CAE 438/538 Control of Building Environmental Systems

Fall 2021

September 28, 2021

Intro to Controllers

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ANNOUNCEMENTS

Announcements

- A possible capstone project:

REGISTER

ASHRAE sponsors these competitions to encourage students to become involved in a profession that is crucial to ensuring a sustainable future for our Earth – the design of energy-efficient HVAC systems. ASHRAE will recognize the outstanding student design projects at the 2023 ASHRAE Winter Meeting scheduled for February in Atlanta, Georgia, United States of America.

The student design competition guidelines provide enough background information to enable the teams to design or select the HVAC system for the given building, or to design a sustainable building implementing an integrated building design process (the architectural and building design for sustainability, and its supporting mechanical and electrical systems) for the given program.

The Integrated Sustainable Building Design (ISBD) competition's aim is to encourage students to extend their knowledge beyond the core mechanical systems. For the ISBD category, the final design level presented may be in a preliminary stage, as the competition's basic intention is to challenge students' imaginative thinking and creative engineering approach to the building and all of its systems.

Teams may compete in one of the three categories:

- HVAC Design Calculations
- HVAC System Selection
- Integrated Sustainable Building Design (ISBD)

https://www.ashrae.org/communities/student-zone/competitions/2022-design-competition

ASSIGNMENT

Assignment

- Assignment 1 will be graded
- Assignment 2 is on Blackboard due this Thursday
- Assignment 3 is posted on Blackboard due next Thursday

Assignment

- Problem 1:

VOLUME 11, NUMBER 1 HVAC&R RESEARCH JANUARY 2005

Flow Resistance Characteristics of Airflow Control Dampers (RP-1157)

Robert Van Becelaere, PE Member ASHRAE
Harry J. Sauer, PhD, PE Fellow ASHRAE
Fathi Finaish, PhD

Received December 3, 2003; accepted May 13, 2004

This paper presents the experimental results of the performance of various types of HVAC system airflow control dampers over a wide range of types, installations, and operating conditions. Three hundred and sixty-eight tests have been conducted with the data and results discussed herein. The main fundamental performance parameter for predicting the flow rate through a partially opened damper is the pressure loss coefficient as a function of the degree of damper opening. Major variables included the type of damper, blade movement, manufacturer, installation, approach velocity, and total system pressure drop. Results should prove very useful for HVAC system designers in the proper selection of airflow modulating dampers.

Assignment

- Problem 1:

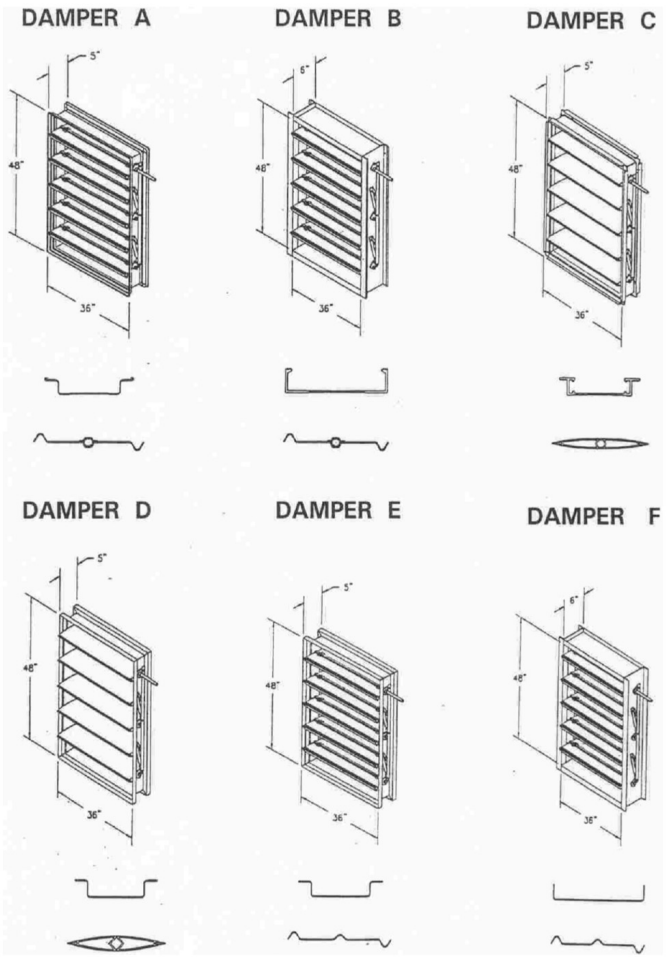


Figure 1. Damper descriptions.

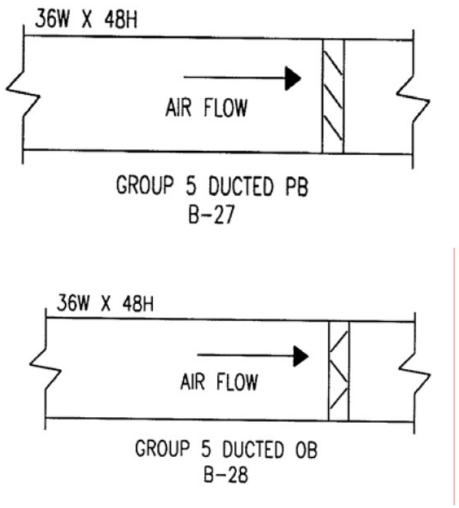
Table 1. Dampers Tested

Damper	Size	Blade Action	Blade Type	Frame	% Free Area
A	36"× 48"	OB	3V	5×1 hat channel	80
A	36"× 48"	PB	3V	5×1 hat channel	80
B	36"× 48"	OB	3V	6×1 flange frame	90
B	36"× 48"	PB	3V	6×1 flange frame	90
C	36"× 48"	OB	AF	5×1 hat channel	80
C	36"× 48"	PB	AF	5×1 hat channel	80
D	36"× 48"	PB	AF	5×1 hat channel	80
D	36"× 48"	OB	AF	5×1 hat channel	80
E	36"× 48"	OB	3V	5×1 hat channel	80
E	36"× 48"	PB	3V	5×1 hat channel	80
F	36"× 48"	OB	3V	6×1 flange frame	90
F	36"× 48"	PB	3V	6×1 flange frame	90

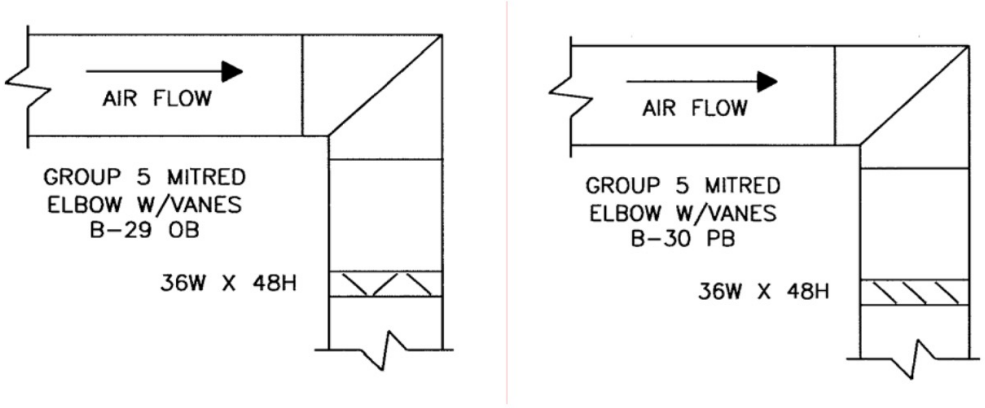
Note:
Dampers A, B, and C are manufactured by one manufacturer.
Dampers D, E, and F are manufactured by another manufacturer.
Louver: 36" × 48", 6" deep louver with 54% free area.

Assignment

- Problem 1:



a. Ducted (PB & OB) (AF & 3V)



b. Ducted with Elbow Upstream (AF & 3V)

Figure 13 – Damper Configurations, Group 5

RECAP

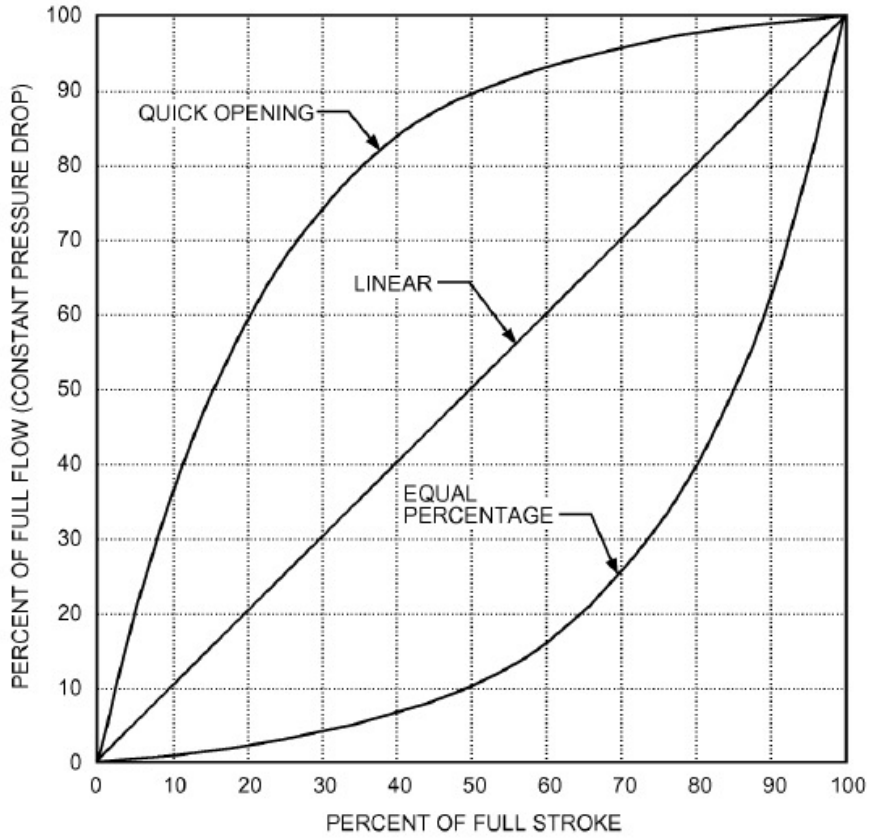
Recap

- We looked at sensors (Examples?)
- We looked controlled devices (Examples?)
- What is next?

Recap

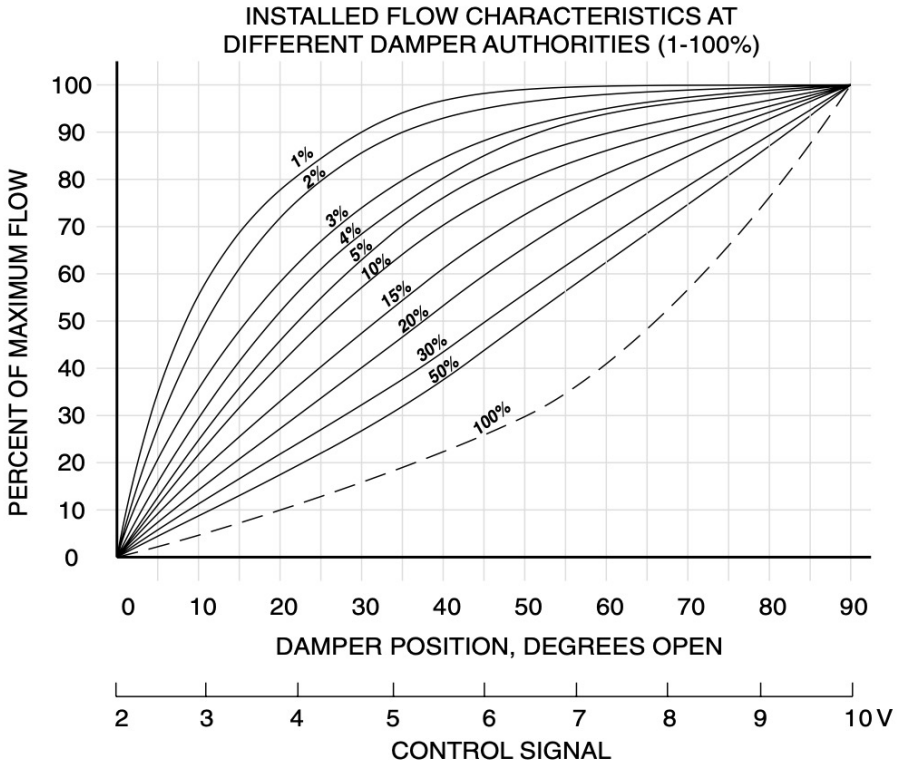
- Valve performance is expressed in terms of its flow characteristics. Common characteristics are:

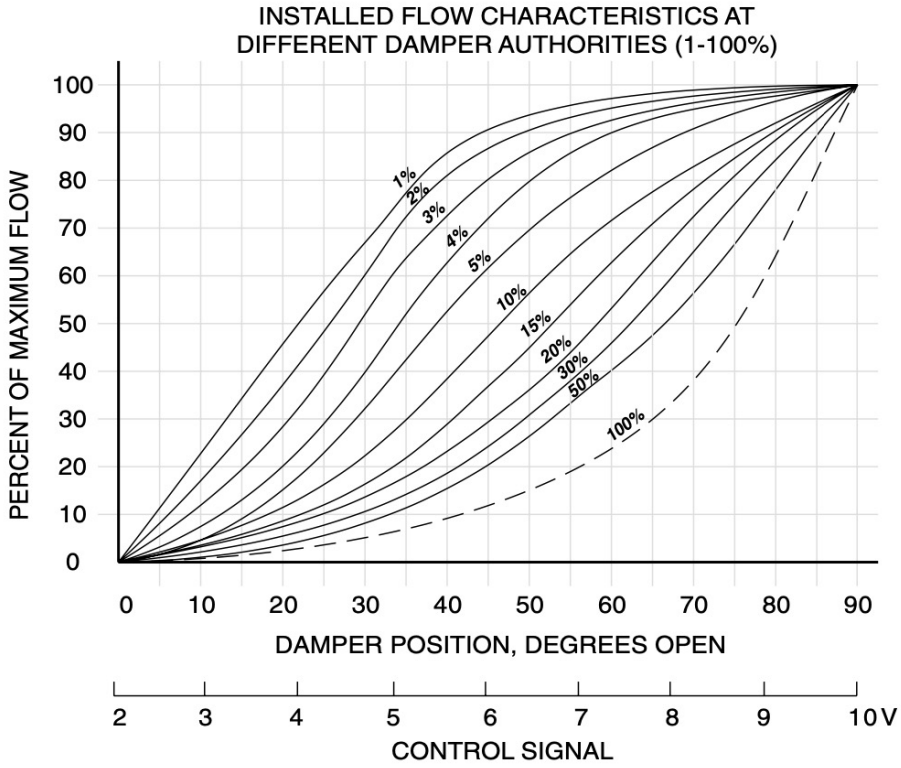
  - **Equal Percentage:** Each equal increment of opening increases flow by an equal percentage over the previous value
  - **Quick Opening:** Maximum flow is approached as valve begins to open
  - **Linear:** Opening and flow are related in direct proportion



Recap

- Consider the two figures for the damper authorities and discuss the pattern?





OPEN LOOP VS CLOSED LOOP

Open Loop vs Closed Loop

- 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

Open Loop vs Closed Loop

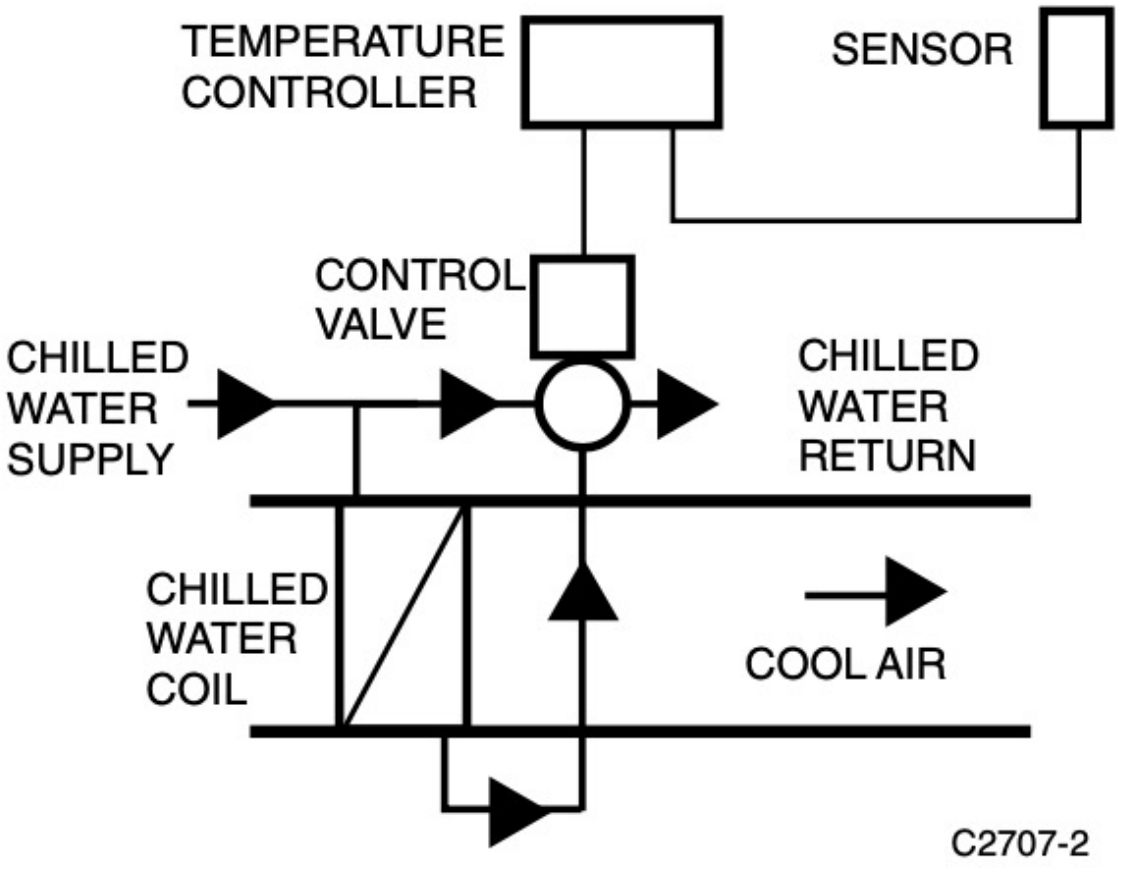
- Closed Loop or feedback require three components:
  1. **Sensor:** measures the controlled variable and transmits to the controller a signal

  2. **Controlled device:** is typically a valve, damper, heating element, or variable-speed drive

  3. **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) 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

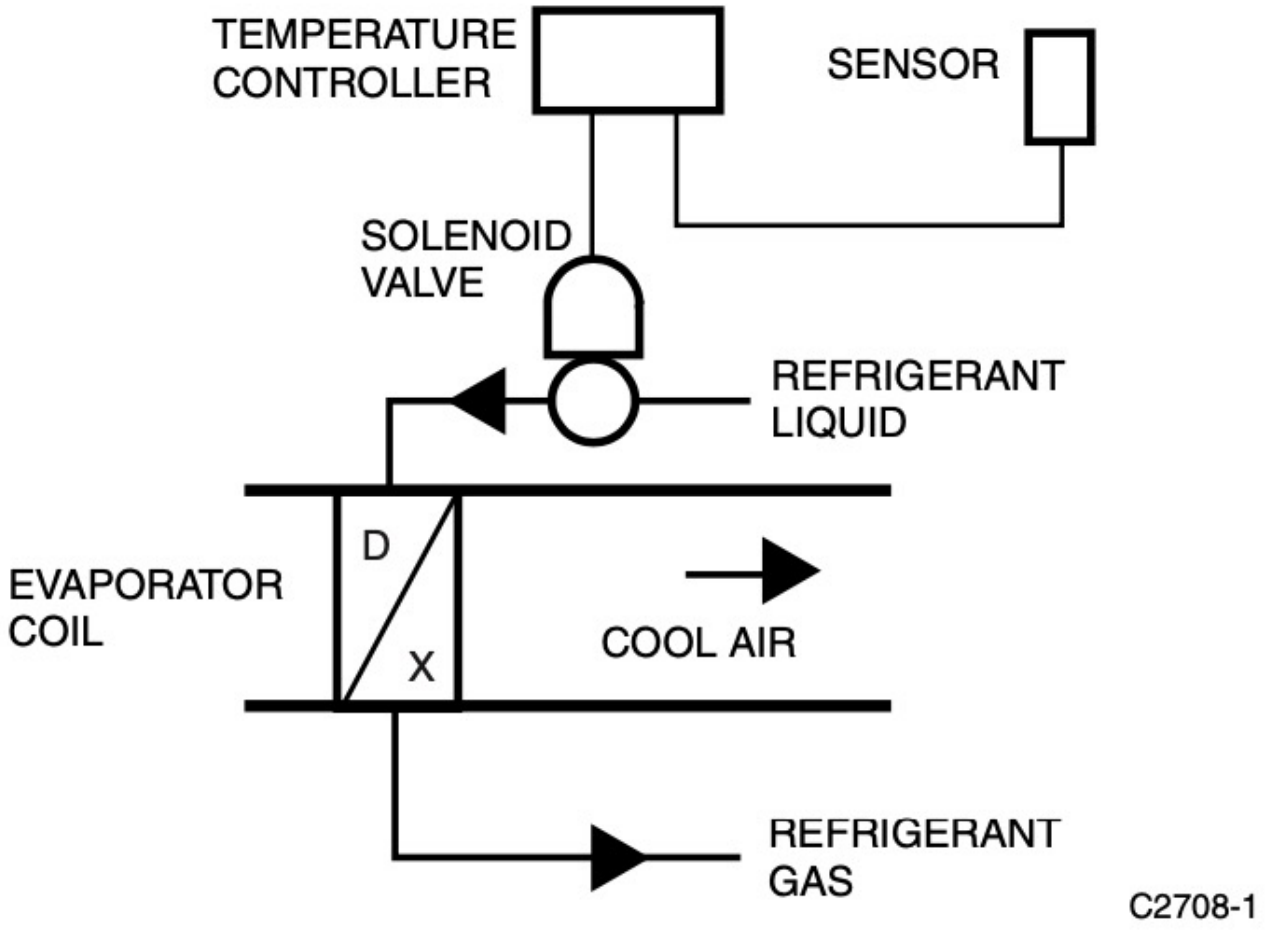
Open Loop vs Closed Loop

- An example of a closed loop controller



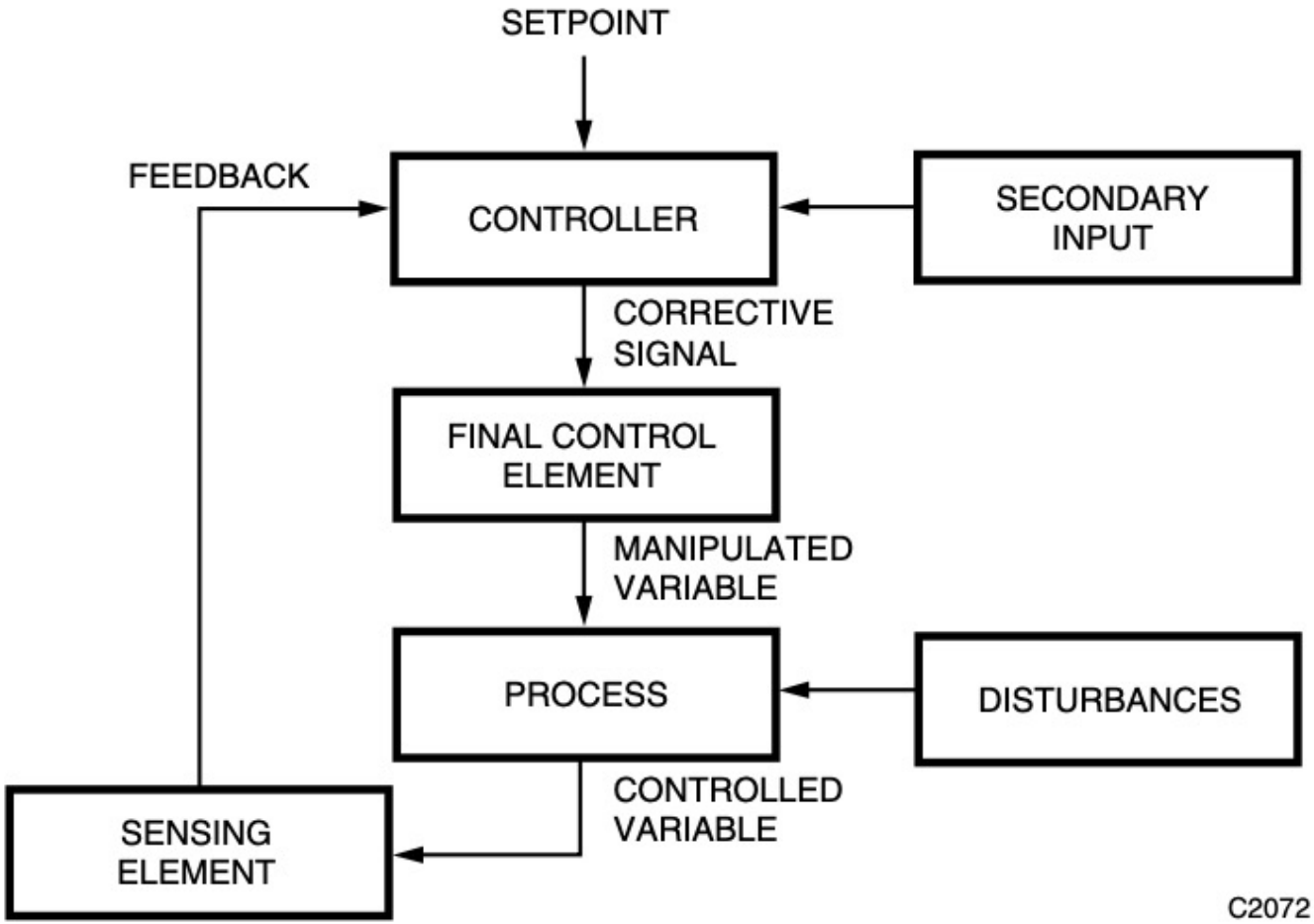
Open Loop vs Closed Loop

- An example of a closed loop controller:



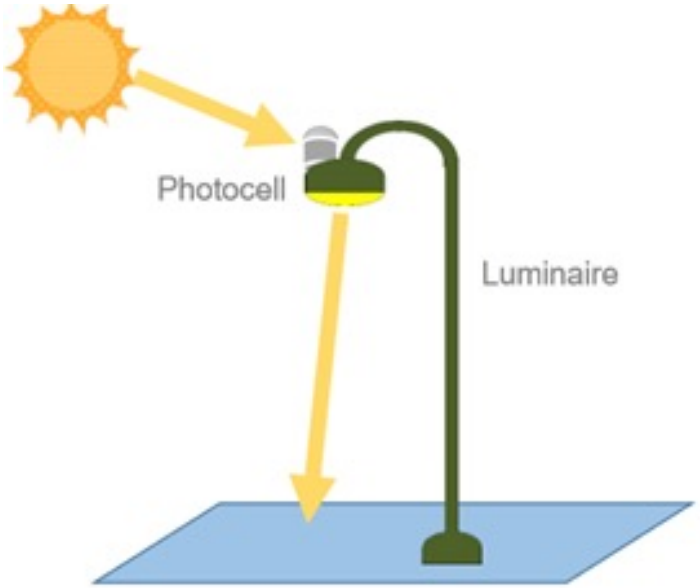
Open Loop vs Closed Loop

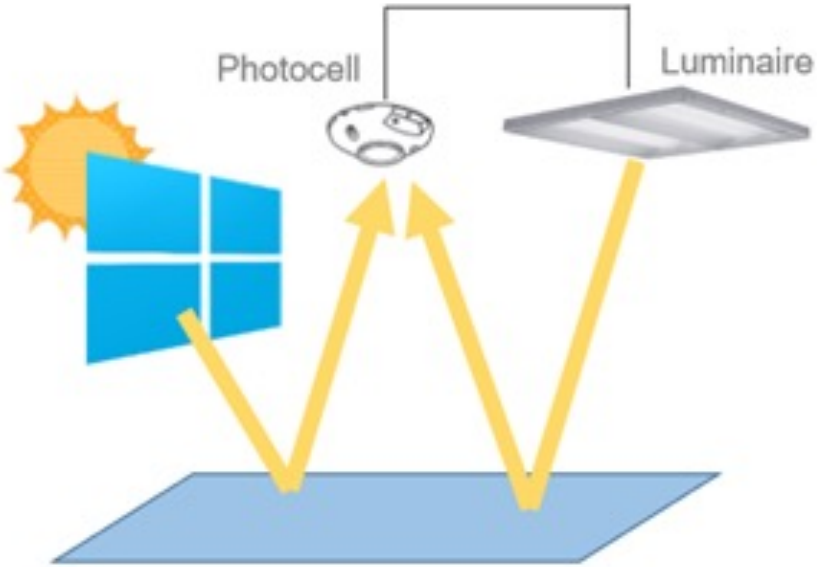
- In general, a closed loop includes:



Open Loop vs Closed Loop

- What do you think of this control strategy?

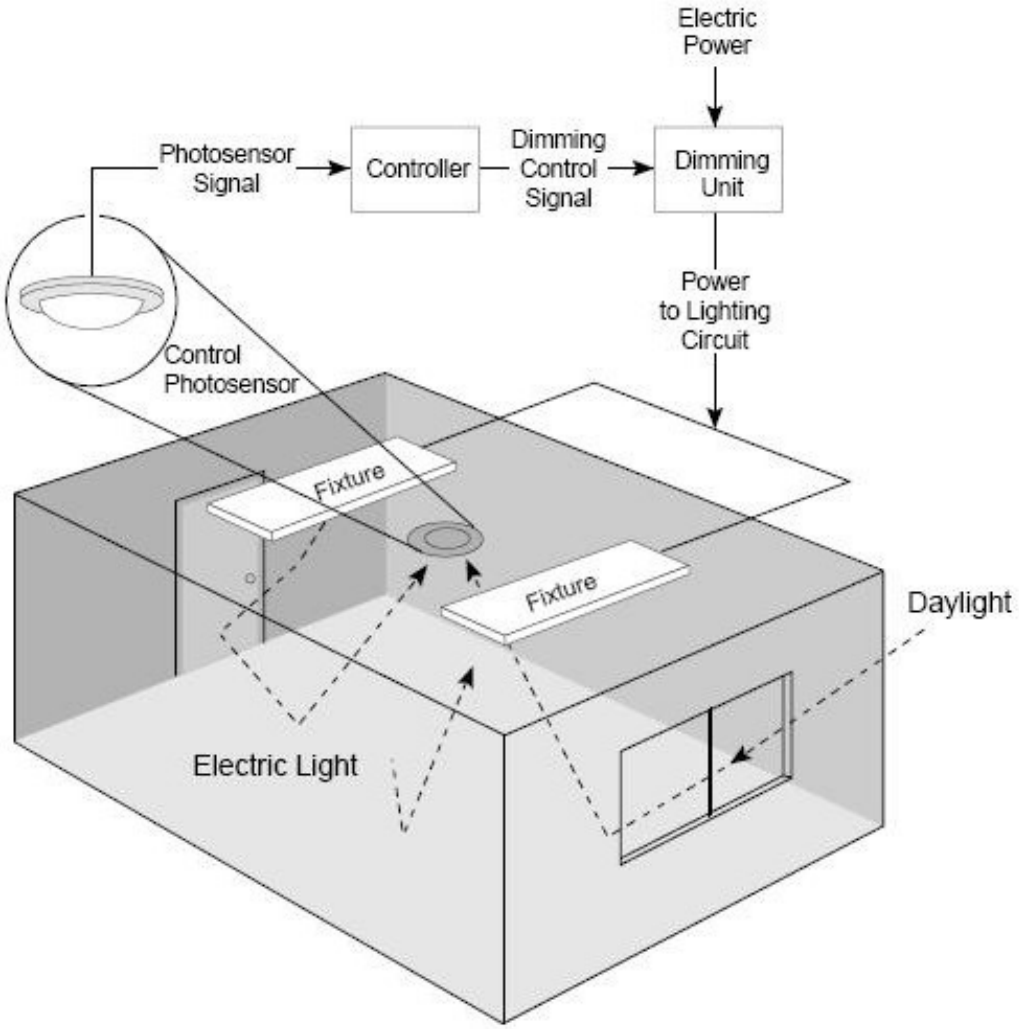




https://acuitybrands.force.com/s/article/What-is-the-difference-between-Open-loop-and-Closed-loop

Open Loop vs Closed Loop

- What do you think of this control strategy?



https://automatedbuildings.com/news/aug07/articles/zing/070723051101dilouie.htm

CLASS ACTIVITY

Class Activity

- Form your groups
- Spend 15 minutes
- Identify at least 10 different application from different building system domains
  - ❑ Make sure to identify the controlled variable first
  - ❑ Comments are added to the spreadsheet
- Fill in the spreadsheet - “Open vs Closed Loop (20210928)” sheet:

https://docs.google.com/spreadsheets/d/1duxKfuy1kpYNJxXT6e9bHjVBBqUXnwBSBuR8Dkz4f7c/edit#gid=1245867141

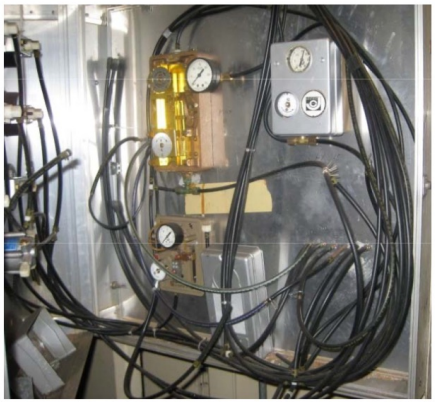
INTRODUCTION TO CONTROLLERS

Introduction to Controllers

- In general, there are fundamentally five different types of controllers based on:
  - ❑ Their power source
  - ❑ How they receive and transmit signals

Introduction to Controllers

- Controller types are
  - ❑ Pneumatic
  - ❑ Electrical
  - ❑ Electronics
  - ❑ Microprocessor-based (e.g., DDC)
  - ❑ Hybrid

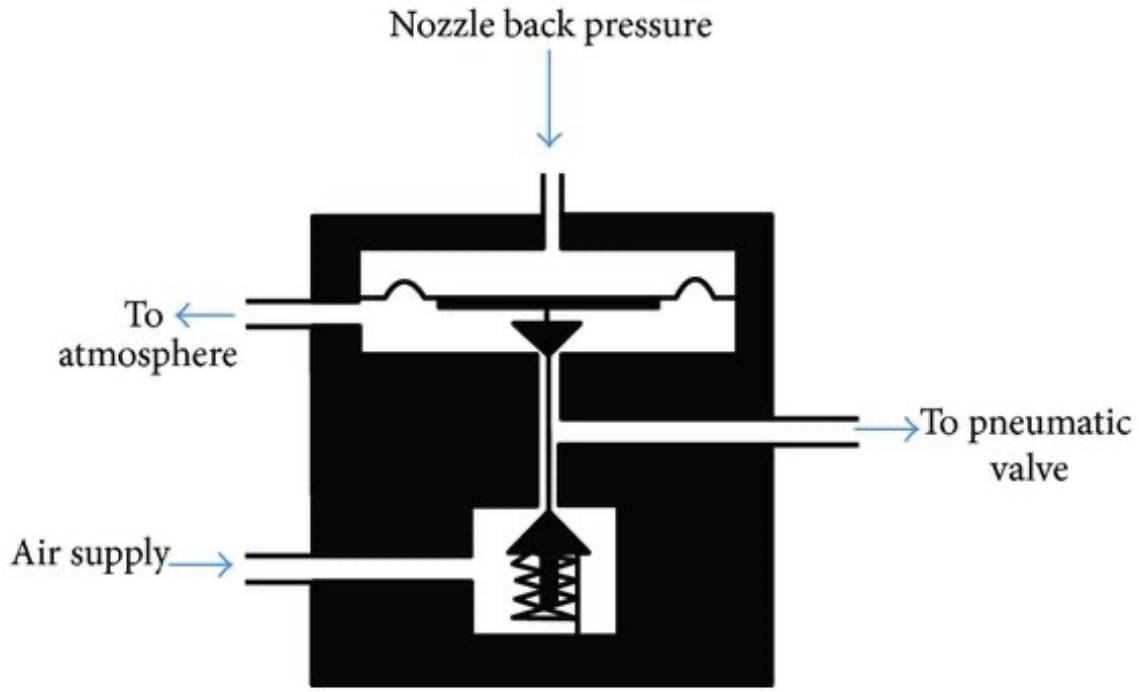


Introduction to Controllers

- Pneumatic control:
  - It works based on mechanical devices respond to change in air pressure from a pneumatic transmitter and produce a proportional pressure output
  - It can include the integral function for reset control
  - The controller output usually operates or positions a pneumatic actuator, although relays and switches are often in the circuit
  - It is also called receiver-controller

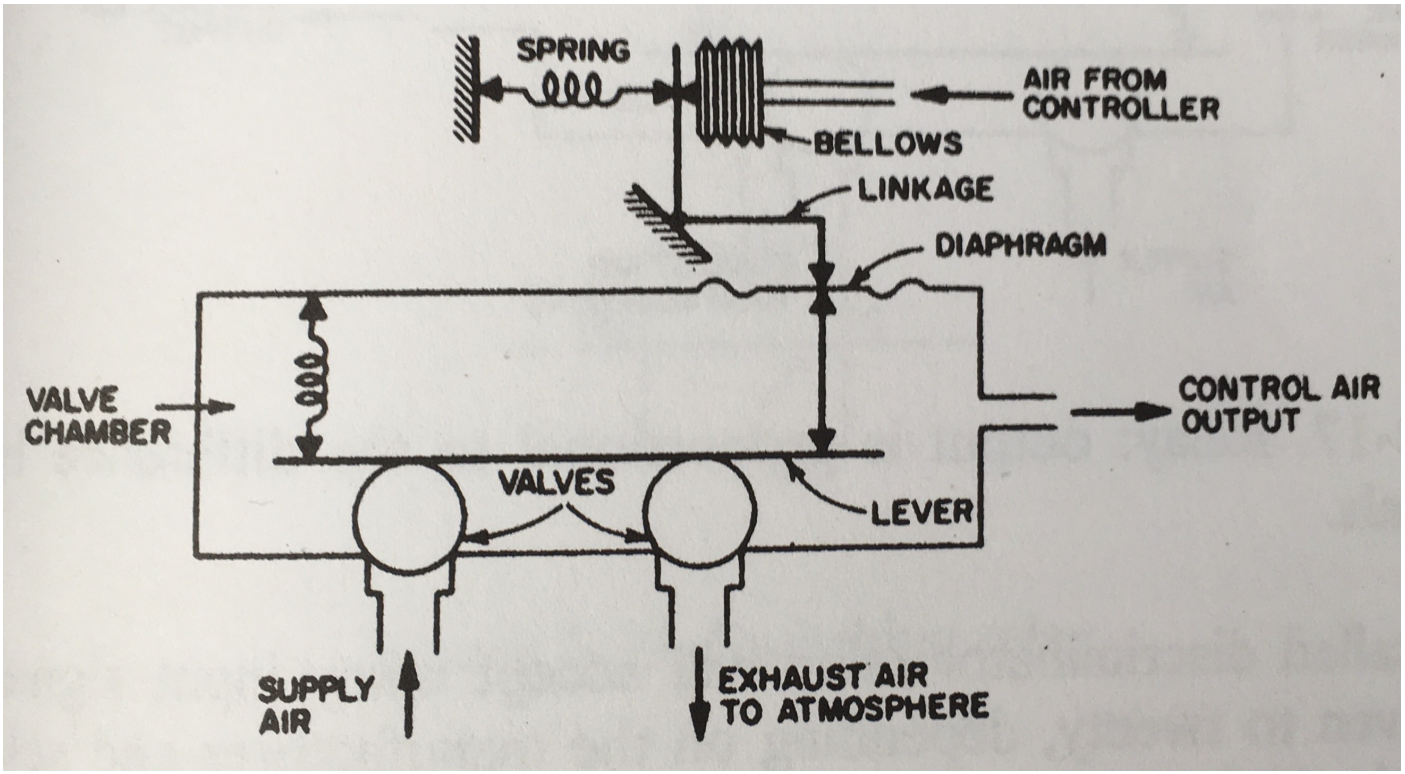
Introduction to Controllers

- Two different type of pneumatic controllers
  - ❑ Bleed-type controllers
  - ❑ Relay-type controllers



Introduction to Controllers

- Two different type of pneumatic controllers
  - ❑ Relay-type controllers
    - Relay is a device that takes a signal from a controller, changes it in some way, and relays it to another controller or actuator



Haines, Control systems for heating, ventilating, and air conditioning

Introduction to Controllers

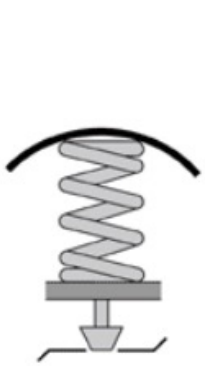
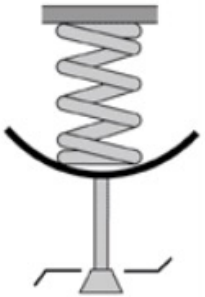
- Pneumatic controller configuration
  - Direct-acting
    - As input increases then output increases
    - As input decreases then output decreases
  - Reverse-acting
    - As input increases then output decreases
    - As input decreases then output increases

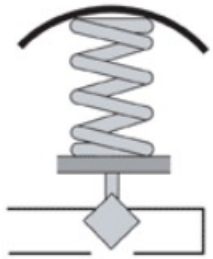
Introduction to Controllers

- Pneumatic controller configuration
  - What do you think of a pneumatic room thermostat's response to the increase of hot water and heat from a room fan coil?

Introduction to Controllers

- Pneumatic controller configuration
  - ❑ Examples could be:

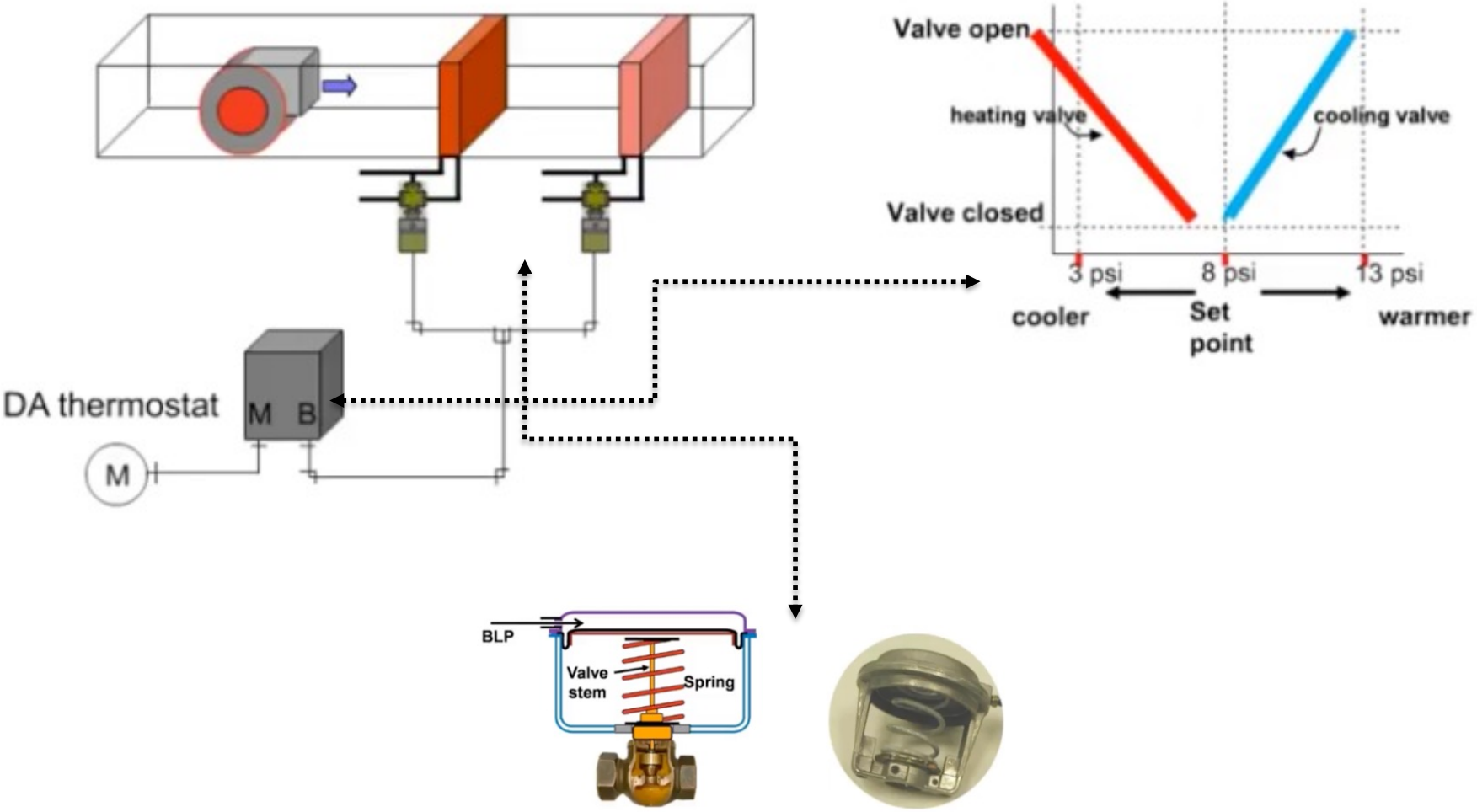
Two port valves				
Actuator action	Direct	Reverse	Reverse	Direct
Valve action	Direct	Reverse	Direct	Reverse
On air failure	Valve opens		Valve closes	

Three port valves (typical mixing valve depicted)		
Actuator action	Direct	Reverse
On air failure	Top seat closes bottom seat opens	Bottom seat closes top seat opens

https://www.hirameng.com/wp-content/uploads/2015/07/DirectandReverseAction-3.pdf

Introduction to Controllers

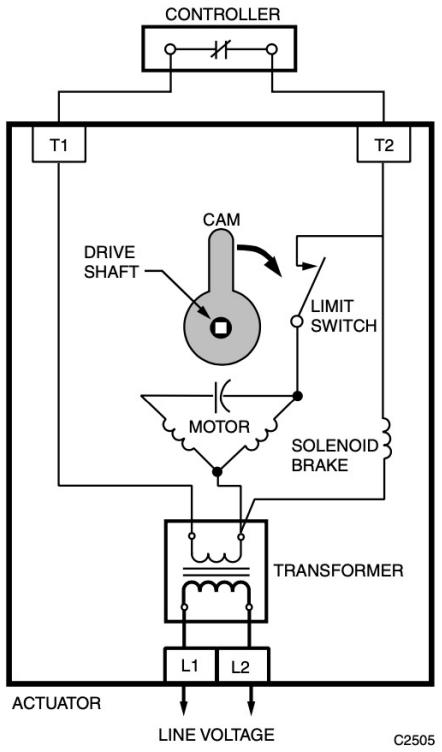
- An example of pneumatic controller configurations



Honeywell, https://www.youtube.com/watch?time_continue=578&v=iZ6mycTBctI&feature=emb_title

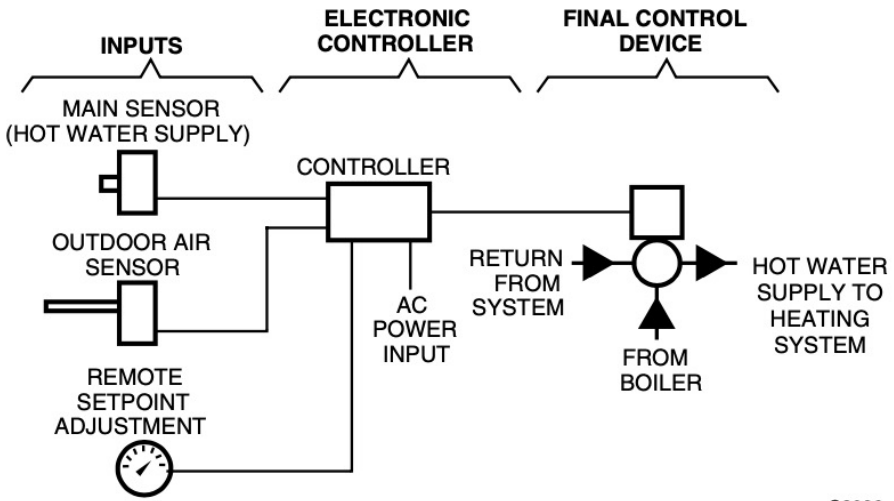
Introduction to Controllers

- Electric control:
  - A control circuit that operates on a line or low voltage and uses a mechanical means, such as a temperature-sensitive bimetal or bellows, to perform control functions, such as actuating a switch or positioning a potentiometer
  - The controller signal usually operates or positions an electric actuator or may switch an electrical load directly or through a relay



Introduction to Controllers

- Electronic control:
  - A control circuit that operates on low voltage and uses solid-state components to amplify input signals and perform control functions, such as operating a relay or providing an output signal to position an actuator
  - The controller usually furnishes fixed control routines based on the logic of the solid-state components.

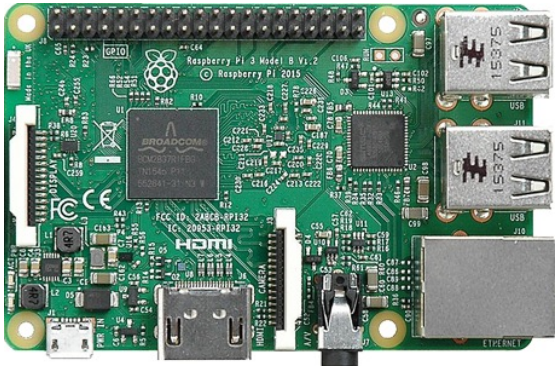


Introduction to Controllers

- Microprocessor-based control
  - A control circuit that operates on low voltage and uses a microprocessor to perform logic and control functions, such as operating a relay or providing an output signal to position an actuator
  - Electronic devices are primarily used as sensors. The controller often furnishes flexible Direct Digital Control (DDC) and energy management control routines

Introduction to Controllers

- What could be an inexpensive microprocessor-based or micro-controller?



MICROCONTROLLERS

VERSUS

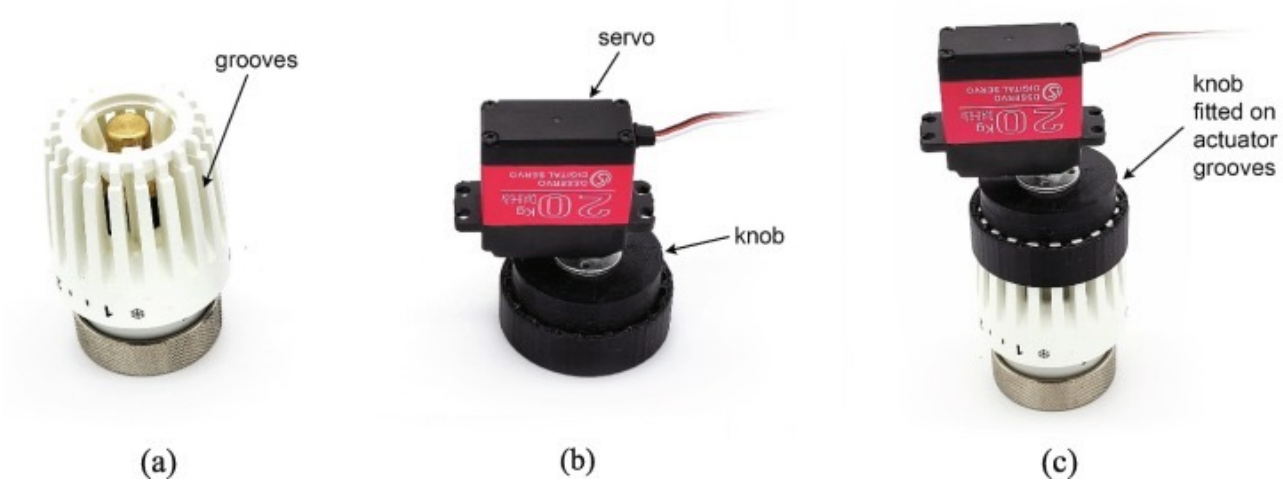
MICROPROCESSORS

ARDUINO VS. RASPBERRY PI

An Arduino is a microcontroller. They are a self contained chip. They can generally be used with very little supporting circuitry	A Raspberry Pi board has many different chips, including a microprocessor, to create a functional computer
Sensors and other hardware can be controlled directly through the I/O pins	To control the I/O pins for sensors, motors etc... you must write code on it that controls the lower level software
They don't run an operating system, rather they step through the code that is given to them	It can run as a standalone computer, and code can be written inside it
Designed for circuitry/low level hardware, and direct programming	Designed for software and high level hardware interaction

Introduction to Controllers

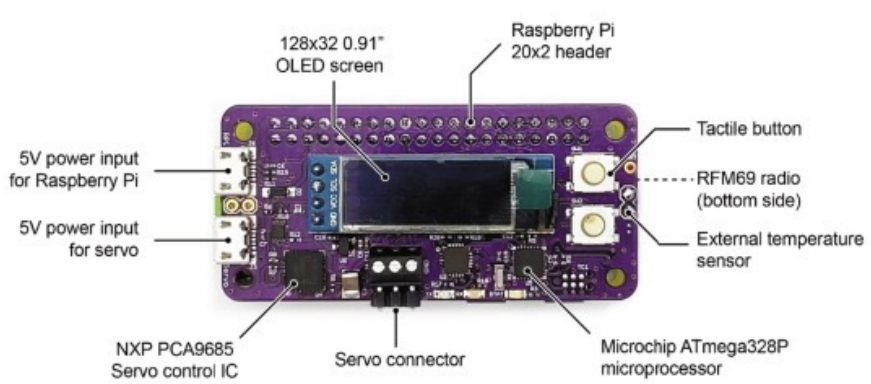
- What could be an inexpensive microprocessor-based or micro-controller?



https://www.sciencedirect.com/science/article/pii/S0378778821006289

Introduction to Controllers

- What could be an inexpensive microprocessor-based or micro-controller?



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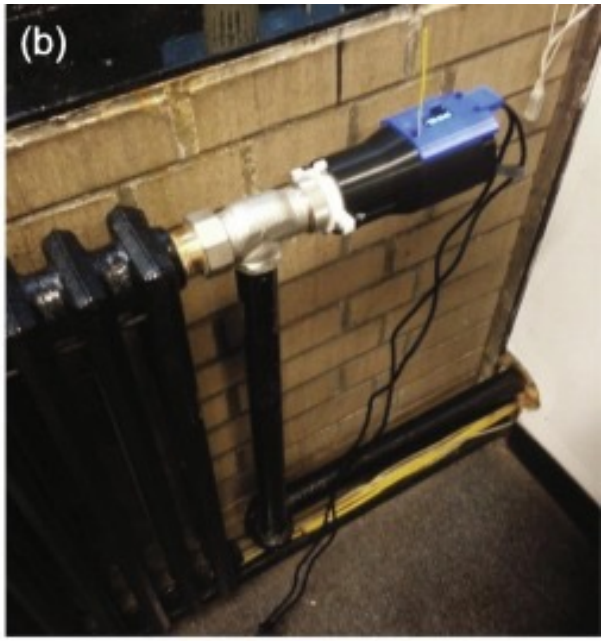

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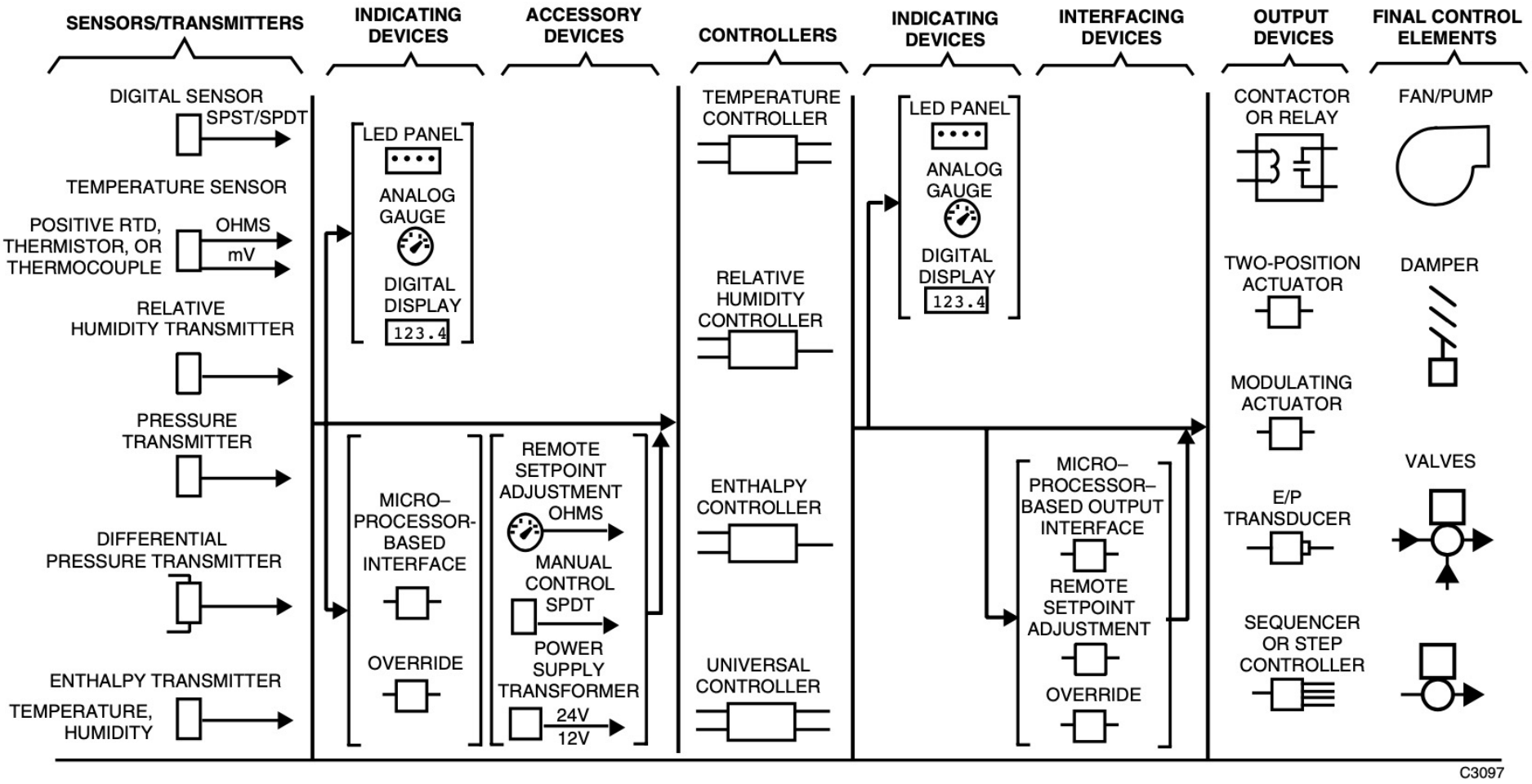
Introduction to Controllers



MICROPROCESSOR-BASED CONTROLLERS

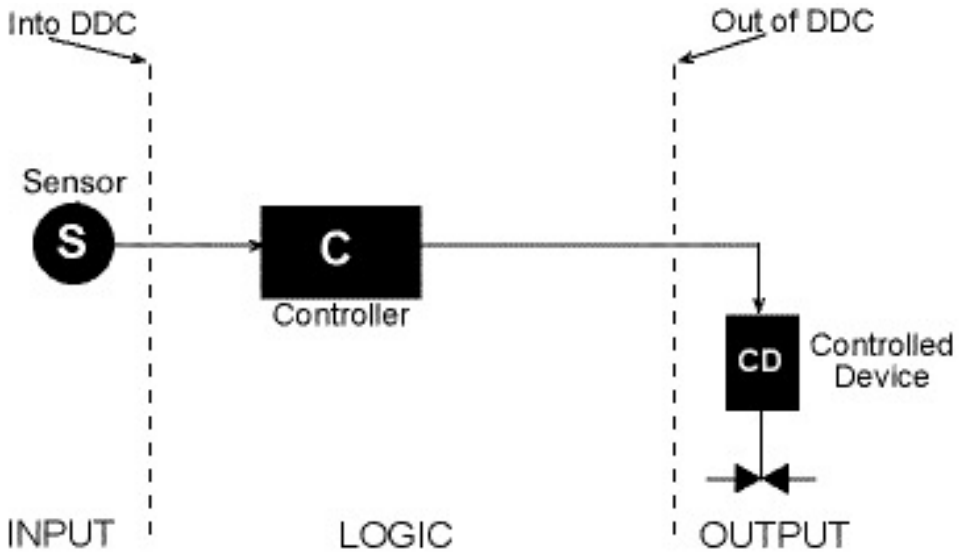
Microprocessor-Based Controllers

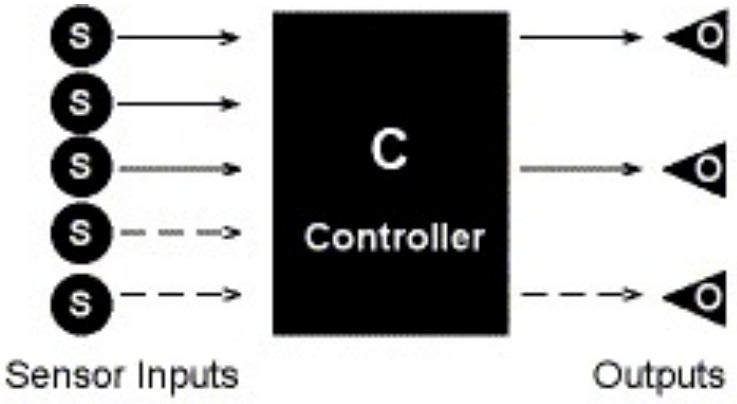
- Microprocessor-based controller include:
  - A device consisting of a microprocessor unit, digital input and output connections, A/D and D/A converters, a power supply, and software to perform direct digital control and energy management routines in a HVAC system

- Direct digital control (DDC) is:
  - A control loop in which a digital controller periodically updates a process as a function of a set of measured control variables and a given set of control algorithms

Microprocessor-Based Controllers

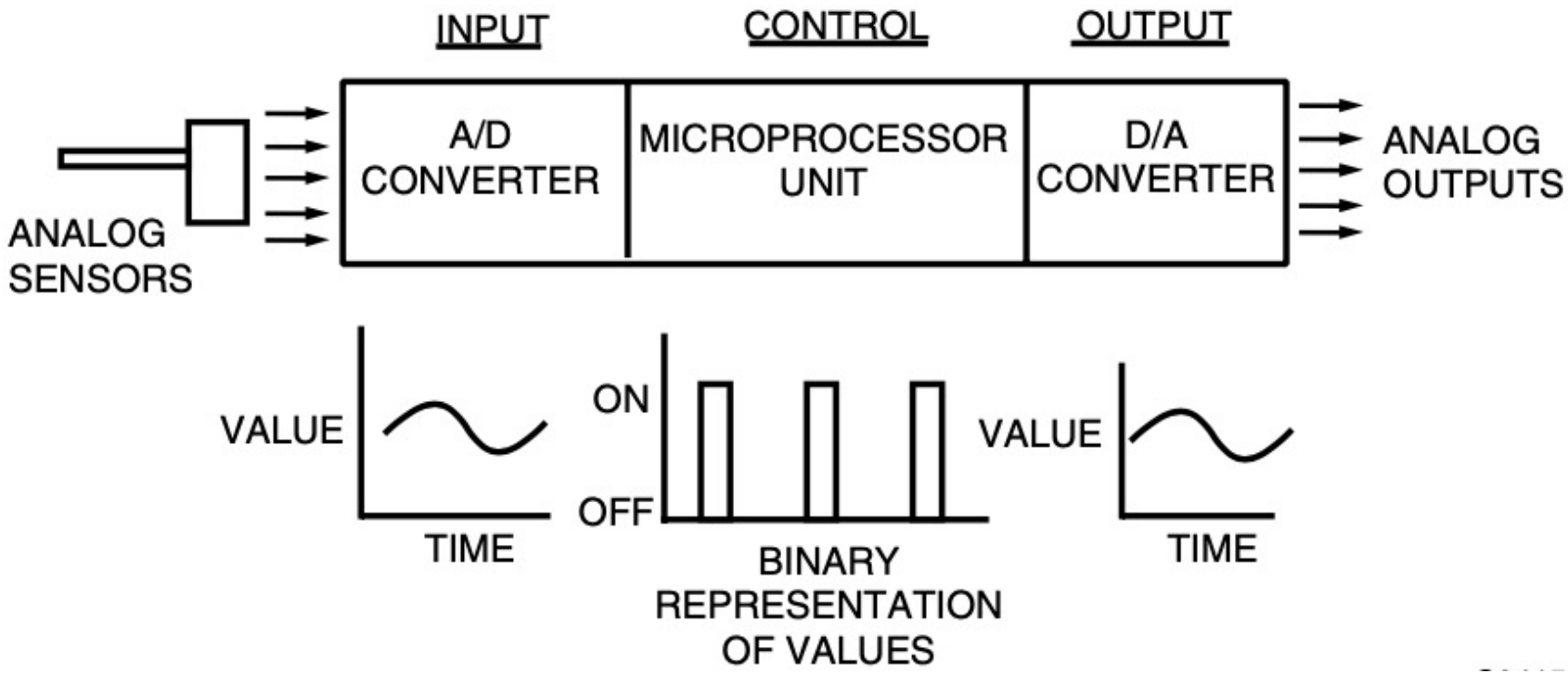
- A DDC control is mostly:
  - ❑ Controller with programmable logic
  - ❑ Signals to/from end devices





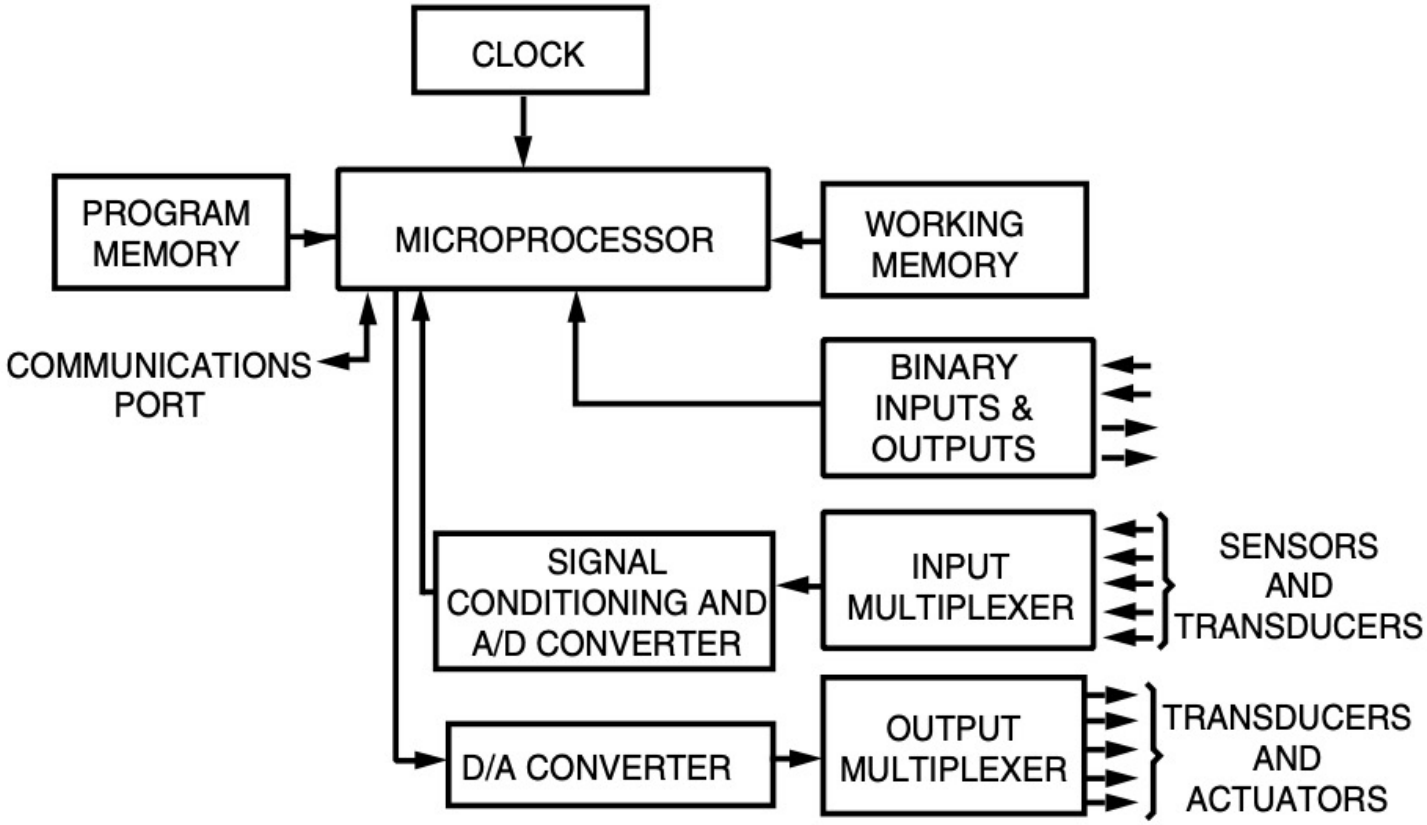
Microprocessor-Based Controllers

- Consideration of A/D and D/A signals



Microprocessor-Based Controllers

- All input signals undergo conditioning to eliminate the adverse affects of contact bounce, induced voltage, or electrical transients.



Microprocessor-Based Controllers

Table 1. Typical DDC Operators.

Operator	Description
Sequence	Allows several controller outputs to be sequenced, each one operating over a full output range.
Reversing	Allows the control output to be reversed to accommodate the action of a control valve or damper actuator.
Ratio	Translates an analog output on one scale to a proportional analog output on a different scale.
Analog controlled digital output	Allows a digital output to change when an analog input reaches an assigned value. Also has an assignable dead band feature.
Digital controlled analog output	Functionally similar to a signal switching relay. One state of the digital input selects one analog input as its analog output; the other state selects a second analog input as the analog output.
Analog controlled analog output	Similar to the digital controlled analog output except that the value and direction of the analog input selects one of the two analog signals for output.
Maximum input	Selects the highest of several analog input values as the analog output.
Minimum input	Selects the lowest of several analog input values as the analog output.
Delay	Provides a programmable time delay between execution of sections of program code.
Ramp	Converts fast analog step value changes into a gradual change.

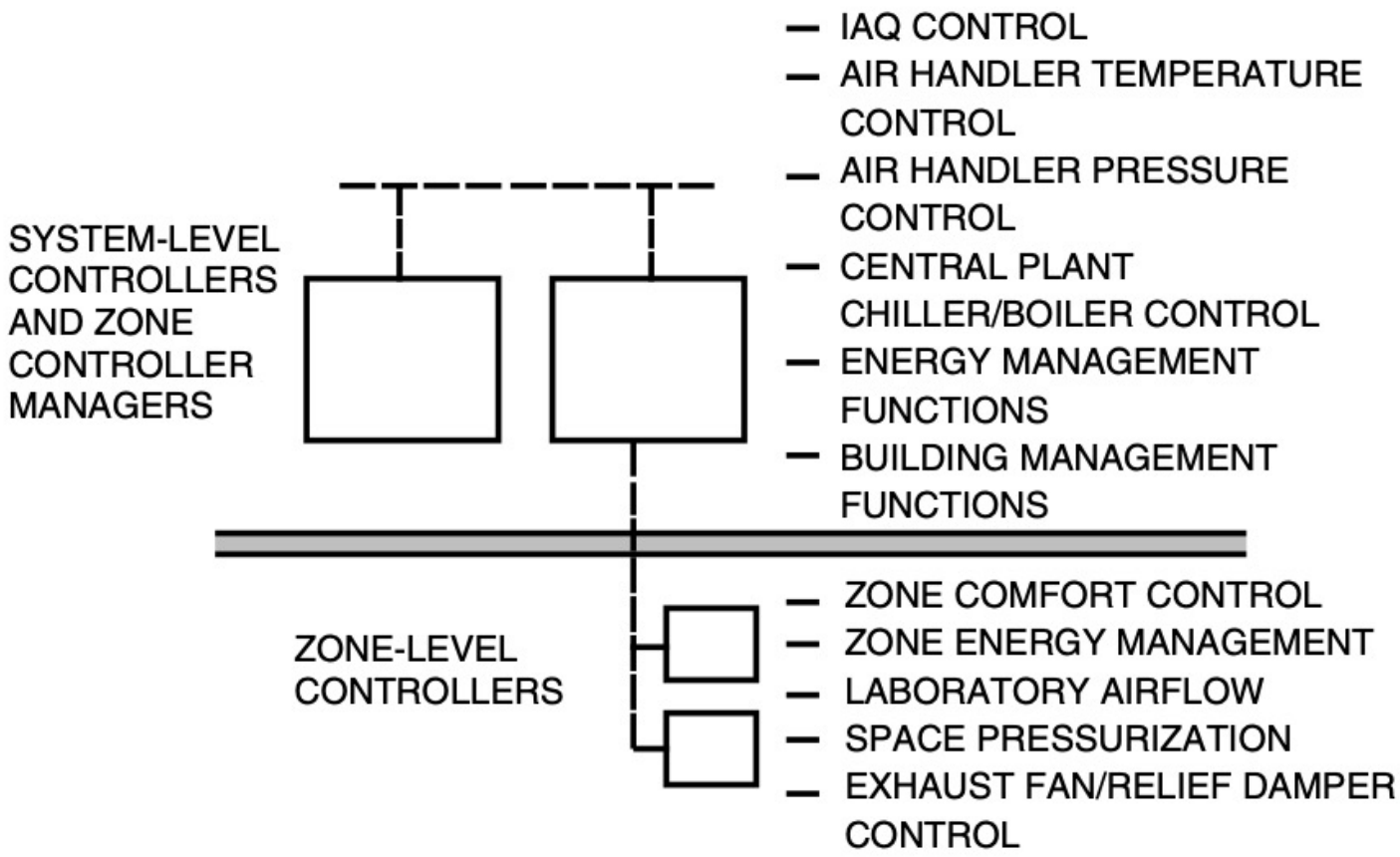
INPUTS / OUTPUTS OF CONTROLLERS

Inputs and Outputs of Controllers

- One classification of controllers consider their applications
  - ❑ Zone-level controllers (e.g., VAV, fan coil units)
  - ❑ System-level controllers

Inputs and Outputs of Controllers

- Microprocessor-based controllers operate mostly based on two levels:
  - System
  - Zone

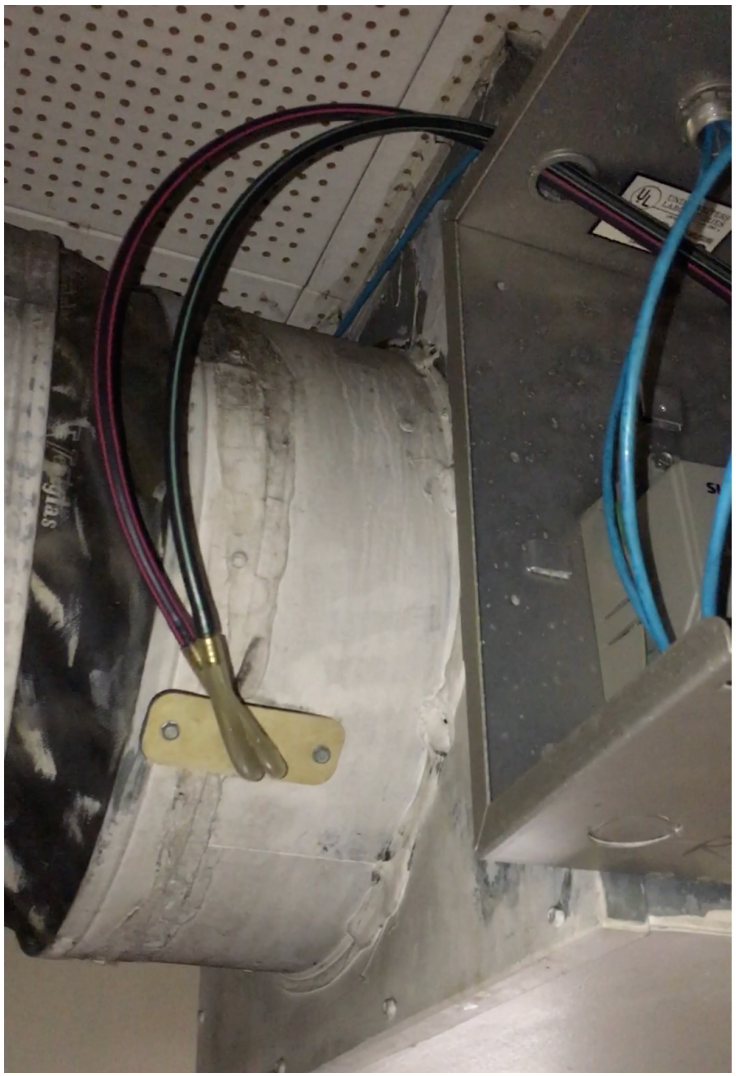


Inputs and Outputs of Controllers

- Zone-level controllers are mostly used for the terminal units (e.g., VAV, fan coil units). They
  - ❑ Have specific requirements for the application
  - ❑ Specific input/output (IO)

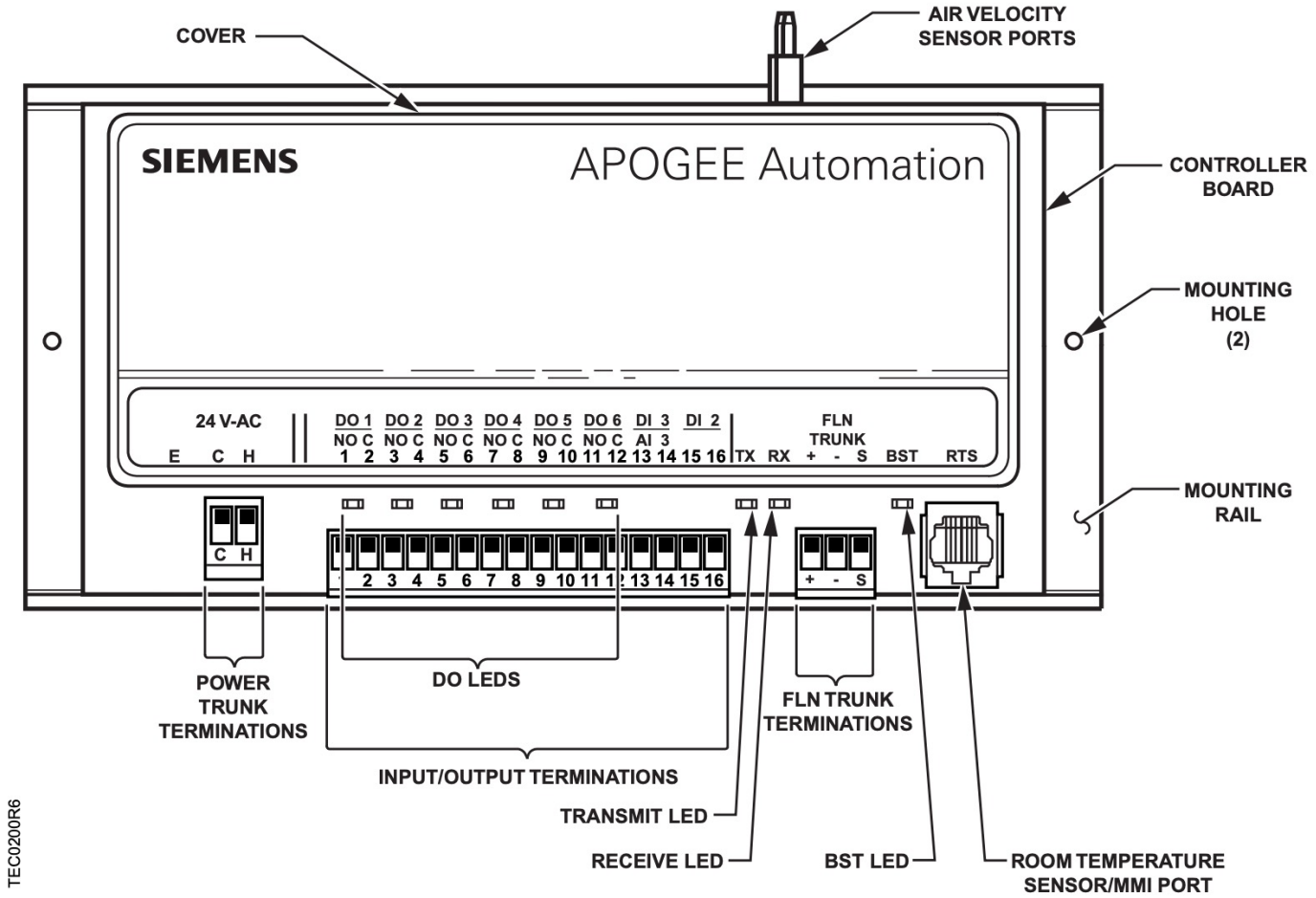
Inputs and Outputs of Controllers

- An example:



Inputs and Outputs of Controllers

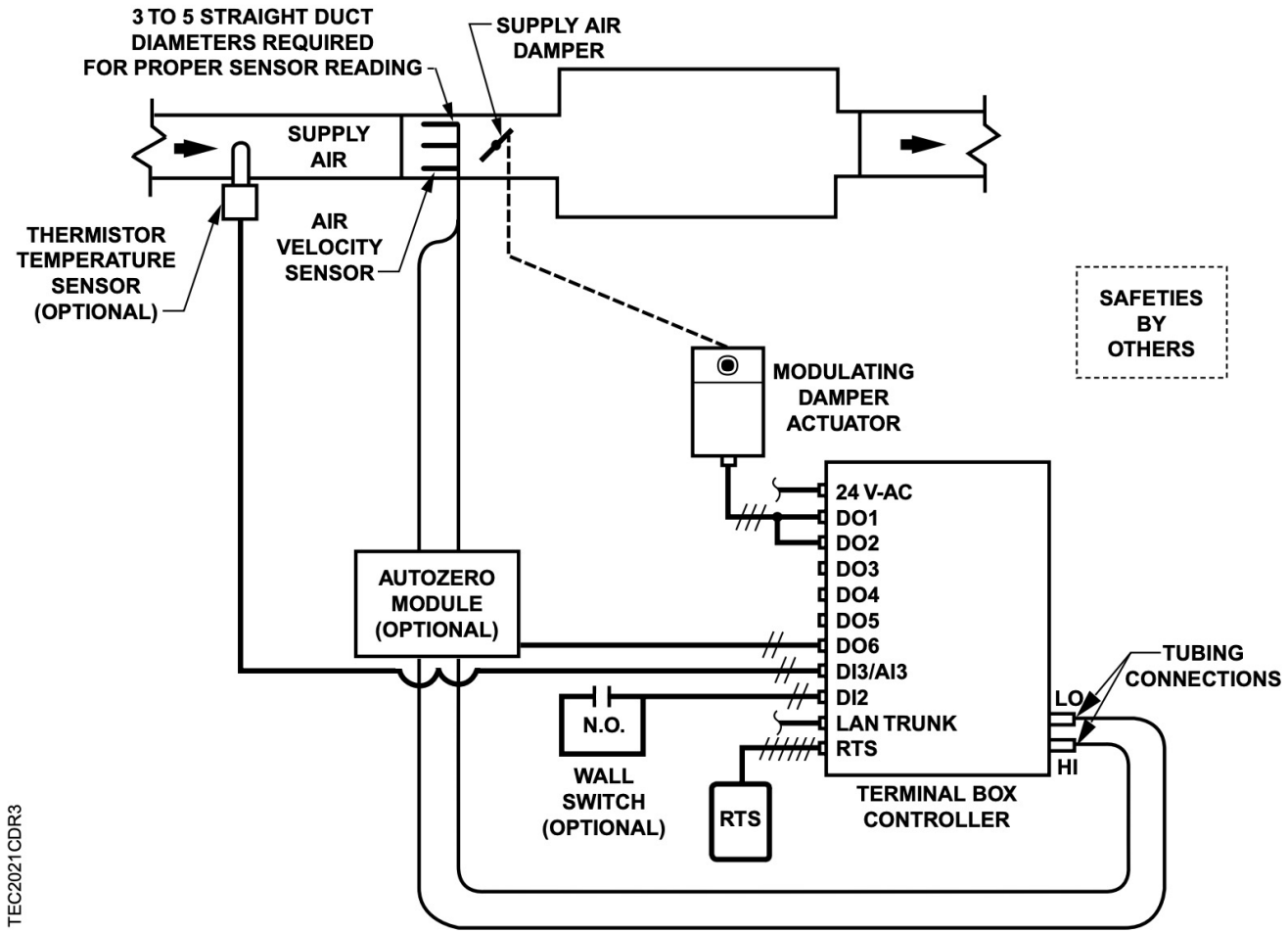
- An example of VAV controller that usually operate for pressure independent VAV:



https://www.downloads.siemens.com/download-center/Download.aspx?pos=download&fct=getasset&id1=A6V10308412

Inputs and Outputs of Controllers

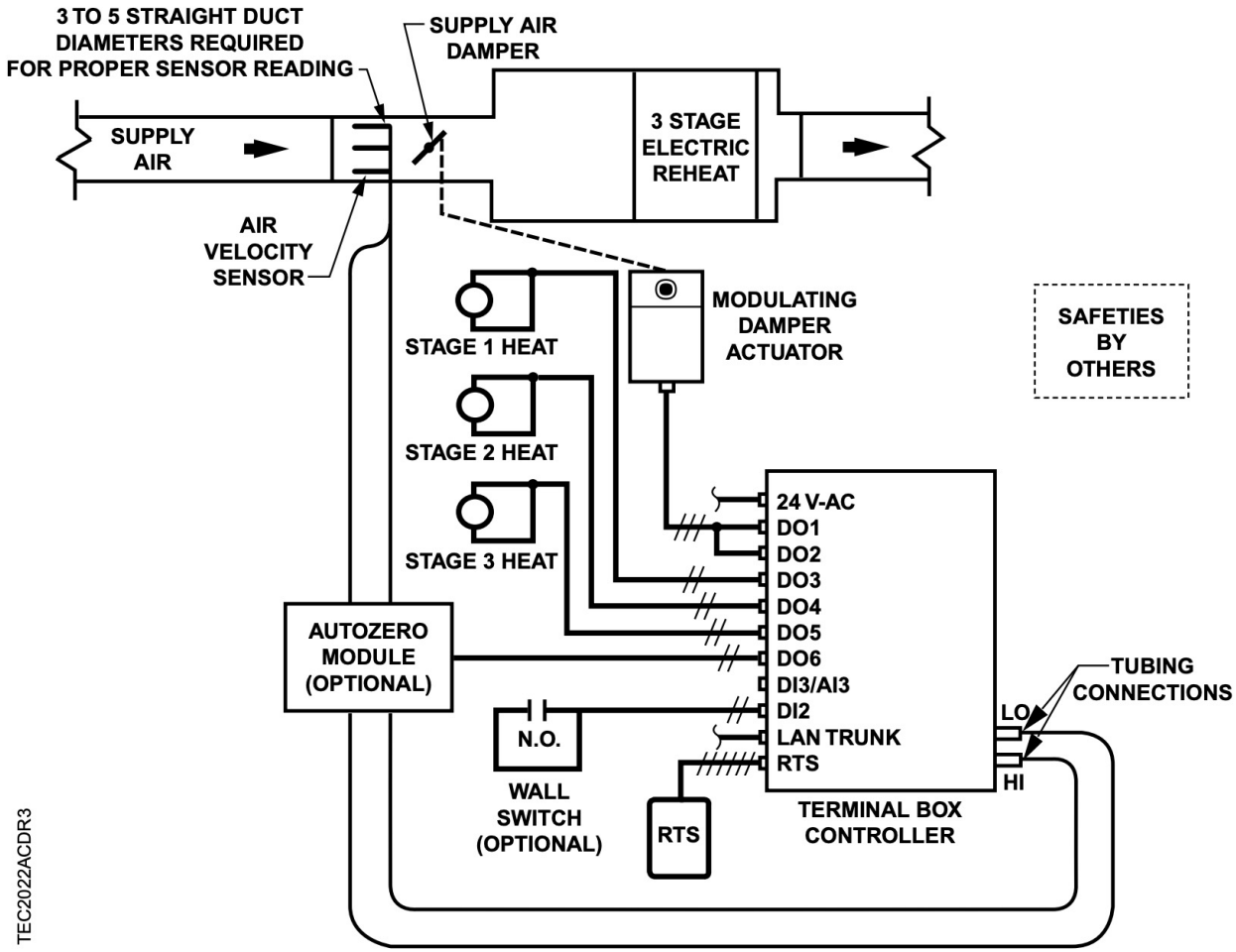
- An example of VAV controller that usually operate for pressure independent VAV:
  - ❑ A simple usage:



https://www.downloads.siemens.com/download-center/Download.aspx?pos=download&fct=getasset&id1=A6V10308412

Inputs and Outputs of Controllers

- An example of VAV controller that usually operate for pressure independent VAV:
  - ❑ A more complex with reheat coils:



https://www.downloads.siemens.com/download-center/Download.aspx?pos=download&fct=getasset&id1=A6V10308412

Inputs and Outputs of Controllers

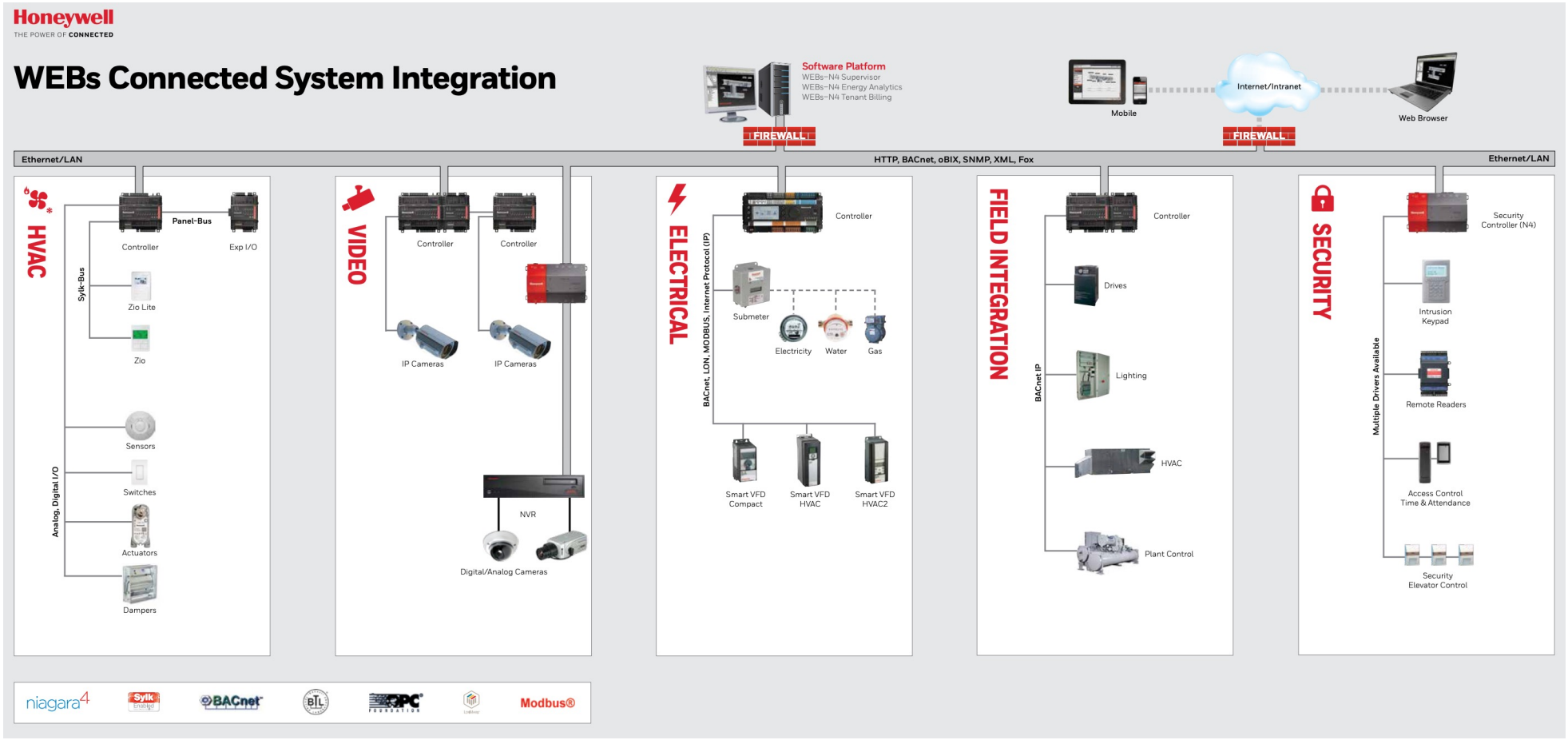
- System-level controllers are more flexible than zone-level controllers in application and have more capacity

- Allows various types of inputs and outputs required for a system- level controller. Several different packaging approaches have been used:

  - ❑ Fixed I/O configuration
  - ❑ Universal I/O configuration
  - ❑ Card cage with plug-in function boards
  - ❑ Master/Slave I/O modules

Inputs and Outputs of Controllers

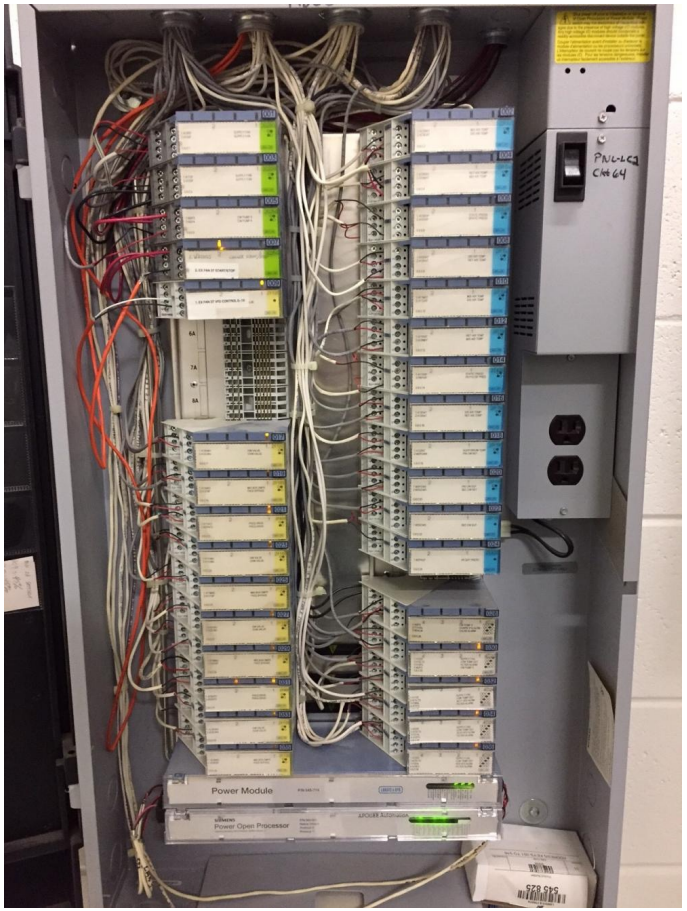
- Consider this hierarchy of components:



https://buildingcontrols.honeywell.com/literature/01-00074_WEBsN4_SystemArch.pdf

Inputs and Outputs of Controllers

- Some examples of controllers:



https://hvac-talk.com/vbb/threads/2144431-Basic-Siemens-Apogee-Questions

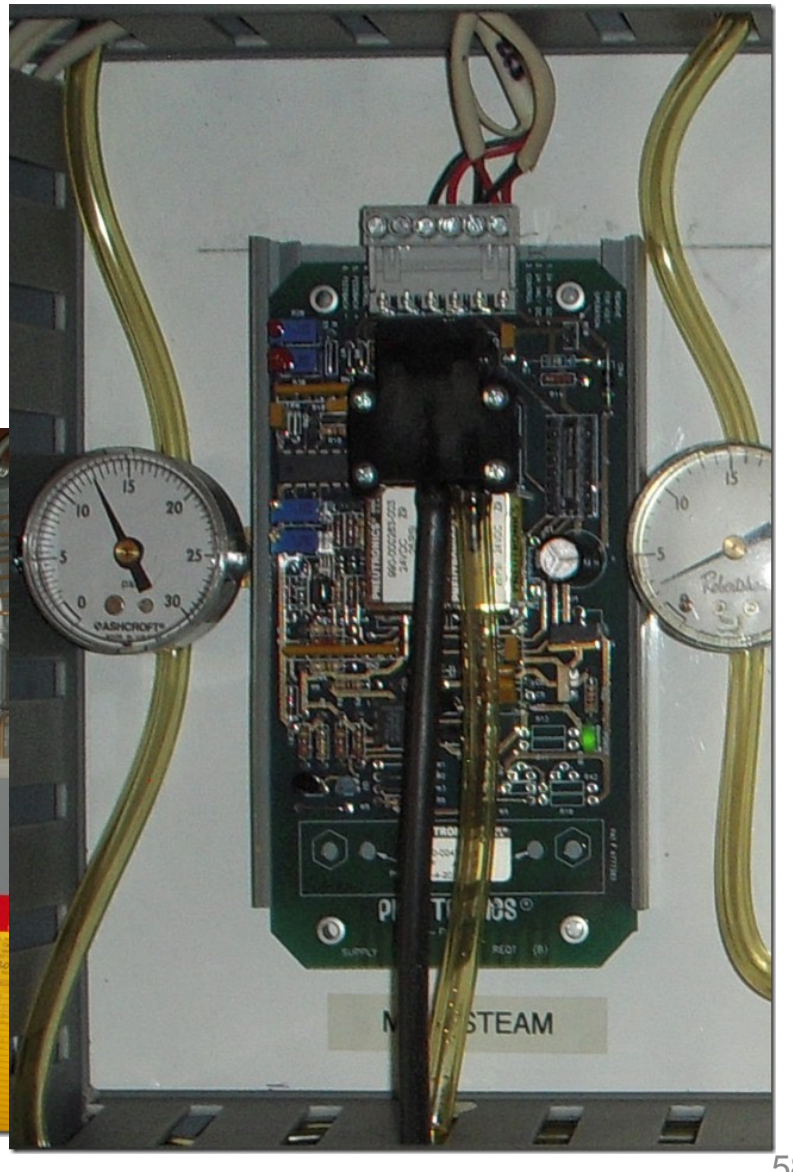
Inputs and Outputs of Controllers

- Some examples of controllers:

https://nmdgreen.com/nmd-showcase/projects-for-businesses/controls-ddc-direct-digital-control-upgrade-for-complete-remote-control/

Inputs and Outputs of Controllers

- Some examples of controllers:

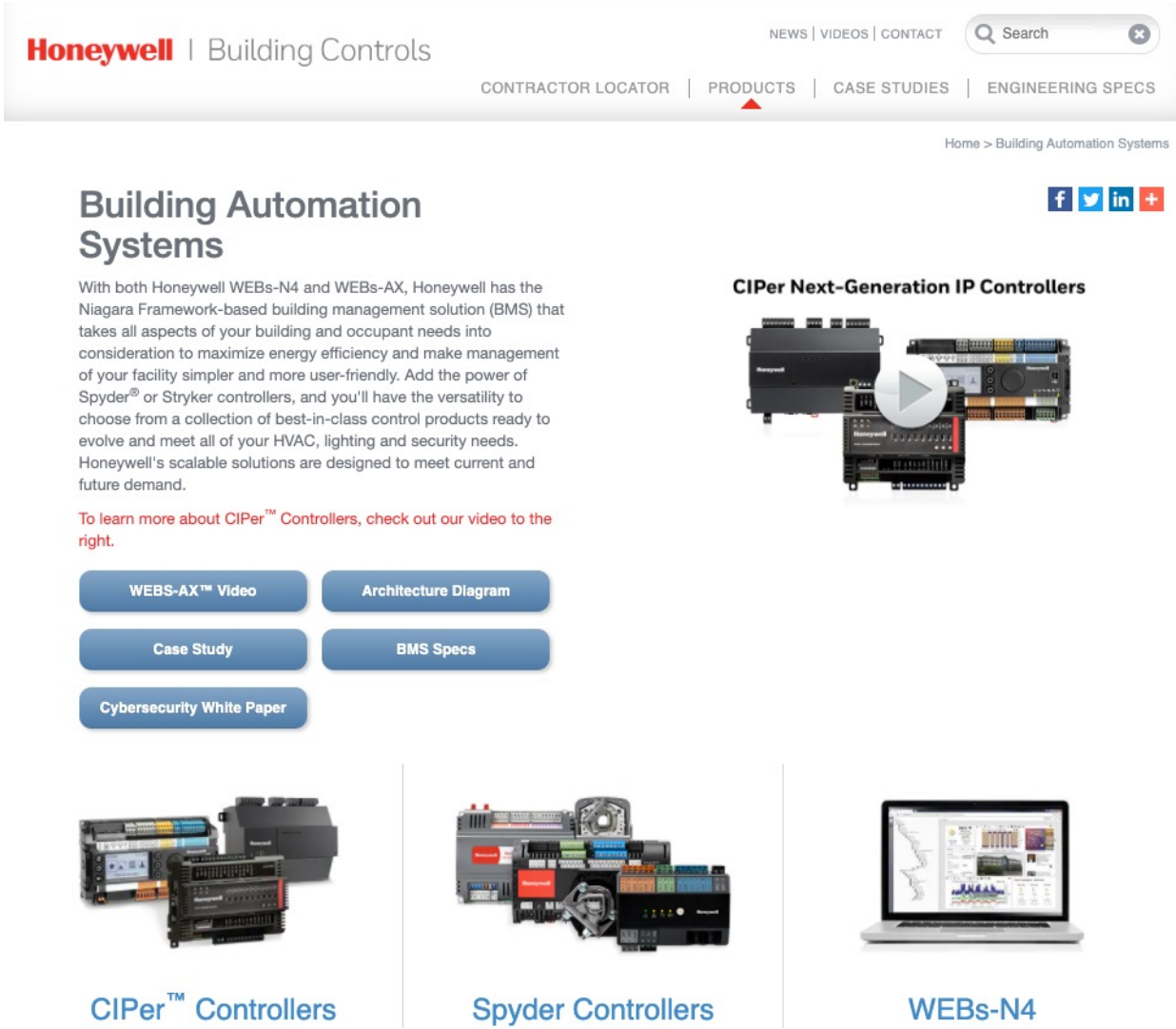


https://av8rdas.wordpress.com/2013/03/03/pneumatic-controls-resources/

CLASS ACTIVITY

Class Activity

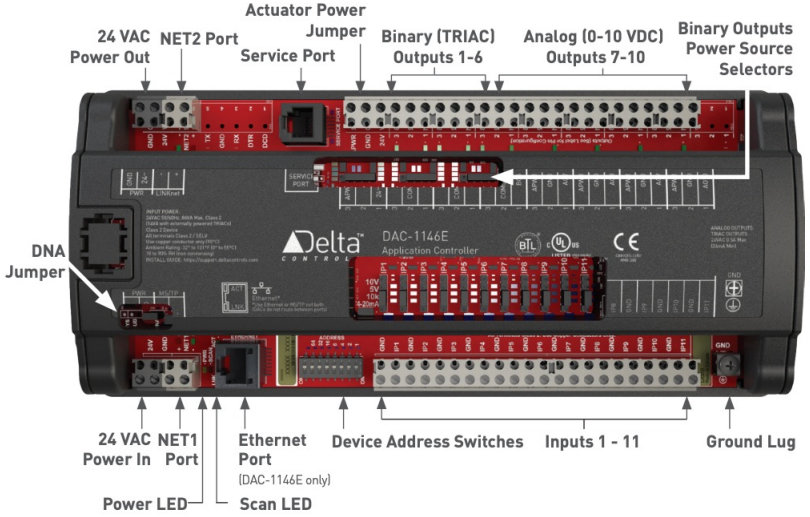
- Let's look at some manufacturers



https://buildings.honeywell.com/us/en/brands/our-brands/bms/controllers

Class Activity

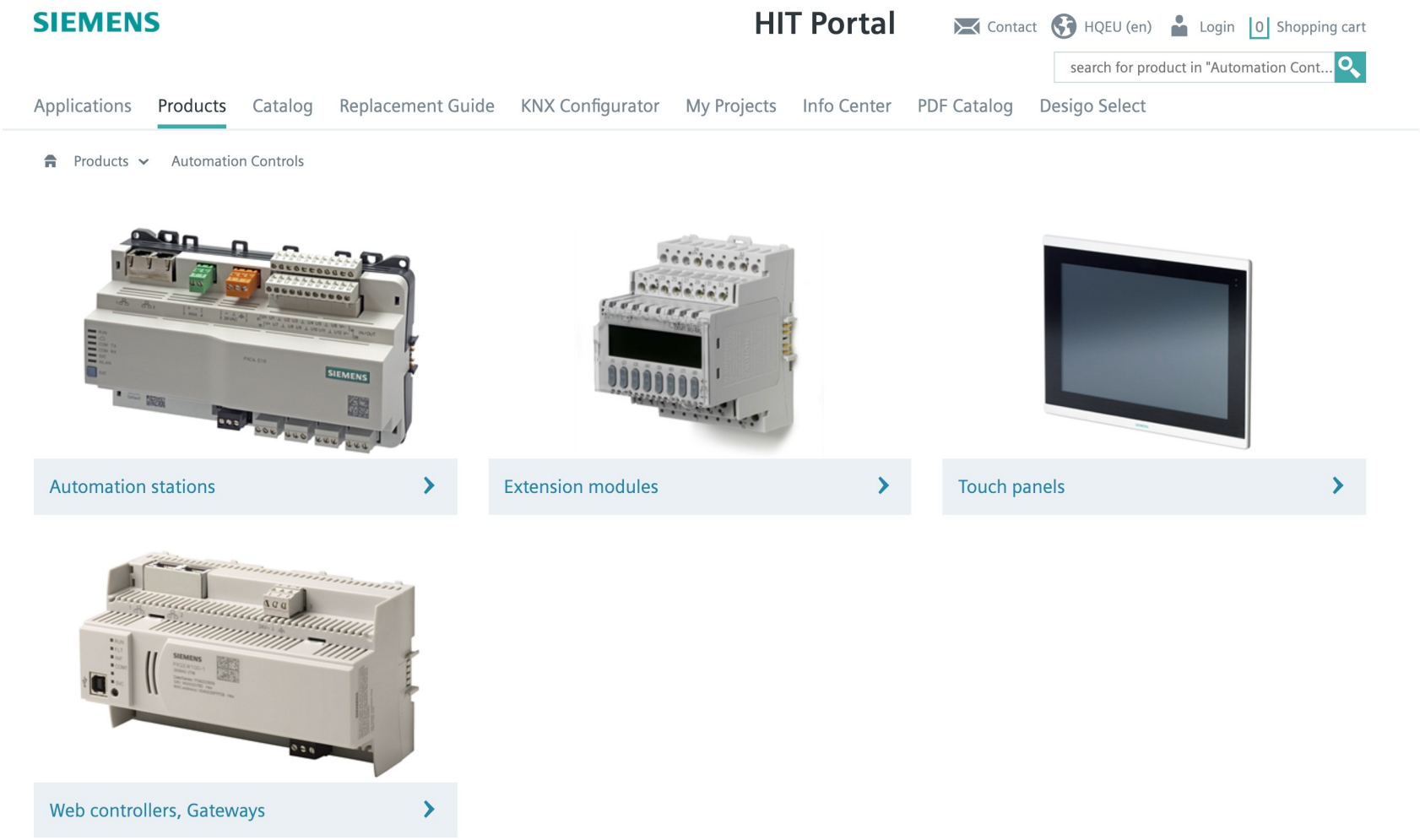
- Let's look at some manufacturers



https://dci.deltacontrols.com/products/facilities-management/local-user-interface/ebmgr-touch#tabSpecification
https://greatnortherncontrols.com/wp-content/uploads/2016/08/DAC-1146E-Catalog-Sheet.pdf.pdf
https://dci.deltacontrols.com/products/hvac-controls/individual-zone-controllers/programmable/dvc-v322

Class Activity

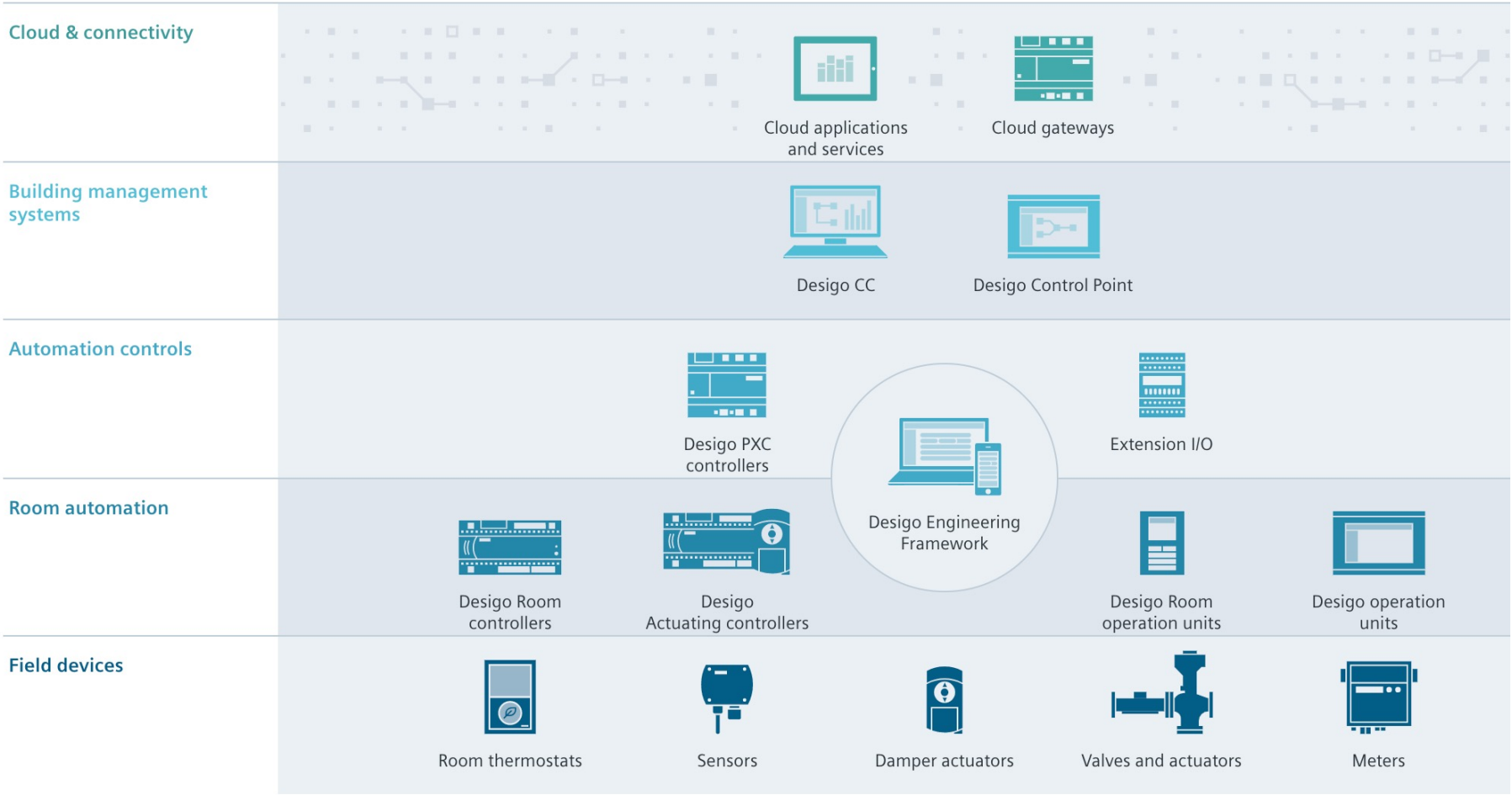
- Let's look at some manufacturers



https://hit.sbt.siemens.com/RWD/app.aspx?RC=HQEU&lang=en&MODULE=Product&ACTION=ShowGroup&KEY=HIT_Prod_Grp_1987229

Class Activity

- Let's look at some manufacturers



https://new.siemens.com/global/en/products/buildings/automation/desigo.html

Class Activity

- Let's look at some manufacturers

Johnson Controls

HOME PRODUCTS & SOLUTIONS SELECTOR CONTACT US

Home : Building Automation & Controls

EasyIO Building Management System

EasyIO Supervisory Network Controllers

EasyIO Programmable Controllers

EasyIO Android Display

Metasys Building Management System

Supervisor Software and Tools

Supervisory Network Controllers

Integration & Gateways

Programmable Controllers

Configurable Field Controllers

Network Displays, Webserver & Gateways

https://be-ebusiness.eu.johnsoncontrols.com/vb/groups?id=2

Class Activity

- Form your groups
- Fill in the spreadsheet - “controller” sheet:

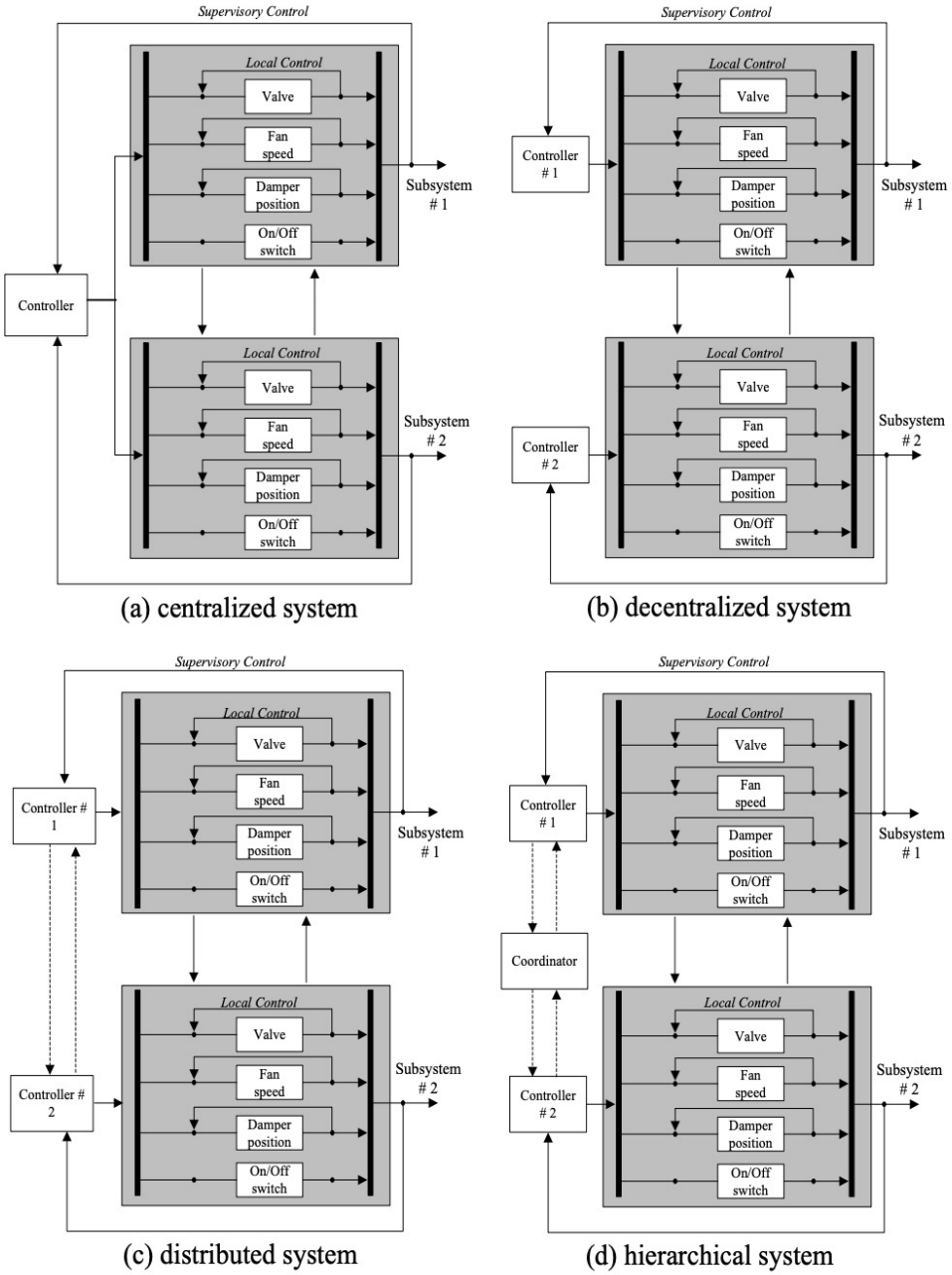
https://docs.google.com/spreadsheets/d/1duxKfuy1kpYNJxXT6e9bHjVBBqUXnwBSBuR8Dkz4f7c/edit#gid=1855737288

CONTROL SYSTEM STRUCTURES

Class Activity

- Multiple controllers could operate based on:
  - ❑ Centralized
  - ❑ Decentralized
  - ❑ Distributed
  - ❑ Hierarchical

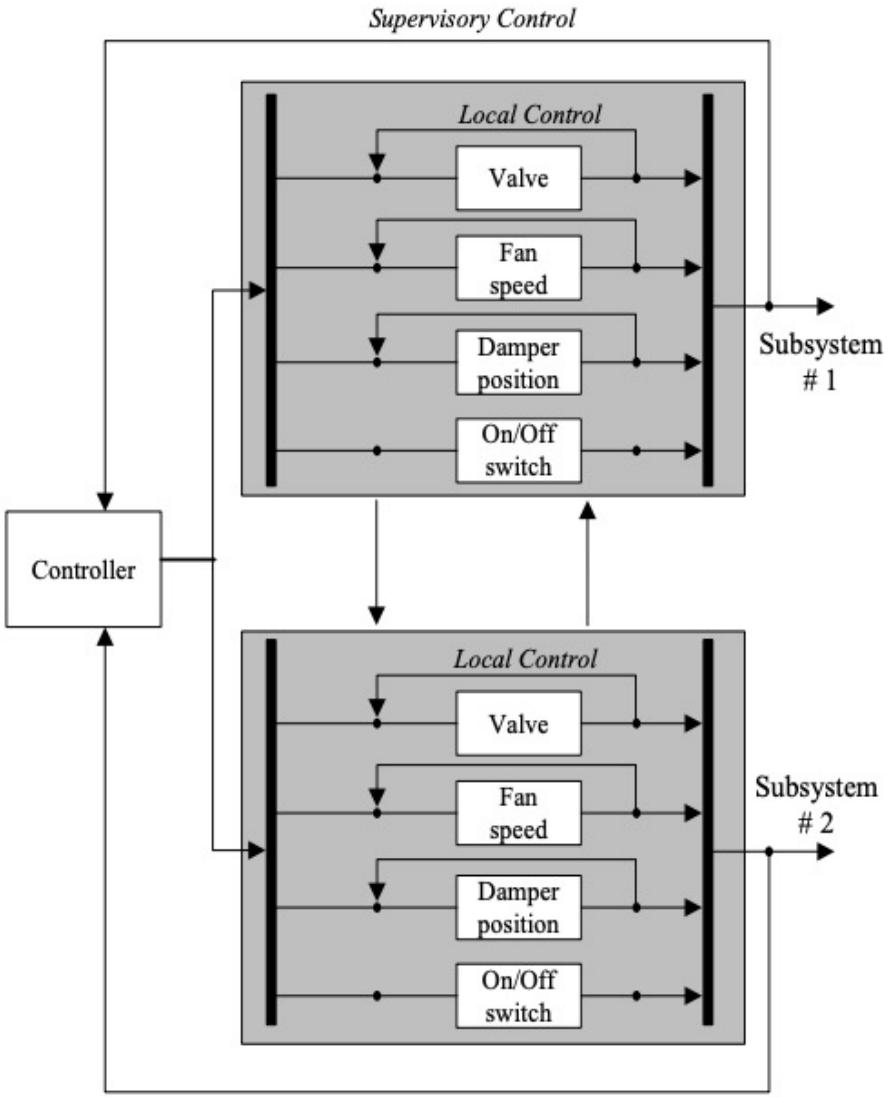
Control System Structures



Control System Structures

- Centralized system

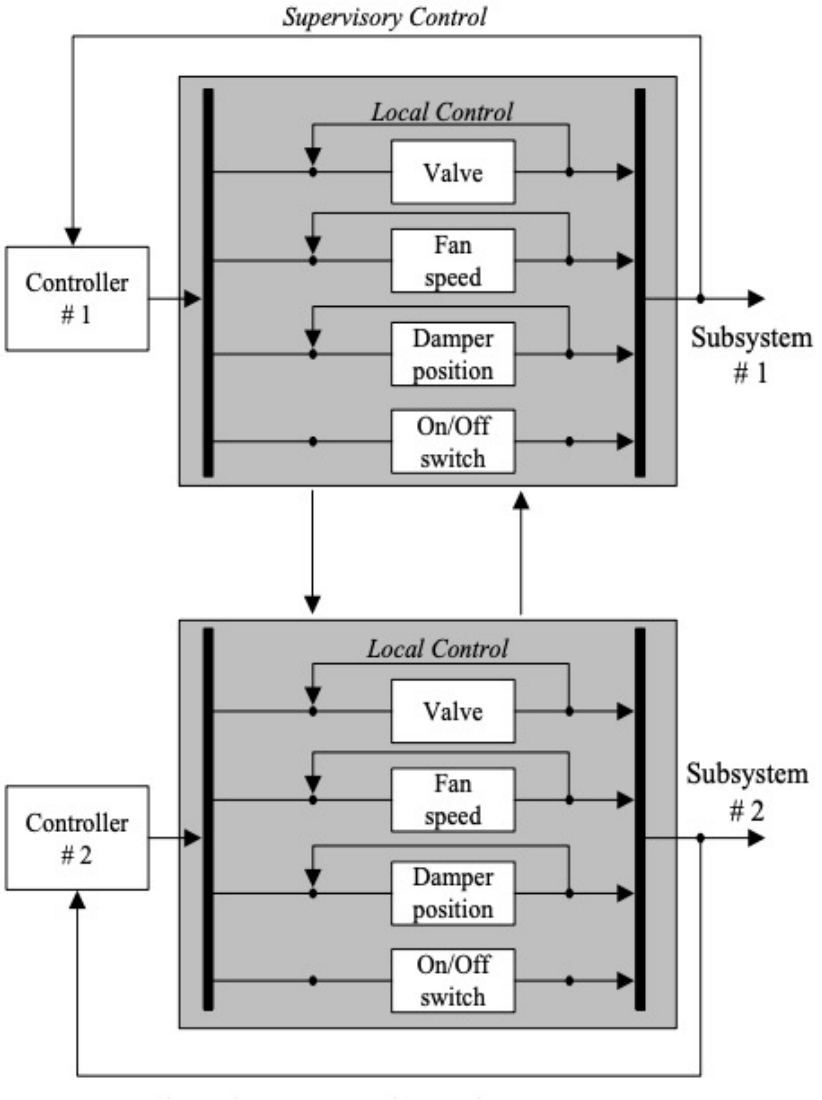
Can you think of an example?



Control System Structures

- Decentralized system

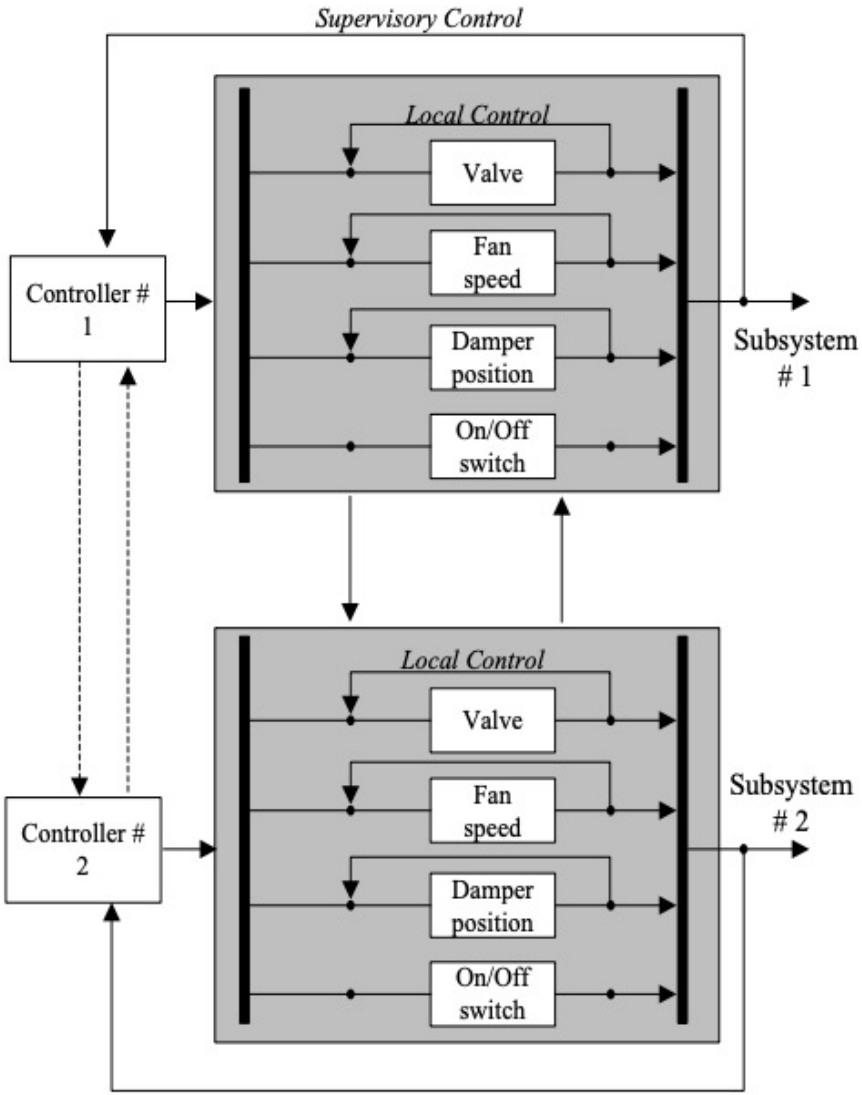
Can you think of an example?



Control System Structures

- Distributed system

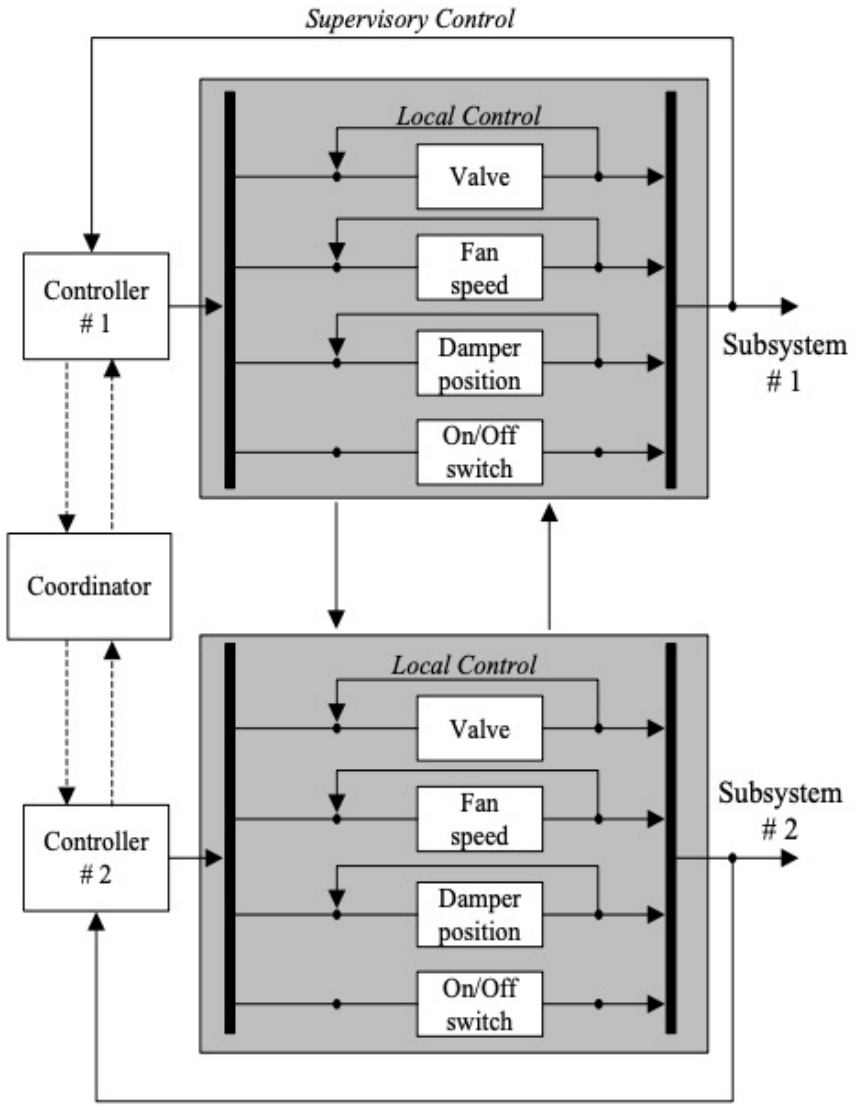
Can you think of an example?



Control System Structures

- Hierarchical system

Can you think of an example?



CLASS ACTIVITY

Class Activity

- Form your groups
- Receive your controller
- Identify all the ports and its application
- Use the spreadsheet - “Controller Hands On” sheet:

  https://docs.google.com/spreadsheets/d/1duxKfuy1kpYNJxXT6e9bHjVBBqUXnwBSBuR8Dkz4f7c/edit#gid=1808283228

- Present your findings to the class