slipstream

Building systems

Building HVAC - complex systems, Building Automation System

Kevin Frost | Slipstream

2024

1

Learning Objectives

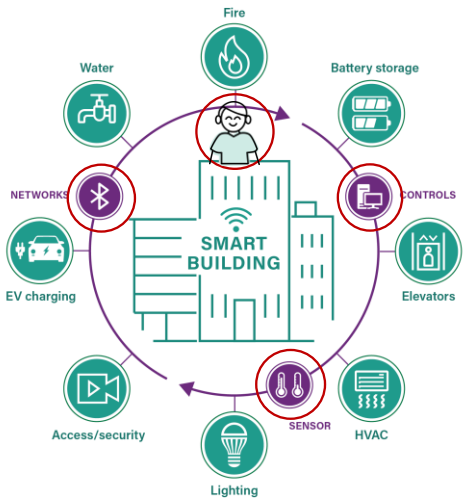
- Discuss more complex HVAC equipment and system types
- Name typical control sequences for more complicated equipment and systems
- Know the components of a Building Automation System (BAS)
- Highlight trends in modern building automation system

2

Outline

- **HVAC System Types**
  - Air Handling Units
  - Variable Air Volume Systems
  - Decentralized Systems
  - Hydronic Systems
- **HVAC Control Sequence**
  - Multizone controls
  - Demand Control Ventilation
  - ASHRAE Guideline 36
- **Building Automation System**
  - Architecture
  - Hardware
  - Communication and Software
- **Trends in Modern Building Automation Systems**

Smart Building Elements



1) Building systems
   1) Envelope
   2) HVAC
   3) Lighting
   4) Water
   5) Solar PV + battery energy storage
   6) EV charging
   7) Other (elevator, fire, access/security)
2) Sensors
3) Controls
   1) Platform
   2) Control methods
4) Networks
5) Occupants!

HVAC System Types - Complex Systems

5

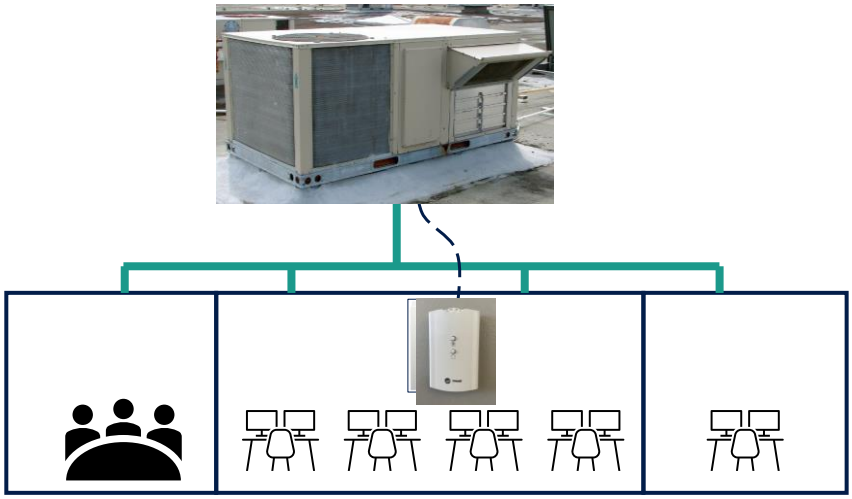
5

Air Handling Units

6

6

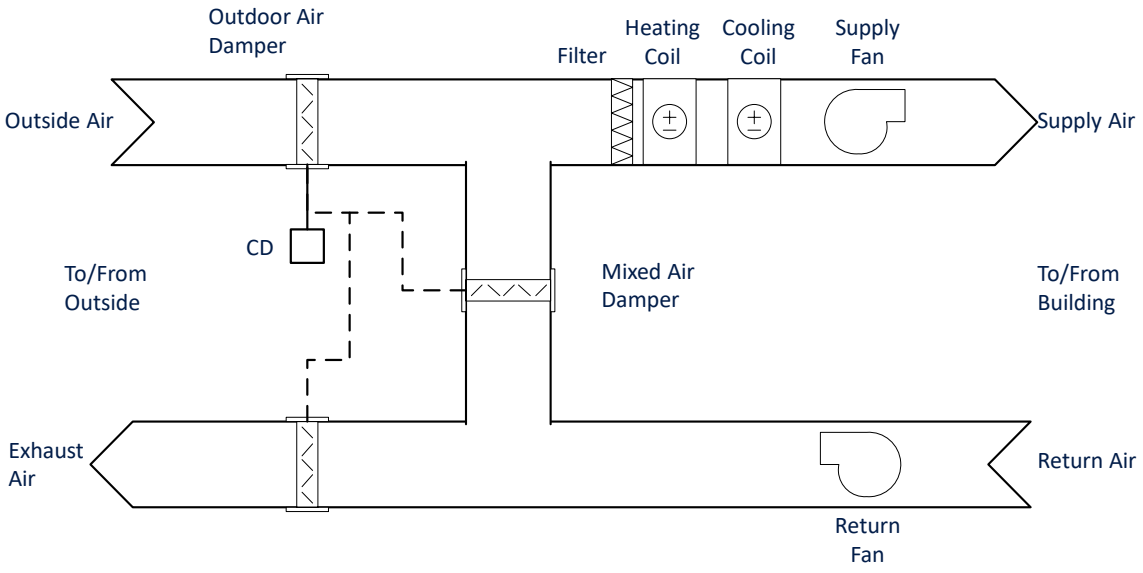
Single Zone Rooftop Unit (RTU)



For RTU, see Session #2 Building HVAC – Simple Systems

Air Handling Unit (AHU)

- A larger, built-up unit compared to an RTU
- Some components may be assembled in the field rather than in the manufacturer
- More complex sensing and controls
- Often served by chilled water or hot water plants.



9

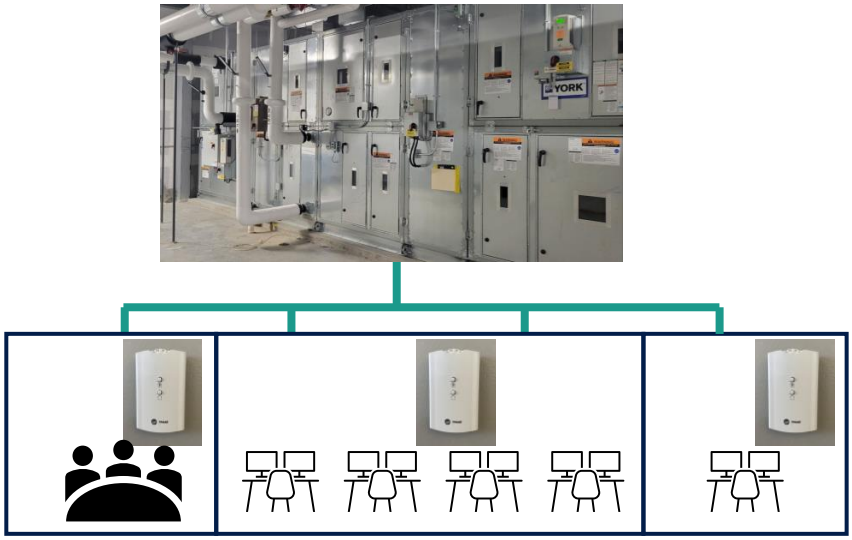
9

Variable Air Volume (VAV) Systems

10

10

Multi-zone Air Systems



Variable Air Volume (VAV) System

- Multiple zone system.
- Variable Frequency Drives (VFDs) on the supply and return fans to change fan speeds (and airflow rates).
- The central AHU supplies cool air to air terminal devices at each zone, often called VAV boxes.

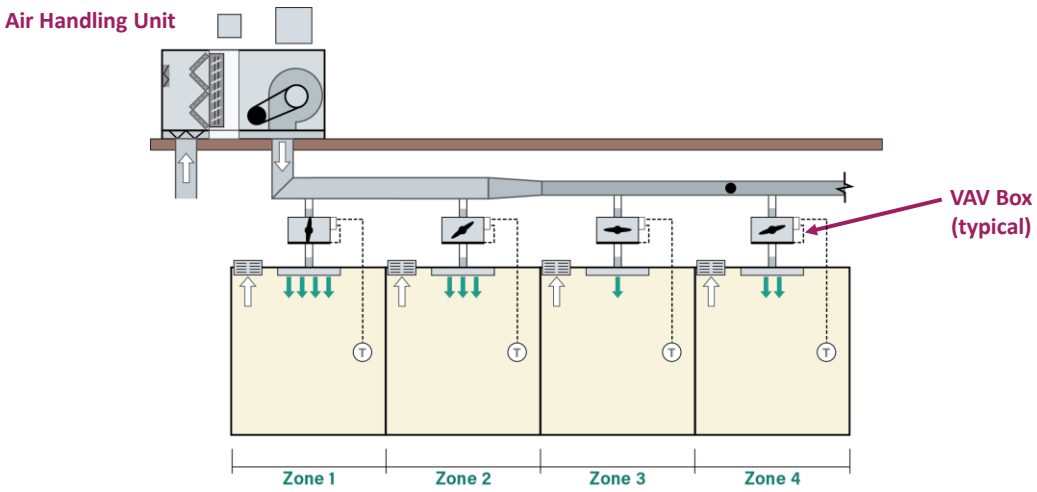
Example of VFDs

Variable Air Volume (VAV) System – The VAV Box

- Each zone has a VAV box.
- The VAV Box is controlled by a thermostat in the space.
- The VAV Box varies airflow for cooling.
- Reheat devices at the VAV box provide heat.
- Saves more energy than constant volume and old multizone systems.

13

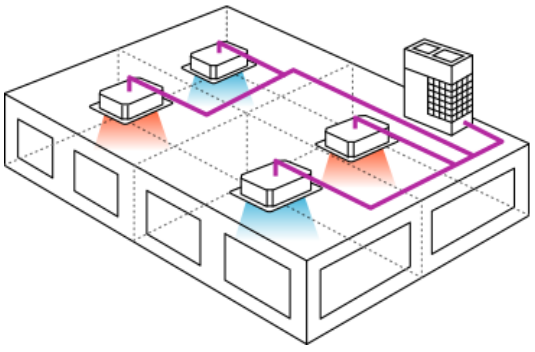
Variable Air Volume (VAV) System

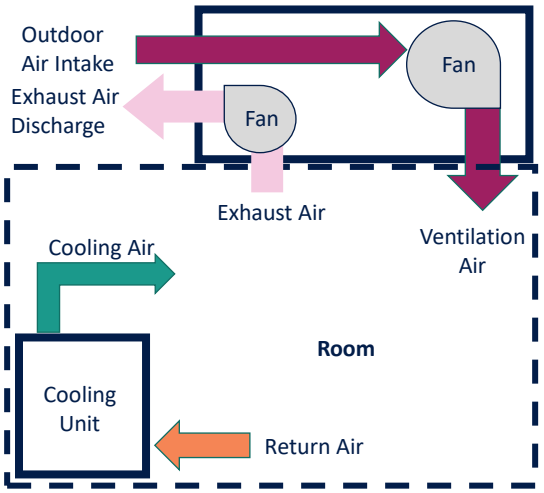


14

Decentralized Air Systems

Decentralized Air Systems





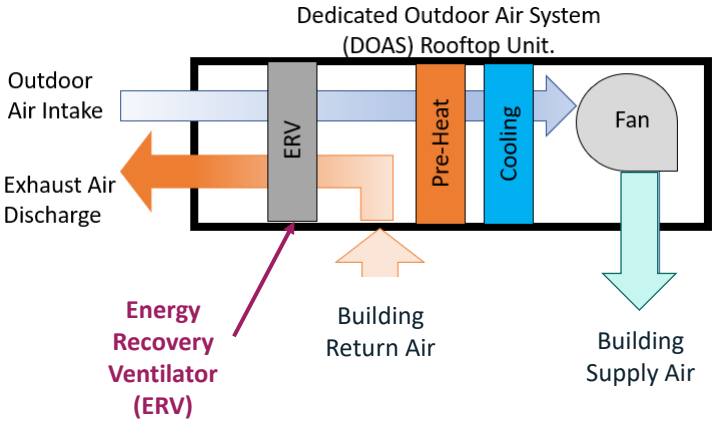
Examples of Decentralized Systems – Heating and Cooling

- Fan Coil Units
- Water Source Heat Pumps (WSHPs)
- Variable Refrigerant Flow (VRF)
- Chilled Beams
- Radiant Heating and Cooling

17

17

Makeup Air Unit (MAU) and Dedicated Outside Air System (DOAS)



18

18

Hydronic Systems

Hydronic Systems

- Moving air around a large building takes a lot of energy
- Observe
  - Water can store more energy than air.
  - Water takes less energy to move than air.
  - Piping occupies less space than ducts
- Exploit
  - Heat/cool water centrally
  - Move water around the building efficiently
  - Transfer heat from water to air near the zones
- Downside
  - Piping and hydronic equipment is more expensive and requires more maintenance.

Hydronic Systems – Boilers and Chillers

Natural gas-fired boilers

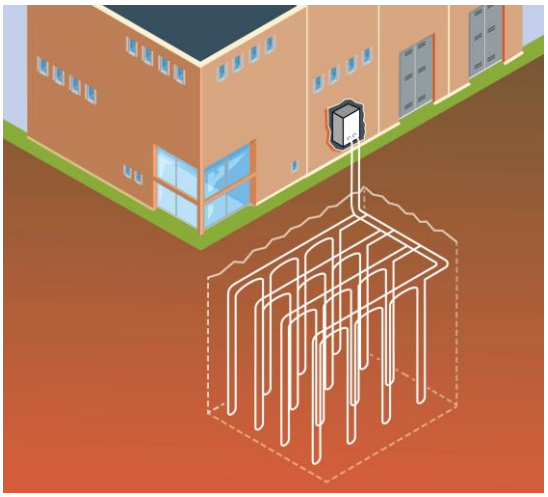
Air-cooled chiller

Pump set

21

Geothermal Heat Pump Systems

Ground source heat pump bore field



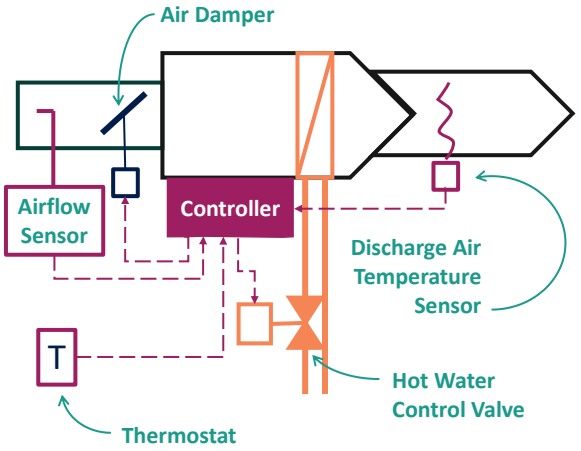
Ground loop pumps

22

HVAC Controls Sequences – Complex Systems

Variable Air Volume (VAV) Controls

Zone Control – VAV Box

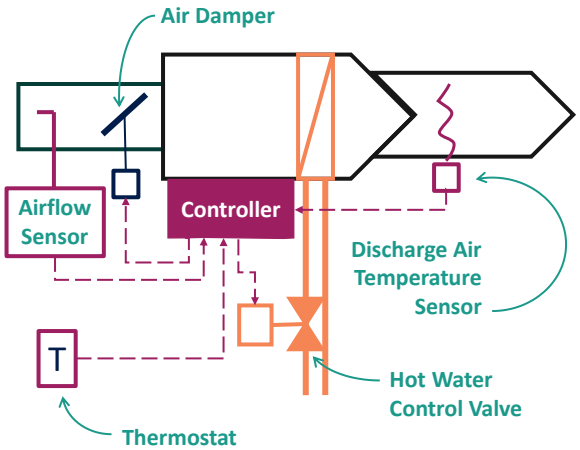


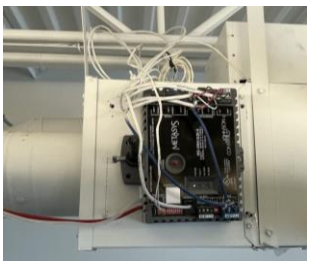
25

25

Airflow Sensor

Zone Control





VAV Box Controller

VAV Zone Thermostat

Hot Water Control Valve and Actuator

26

26

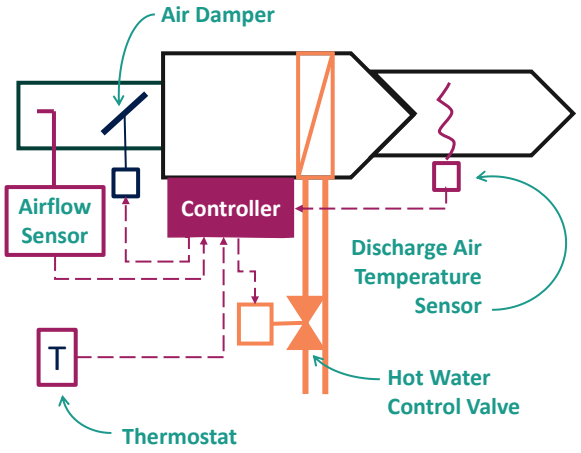
Zone Control – VAV Box Cooling

Controller: Reset the airflow setpoint from 250 cfm to 1,000 cfm

The airflow is still 250 cfm

Controller: Ok. Open the air damper

Damper opens



It's hot in here

It's comfortable in here

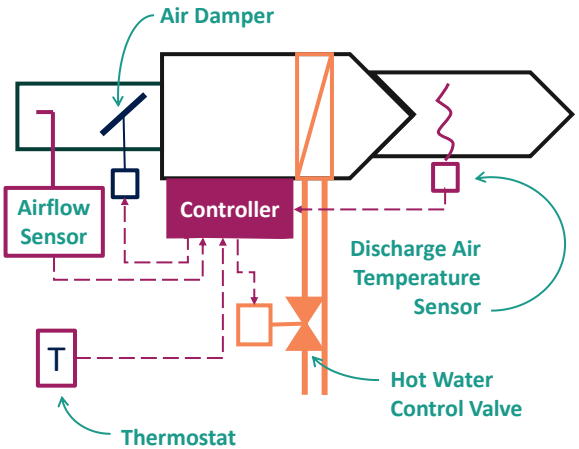
Zone Control – VAV Box Heating

Controller: Reset the airflow setpoint from 1,000 cfm to 250 cfm

The airflow is still 1,000 cfm

Controller: Ok. Close the air damper

Damper Closes



It's cold in here

It's still cold in here

Zone Control – VAV Box Heating

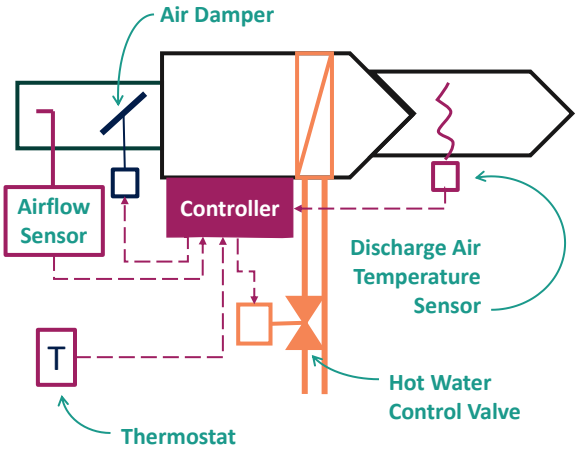
Controller: Open the hot water valve.

Hot water valve open

Controller: Ok, is it still cold?

Discharge air temperature is at 95°F

Controller: That's as high as we can go…



It's still cold in here
It's still cold in here

29

29

Zone Control – VAV Box Heating

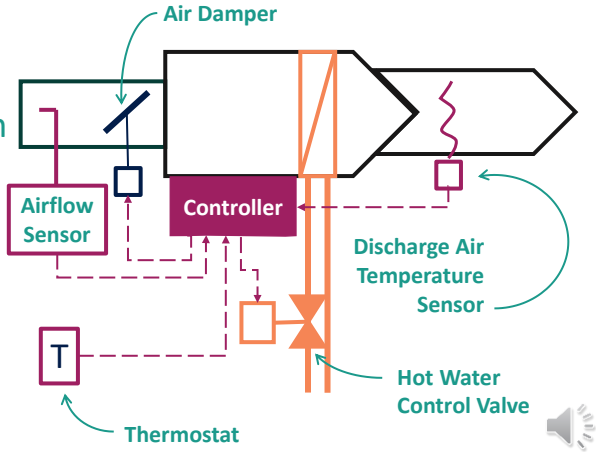
Controller: Ok, reset airflow to 500 cfm.

Airflow is 500 cfm

Controller: Open air damper

Damper opens

Controller: Ok, what about now?

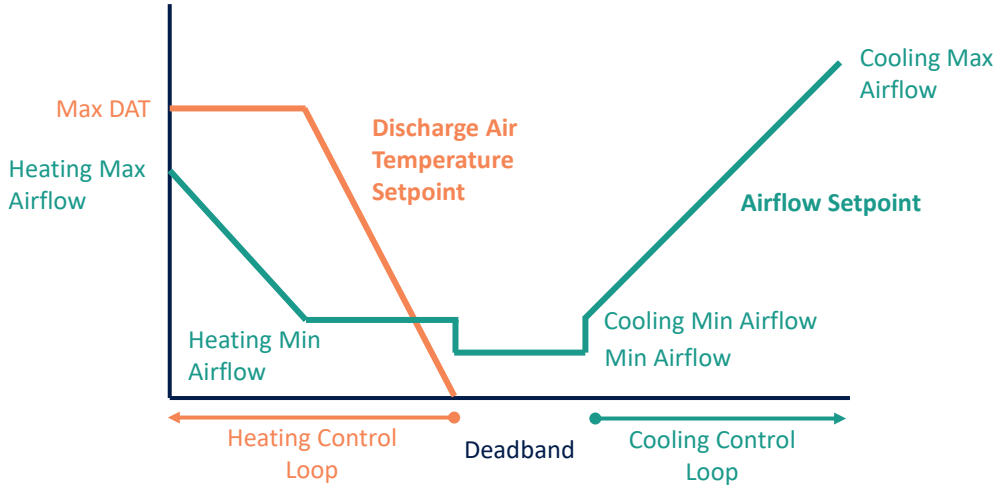


It's still cold in here
It's comfortable in here

30

30

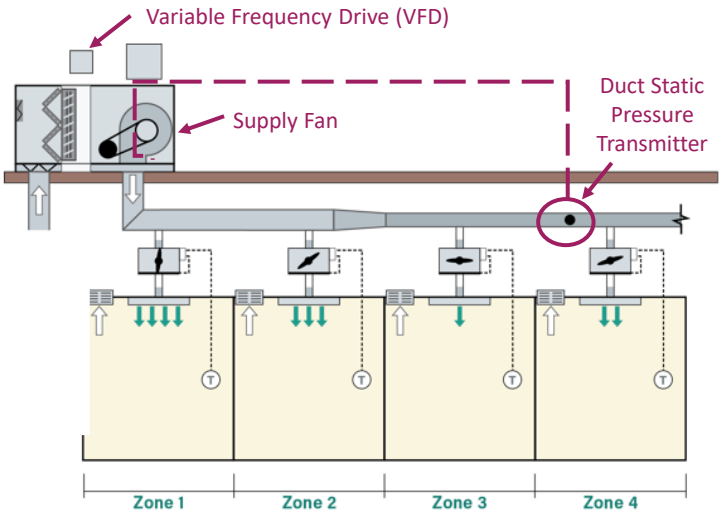
Variable Air Volume (VAV) System – Air Terminal Control



31

31

Variable Air Volume (VAV) System – AHU Control



32

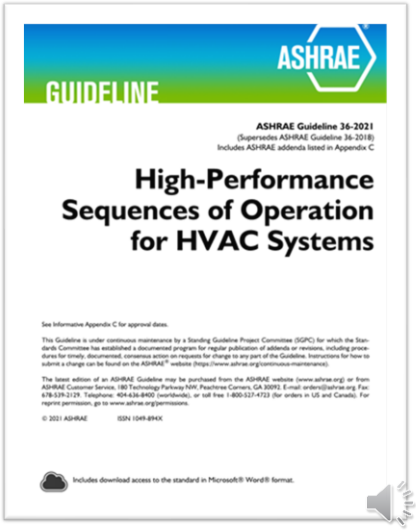
32

Variable Air Volume (VAV) System – Other Control Loops

- Could be packaged or custom controls.
- Schedule: Occupied, Unoccupied, Morning Warmup, and Failure
- Preheat Coil and Cooling Coil Control
- Outdoor Air – Economizer Control, Demand-Controlled Ventilation
- Return fan control
- Safeties

ASHRAE Guideline 36

- Guideline of high-performance control sequences to improve occupant comfort and save energy.
- Based on Industry Best Practices
- First published in 2018
- Under continuous improvement
- Latest version released in 2021

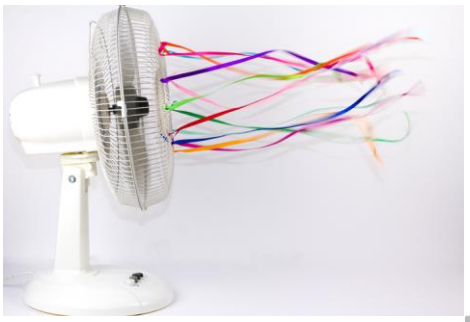


Used with permission from ASHRAE

Demand-Controlled Ventilation

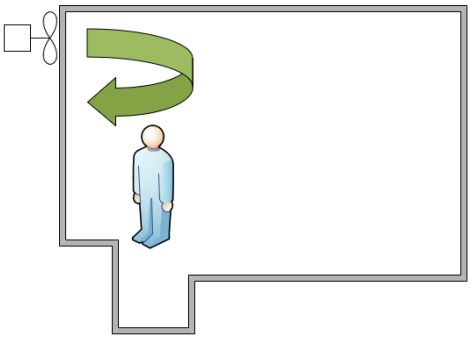
Ventilation

- Ventilation is the removal of contaminated building air and it's replacement with clean, fresh, air.
- Introducing outdoor air requires heating and cooling energy to make the air suitable for the indoors.
- We want to provide the minimum outdoor air for a healthy building while limiting energy use.



Demand-Controlled Ventilation

- Demand-Controlled Ventilation (DCV) uses the building automation system (BAS) to adjust outdoor airflow to match building occupancy.
- Ideally, we only introduce the most outdoor air when the building is fully occupied.
- When the building is at partial occupancy and not in economizer mode, we reduce outdoor air intake to try to match the current occupancy.



37

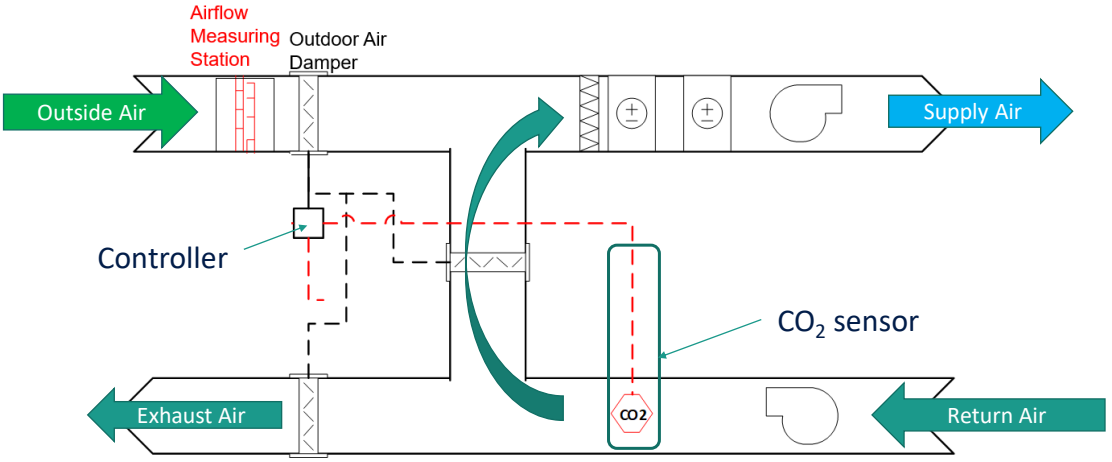
Determining Demand

Detecting Occupancy

- Occupancy Sensors
- Carbon Dioxide (CO_2) Sensors
- Window Switches

38

Single Zone, Single-duct DCV



39

39

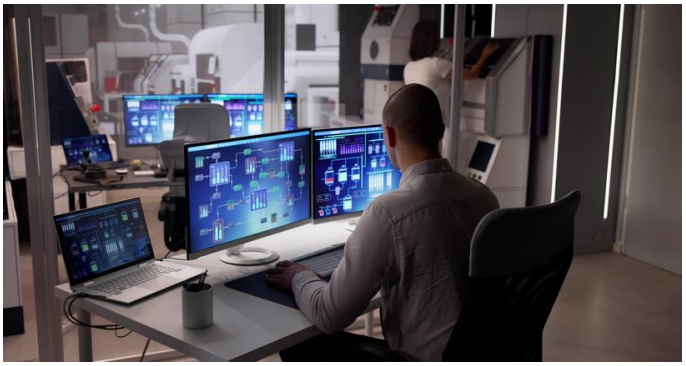
Building Automation System (BAS)

40

40

Why Building Automation System (BAS)?

- Also referred to as Building Management System (BMS) or Direct Digital Controls (DDC) System
- For HVAC systems too large or complex to manage using standalone/packaged controls
- Energy efficiency
- O&M
- Comfort
- Building management



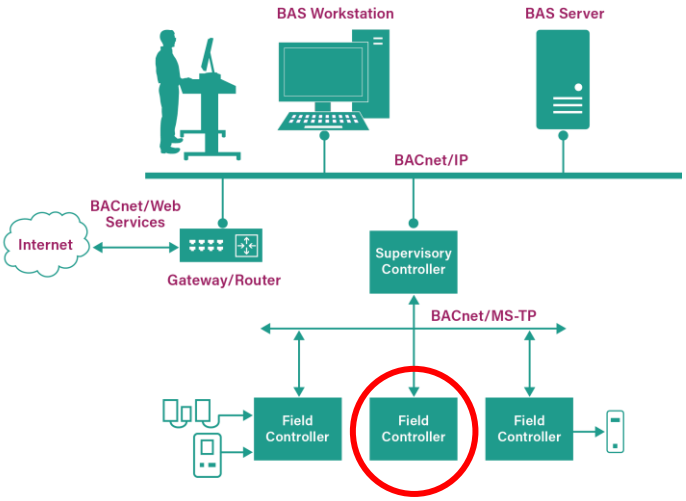
41

41

Building Automation System

Field Controller

- Local HVAC equipment control
- Run on field control network
- Low-speed Communication
- Fully programmable or configurable (AAC or ASC)



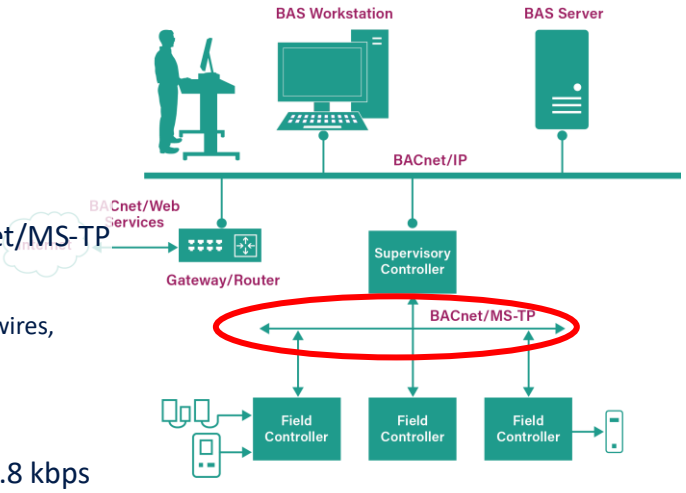
42

42

Building Automation System

Field Control Network

- This is the wiring network that connects field controllers to supervisory controllers.
- Most common protocol: BACnet/MS-TP
- Wiring:
  - Stranded, shielded twisted-pair wires,
  - Max length 4000 ft
  - Bused or daisy chained
  - Max 128 controllers
- Low-speed network – 9.6 to 76.8 kbps



43

43

BAS Communications - BACnet

- A data communication protocol for **B**uilding **A**utomation and **C**ontrol **Net**works
- A public, open, international standard
- Intended to improve BAS communication compatibility, interoperability, and encourage fair competitions
- Developed by ASHRAE since 1987
- Supported by ASHRAE Standing Standard Project Committee SSPC 135 – ASHRAE/ANSI Standard 135
- Licensee fee: none

44

44

BAS Communications

Proprietary System

- Owned by a specific company
- Could be Open or Closed

Closed System

- Patented, copyrighted
- Not compatible with other systems

Open System

- Codes are disclosed
- Encourage interoperability and competition

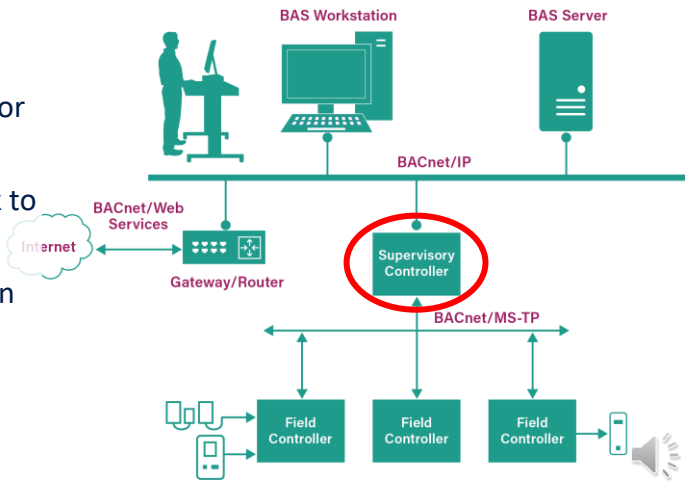
	Open System	Closed System
Proprietary	LonWorks (Echelon)	Many BAS Manufacturers
Non-proprietary	BACnet (ASHRAE)	-

45

Building Automation System

Supervisory Controller

- Also called network controller or building controller (BC)
- Connects field control network to building control network
- Global, networked coordination and controls
- Fully programmable
- Doesn't control equipment directly (no sensors/actuators)

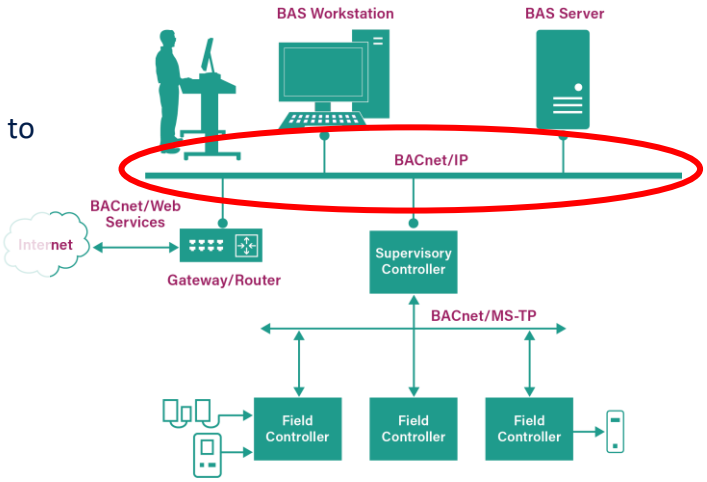


46

Building Automation System

Building Network

- This is the wiring network that connects supervisory networks to the BAS workstation.
- Most common protocol: BACnet/IP – Internet Protocol
- Wiring:
  - Ethernet
  - Max length 328 ft
  - Star, Chain, Ring, or Mixed
  - Max 254 controllers
- High-Speed Network – 100 to 1,000 Mbps



47

47

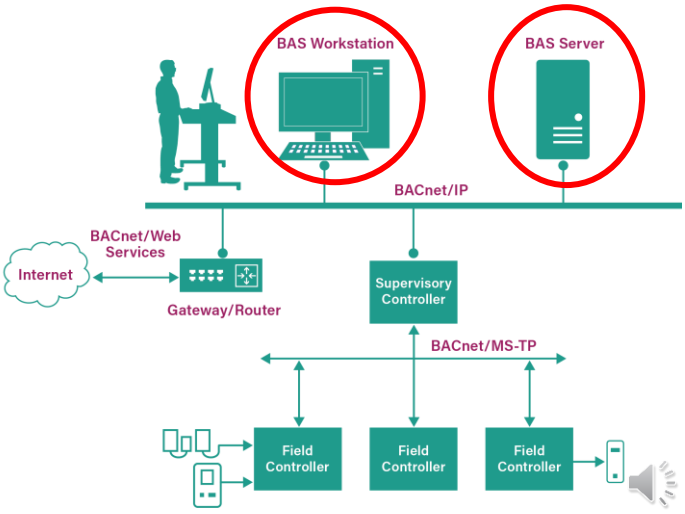
Building Automation System

BAS Workstation

- User interface for monitoring, control, and maintenance
- Web-based interface are common

BAS Server

- Collect, store, and serve BAS data and web pages.
- Optional for small systems



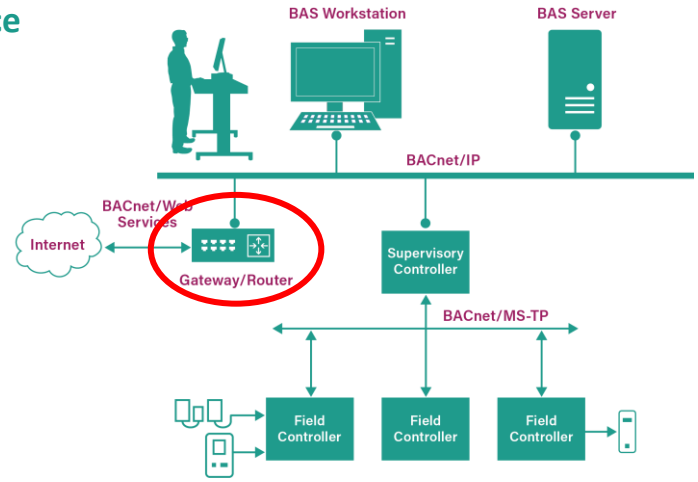
48

48

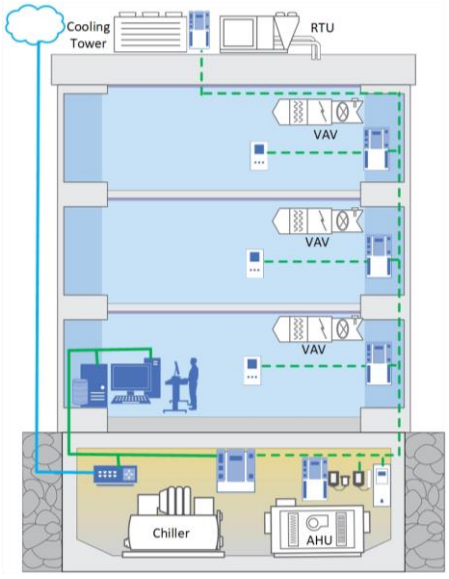
Building Automation System

BAS Communication Interface

- For integration with other systems – Connect to:
  - Other Buildings
  - The internet
  - Other BAS Devices
- Translates BAS data from a BAS network protocol to the Internet protocol (IP) or other communication protocols
- Optional – not every BAS needs one



BAS in Commercial Buildings



BAS components

- Field controller
- Field controller inputs
- Supervisory controller
- Operator workstation
- Server
- Network communication interface

BAS network legend

- Field control network (low speed)
- Building control network (high speed)
- Enterprise IT network (high speed)

Trends in Modern Building Automation System

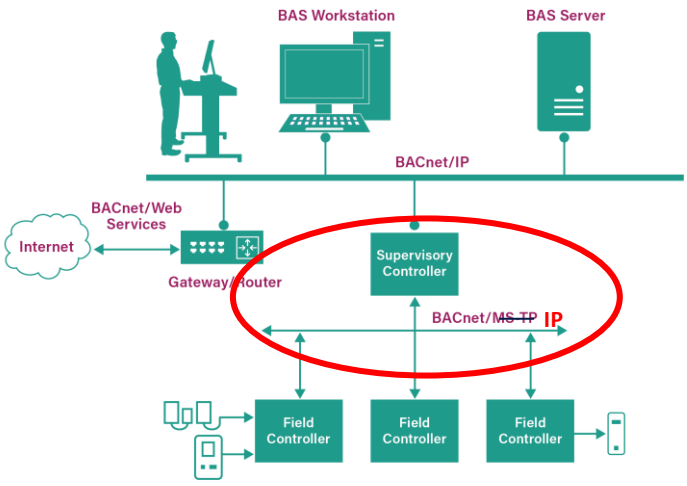
Integration with IoT and Cloud

IP-based controllers

- Easier to integrate with IT networks
- More secure (BACnet is not consider a “secure” protocol)
- Faster (compared to BACnet/MS-TP)

Move advanced monitoring and control functions to the Cloud

- Virtually no limit in computer power and storage space
- Allows the system to run complex algorithms
- Easy access from anywhere



Advanced Building Monitoring and Controls

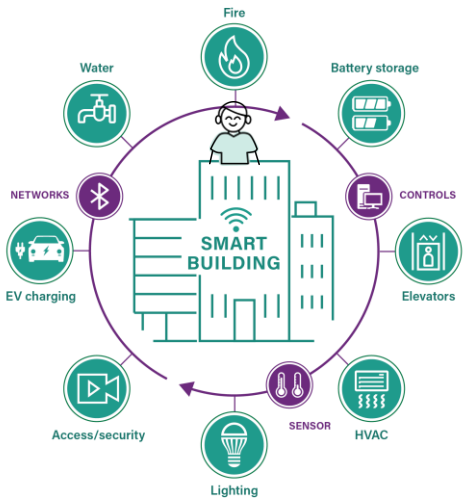
- Advanced energy information system and reporting
- Automatic Fault Detection and Diagnostics (AFDD)
- Automated System Optimization (ASO)
- Monitoring-based commissioning

For more information, see Session #9 Advanced Building Monitoring and Controls

53

53

Smart Building Elements – Interoperability



1) Building systems
   1) Envelope
   2) HVAC
   3) Lighting
   4) Water
   5) Solar PV + battery energy storage
   6) EV charging
   7) Other (elevator, fire, access/security)
2) Sensors
3) Controls
   1) Platform
   2) Control methods
4) Networks
5) Occupants!

54

54

Open Protocols and Interoperability

- Edge-to-Cloud solution computing
- Integrate with other sensors, devices and building systems
- Enable smart building applications beyond HVAC monitoring and controls
- Open protocols is preferred for better interoperability
- Digital Twin

For more information, see Session #10 Smart Building Control Platform

55

55

Cybersecurity

BACnet Secure Connect (BACnet/SC)

- Addendum to the BACnet protocol. Secure, encrypted protocol in a professionally managed IP infrastructure.

Important when integrating building systems with the cloud.

For more information, see Session #11 Smart Building Control Platform Cybersecurity

56

56

Artificial Intelligence (AI) and Machine Learning (ML)

- AI: use computers to mimic human cognitive functions.
- ML: a subset of AI. use computers to analyze data, learn from it, and make decisions.

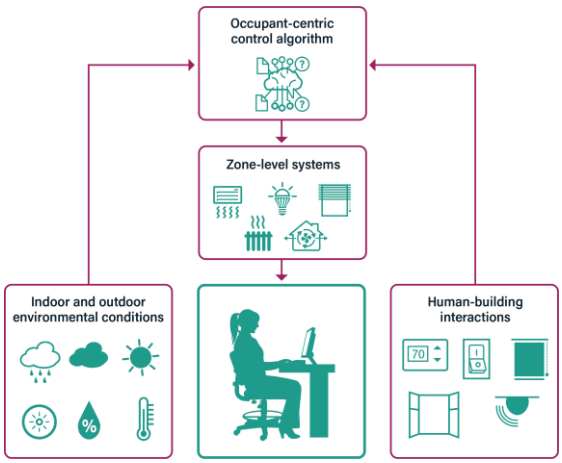
Self-operating, autonomous building concept.

For more information, see Session #12 Smart Building Control Algorithms

57

57

Occupant-Centric Controls



- Rely on real-time occupancy and occupant preference data as inputs
- Can be categorized as either reactive control or predictive control
- May use advanced control algorithm such as machine leaning
- ASHRAE TC 7.10 Occupant Behavior in Building Design and Operation

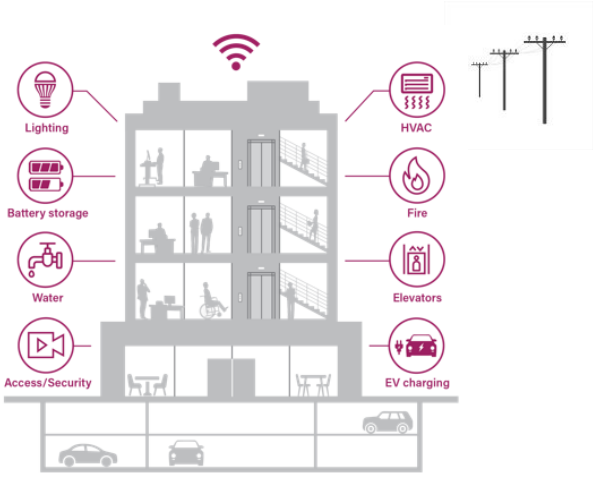
For more information, see Session #13 Occupant-Centric Controls

58

58

Demand Response and Grid-interactive Efficient Buildings (GEB)

- Growing peak electricity demand
- Increasing share of variable renewable electricity generation
- Available behind-the-meter distributed energy resources (solar PV, battery storage, EV)
- Combined with HVAC, can make buildings much more flexible in controlling building load



For more information, see Session #5 Solar PV, BESS, and EV Charging and #14 GEBs and Connected Communities

59

59

Recap

60

60

Learning Objectives

- Discuss more complex HVAC equipment and system types
- Name typical control sequences of these equipment and systems
- Introduce Building Automation System
- Highlight trends in modern building automation system

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), Building Technologies Office (BTO) Award Number DE-EE0009703.

The views expressed herein do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

This presentation is for educational purposes only. Any materials shown herein are exhibited solely for the furtherance of the public good.

Thank you!