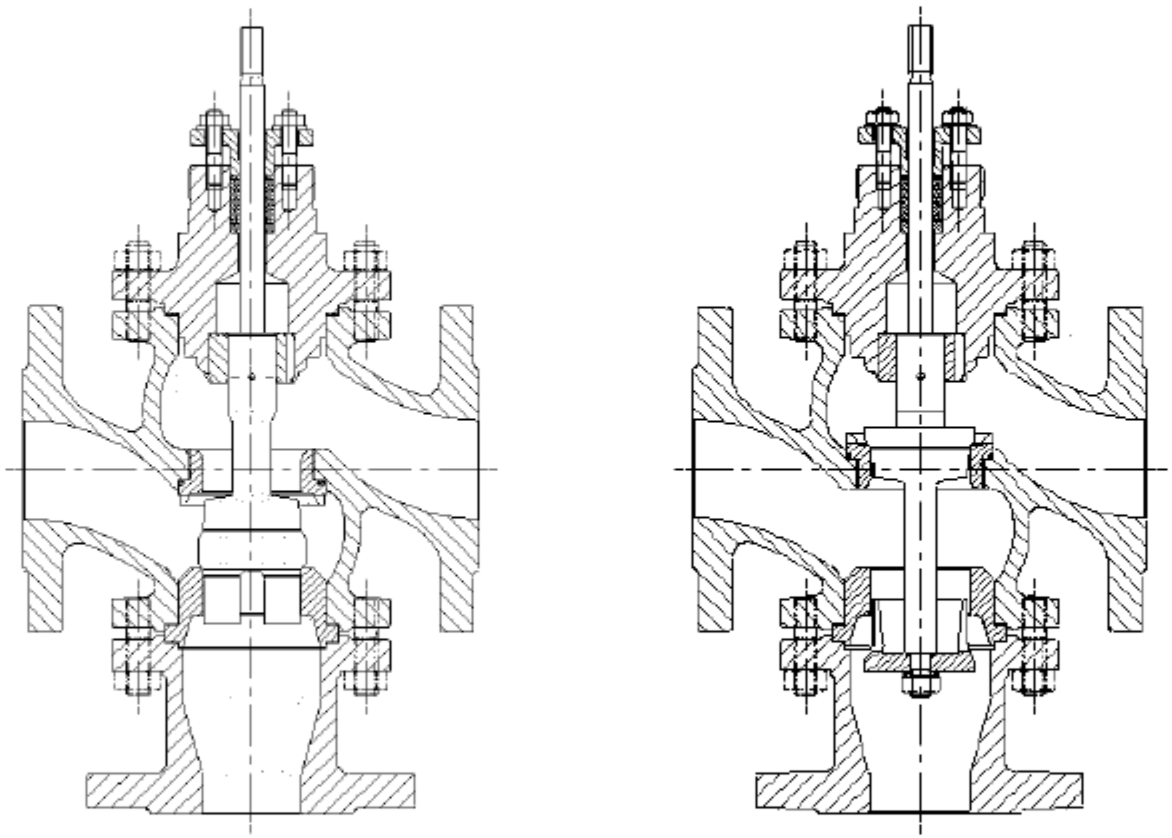




https://www.youtube.com/watch?v=pTzx2ecA7Dc

Valves

- Three-way mixing valve and three way diverting valves



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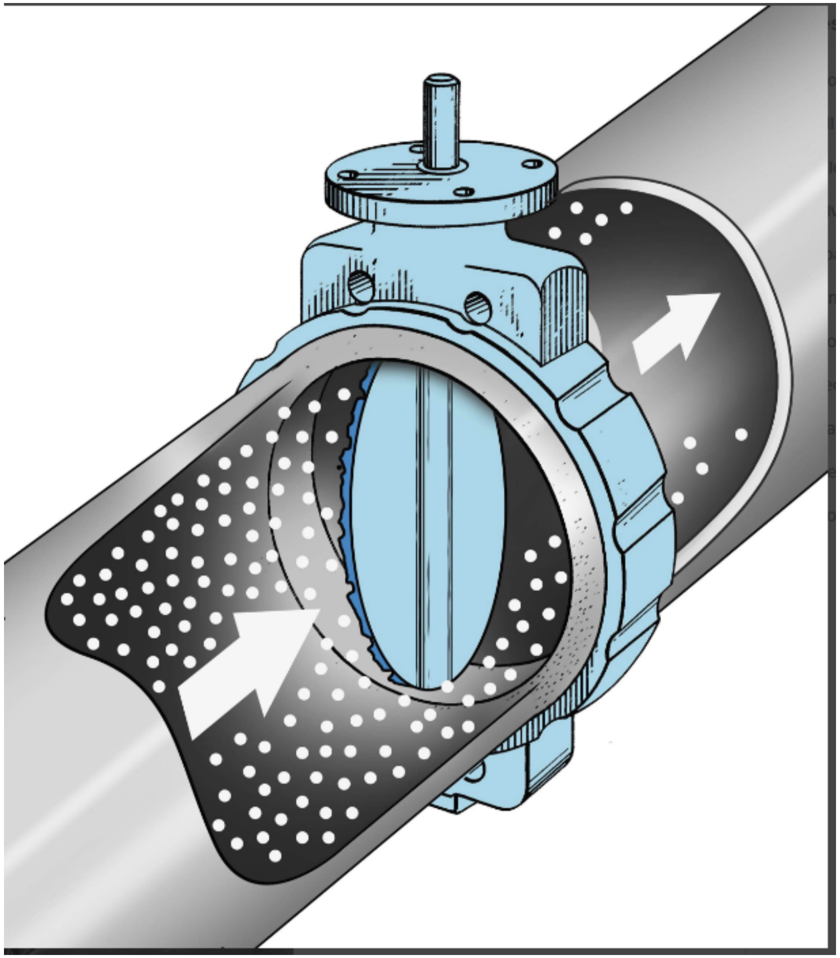
Valves

- Butterfly valve



https://www.youtube.com/watch?v=zhi7_YQZhOs

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

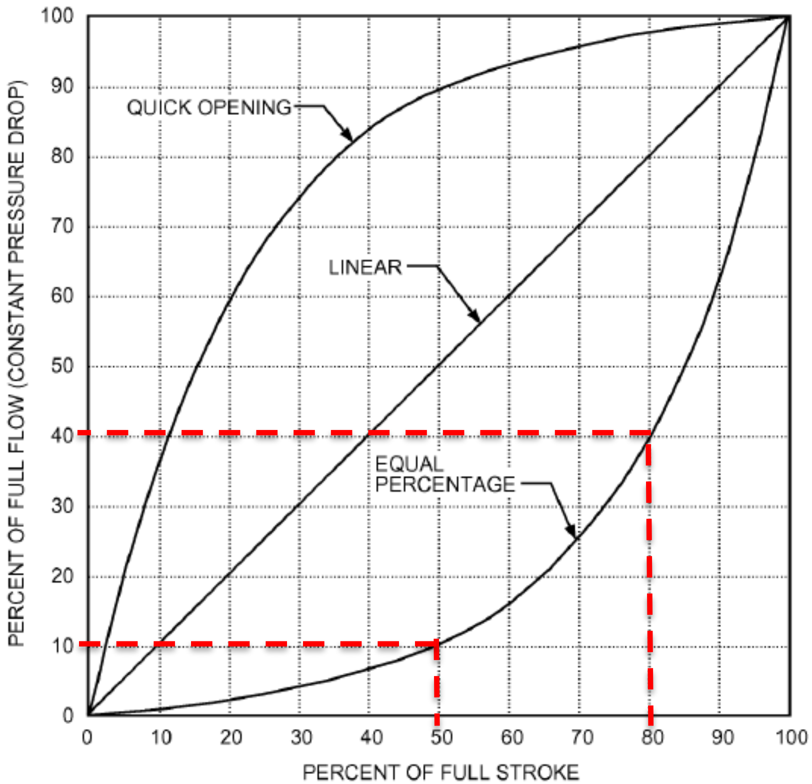
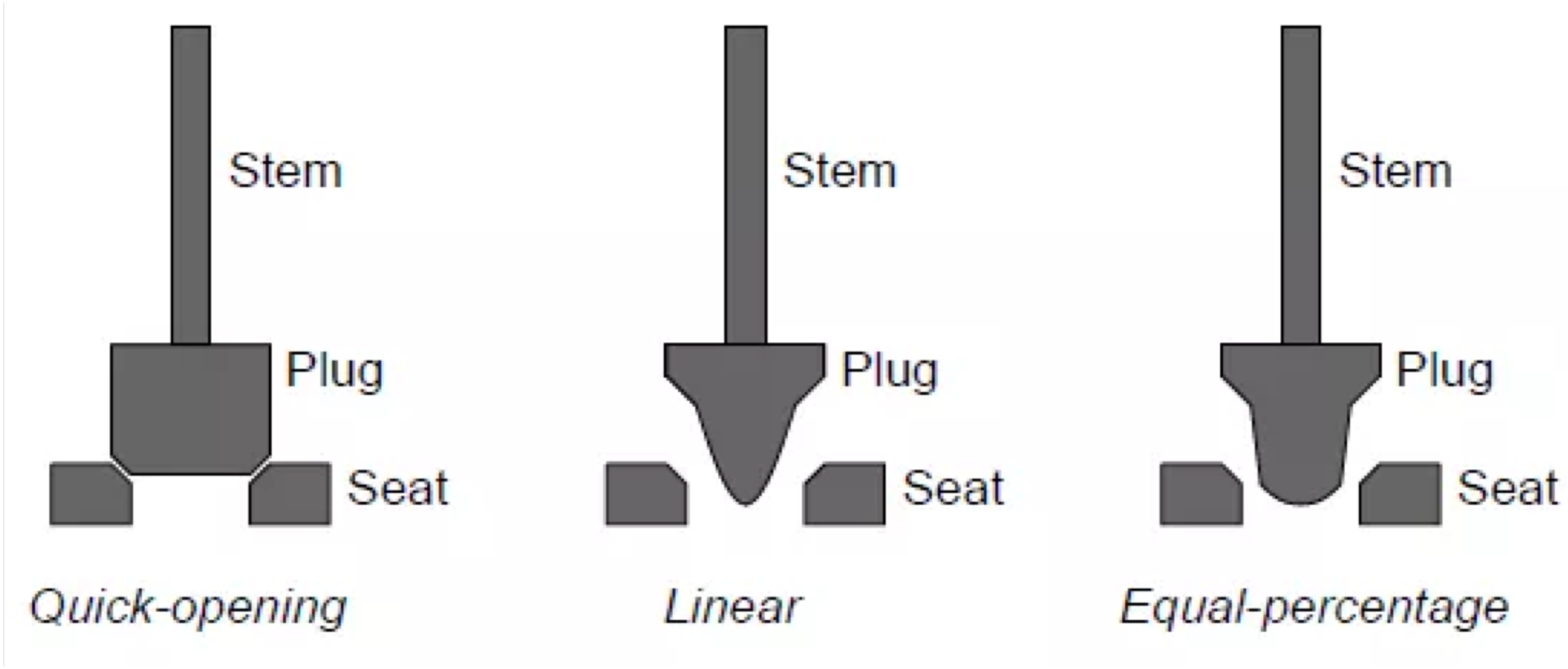


Fig. 10 Typical Flow Characteristics of Valves

Flow Characteristics



Flow Characteristics

- Valves seldom remains constant as its opening changes, actual performance usually deviates from the published characteristic curve

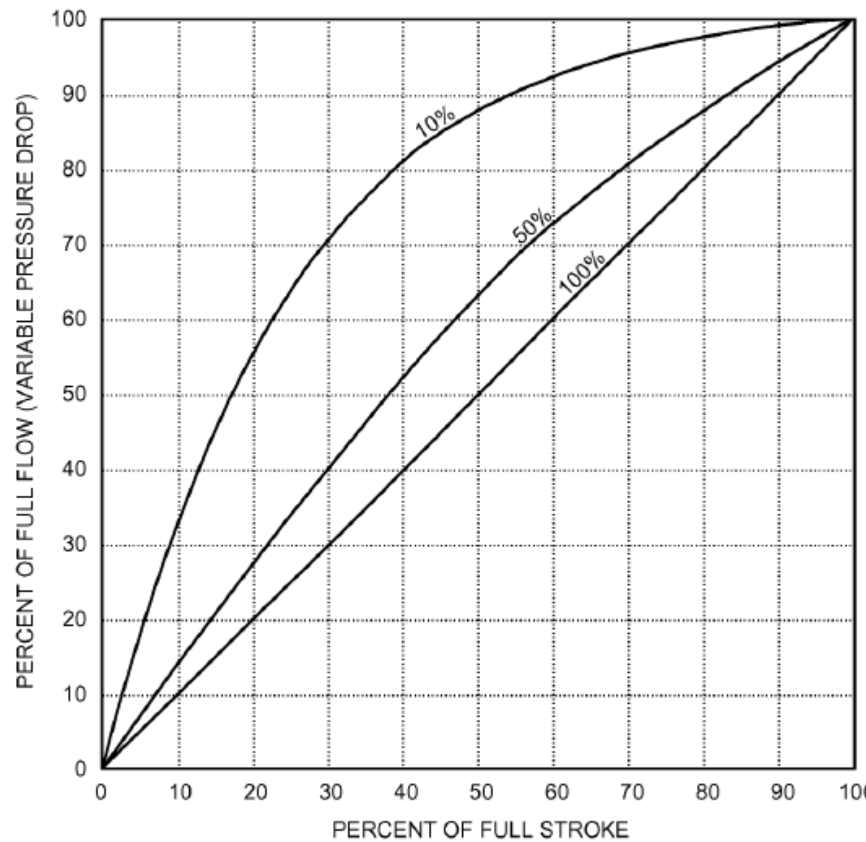
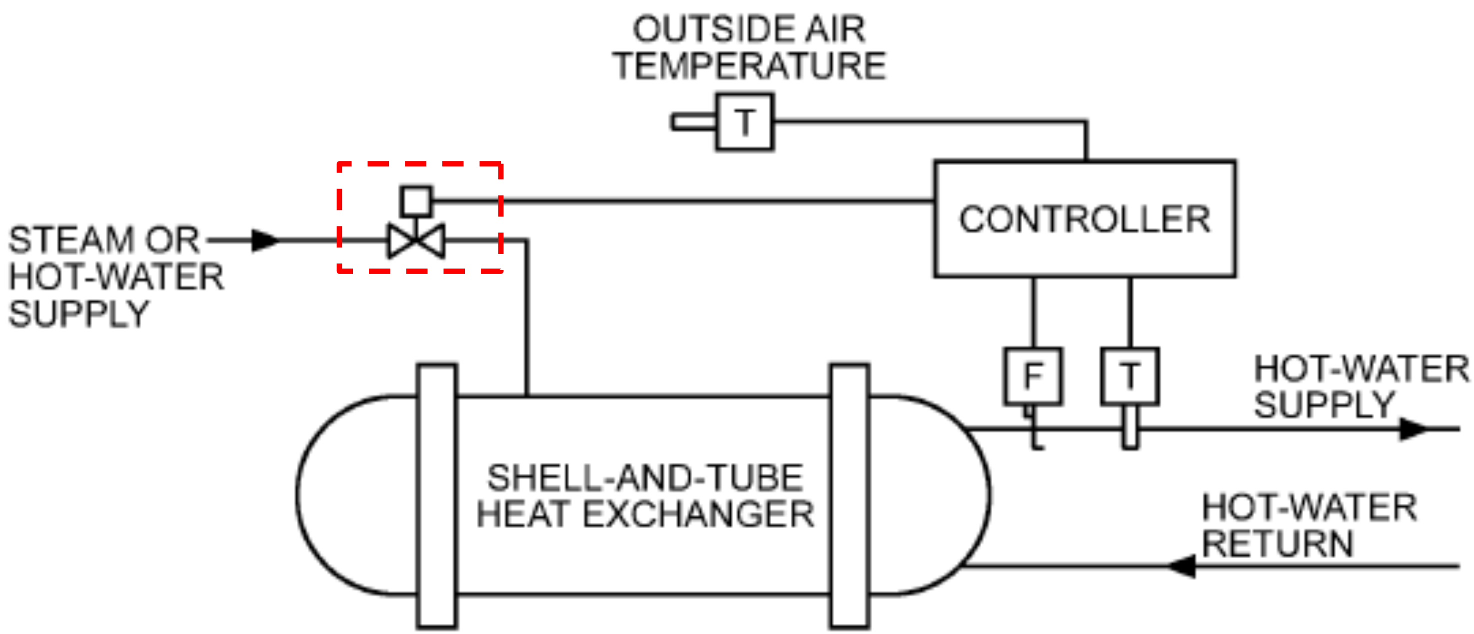


Fig. 11 Typical Performance Curves for Linear Devices at Various Percentages of Total System Pressure Drop

Valve Selection and Sizing

- **Steam Valves:** Steam-to-water and steam-to-air heat exchangers are typically controlled through regulation of steam flow using a two-way throttling valve
- One-pipe steam systems require
    - ❑ a linesize two-position valve for proper condensate drainage and steam flow



ACTUATORS & DAMPERS & SENSORS

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)

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

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

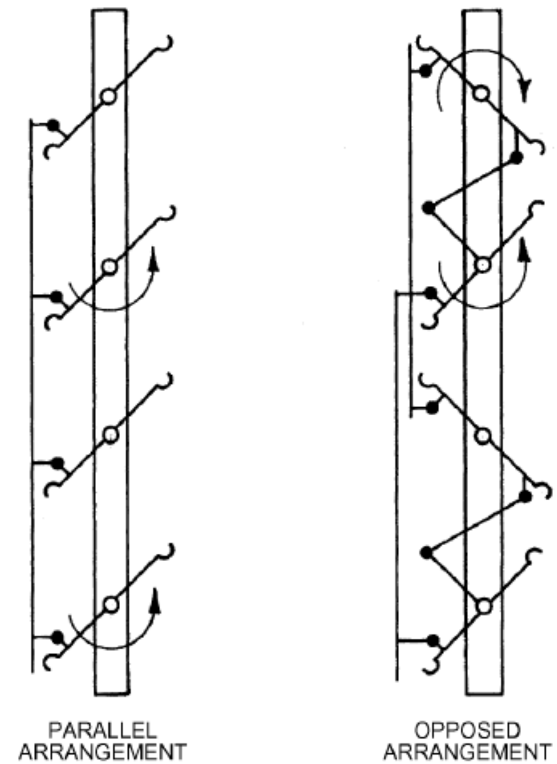


Fig. 12 Typical Multiblade Dampers

Dampers

Dampers

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

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

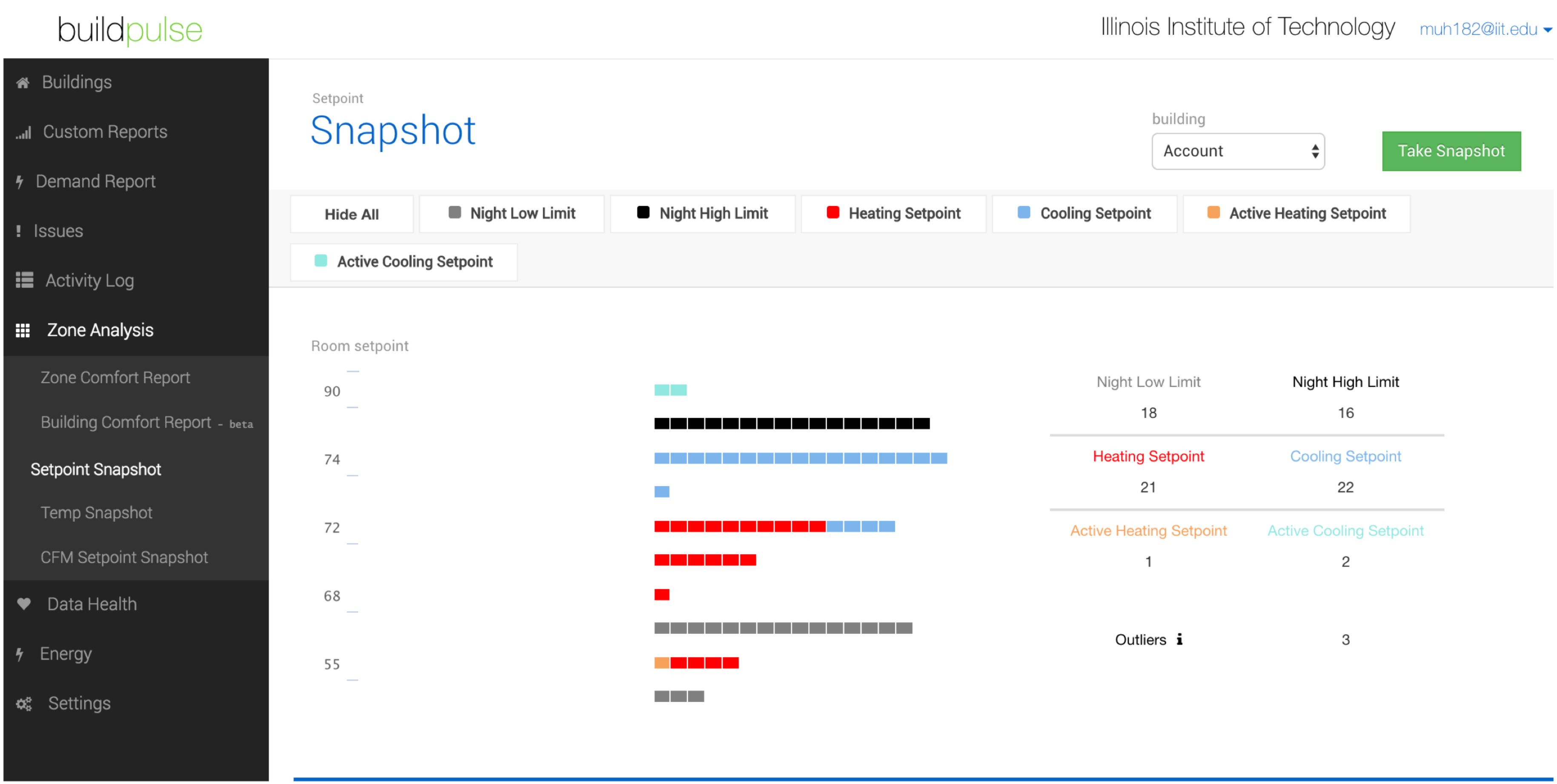
- Some applicable standard protocols used in BAS are:

Protocol	Definition
BACnet®	ANSI/ASHRAE 135-2004, EN ISO 16484-5 (2003)
LonTalk	ANSI/CEA *Standard* 709.1
PROFIBUS FMS	EN 50170:1996 Volume 2
Konnex	EN 50090
MODBUS	Modbus Application Protocol Specification V1.1

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

IIT BAS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Demand Report
Issues
Activity Log
Zone Analysis
Zone Comfort Report
Building Comfort Report - beta
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Temp Snapshot
CFM Setpoint Snapshot
Data Health
Energy
Settings
Setpoint
Snapshot
building
Account
Take Snapshot
Hide All
Night Low Limit
Night High Limit
Heating Setpoint
Cooling Setpoint
Active Heating Setpoint
Active Cooling Setpoint
Room setpoint
90
74
72
68
55
Night Low Limit
18
Night High Limit
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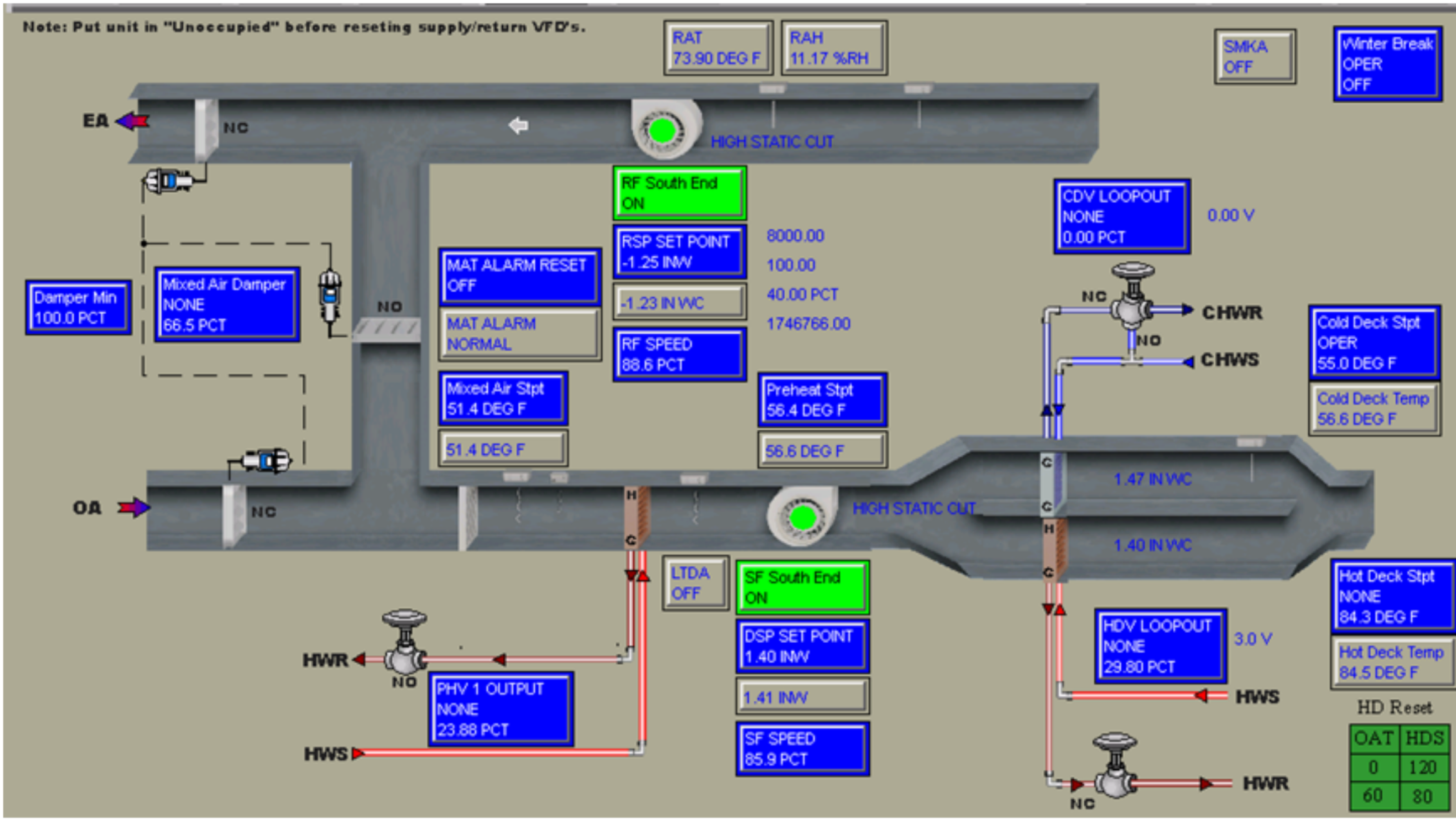
Heating Setpoint
21
Cooling Setpoint
22
Active Heating Setpoint
1
Active Cooling Setpoint
2
Outliers
3

IIT BAS



Note: Put unit in "Unoccupied" before reseting supply/return VFD's.
RAT 73.90 DEG F
RAH 11.17 %RH
SMKA OFF
Winter Break OPER OFF
EA
NC
HIGH STATIC CUT
RF South End ON
CDV LOOPOUT NONE 0.00 PCT
0.00 V
RSP SET POINT -1.25 INW
8000.00
100.00
40.00 PCT
1746766.00
MAT ALARM RESET OFF
-1.23 IN WC
MAT ALARM NORMAL
RF SPEED 88.6 PCT
Damper Min 100.0 PCT
Mixed Air Damper NONE 66.5 PCT
NO
NC
CHWR
NO
CHWS
Cold Deck Stpt OPER 55.0 DEG F
Cold Deck Temp 56.6 DEG F
Mixed Air Stpt 51.4 DEG F
51.4 DEG F
Preheat Stpt 56.4 DEG F
56.6 DEG F
OA
NC
HIGH STATIC CUT
1.47 IN WC
1.40 IN WC
LTDA OFF
SF South End ON
DSP SET POINT 1.40 INW
1.41 INW
SF SPEED 85.9 PCT
HWR
NO
PHV 1 OUTPUT NONE 23.88 PCT
HWS
HDV LOOPOUT NONE 29.80 PCT
3.0 V
HWS
HWR
NC
Hot Deck Stpt NONE 84.3 DEG F
Hot Deck Temp 84.5 DEG F
HD Reset
OAT HDS
0 120
60 80

CLASS ACTIVITY

Class Activity

- Form 5 groups:
  - Team 1: BACnet
  - Team 2: Modbus
  - Team 3: LonWorks
  - Team 4: Konnex
  - Team 5: PROFIBUS

- Review and understand materials for each communication protocol (75 minutes)

- Present your communication protocol to the class (7 to 10 minutes)