CAE 438/538 Control of Building Environmental Systems

Fall 2021

October 05, 2021

Sequences of Operation (SOO)

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ASSIGNMENTS

Assignment

- Assignments 1 is graded
- Assignment 2 will be graded
- Assignment 3 is due this Thursday
- Assignment 4 is posted

REVIEW OF ASSIGNMENT 1

RECAP

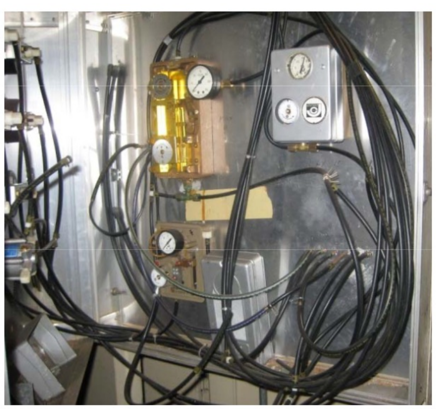
Recap

- We looked at open loop control vs closed loop control

  - ❑ What was the definition?
  - ❑ What components do a closed loop system need to have?
  - ❑ How different or similar are they?
  - ❑ Could you provide a few examples?
  - ❑ What are the controlled variables?

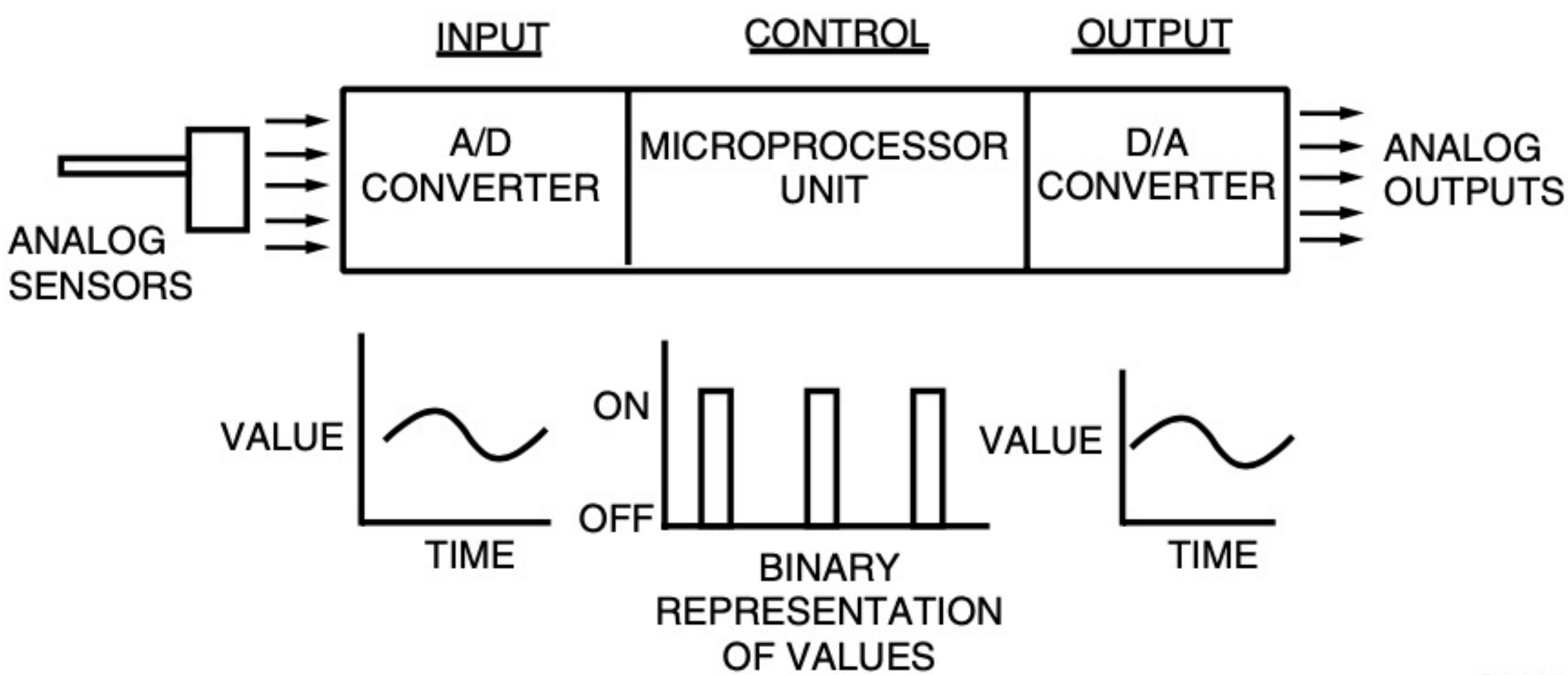
Recap

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



Recap

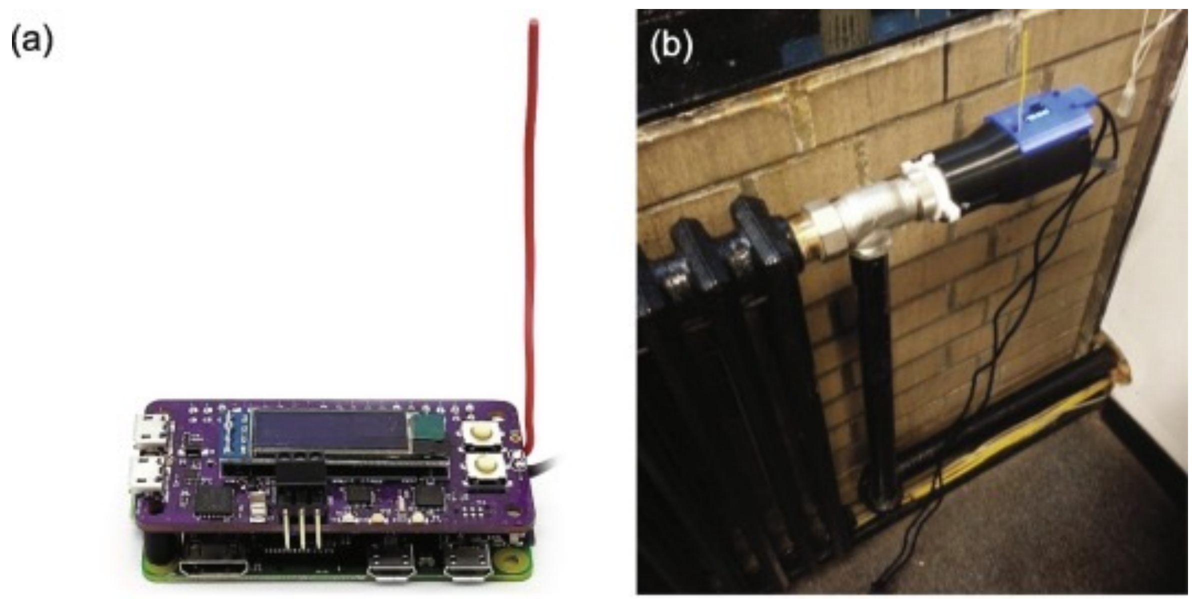
- A DDC control is mostly:
  - ❑ Controller with programmable logic
  - ❑ Signals to/from end devices



Recap

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

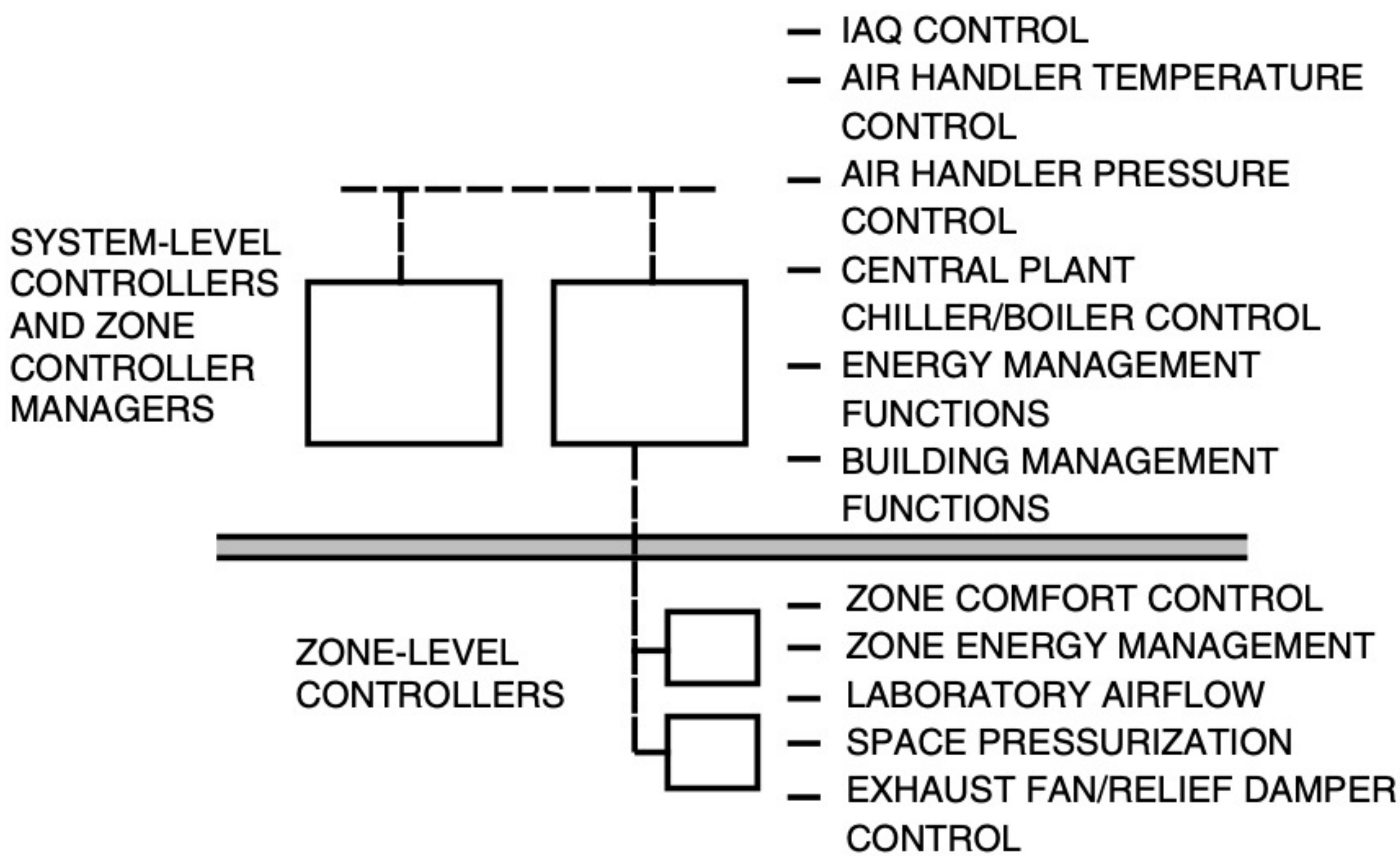
(a) (b) (c)



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

Recap

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



Recap

- Looking from the controller installation, there are two options:
  - ❑ Factory mounted controls
  - ❑ Field applied controls

What are the pros and cons of each?

Recap

- We looked at some examples of controllers:

CIPer Model 30 controller

WEB-09056H

WEB-0302H

https://prod-edam.honeywell.com/content/dam/honeywell-edam/hbt/en-us/documents/literature-and-specs/datasheets/HBT-BMS-CIPer_Model_30_Product_Data_31-00236.pdf

Recap

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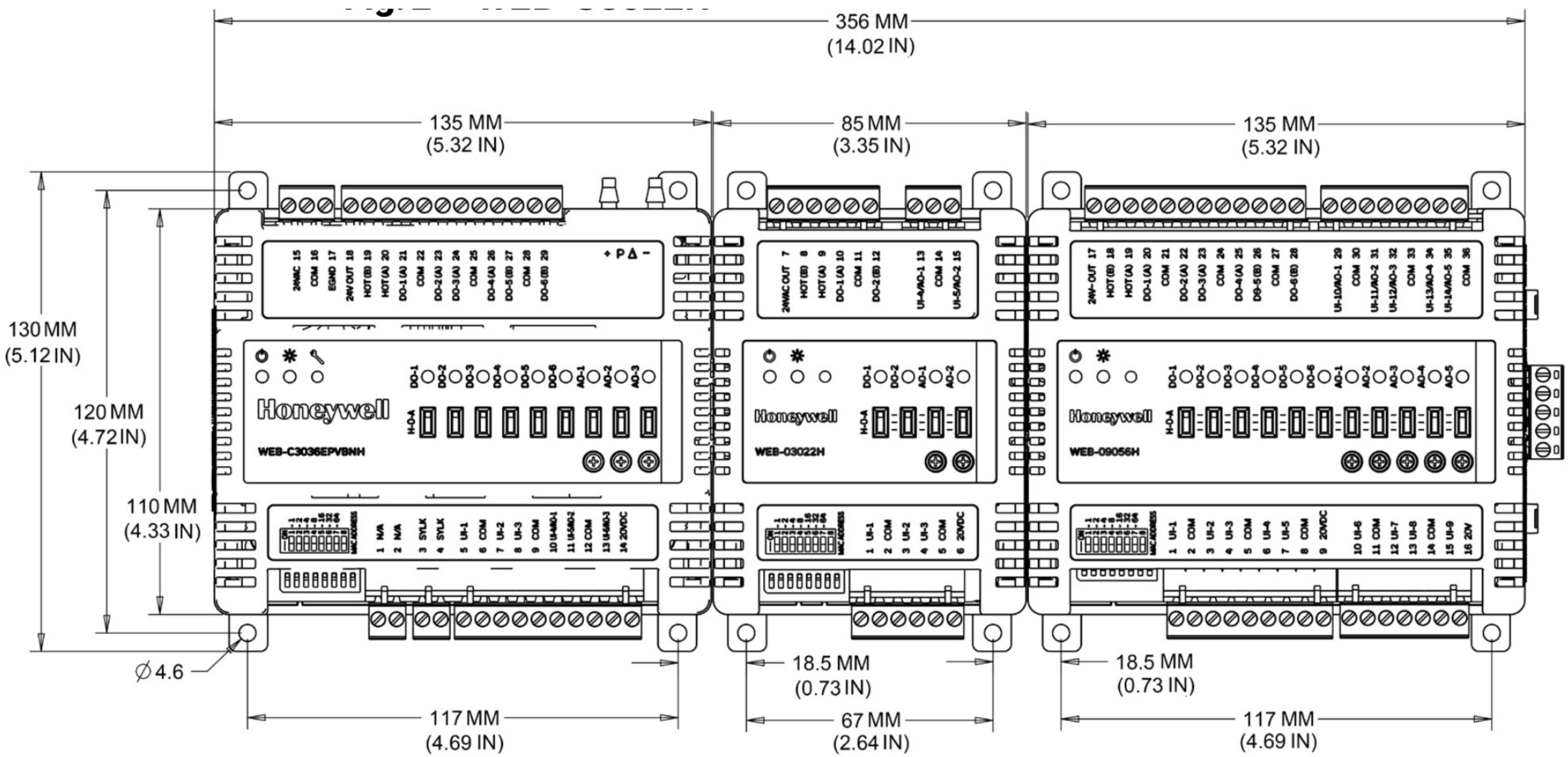

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Recap

- We looked at some examples of controllers:

INPUT/OUTPUT SPECIFICATION

INPUTS AND OUTPUTS	UNIVERSAL INPUTS (UI)	UNIVERSAL INPUT/OUTPUT (UIO)	DIGITAL OUTPUTS (DO)
Function	Voltage, current, resistive or digital input	Voltage, current, resistive or digital input, or analogue (voltage/current) output	Direct (on/off); Slow PWM
Resolution	16 bit (65536 steps)		NA
Pulse inputs	Frequency: 100 Hz max, minimum duty cycle: 5 mS ON / 5 mS OFF		NA
Voltage Input	**Input range**: 0 to 10 VDC, **Input resistance**: 189 kΩ, **Accuracy**: ≤5% of full-scale (i.e. ±50 mV		As per supply voltage (20 - 30 VAC) Output Type solid state relays.
Current Input	**Input range**: 0 to 20 mA, **Current source**: Internal (loop power) or external PSU, **Input resistance**: 500 Ω.w, **Accuracy**: ≤±0.5% of full-scale (i.e. 100 A)		1.5 A continuous, 3.5 A (100 ms inrush)
Resistive Input	**Resistance Input range**: 0 to 300 kΩ, **Accuracy**: Not specified, **Bridge resistor**: 10 kΩ, **Bridge supply**: 3.3 V		NA
Digital Input	Voltage (open circuit): 3.3 V, Wetting current: 330 A (3.3 V / 10 kΩ)		
Analogue Output	NA	***Voltage mode*** **Range:** 0 to 10 VDC (source 10 mA max, sink 1 mA max, load ≥1 kW) **Accuracy**: ±0.5% of full-scale (i.e. 50 mV) ***Current mode*** **Range**: 0 to 20 mA (load ≤550 W) **Accuracy**: ±1% of full-scale (i.e. ±200 A)	
Slow PWM Mode	NA		**Duty cycle**: 0.1 to 3276.7s (in 0.1s increments) **Total cycle**: 0.1 to 3276.7s (in 0.1s increments)

https://prod-edam.honeywell.com/content/dam/honeywell-edam/hbt/en-us/documents/literature-and-specs/datasheets/HBT-BMS-CIPer_Model_30_Product_Data_31-00236.pdf

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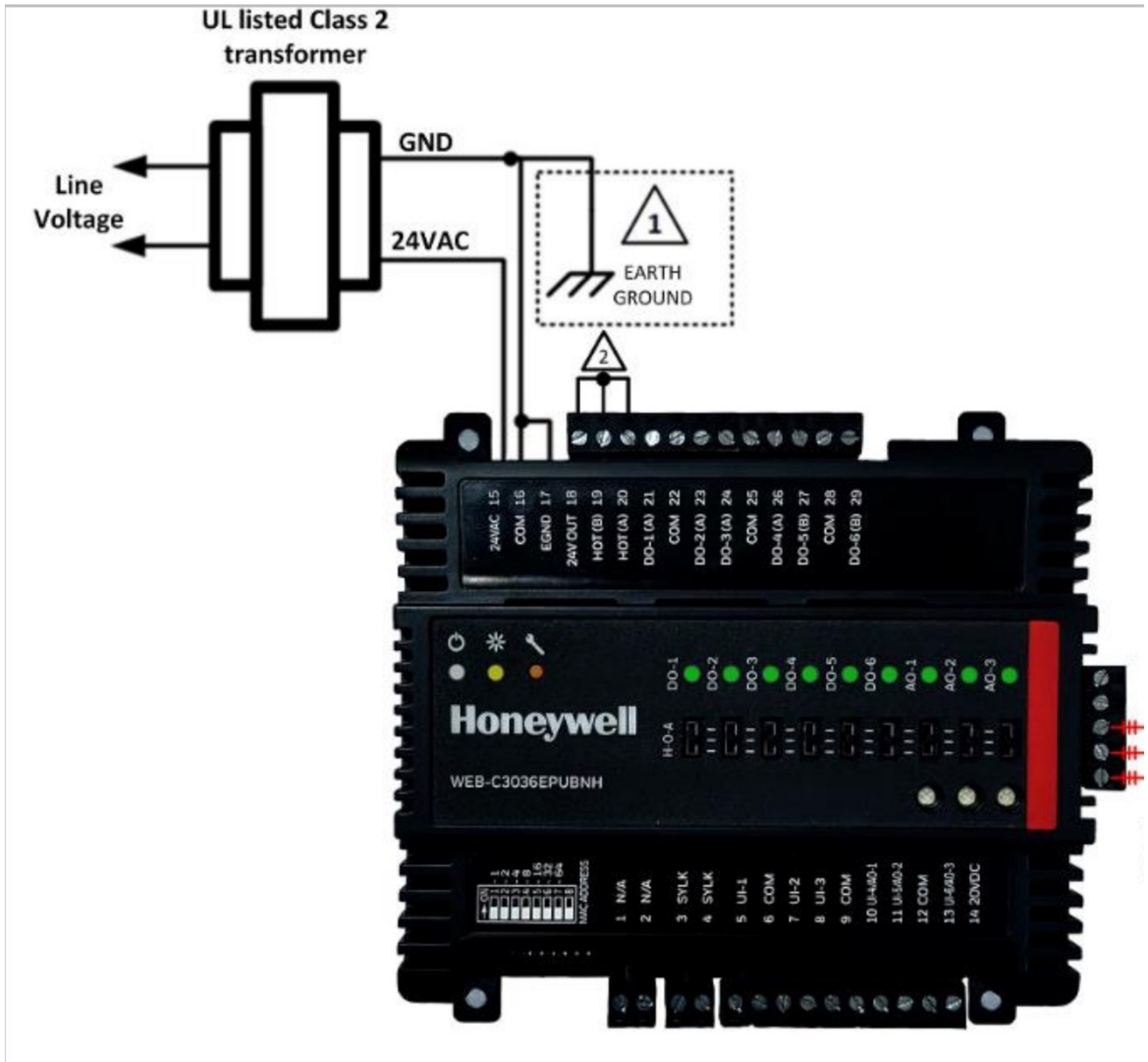

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Recap

- We looked at some examples of controllers:

WEB-O3022H

Terminal	Description
1, 3	Universal inputs UI-1 & UI-2
2	COM terminal for UI-1 & UI-2
4	Universal inputs UI-3
5	COM terminal for UI-3
6	Supplies 20V DC
7	24V AC output from controller for DO devices
8	HOT (B) terminal. Supplies power to common side of controller's DO-2
9	HOT (A) terminal. Supplies power to common side of controller's DO-1
10	DO-1(A)
11	GND terminal for DO-1(A) & DO-2(B)
12	DO-2(B)
13, 15	Universal inputs UI-4/AO-1 & UI-5/AO-2
14	COM terminal for UI-4/AO-1 & UI-5/AO-2

https://prod-edam.honeywell.com/content/dam/honeywell-edam/hbt/en-us/documents/literature-and-specs/datasheets/HBT-BMS-CIPer_Model_30_Product_Data_31-00236.pdf

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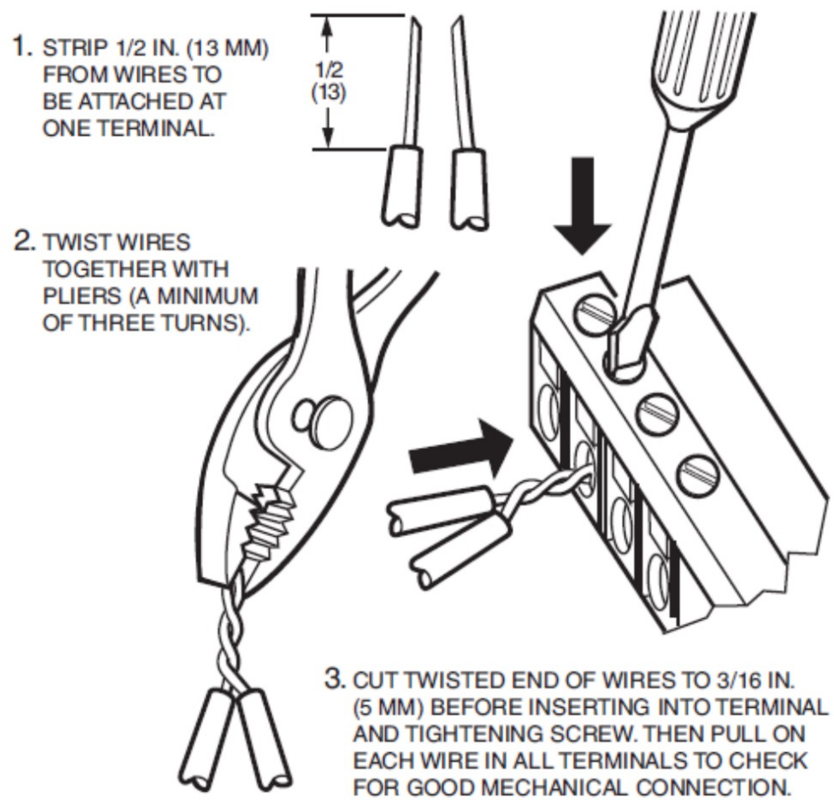

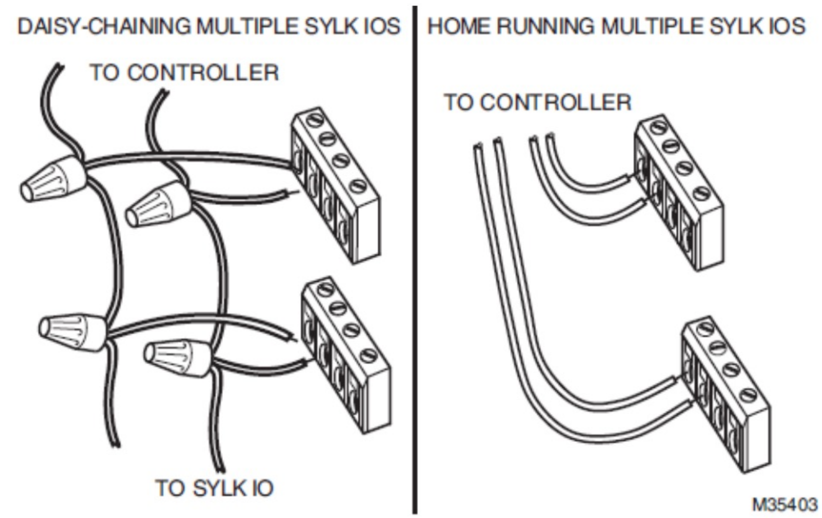

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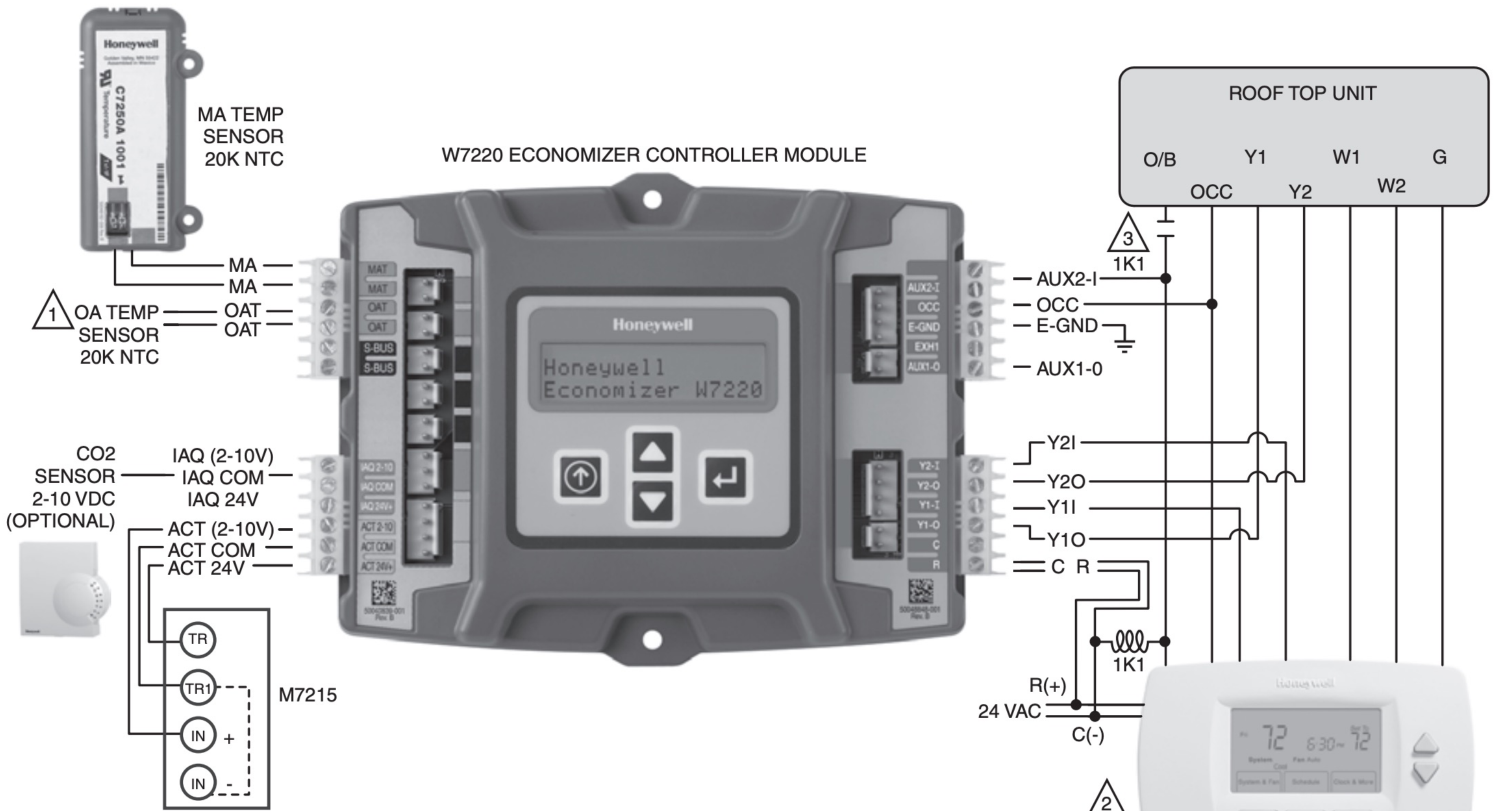
Recap

- We looked at sensors (Examples?)



1 NOTE THAT THE C7250 20K NTC SENSOR CAN BE MOUNTED IN THE OAT ONLY IN THIS CONFIGURATION.

2 WHEN USING A HEAT PUMP THERMOSTAT, THERMOSTAT TERMINALS MAY DIFFER: W1 MAY BE LABELED O OR B AND W2 MAY BE LABELED W.

3 WHEN USING A HEAT PUMP WITH DEFROST FEEDBACK, ADD AN ISOLATION RELAY BETWEEN O AND C.

M28980C

https://prod-edam.honeywell.com/content/dam/honeywell-edam/hbt/en-us/documents/manuals-and-guides/reference-guides/63-8594.pdf

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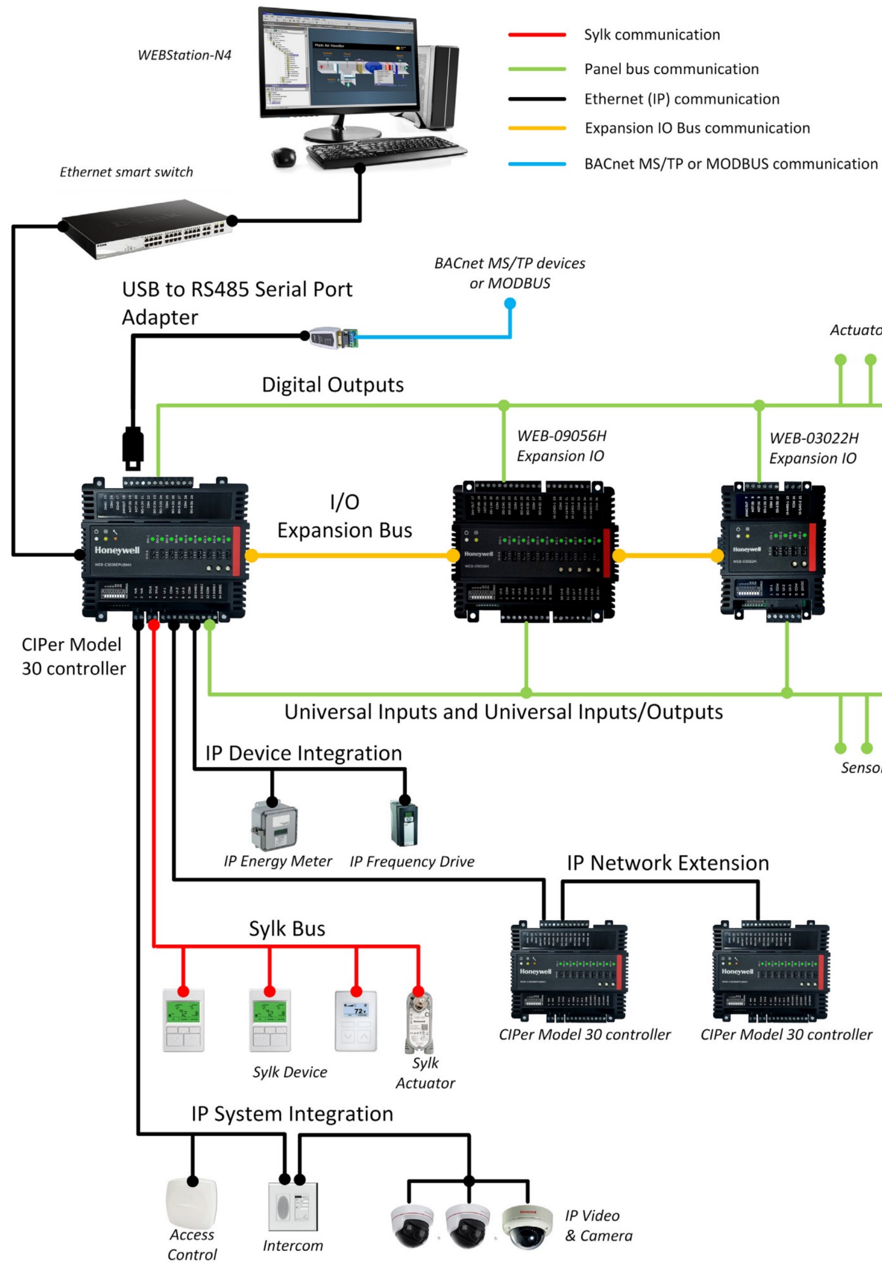

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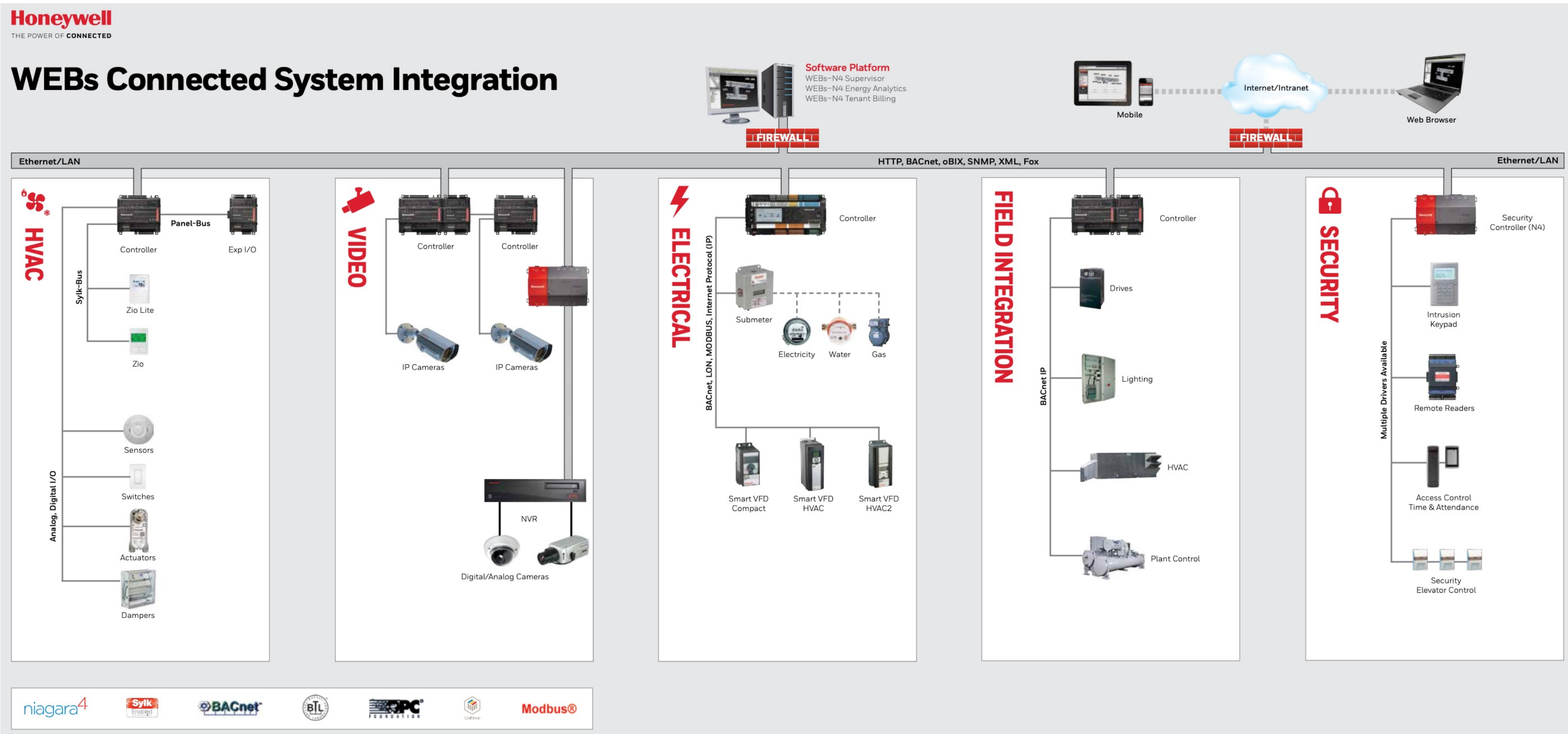

https://buildingcontrols.honeywell.com/literature/01-00074_WEBsN4_SystemArch.pdf

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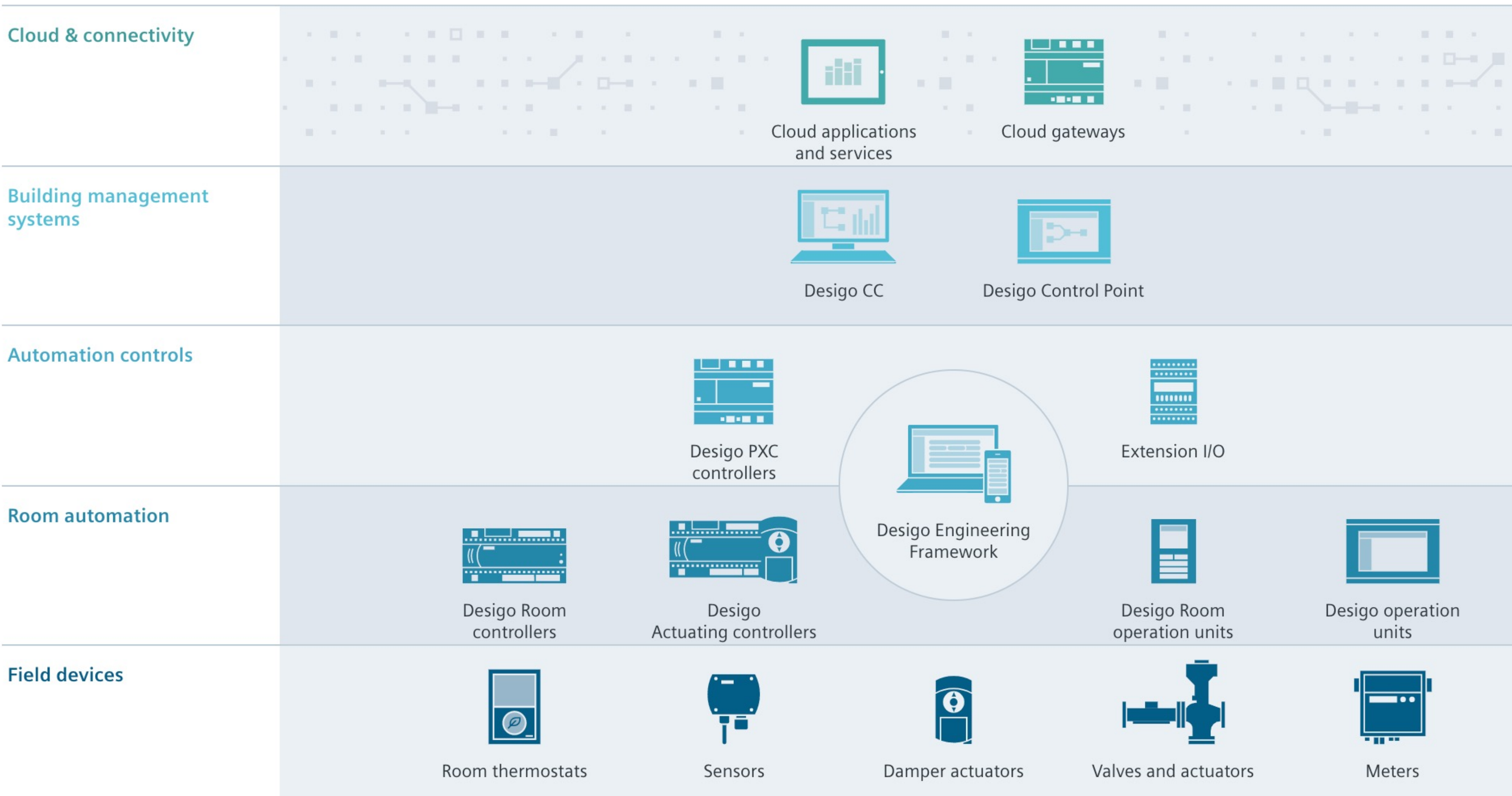


https://new.siemens.com/global/en/products/buildings/automation/desigo.html

INTRO TO SEQUENCES OF OPERATION (SOO)

Into to Sequences of Operation

- Building management system (BMS) or known as BAS, BEMS, EMS, BACS

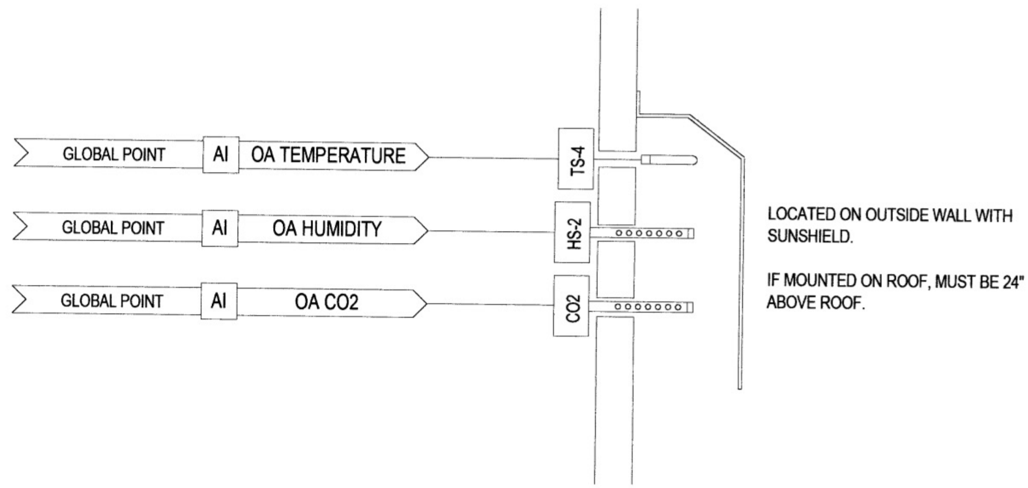
- Buildings entail different systems (not only mechanical):
  - Lighting
  - Shades
  - Energy / Power
  - Fire protection
  - Security

Into to Sequences of Operation

- Sequences of operation describe how the system shall function and are the designer's primary method of communication to the control system programmer
- A sequence should be written for each system to be controlled
- In writing a sequence, care must be taken to describe all operational modes and to ensure that all I/O devices needed to implement the sequence are shown on the object list and drawings

Into to Sequences of Operation

- Sequences of operation are intended to specify the functional result of the programming logic



SEQUENCE OF OPERATION

1. OUTDOOR AIR TEMPERATURE, RELATIVE HUMIDITY, AND CO2 SENSORS SHALL BE MEASURED FOR GLOBAL OPERATION OF THE BAS SYSTEM.

OUTSIDE AIR SENSORS

Into to Sequences of Operation

- Existing issues with the control configurations:
  - ❑ It is mostly a manual based process
  - ❑ It is important to make sure the process involves different stakeholders:
    - HVAC system designer
    - Control system designer
    - Control system programmer and commissioner
    - Facility operator and maintainer

Intro to Sequences of Operation

- Common issues can be:
  - ❑ Inaccurate or incomplete control sequences
  - ❑ Lack of details in specifying the control sequences
  - ❑ Copy and paste previously written sequences
  - ❑ Sequences contradicted with other supplementary drawings
  - ❑ Mistakenly specifying the control sequences
  - ❑ Programming error

Intro to Sequences of Operation

- ASHRAE Guideline 13 “Specifying Direct Digital Control Systems” provides two methods of organizing control sequences by:
  - ❑ Operation mode
  - ❑ Component

- In practice, both methods are used to organize control sequences and programming codes

Into to Sequences of Operation

- Most of the control sequences are:
  - ❑ The organization of sequences could start with components
  - ❑ Each major section of the systems can be organized by operation modes

Into to Sequences of Operation

- Although there are efforts to introduce a standard language for the sequences of operations, no standard languages exist to specify the control sequences

- There is a need to define a standard format for each of the components and control modes

- Pseudocode are good example of the common practice at the moment

Intro to Sequences of Operation

- An example of using control sequence organized by component output value vs by operation model:

	By components output values	By operation mode
Rules	y_1 **SHALL** be $Y_1 \ldots y_m$ **SHALL** be Y_m a) **WHEN** x_1 is X_1 b) **OR WHEN** x_2 is X_2 **AND,…OR** x_n is X_n. where x_1 stands for the operation mode variable x_2- x_n stand for the other conditions variables that need to satisfy when x_1 is enable. X_1, X_2, X_n, are the linguistic variables of x_1, x_2, x_n, respectively y_1 - y_m stand for control outputs Y_1- Y_m stand for control outputs values under this rule	**IF** x_1 is X_1 **AND** (x_2 is X_2 …**OR** x_n is X_n), **THEN** y_1 is $Y_1 \ldots y_m$ is Y_m. a) **IF** **THEN**
Usage	• Better guide for programming • Useful for trouble shooting and maintenance for specific components	• Generally easier to understand • Better explain operating concept • Highlight differences between the operating modes

Chen dissertation, PSU 2015

Intro to Sequences of Operation

- Layout of control sequences and programming code from a template example in EquipmentBuilder for Educators:

Control Sequences (Viewed in Word: the alarm and data point sections are excluded)	**Programming Code** (Viewed in EIKON: the alarm and data point sections are excluded)

• Run Conditions – Scheduled
• Minimum Ventilation on Carbon Dioxide (CO_2) Concentration
• Demand Limiting – Zone Setpoint Optimization
• Zone Setpoint Adjust
• Zone Optimal Start
• Zone Unoccupied Override
• Reversing Variable Volume Terminal Unit – Flow Control
    o Occupied
    o Unoccupied
• Reheating Coil Valve
	• Zone - Run Conditions – Scheduled
	    o Outgoing Requests to Run Interlocked Equipment
	        ▪ Request Heat Source
	        ▪ Request Cool Source
	        ▪ Zone Occupied for - Minutes
	• Zone CO_2 Control
	• Airflow Control – Reversing – Internal Actuator
	    o Outgoing Requests to Run Interlocked Equipment
	• Heating Control

Chen dissertation, PSU 2015

Into to Sequences of Operation

- An example of the operation mode is as follow:

A General

1. The occupancy mode (occupied or unoccupied) shall be determined through a user-definable time schedule.

B Occupied Mode

1. There shall be separate heating and cooling space temperature setpoints …
2. Whenever the outside air temperature is less than 18.3°C (65°F)

C Unoccupied Mode

1. Unoccupied OFF: The supply fan

D Safety shutdowns

1. Duct smoke detection, and low temperature limit …..
2. The cooling valve shall open 50% when ever the low temperature limit is on

E Alarms

1. a. High zone temp: If the zone temperature is 2.8°C (5°F) greater than the cooling setpoint

Into to Sequences of Operation

- An example of structuring by component includes

Run Conditions:

The unit shall run according to a user-definable time schedule in the following modes:

Occupied Mode: …

Unoccupied Mode: ….

Alarms shall be provided:

High Zone Temp ….

Cooling Coil Valve:

The cooling coil valve shall be enabled whenever:

….

….

…

CLASS ACTIVITY

Class Activity

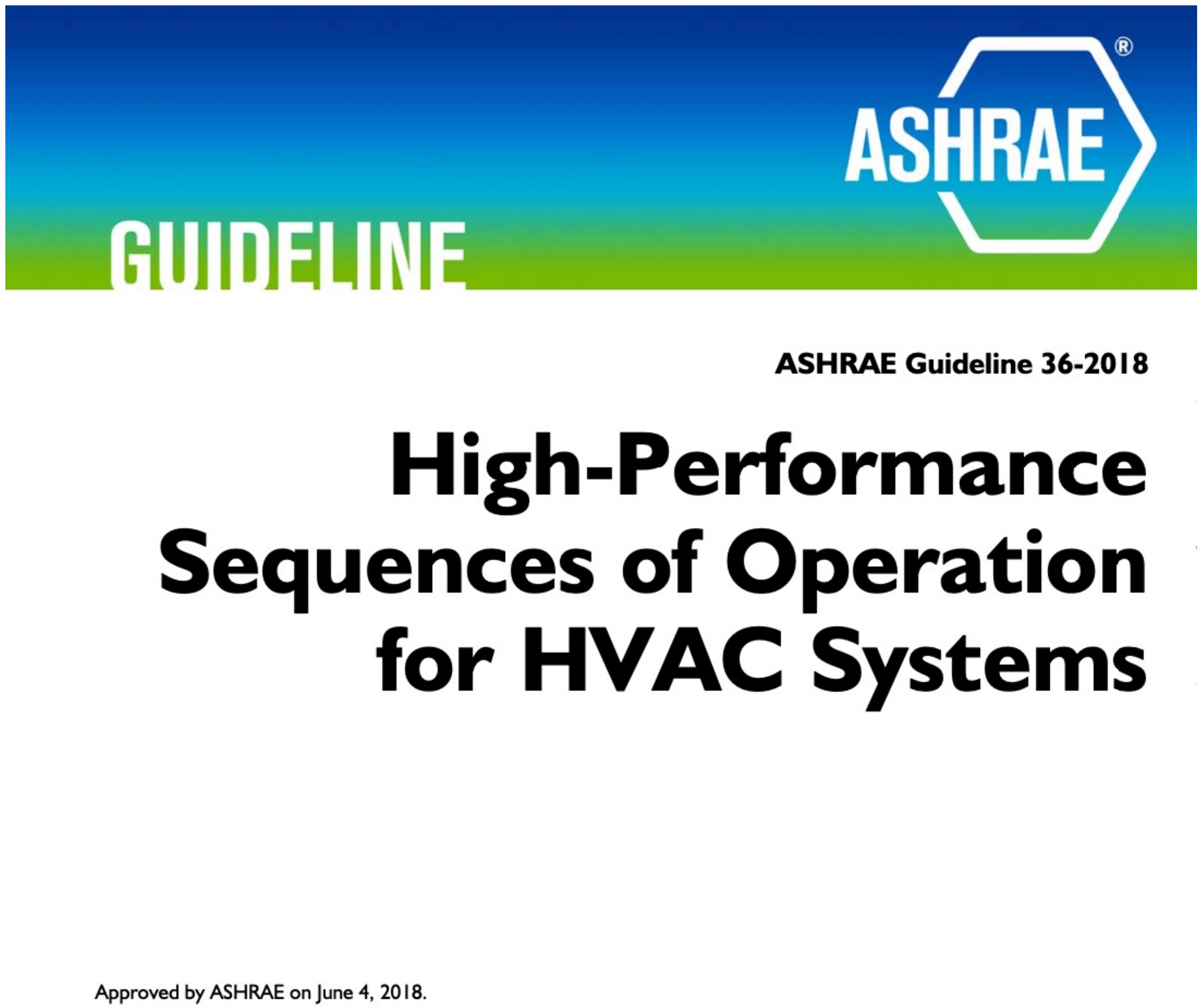
- Form your groups
- Let's look at some existing SOO in a real building. Open file named "cae438_538_f21 lecture07 Sequences of Operation - Kaplan Building"
- Select three components/equipment and add them here:
- What are the pros and cons for each of these SOOs?

https://docs.google.com/spreadsheets/d/1duxKfuy1kpYNJxXT6e9bHjVBBqUXnwBSBuR8Dkz4f7c/edit#gid=306213051

ASHRAE GUIDELINE 36

ASHRAE Guideline 36

- A 2018 version of ASHRAE Guideline aimed to determine high-performance sequences of operation for HVAC systems



ASHRAE Guideline 36

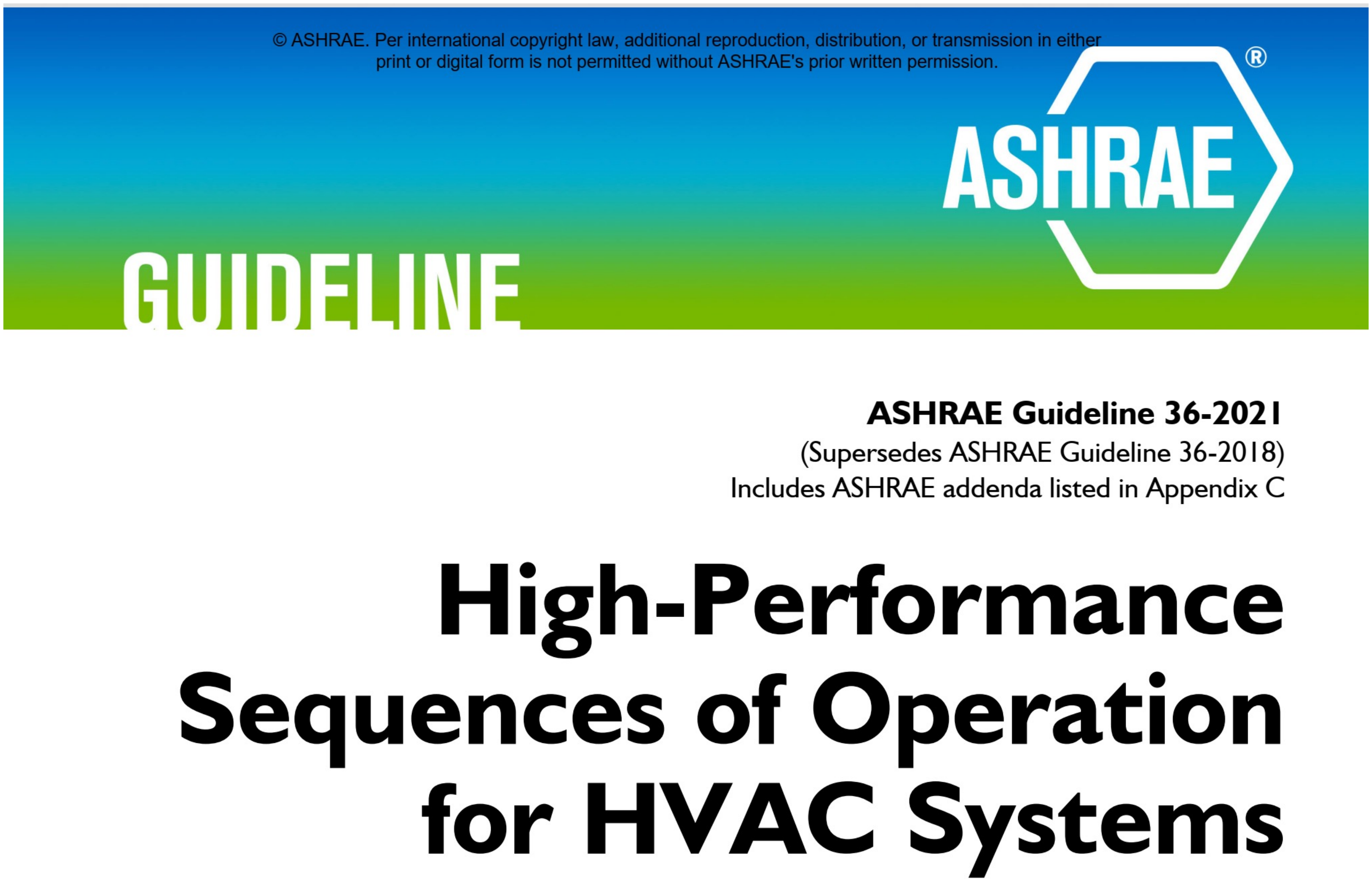
- The 2018 version was mostly focused on the air side:
  - ❑ VAV terminal unit (cooling only)
  - ❑ VAV terminal unit with reheat
  - ❑ Fan powered terminal unit (series/parallel, constant/variable speed fan)
  - ❑ Dual duct terminal unit with inlet sensors
  - ❑ Dual duct terminal unit with discharge sensor
  - ❑ Multiple zone VAV air handling unit
  - ❑ Dual fan dual duct heating VAV air handling unit
  - ❑ Single zone VAV air handling unit

ASHRAE Guideline 36

- There have ongoing maintenance to add other components such as hydronic systems “Continuous Maintenance Protocol (CMP)” in the past three years

ASHRAE Guideline 36

- The 2021 version was just released:



GUIDELINE

ASHRAE®

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

High-Performance Sequences of Operation for HVAC Systems

https://www.ashrae.org/technical-resources/standards-and-guidelines

ASHRAE Guideline 36

- The 2021 version includes hydronic systems:
  - Chilled water plant
  - Hot water plant
  - Fan coil unit

ZONE TEMPERATURE AND VENTILATION SET POINTS

Zone Temperature and Ventilation Set Points

- Zone temperature set points are specified in different ways:
  - ❑ In the zone equipment (e.g., variable air volume (VAV) boxes)
  - ❑ In the air handling unit (AHU) equipment schedules
  - ❑ In the zone based on the zone type

Table 3.1.1.1 Default Setpoints

	Occupied		Unoccupied	
Zone Type	Heating	Cooling	Heating	Cooling
VAV	21°C (70°F)	24°C (75°F)	16°C (60°F)	32°C (90°F)
Mechanical/electrical rooms	18°C (65°F)	29°C (85°F)	18°C (65°F)	29°C (85°F)
Networking/computer	18°C (65°F)	24°C (75°F)	18°C (65°F)	24°C (75°F)

Zone Temperature and Ventilation Set Points

- Zone ventilation set points are specified in different ways:
  - ❑ ASHRAE 62.1
  - ❑ Title 24

The engineer must select between ventilation logic options:

- **If the project is to comply with ASHRAE Standard 62.1 ventilation requirements, keep subsection (a) and delete subsection (b).**
- **If the project is to comply with California Title 24 ventilation requirements, keep subsection (b) and delete subsection (a).**

Zone Temperature and Ventilation Set Points

- Carbon dioxide set points are used for demand controlled ventilation (DCV), monitoring, and alarming

- The maximum set point are not completely clear especially in newer standards (Guideline 36 uses the older version of 62.1)

Zone Temperature and Ventilation Set Points

Occupancy Category	CO_2 Setpoint (ppm)	Occupancy Category	CO_2 Setpoint (ppm)
Booking/Waiting	1,200	Main Entry/Lobbies	1,391
Educational Facilities		Miscellaneous Spaces	
Day Care (Through Age 4)	1,027	Bank Vaults/Safe Deposit	805
Day Care Sickroom	716	Computer (Not Printing)	738
Classrooms (Age 5 – 8)	864	Pharmacy (Preparation Area)	820
Classrooms (Age 9+)	942	Photo Studios	983
Lecture Classroom	1,305	Transportation Waiting	1,305
Lecture Hall (Fixed Seats)	1,305	Public Assembly Spaces	
Art Classroom	837	Auditorium Seating Area	1,872
Science Laboratories	894	Place of Religious Worship	1,872
University/College Lab	894	Courtrooms	1,872
Wood/Metal Shop	1,156	Legislative Chambers	1,872
Computer Lab	965	Libraries	805
Media Center	965	Lobbies	2,628
Music/Theater/Dance	1,620	Museums (Children's)	1,391
Multiuse Assembly	1,778	Museum/Galleries	1,620
Food and Beverage Service		Retail	
Restaurant Dining Rooms	1,418	Sales (Except Below)	1,069
Cafeteria/Fast-Food Dining	1,536	Mall Common Areas	1,620
Bars, Cocktail Lounges	1,536	Barbershop	1,267
General		Beauty and Nail Salons	723
Break Rooms	1,267	Pet Shops (Animal Areas)	709
Coffee Stations	1,185	Supermarket	1,116
Conference/Meeting	1,620	Coin-operated Laundries	1,322
Hotels, Motels, Resorts, Dormitories		Sports and Entertainment	
Bedroom/Living Area	910	Spectator Areas	1,778
Barracks Sleeping Areas	1,116	Disco/Dance Floors	1,440
Laundry Rooms, Central	1,249	Health Clubs/Aerobics Room	1,735
Laundry Within Dwelling	983	Health Clubs/Weight Room	1,232
Lobbies/Prefunction	1,494	Bowling Alley (Seating)	1,232
Multipurpose Assembly	2,250	Gambling Casinos	1,368
		Game Arcades	894
		Stages, Studios	1,391

Zone Temperature and Ventilation Set Points

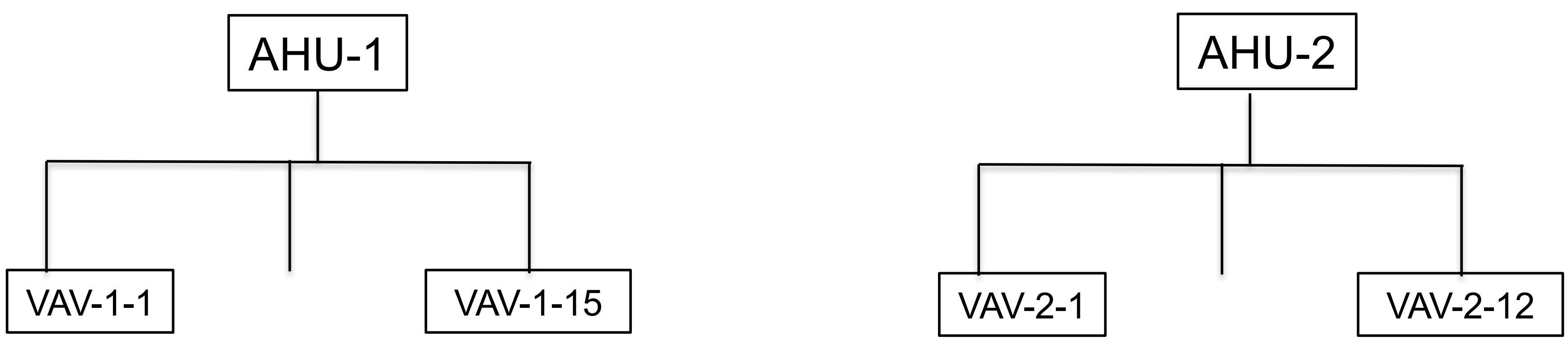
- Critical zones are important to consider for both the zone temperature and ventilation requirements

Zone Temperature and Ventilation Set Points

- Zone Group (assignments) include:
  - Each zone served by a single-zone air handler
  - Rooms
  - Occupied 24/7, such as computer rooms, networking closets, mechanical, and electrical rooms served by the air handler
    - A Zone Group shall not span floors
    - A Zone Group shall not exceed 25,000 ft^2
    - If future occupancy patterns are known, a single Zone Group shall not include spaces belonging to more than one tenant
    - A zone shall not be a member of more than one zone group

Zone Temperature and Ventilation Set Points

- Various strategies are needed to specify the zone assignments:
  - ❑ Tabular
  - ❑ Drawings
  - ❑ Schematic
  - ❑ In Building Automation System (BAS) specifications
  - ❑ Other formats may be used if they convey the same information



ALARMS

Alarms

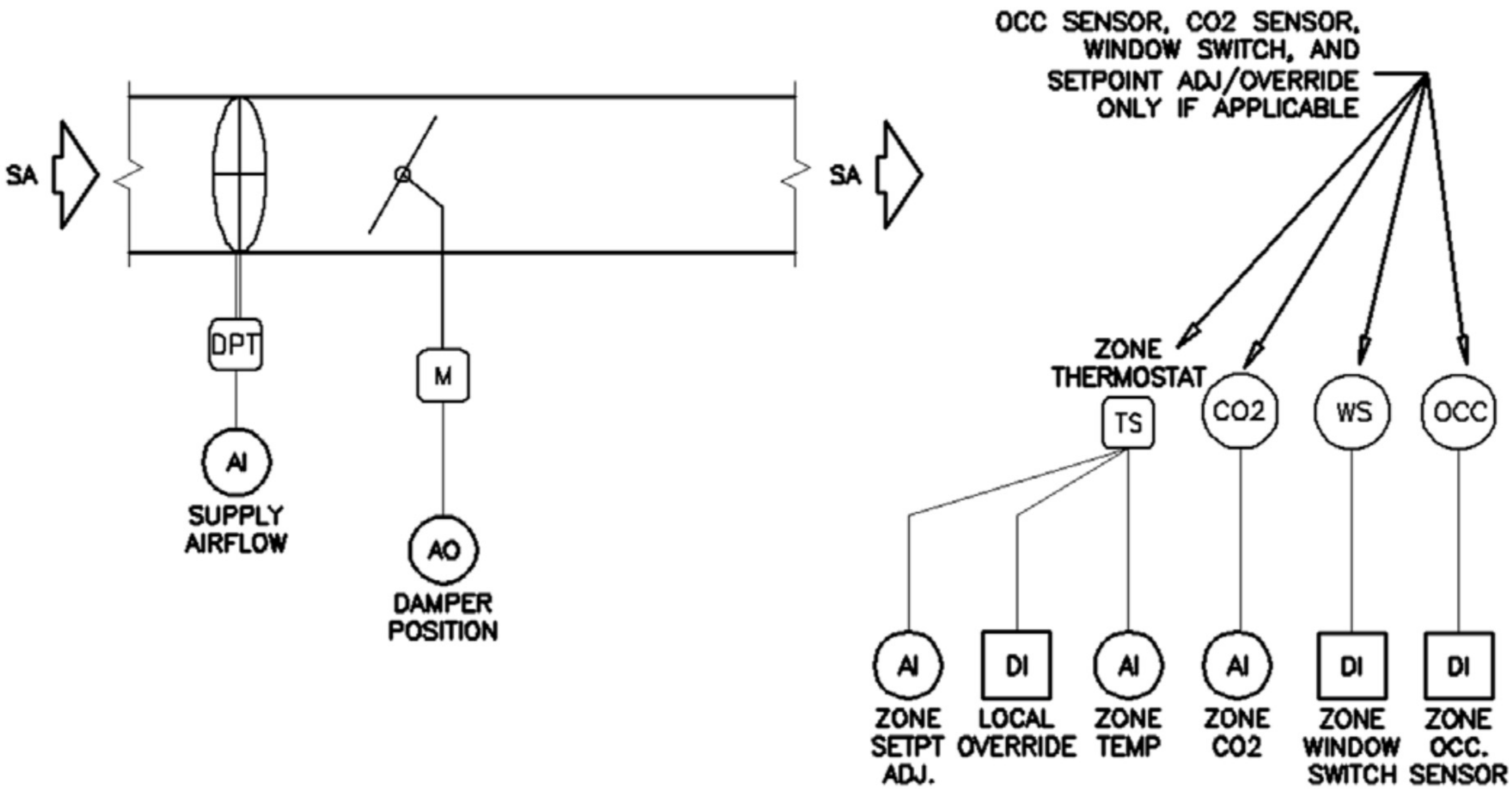
- Alarms should be reported with the following information:
  - ❑ Date and time of the alarm
  - ❑ Level of the alarm
  - ❑ Description of the alarm
  - ❑ Equipment tags for the units in alarm
  - ❑ Possible causes of the alarm if provided by the fault detection routines
  - ❑ The source for the equipment that is being served

Alarms

- There shall be 4 levels of alarm
  - ❑ Level 1: Life-safety message
  - ❑ Level 2: Critical equipment message
  - ❑ Level 3: Urgent message
  - ❑ Level 4: Normal message

VAV TERMINAL UNIT (ONLY COOLING)

VAV Terminal Unit (Only Cooling)



ASHRAE 36

VAV Terminal Unit (Only Cooling)

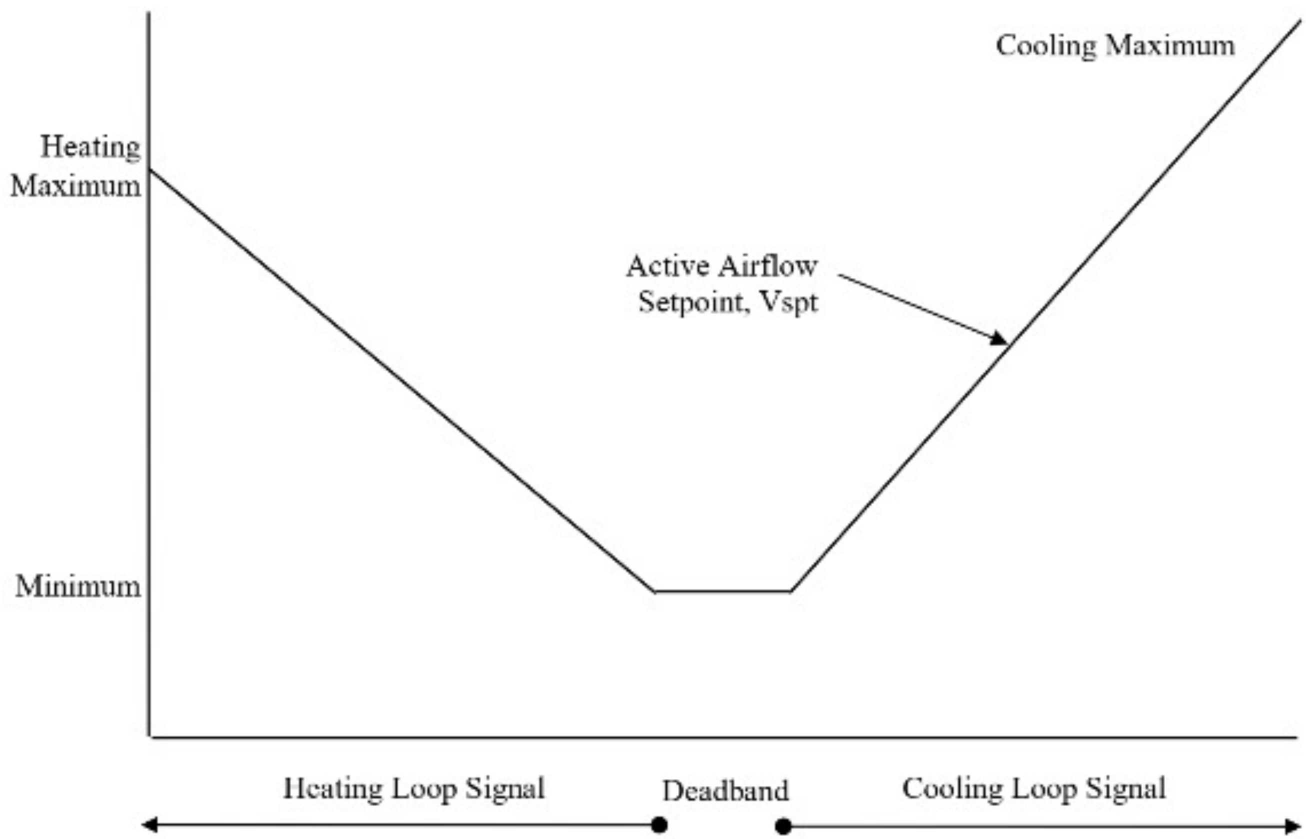


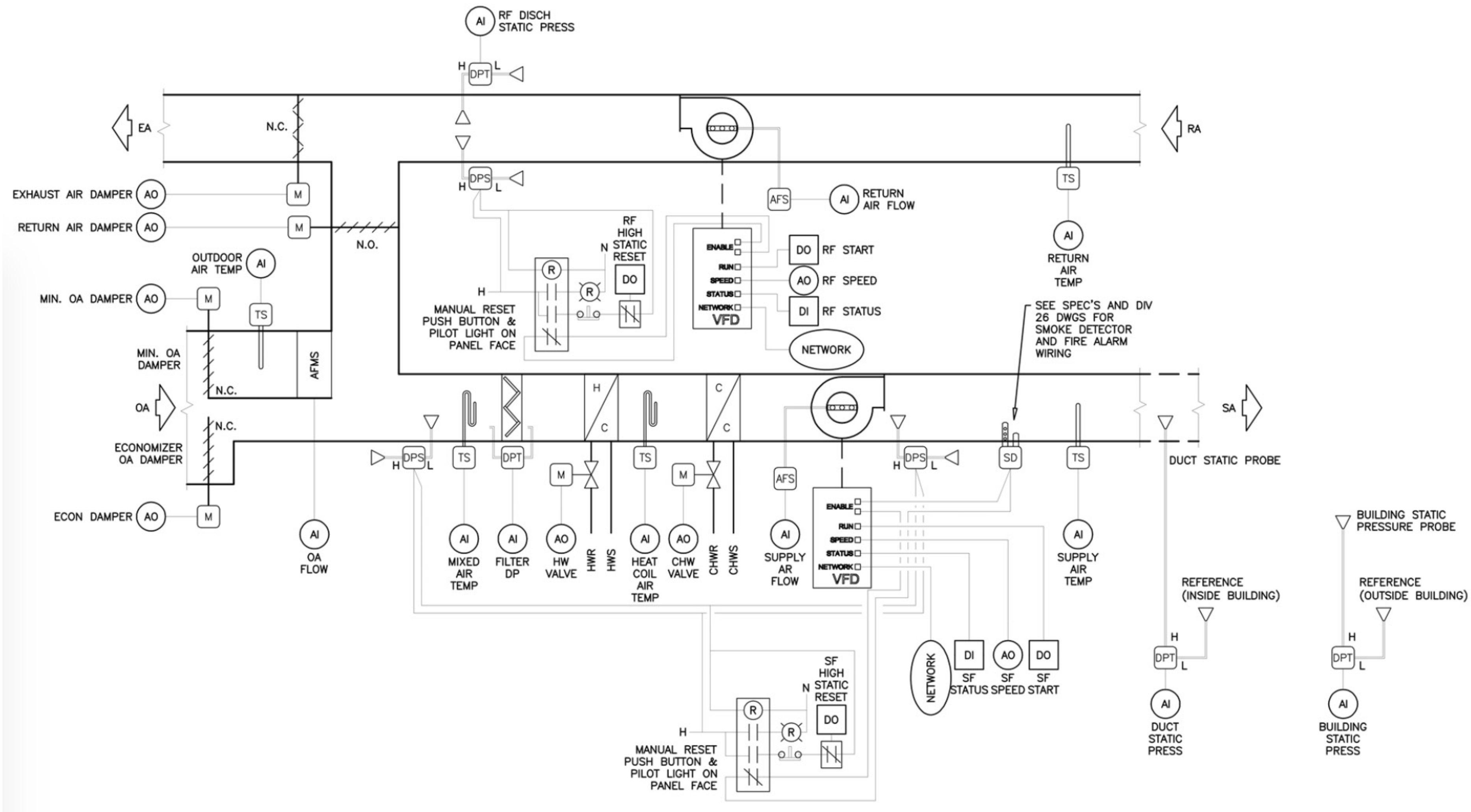
Figure 5.5.5 Control logic for cooling-only VAV zone.

ASHRAE 36

MULTIPLE-ZONE VAV AIR-HANDLING UNIT WITH RETURN FAN AND MINIMUM OA MEASUREMENT STATION

Multi-zone VAV Air Handling Unit with Return Fan

- Multiple-zone VAV air-handling unit with return fan and minimum OA measurement station



ASHRAE Guideline 36

CLASS ACTIVITY

Class Activity

- Form your groups and pick one system from ASHRAE Guideline 36
- Spend 30 to 45 minutes to complete the sections
- Present to the class
- Do you think the sequences of operation are based on the operation mode or components? Can we convert a few of them to the other format?

https://docs.google.com/spreadsheets/d/1duxKfuy1kpYNJxXT6e9bHjVBBqUXnwBSBuR8Dkz4f7c/edit#gid=764140978

BEYOND ASHRAE GUIDELINE 36

Beyond ASHRAE Guideline 36

- Looking into existing building systems:

Assessing ventilation control strategies in underground parking garages

Afshin Faramarzi, Jongki Lee, Brent Stephens, Mohammad Heidarinejad (✉)

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Abstract

Enclosed parking garages require mechanical ventilation fans to dilute concentrations of pollutants emitted from vehicles, which contributes to energy use and peak electricity demand. This study develops and applies a simulation framework combining multi-zone airflow and contaminant transport modeling, fan affinity laws, and realistic assumptions for vehicle traffic patterns and carbon monoxide (CO) emissions to improve our ability to predict the impacts of various ventilation control strategies on indoor air quality and fan energy use in parking garages. The simulation approach is validated using measured data from a parking garage case study and then applied to investigate fan energy use, peak power demand, and resulting CO concentrations for four different ventilation control strategies in a model underground parking garage under a variety of assumptions for model inputs. The four ventilation control strategies evaluated include one simplistic schedule (i.e., Always-On) and three demand-based strategies in which fan speed is a function of CO concentrations in the spaces, including Linear-Demand Control Ventilation (DCV), Standardized Variable Flow (SVF), and a simple On-Off strategy. The estimated annual average fan energy consumption was consistently lowest with the Linear-DCV strategy, resulting in average (± standard deviation) energy savings across all modeled scenarios of 84.3%±0.4%, 72.8%±3.6%, and 97.9%±0.1% compared to SVF, On-Off, and Always-On strategies, respectively. The utility of the framework described herein is that it can be used to model energy and indoor air quality impacts of other parking garage configurations and control scenarios.

Keywords

carbon monoxide,
demand control ventilation,
energy efficiency,
indoor air quality,
underground parking garage

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https://link.springer.com/article/10.1007/s12273-020-0677-3

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- Consider different SOOs to maintain indoor air quality requirements in parking garages and save energy:
  - ❑ Always-On: Fans operates at 100% of maximum speed during operating hours regardless of the CO concentration
  - ❑ On-Off: The fan operates at 100% of maximum speed only when CO concentrations in any zone reach a threshold of 25 ppm
  - ❑ Standardized Variable Flow (SVF): Fans operate at 50% of maximum speed until CO concentrations reach 25 ppm, at which point they increase to 100% of maximum speed
  - ❑ Linear-DCV: Fan speed stays at a minimum of 25% of maximum speed until the average CO concentration in all zones reaches 10 ppm, at which point the fan speed increases linearly until the average CO concentration reaches 35 ppm

https://link.springer.com/article/10.1007/s12273-020-0677-3

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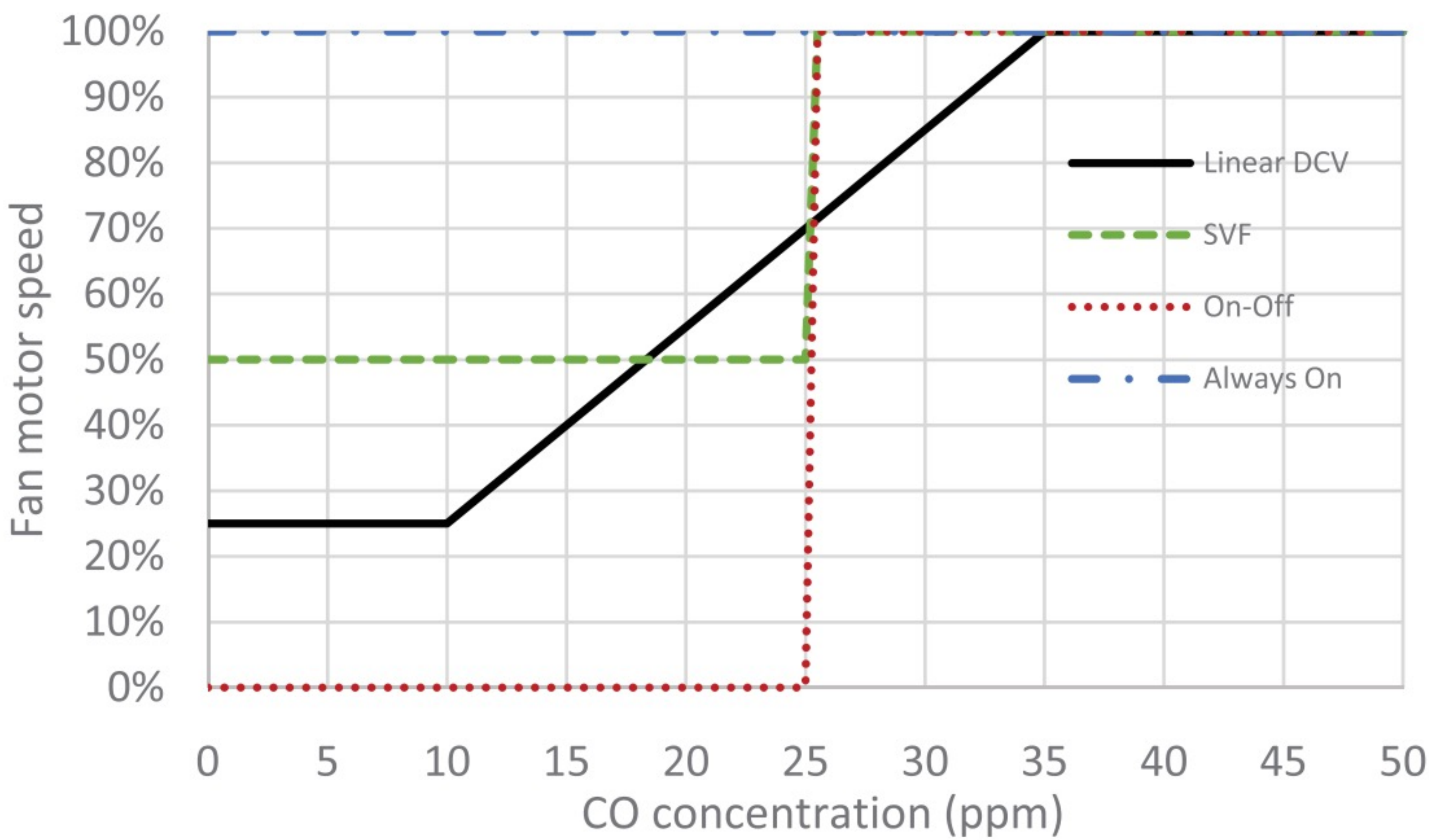
- The schematic of these SOOs for parking garages are:



https://link.springer.com/article/10.1007/s12273-020-0677-3

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- The schematic of these SOOs for Kaplan Building Institue

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Optimal control of switchable ethylene-tetrafluoroethylene (ETFE) cushions for building façades

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ARTICLE INFO

Keywords:
Building energy performance
ETFE cushion, office building
Optimal control
Sequences of operation

ABSTRACT

Switchable ethylene-tetrafluoroethylene (ETFE) cushions with kinetic shading mechanisms are increasingly being used in building enclosures to dynamically control the transmission of solar and visible light. While buildings with switchable ETFE façades typically utilize simple Rule-Based logic to control their operation, this study uses a novel co-simulation approach to optimize the operation of switchable ETFE façades on two hypothetical office buildings in Chicago, IL. Four seasonally representative simulation days are used to demonstrate the approach. The daily source energy savings potential of the Optimal Control schedule is up to 8.2%, 11.1%, and 25.5% compared to Rule-Based, Always-Dark, and Always-Bright control strategies, respectively.

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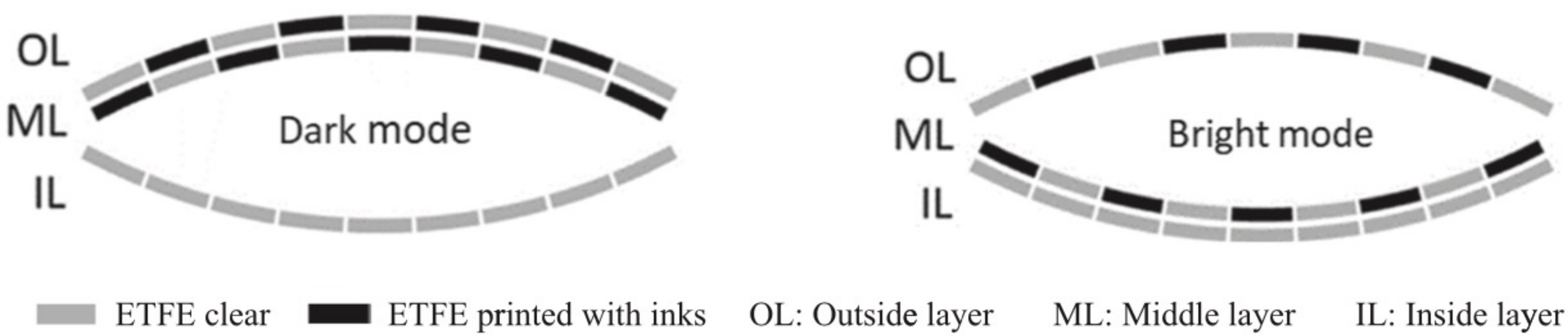
- The schematic of these SOOs for Kaplan Institute building:



Beyond ASHRAE Guideline 36

- The schematic of these SOOs for Kaplan Institute building:
  - ❑ Always-Dark: ETFE actuators are always acting, which results in constant dark status regardless of the time of day, occupancy, or orientation of the space
  - ❑ Always-Bright: ETFE actuators are never acting, which results in constant bright status. Similar to the Always-Dark strategy, the time of day, occupancy, and orientation of the spaces do not impact ETFE operation
  - ❑ Rule-Based: ETFE actuators act when the outdoor air temperature is above 15.6 C
  - ❑ Optimal Control: ETFE actuators will act based on the optimal schedule derived from minimization of total daily heating, cooling, and lighting energy consumption

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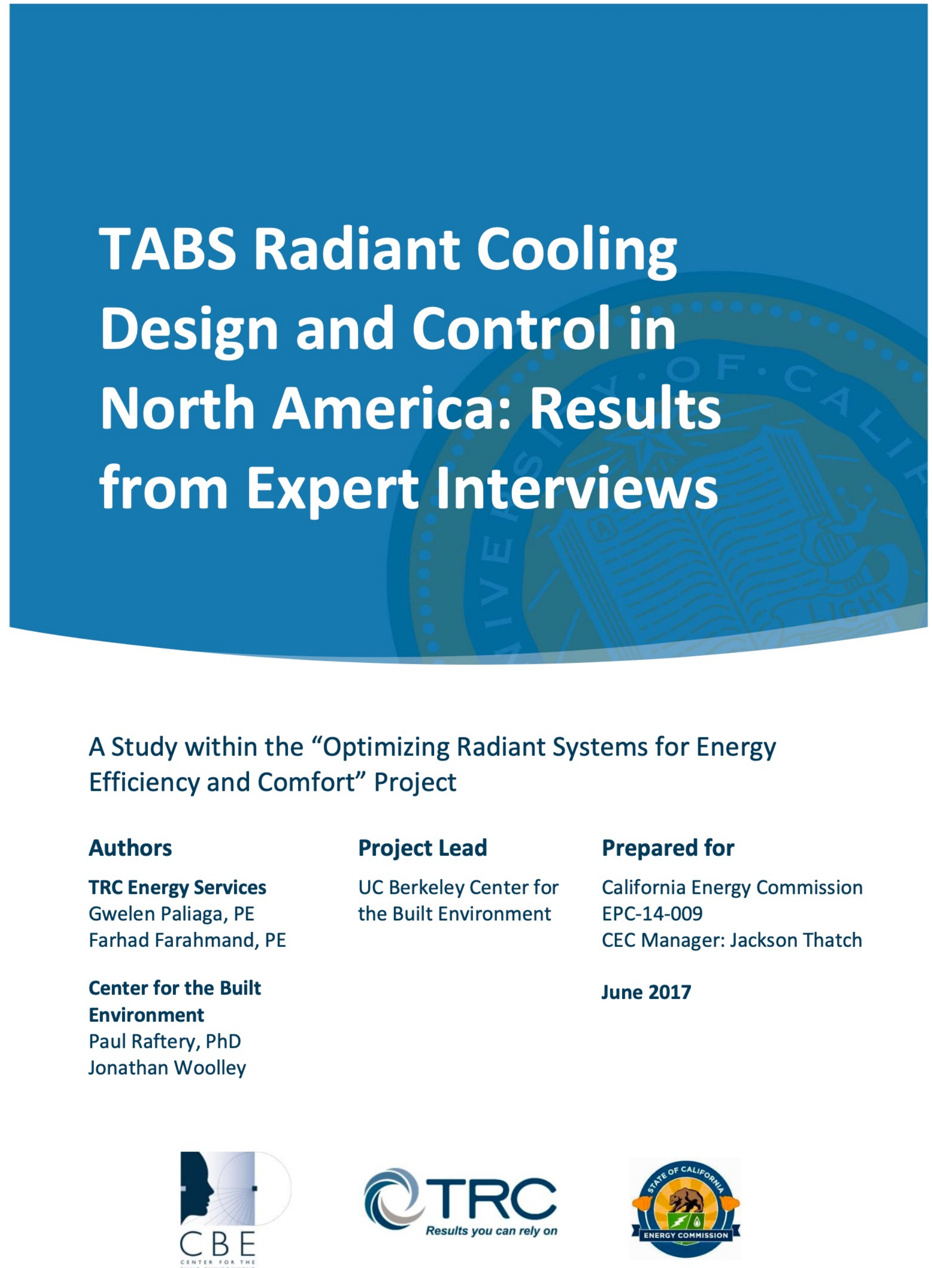
- Another example is the design and control of high thermal mass radiant systems – referred to as Thermally Activated Building Systems (TABS)



TABS Radiant Cooling Design and Control in North America: Results from Expert Interviews

A Study within the "Optimizing Radiant Systems for Energy Efficiency and Comfort" Project

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Prepared for

California Energy Commission
EPC-14-009
CEC Manager: Jackson Thatch

June 2017

https://escholarship.org/uc/item/0w62k5pq

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- Conduct surveys to identify the best practices:

3.1.1.1 What was your primary role on these projects?

Most interviewees described themselves as the engineer of record or lead designer on a project, although three interviewees made the distinction that they were the principal or a consultant (Figure 1).

Figure 1.

What was your primary role on these projects?	Count
Engineer of record, lead designer, or engineer	9
Overseeing principal	3
Consultant to architect	2

https://escholarship.org/uc/item/0w62k5pq

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- Conduct surveys to identify the best practices:

Figure 2.

How many radiant cooling projects have you worked on that were TABS?	Count
1 to 5	2
6 to 10	4
11 to 20	1
More than 20	4

Figure 3.

Where have your radiant cooling projects been installed?	Count
United States - west coast	1
United States - other locations	3
Canada - west coast	4
Canada - other locations	1
United States, Canada, and International	4

https://escholarship.org/uc/item/0w62k5pq

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- 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.

https://escholarship.org/uc/item/0w62k5pq

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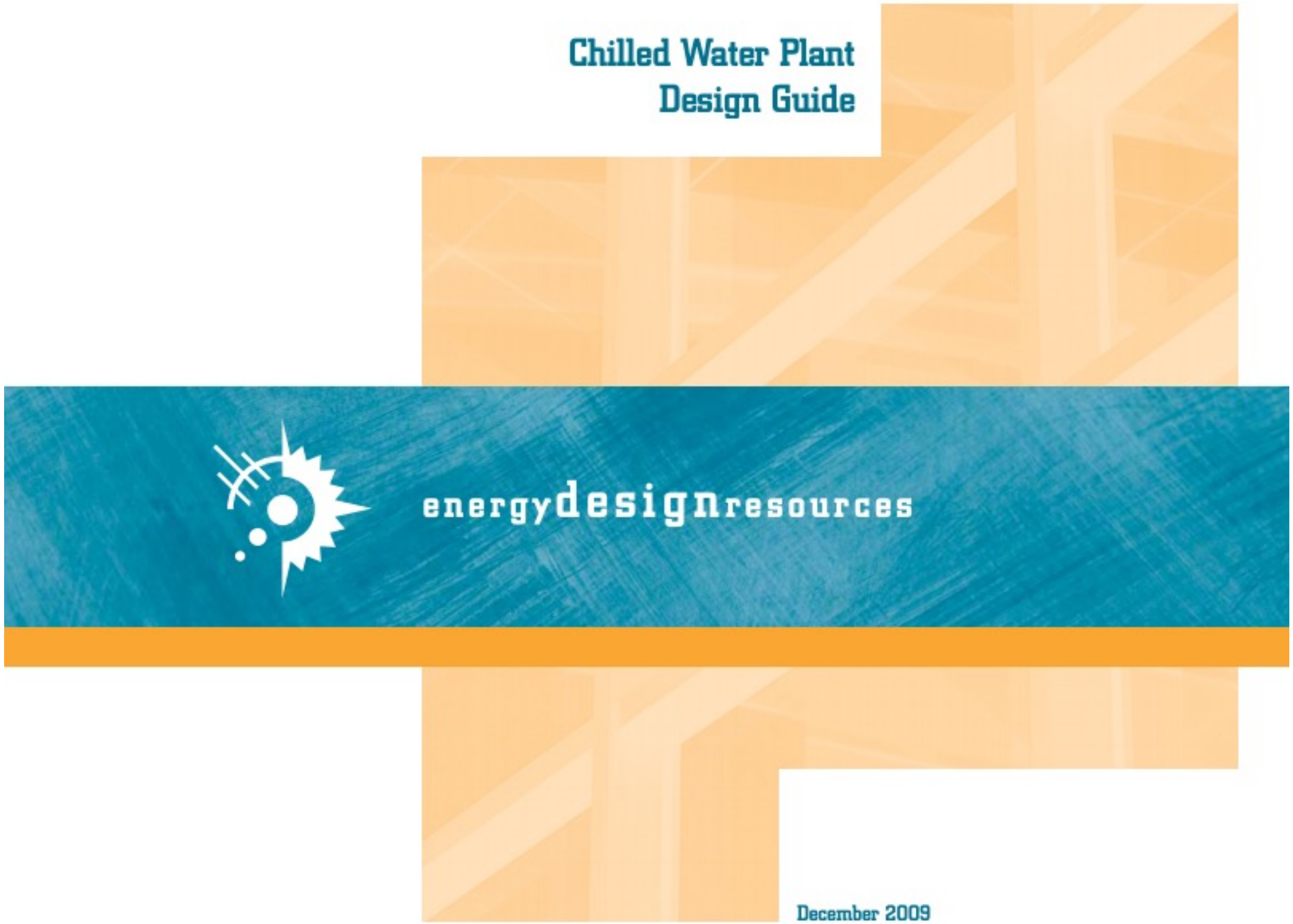
- Sequence of controls of chilled water plants:



https://www.taylor-engineering.com/wp-content/uploads/2020/04/EDR_DesignGuidelines_CoolToolsChilledWater.pdf

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- Sequence of controls of chilled water plants:

Sequence of Controls

Chiller plant

1. If a chiller fails or has been manually switched off, as indicated by its alarm contact or if its leaving water temperature remains 5°F above setpoint (see reset strategy below) for 15 minutes or if its kW is zero for 15 minutes while its on/off point is on, the chiller is placed in a high level alarm (Level 2). A failed chiller is not locked out, but the chiller stage where the failed chiller runs alone is locked out. (See staging below.)
2. If a chiller has been manually turned on, as indicated by a chilled water delta-T across the chiller greater than 3°F and chilled water supply temperature within 5°F of setpoint and kW>10% and its on/off point is off, the chiller stage where the other chiller operates alone shall be locked out and a low level chiller alarm (Level 4) shall be set. (See staging below.)
3. The chiller plant is enabled if any secondary pump is on for 2 minutes, and disabled if all secondary pumps are off.
4. Chillers are staged based on calculated load. Load is calculated by secondary delta-T and flow. Once both chillers are operating, load is calculated by assuming flow is balanced between chillers proportional to design flow.
5. Due to the chiller variable speed drives, it is more efficient to operate chillers at low load (above about 20%) than at high load. Thus the normal staging rules that tend to max-out chillers before staging the next one on do not apply.
6. Staging shall be:
   a. Stage 1: CH-1 on alone.
      A. Locked out if:
         i. CH-1 has failed, or
         ii. CH-2 is manually on.
      B. Minimum operating load: 0%
      C. Stage down point: none
      D. Stage up point: 30% of total plant load
   b. Stage 2: CH-2 on alone
      A. Locked out if:
         i. CH-1 is manually on, or
         ii. CH-2 has failed.
      B. Minimum operating load: 15% of total plant load
      C. Stage down point: 20% of total plant load
      D. Stage up point: 50% of total plant load
   c. Stage 3: CH-1 and CH-2 on
      A. Locked out if:
         i. Either CHP is in alarm.
      B. Minimum operating load: 30% of total plant load
      C. Stage down point: 40% of total plant load
      D. Stage up point: NA
7. Stage up (1 to 2 or 2 to 3) if the current stage is on and has been on for 15 minutes, and either:
   a. Any secondary pump is at full speed for 15 minutes and chiller load is above the minimum operating range of next stage, or
   b. The plant load becomes larger than the stage up point for the stage.
8. Stage down (2 to 1 or 3 to 2) if the current stage is on and has been on for 45 minutes, and the plant load becomes lower than the stage down point for the stage.

https://www.taylor-engineering.com/wp-content/uploads/2020/04/EDR_DesignGuidelines_CoolToolsCh

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- SOO for VAV units:

NIST Technical Note 2024

Commissioning ASHRAE High-Performance Sequences of Operation for Multiple-Zone Variable Air Volume Air Handling Units

Natascha Milesi Ferretti
Michael A. Galler
Steven T. Bushby
Justin Sorra

This publication is available free of charge from:
https://doi.org/10.6028/NIST.TN.2024

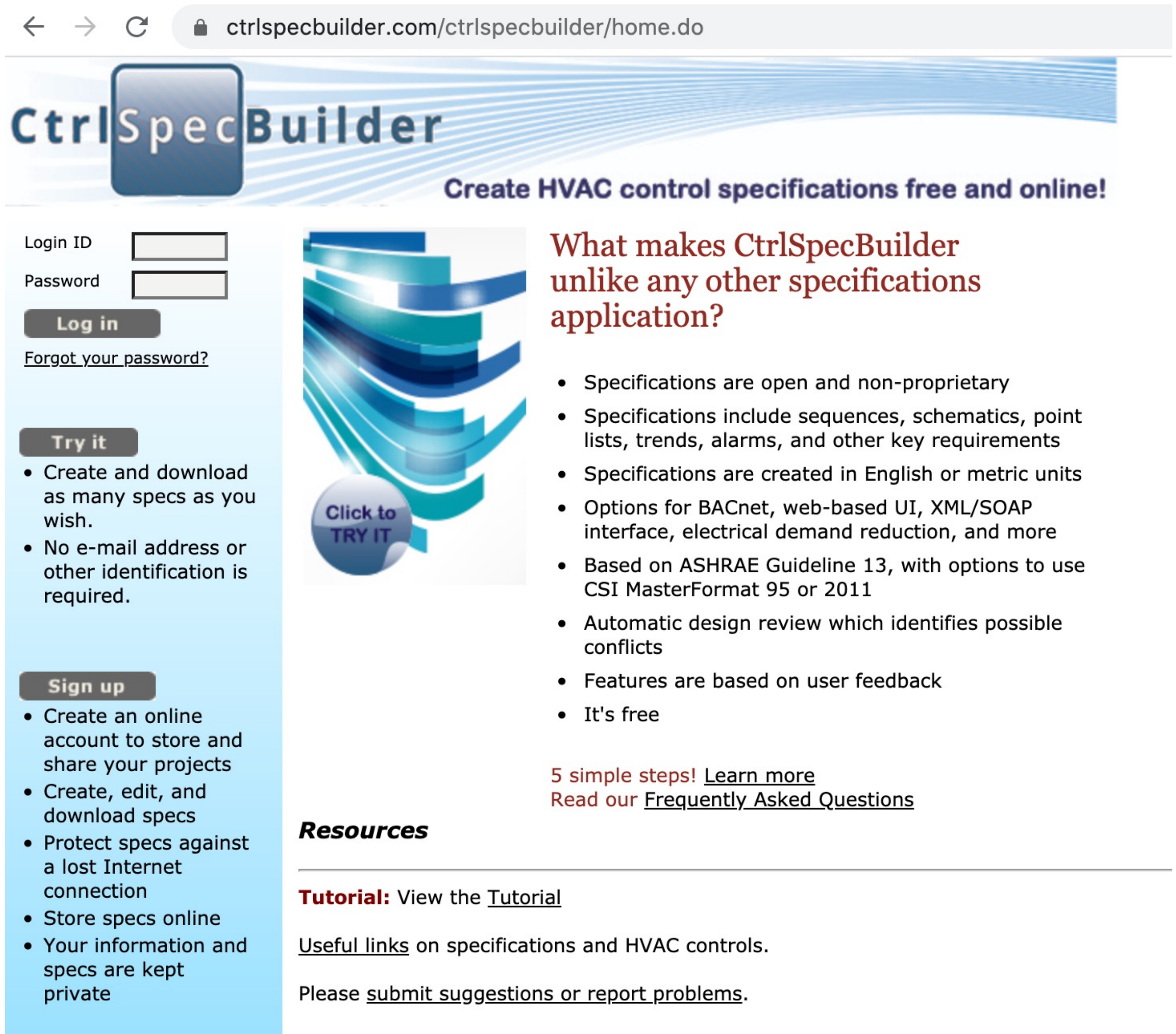
https://www.govinfo.gov/content/pkg/GOVPUB-C13-386b4a80de7b30becf35a563468898e7/pdf/GOVPUB-C13-386b4a80de7b30becf35a563468898e7.pdf

SPECS WRITER RESOURCES

Specs writer Resources

- Automated Logic (ALC) has a tool named "CtrlSpecBuilder" that uses:
  - ❑ Control sequence
  - ❑ System schematics
  - ❑ Data points
  - ❑ Alarms

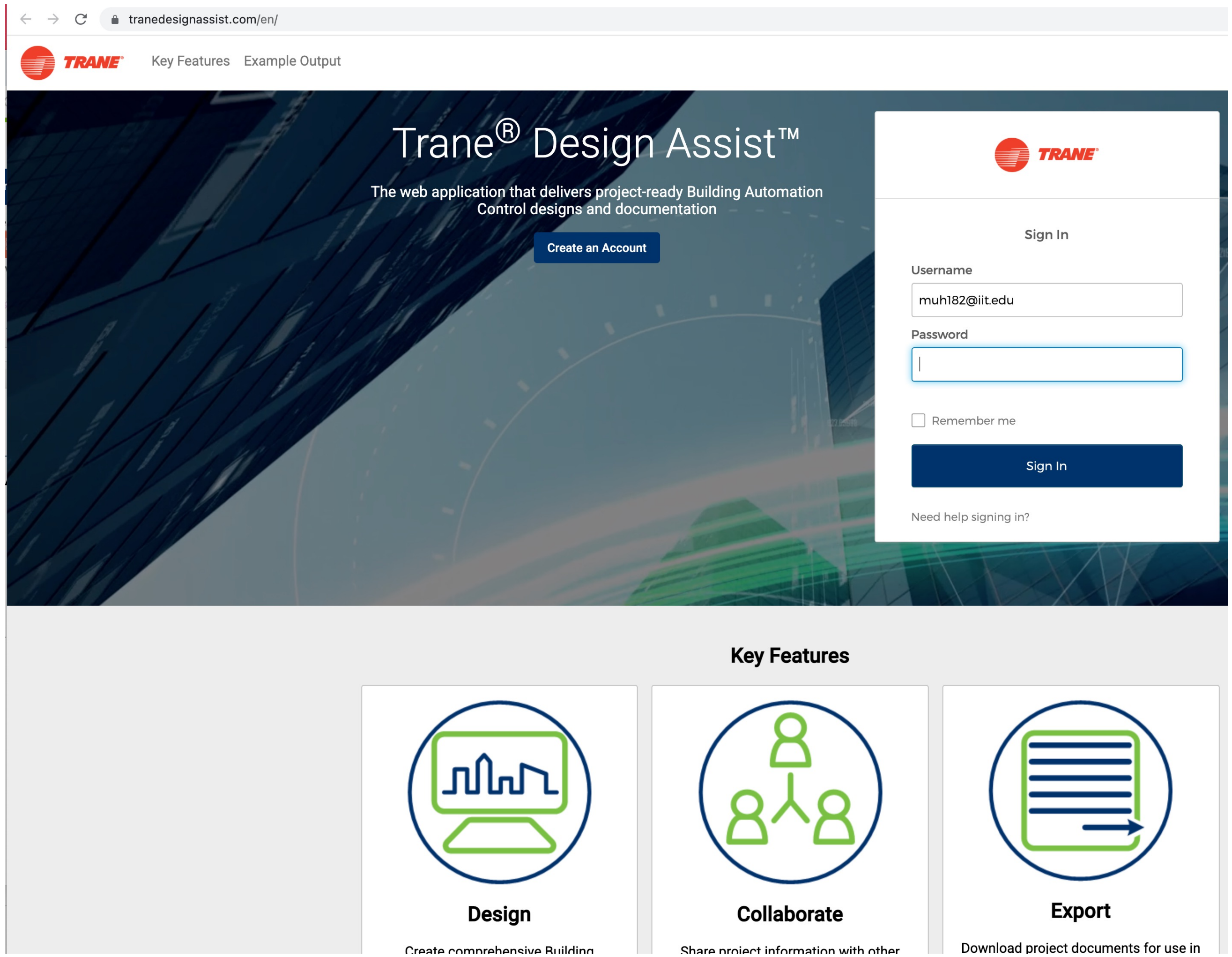
Specs writer Resources



https://www.ctrlspecbuilder.com/ctrlspecbuilder/home.do

Specs writer Resources

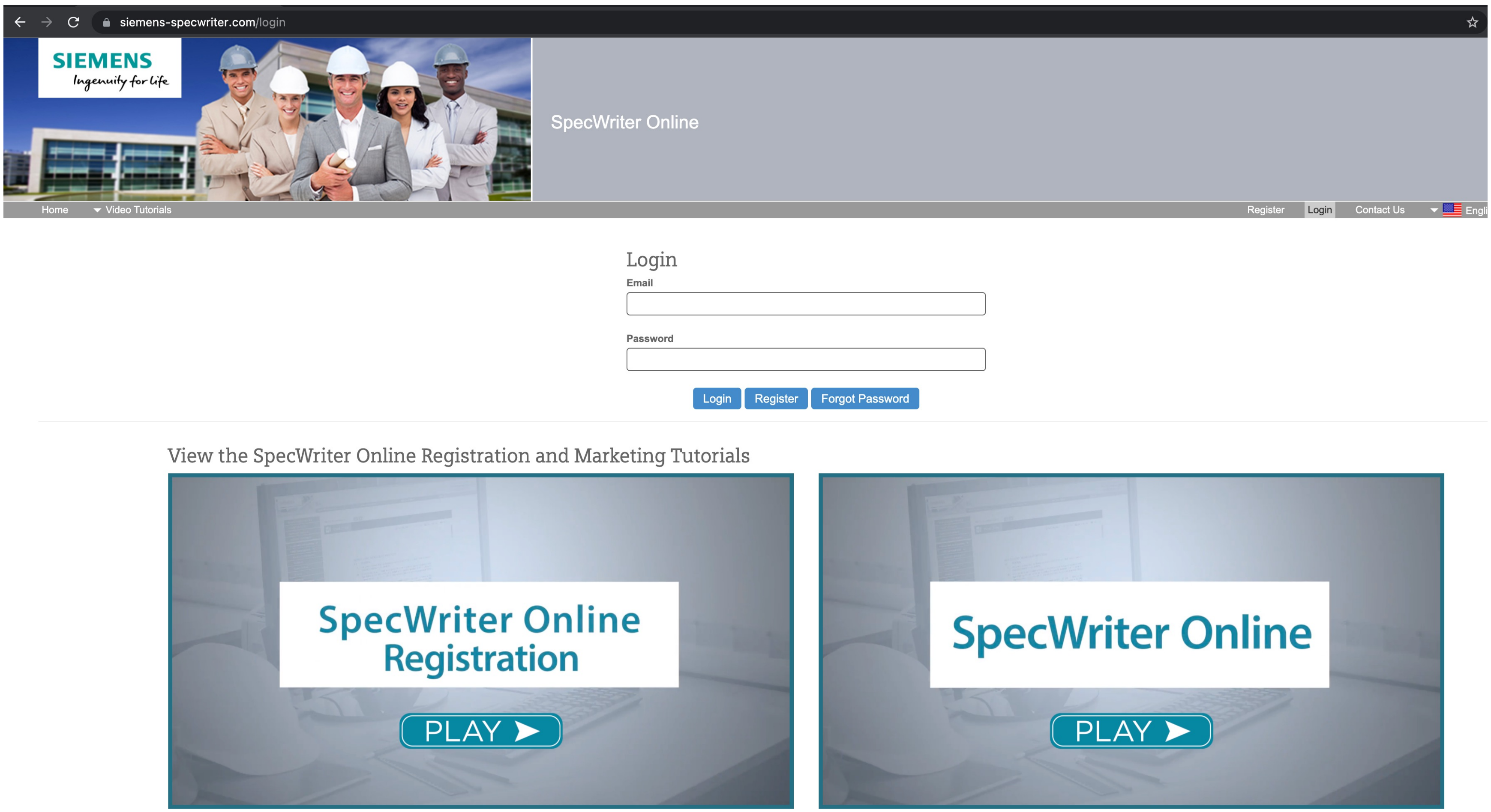
- An example of structuring and building your components and sequences:



https://tranedesignassist.com/en/

Specs writer Resources

- An example of structuring and building your components and sequences:



https://www.siemens-specwriter.com/login

CLASS ACTIVITY

Class Activity

- Form your groups

- Let's look at some existing SOO in a real building. Open file name "cae438_538_f21 lecture07 Points List Kaplan AHU"

- Review the specs and connect the control mode with the component SOOs:

  https://docs.google.com/spreadsheets/d/1duxKfuy1kpYNJxXT6e9bHjVBBqUXnwBSBuR8Dkz4f7c/edit#gid=306213051