Introduction to Commercial Building HVAC Systems and Energy Code Requirements

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Course Description and Learning Objectives

Overview of common commercial building Heating, Ventilating, and Air-conditioning (HVAC) systems as they relate to energy code requirements. Learn about the most common HVAC systems and equipment, along with energy-related components and controls. Several important energy code requirements will be reviewed, including what to look for in the field or on plans.

Learning Objectives:

1. Identify common HVAC system types.
2. Identify important HVAC controls, including economizers.
3. Name high impact energy code items related to HVAC equipment and controls.
4. List the steps in verifying fan power calculations.

Outline

- HVAC system basics
  - Basic controls that save energy
  - Outside air economizers
  - Fan energy limits
- Complex systems:
  - Central plant
  - Secondary HVAC systems
  - High energy impact complex controls
  - Hydronic system controls
- HVAC high efficiency option

References to energy code sections in this presentation are to the commercial provisions of the

2015 International Energy Conservation Code (IECC).

Similar requirements may exist in the 2012 IECC or ASHRAE Standard 90.1-2013, but section numbers will be different, and there will be slight variation in requirements.

HVAC System Basics

Source: https://en.wikipedia.org/wiki/Air_handler

Basic Purpose of HVAC

- Air-conditioning for thermal and humidity comfort
  - Heating
  - Cooling
  - Dehumidification
  - Humidification
- Ventilation
  - Introduction of required outside air
    - International Mechanical Code (IMC) Chapter 4 : Ventilation
    - ASHRAE Standard 62.1
  - Filtration of recirculated air
  - Exhaust of undesirable air (toilet, kitchen, lab exhaust)
  - Air movement in space
- Space pressurization
  - Control infiltration
  - Makeup of exhausted air

Source: ASHRAE Fundamentals Handbook 2013

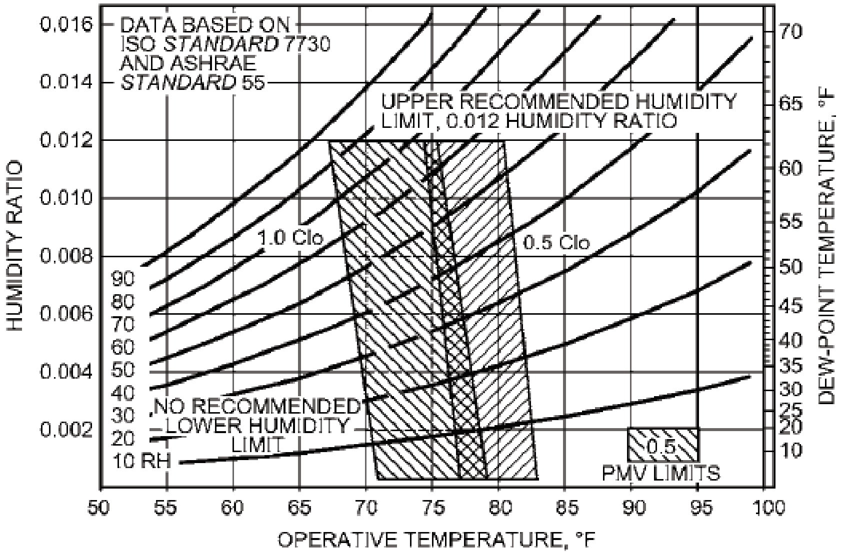

Fig. 5 ASHRAE Summer and Winter Comfort Zones

Heat Gain vs. Heat Loss (Winter)

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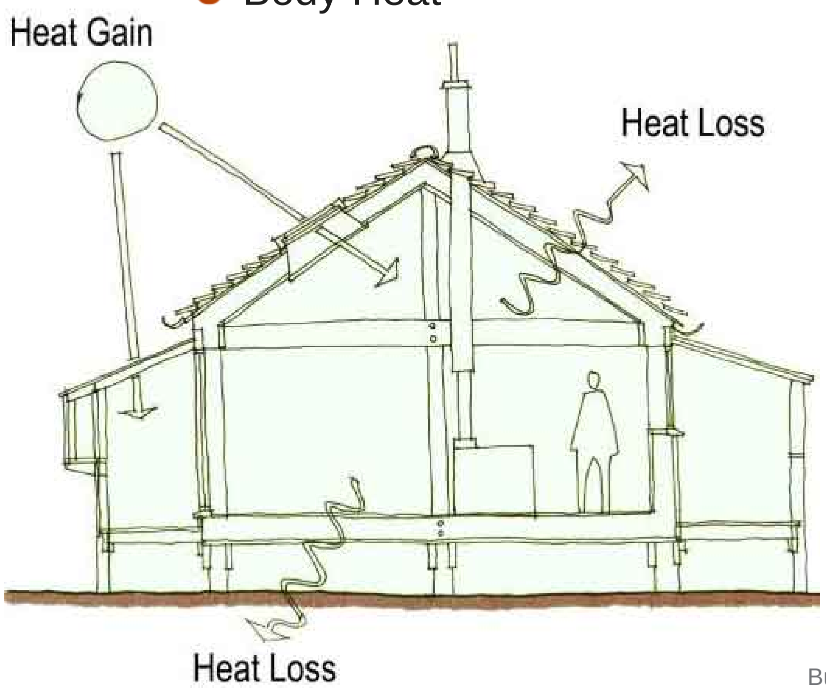
- Heat Gains
  - Solar thru windows/walls
  - Summer transfer/infiltration
  - Internal
    - Electric Use, Lighting
    - Body Heat



- Heat Loss
  - Air Leaks (Infiltration)
  - Transfer (conduction & radiant) through
    - Walls
    - Roofs
    - Floor
    - Windows
- Difference supplied by
  - Heater or
  - Air Conditioner

Air Conditioning

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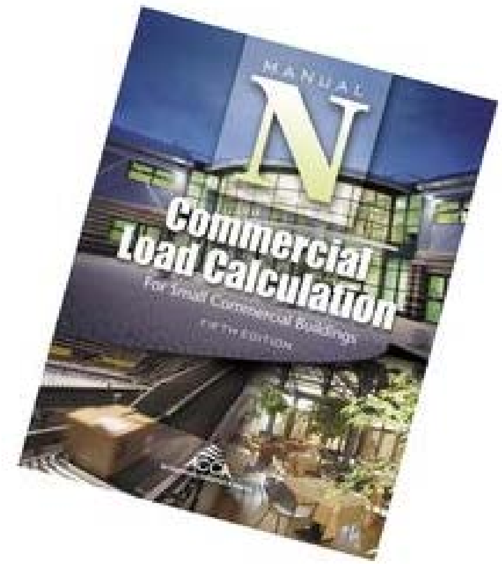
- Two general types of air conditioning (cooling)
  - Refrigerant-based: refrigeration cycle moves heat from one space (indoors) to another (outdoors)
    - Refrigerant evaporates and condenses continuously within cycle
    - Refrigerant has a low boiling point, making it ideal for HVAC systems
    - Similar to car AC system
  - Non-refrigerant: evaporative cooling
- Simple vs. Complex (no longer a code distinction in 2015 IECC)
  - Simple systems often use direct expansion coils or heat
    - Directly use refrigerant to cool or heat air
    - Gas, oil or electricity in a furnace to heat air
    - Simple systems usually serve one zone with direct control
  - Complex systems transfer heating and cooling to secondary units
    - Cooling: the refrigerant is in the chiller and chilled water goes to cooling coils
    - Heating: a boiler generates hot water or steam that is piped to heating coils
    - Complex systems usually serve multiple zones

System Capacity Sizing

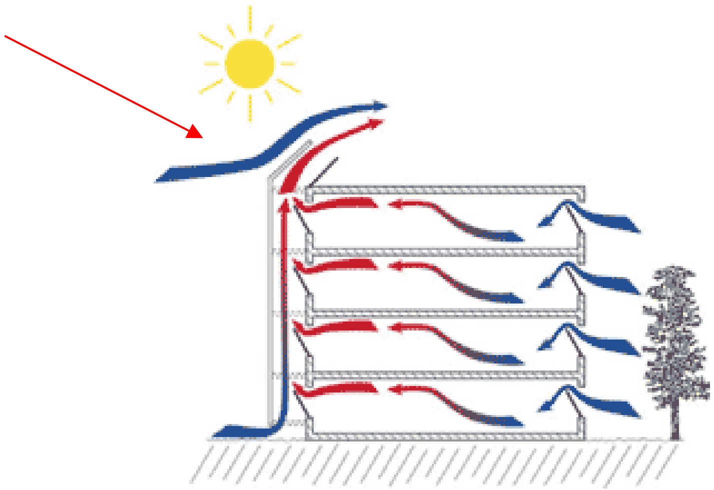
- Verify that cooling and heating capacity sizing (load calculations) have been completed (C403.2.1)
- Verify that equipment is not unreasonably over-sized (C403.2.2)
- Why?
  - For simple constant volume equipment, fan energy use will be significantly higher because fans must run constantly to provide ventilation
  - For larger multiple-zone VAV systems, fan and reheat energy use will be higher because the turndown of oversized zone boxes is limited.



Source: RoadTrafficSigns.com

Ventilating

- Two types:
  - Mechanical ventilation
    - Fans pull outside air into building for ventilation
    - Ventilation includes both outside air and recirculated air
    - Requirements are available for minimum outside air, based on occupancy, floor area and number of occupants (See the International Mechanical Code (IMC) Chapter 4 or ASHRAE Standard 62.1)
  - Natural ventilation
    - No fans



Simple HVAC Systems

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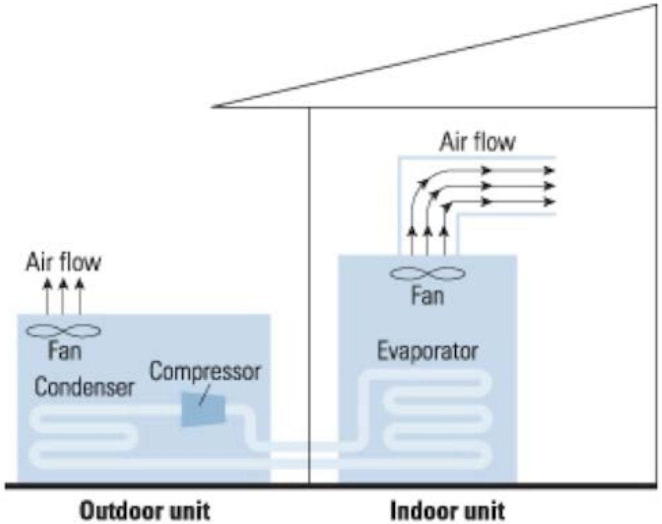
- Package Units
  - Thru-wall air conditioner
  - Package Terminal Air Conditioner (PTAC)
  - Package Terminal Heat Pump (PTHP)
- Unitary
  - Air conditioner
  - Furnace
  - Heat Pumps
  - Packaged, split, mini-split
  - Variable refrigerant flow (VRF)

Source: http://windowairconditioning.kingersons.com/premaire_ptw092h3g_9000btu_PTAC_wall_air_conditioner_heat_pump.htm

Source: https://en.wikipedia.org/wiki/Air_handler



Courtesy: E source; adapted from EPA

Packaged Rooftop Cooling Unit

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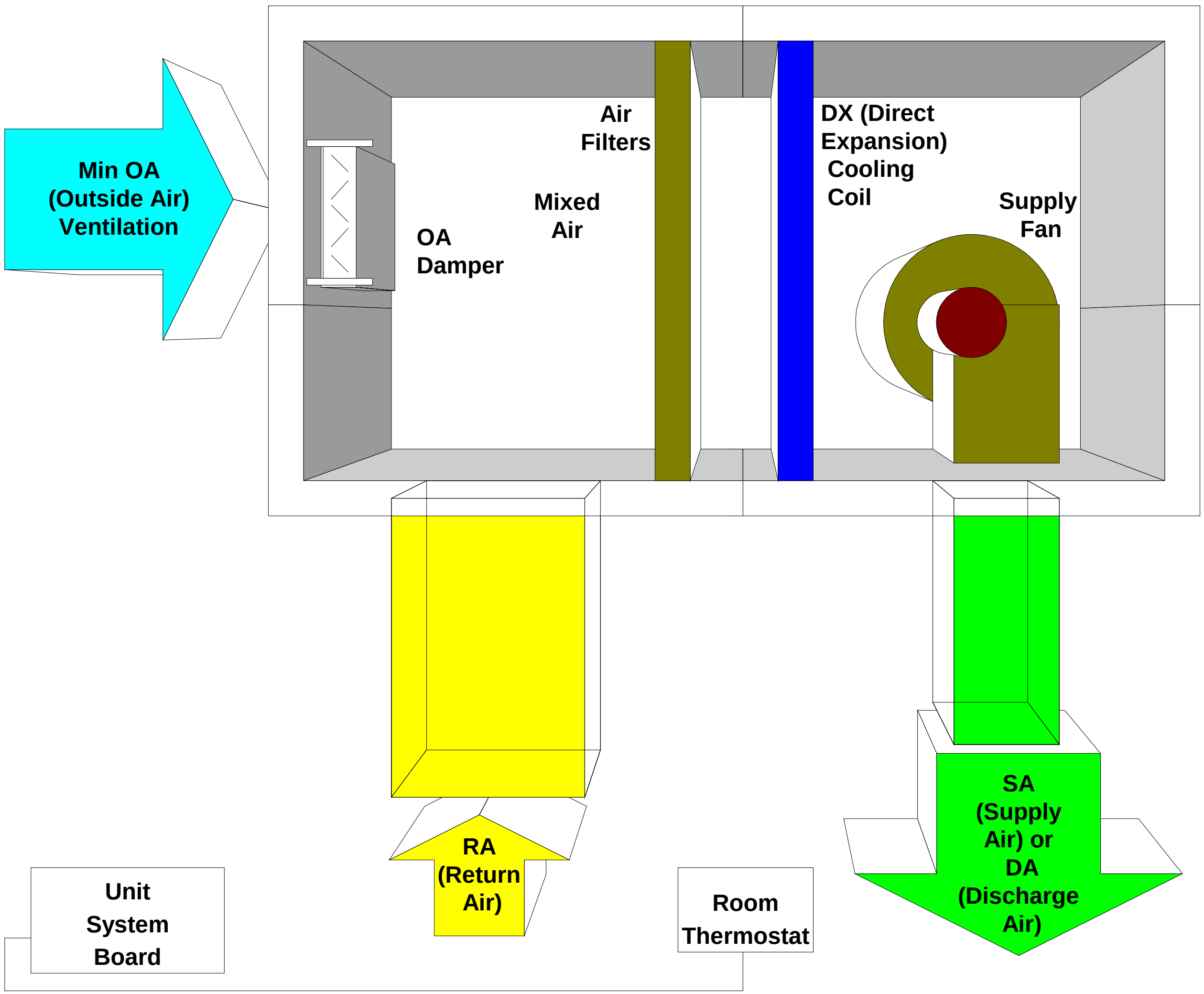
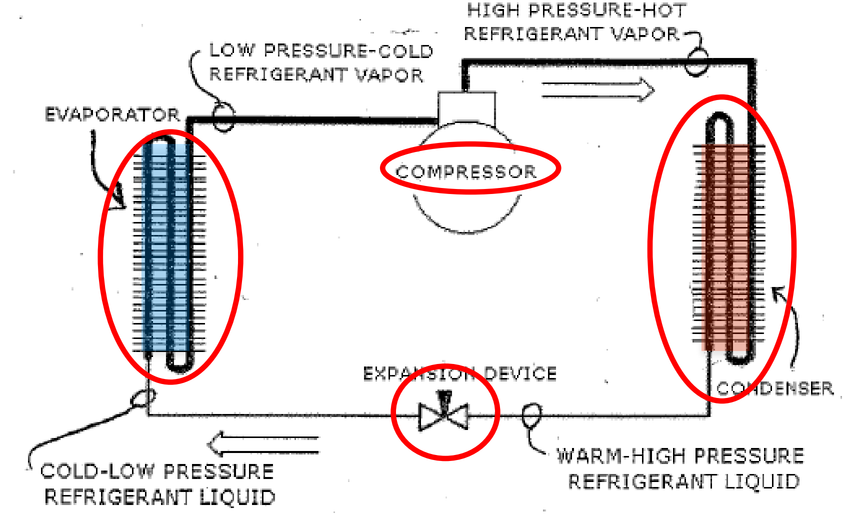
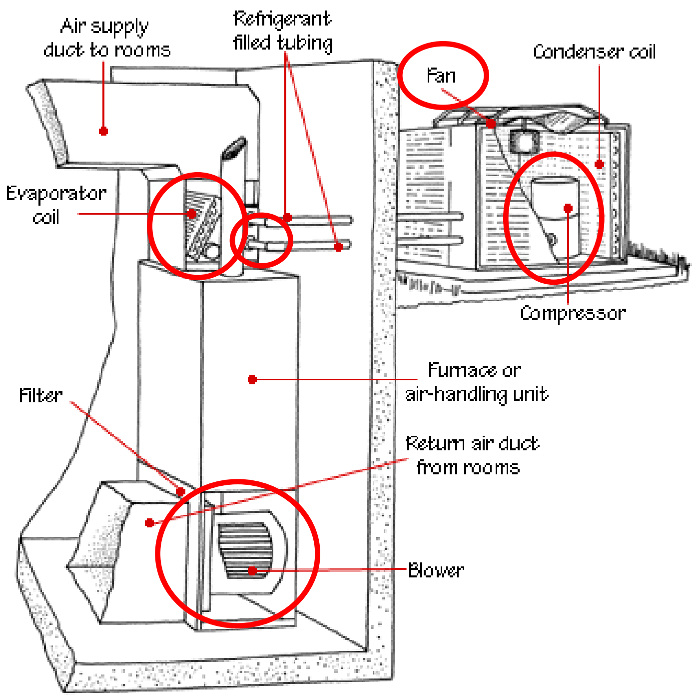
Packaged Unit (DX cooling) Outside Air Ventilation



Refrigeration cycle

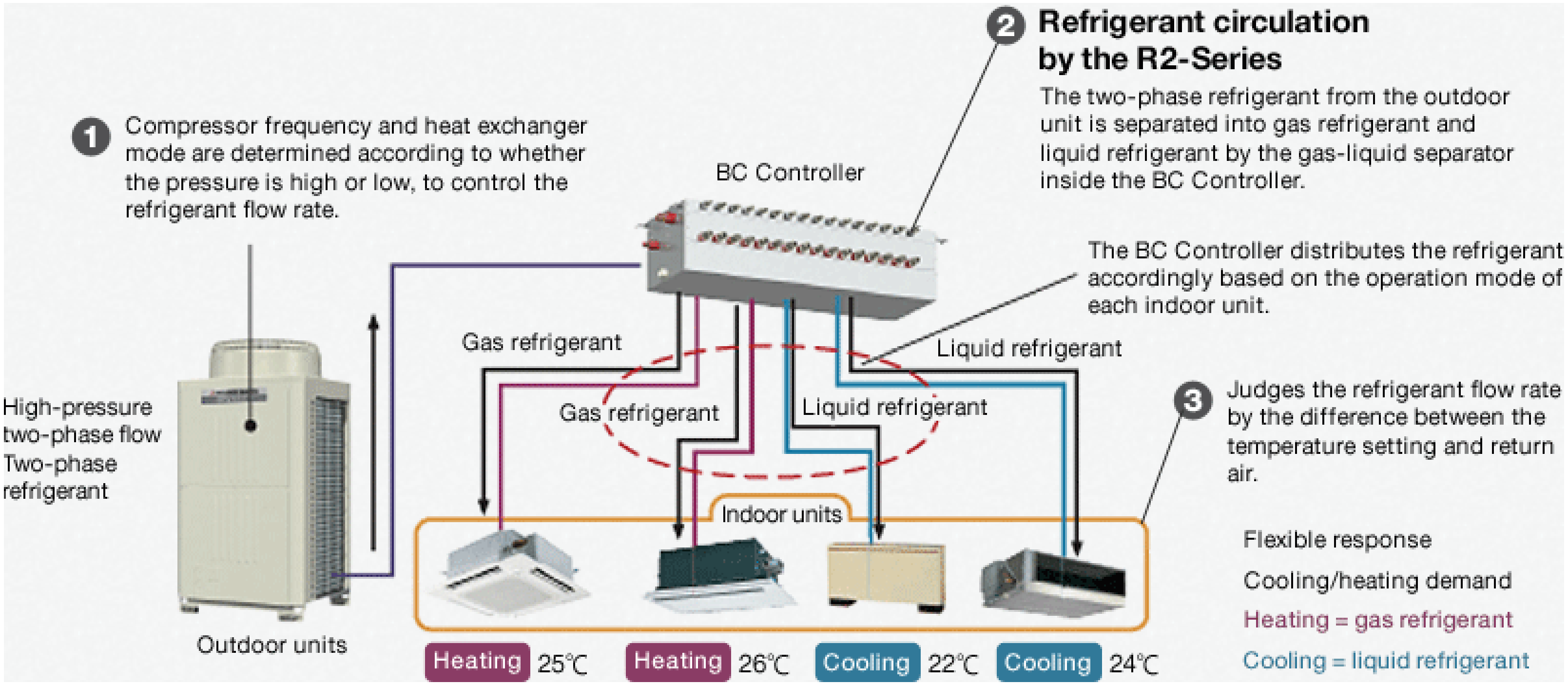
- Compressor uses electric power to increase pressure of refrigerant
- Condenser “cools” refrigerant, refrigerant changes from gas to liquid. Removes thermal energy from system
- Expansion device lowers pressure
- Evaporator (cooling coil) “heats” refrigerant and cools air, refrigerant changes back to gas. Adds thermal energy to system
- Power: compressor, condenser fan, furnace blower, furnace in heating mode





Variable Refrigerant Flow (VRF)

- Could be single zone (mini-split)
- Or multiple zone (VRF System)
- Just a complex heat pump, serving multiple zones



Source: http://www.mitsubishielectric.com/whatschanging/ecochanges/heatpump/

Things to Check in the Energy Code

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TABLE C403.2.3(1)
MINIMUM EFFICIENCY REQUIREMENTS:
ELECTRICALLY OPERATED UNITARY AIR CONDITIONERS AND CONDENSING UNITS

EQUIPMENT TYPE	SIZE CATEGORY	HEATING SECTION TYPE	SUBCATEGORY OR RATING CONDITION	MINIMUM EFFICIENCY		TEST PROCEDURE[a]
				Before 1/1/2016	As of 1/1/2016	
Air conditioners, air cooled	< 65,000 Btu/h[b]	All	Split System	13.0 SEER	13.0 SEER	AHRI 210/240
			Single Package	13.0 SEER	14.0 SEER[c]	
Through-the-wall (air cooled)	≤ 30,000 Btu/h[b]	All	Split system	12.0 SEER	12.0 SEER	
			Single Package	12.0 SEER	12.0 SEER	
Small-duct high-velocity (air cooled)	< 65,000 Btu/h[b]	All	Split System	11.0 SEER	11.0 SEER	
Air conditioners, air cooled	≥ 65,000 Btu/h and < 135,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.2 EER 11.4 IEER	11.2 EER 12.8 IEER	AHRI 340/360
		All other	Split System and Single Package	11.0 EER 11.2 IEER	11.0 EER 12.6 IEER	
	≥ 135,000 Btu/h and < 240,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.0 EER 11.2 IEER	11.0 EER 12.4 IEER	
		All other	Split System and Single Package	10.8 EER 11.0 IEER	10.8 EER 12.2 IEER	
	≥ 240,000 Btu/h and < 760,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	10.0 EER 10.1 IEER	10.0 EER 11.6 IEER	
		All other	Split System and Single Package	9.8 EER 9.9 IEER	9.8 EER 11.4 IEER	

- Equipment Efficiency
  - Tables in C403.2.3
  - Separate tables for each type
  - Different efficiency ratings
  - Higher is generally better
    - Furnace: AFUE v. Et
    - Cooling: SEER vs. EER vs. IEER vs. COP
    - Heat pump heating: HSPF vs. COP
  - If multiple requirements: must meet all
- Equipment Efficiency Importance
  - Most equipment must meet manufacturing requirements
  - Exceptions:
    - Regional requirements
    - Old inventory
  - Variable Refrigerant Flow (VRF) system efficiency is not covered in 2015 IECC, but is in ASHRAE Standard 90.1-2013

Basic Controls that Save Energy

Top of the Charts

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- Most impactful basic HVAC control measures*
  - Snow and ice melt heater control
  - Temperature setback scheduling
  - Full 5 degree thermostat deadband
  - Economizer controls
- Additional impactful complex HVAC control measures
  - Full 5 degree thermostat deadband
  - Limits on simultaneous heating and cooling (VAV reheat)
  - VAV ventilation optimization
  - Supply air temperature & fan static reset controls
- Other impactful HVAC measures*
  - Exterior ductwork insulation (C403.2.9)
  - Fan power within limits
  - Proper equipment sizing

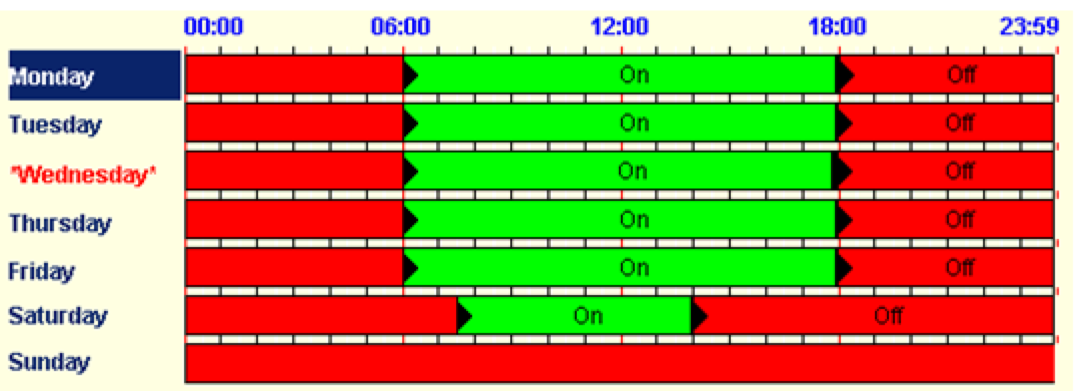
Photo courtesy of Ken Baker, K energy

Snow and ice melt heaters will use a large amount of energy if not properly and automatically controlled!

*Rosenberg, M., Hart, R., Athalye, R., Zhang, J., Wang, W., and Liu, B. (2016). "An Approach to Assessing Potential Energy Cost Savings from Increased Energy Code Compliance in Commercial Buildings." PNNL for USDOE. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24979.pdf

Temperature Setback Scheduling

- Simple control systems
  - Programmable thermostats
    - Seven different daily schedules/week
    - Manual override
  - Occupant sensor is an alternative
- DDC (direct digital control) systems
  - Central scheduling of all units
  - Optimum start activated



Source: http://docplayer.net/5893734-Chapter-5-introduction-to-building-automation-system-bas.html

Energy Myth:
Setback does not save energy because it takes so long to warm up in the morning
Not true:
Savings can be 5%-20% of HVAC energy Use

Full 5 Degree Temperature Deadband

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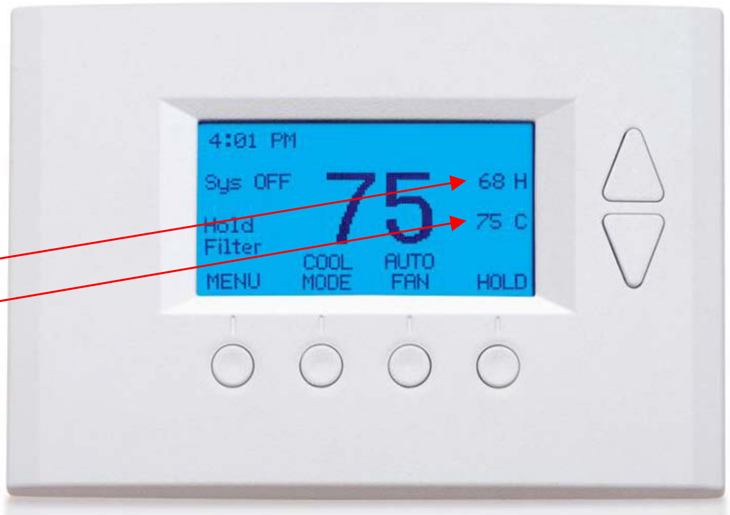
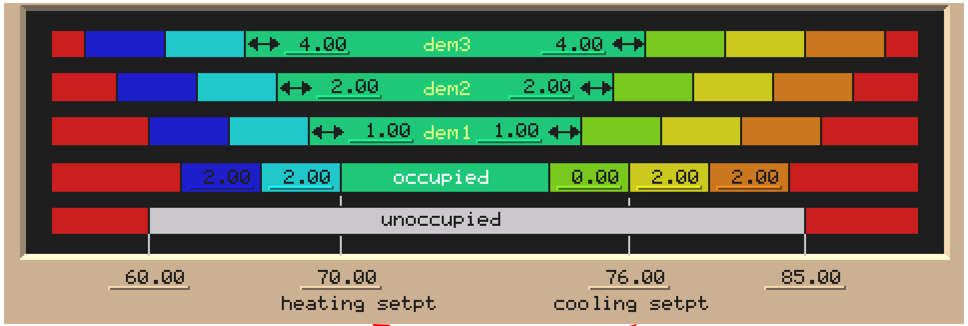
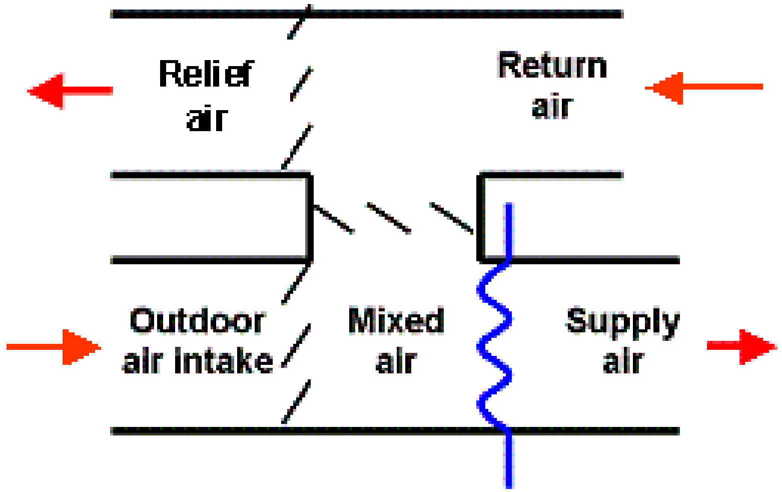
- A most significant control feature is temperature deadband
- If heating is set at 70°F, then cooling should be ≥ 75°F
- Should be the found condition during an inspection
- Why?
  - Simple systems can fight each other in open office areas
  - VAV systems have excessive reheat if settings are too tight
- Energy Star recommended factory default setpoints of:
  - Heating 70°F
  - Cooling 78°F



Source: http://oscac.com/what-you-need-to-know-about-programmable-thermostat/



Source: www.AutomatedLogic.com



Outside Air Economizers

HVAC – Economizers "Free Cooling"

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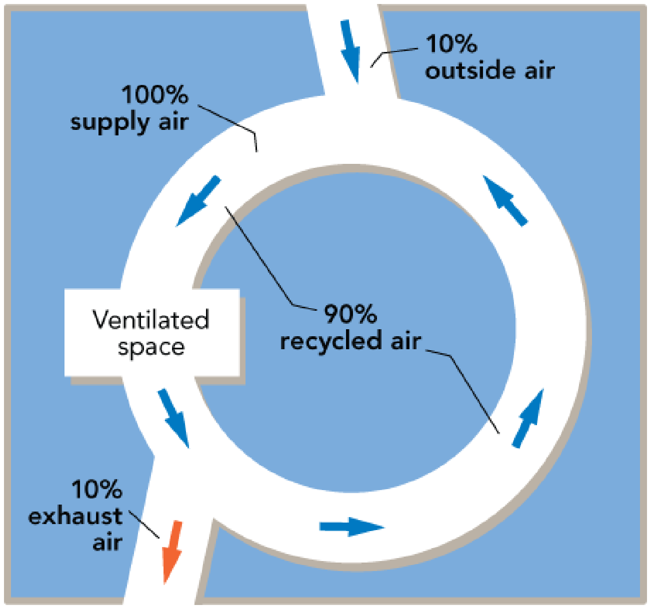
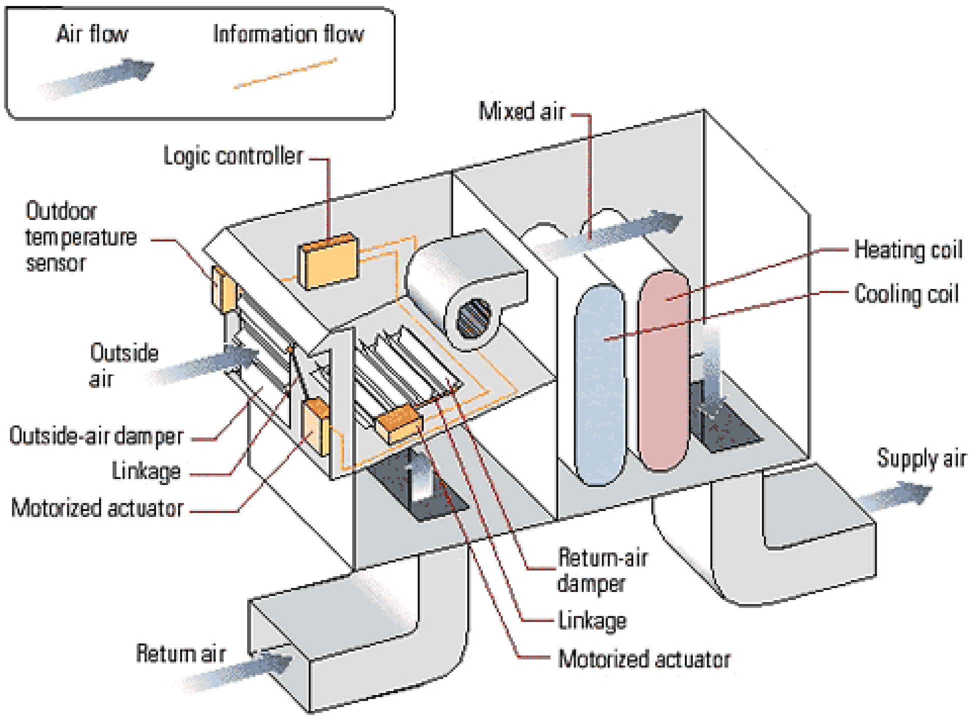
- Quantity of OSA: Meet Minimum Ventilation Requirement
- Economizer Function: Flush out building heat with cool outside air

Economizer



Ventilation Air



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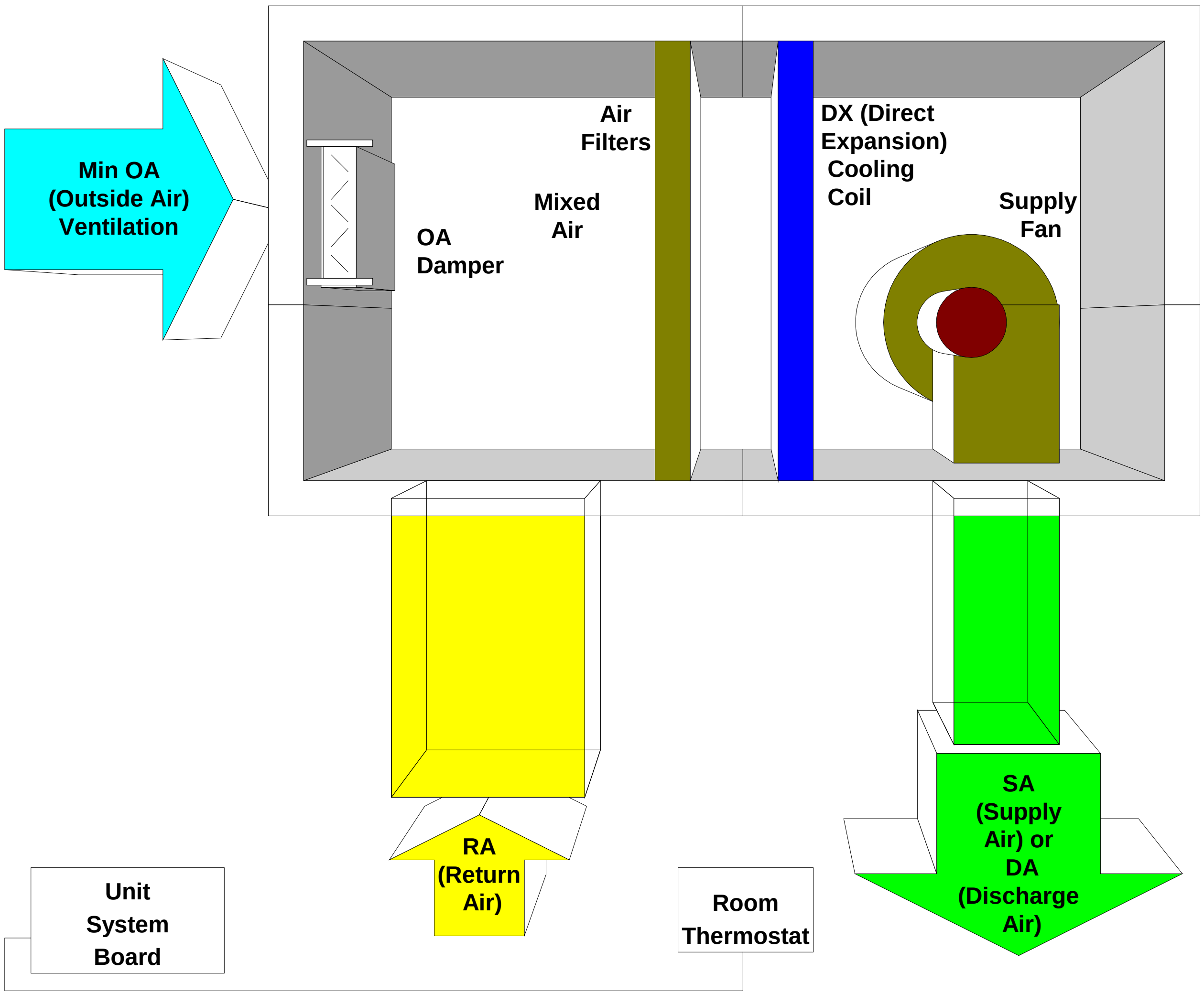

Basic OSA Economizer Idea

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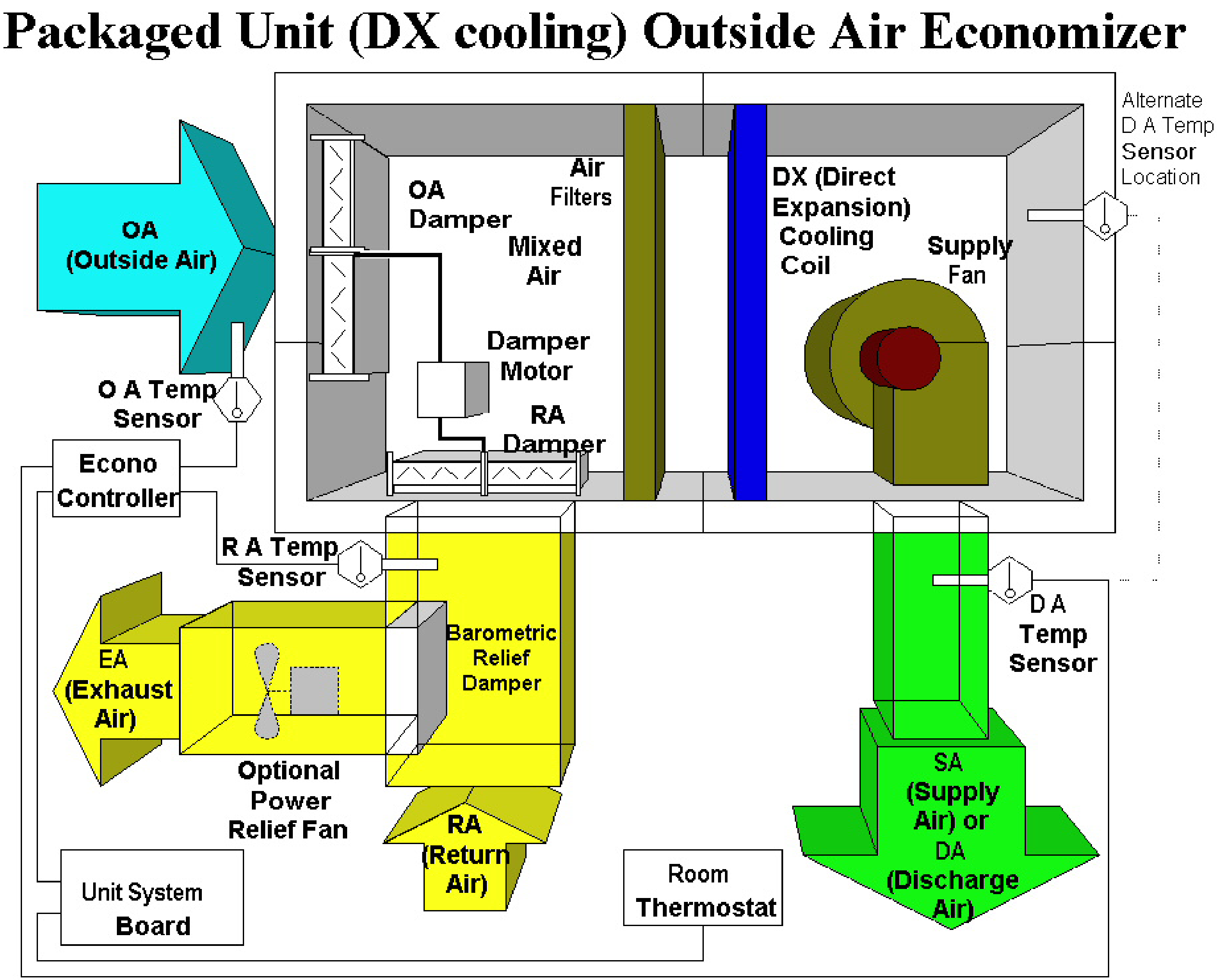
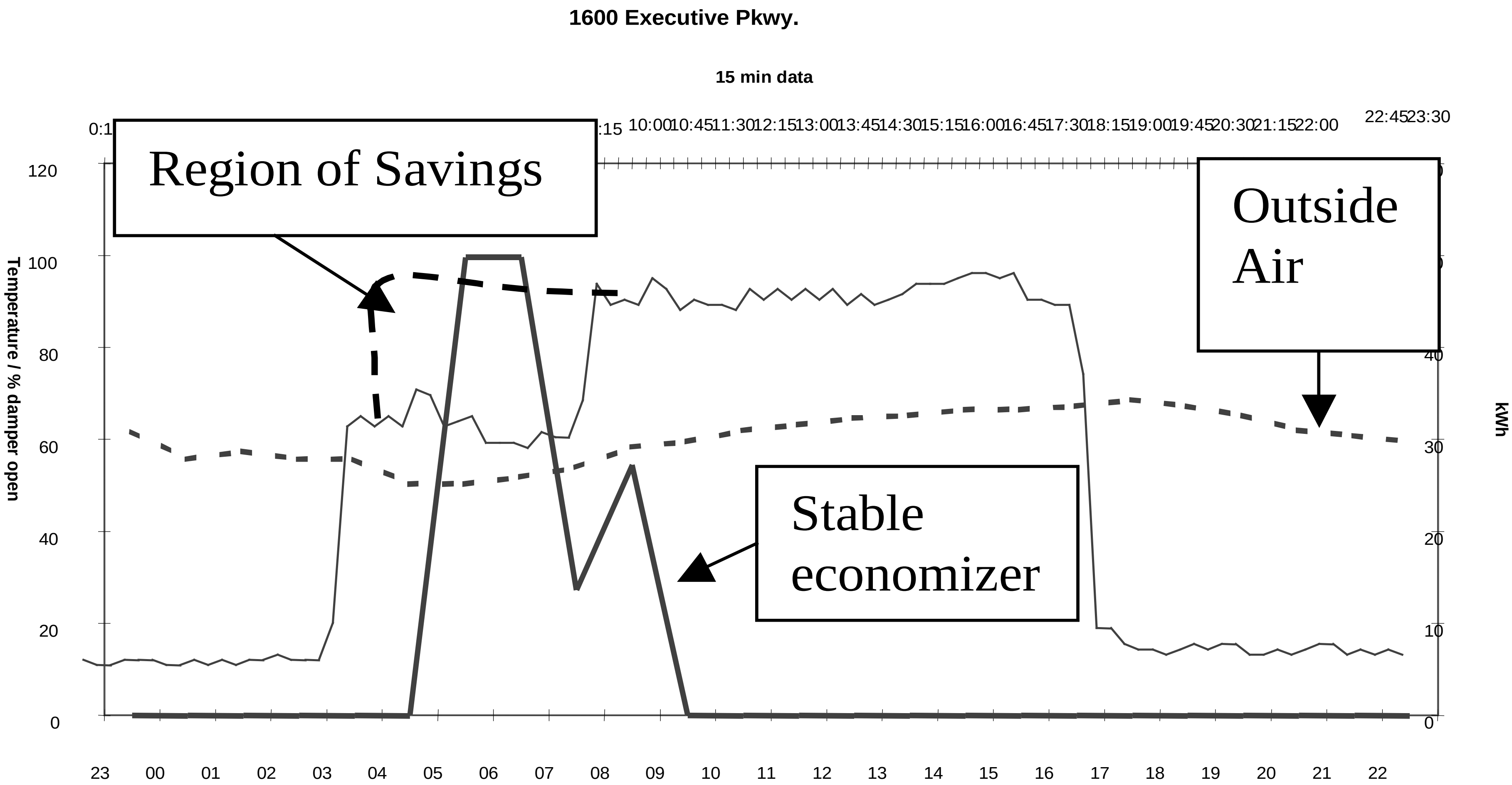


Economizer Components

- Dampers (not shown)
- Damper Motors
- MAT/DAT sensors
- Solid State Controller
- OAT/RAT sensors
  - Dry bulb
  - Enthalpy
- Code econo requirements
  - OSA ductwork = large enough
  - Relief damper provided
  - Integrated
    - Operates with compressor
    - Coordinated with cooling

(Honeywell shown, often basis of OEM brands, out there for 30+ years)

OSA Economizer Savings



Economizer Savings – It's in the Settings!

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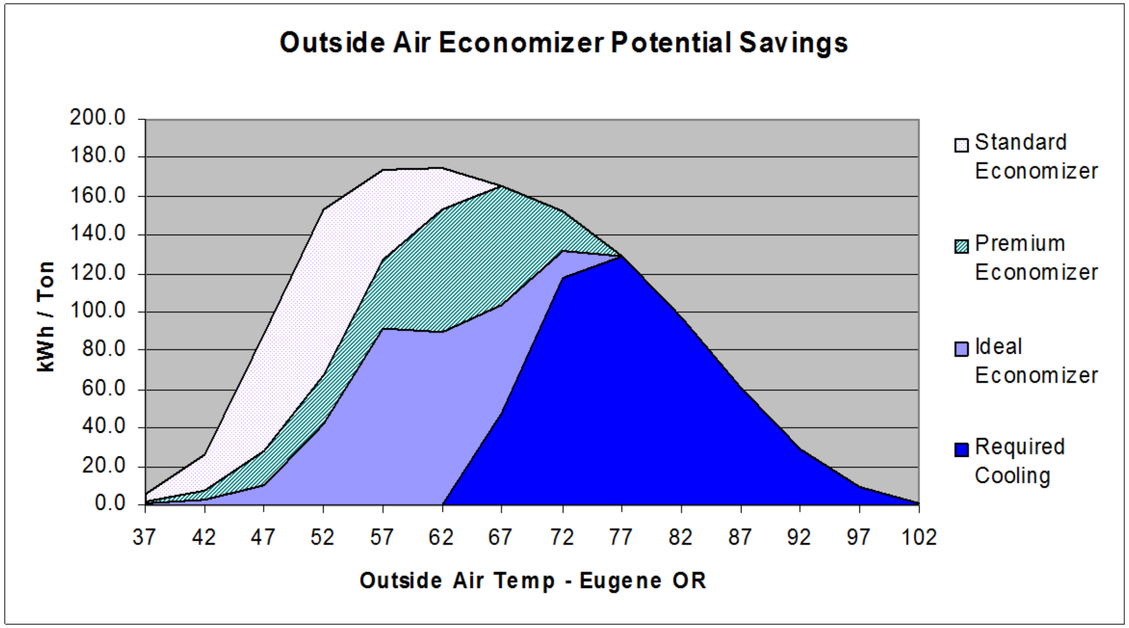
- High limit needed to turn off economizer when not beneficial!
  - Fixed dry bulb cuts off above 75°F, 70°F, or 65°F—depending on CZ
  - Differential dry bulb cuts off when OSA > RA

    Differential DB no longer allowed in Climate Zones 1A, 2A, 3A, 4A
  - Fixed or differential **enthalpy** high limit adjusts for humidity of OSA

    Enthalpy requires a paired dry bulb high limit in event of sensor inaccuracy

- Economizer savings
  - Theoretically ~60%
  - Low high limit settings: 10%-20%
- "Premium economizer" = Code economizer
  - Settings correct
  - Relief air
  - Integrated
  - Checkout & FDD



Economizer: Things to Check in the Energy Code

- Damper and ductwork
  - Full sized OSA damper
  - Relief damper; powered or barometric
- High limit or changeover setting (C403.3.3.3)
  - Proper setpoint a mystery to most field technicians
  - Settings typically too low; reducing or eliminating savings (55°F vs. 75°F)

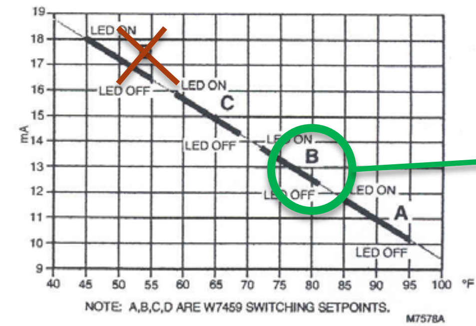
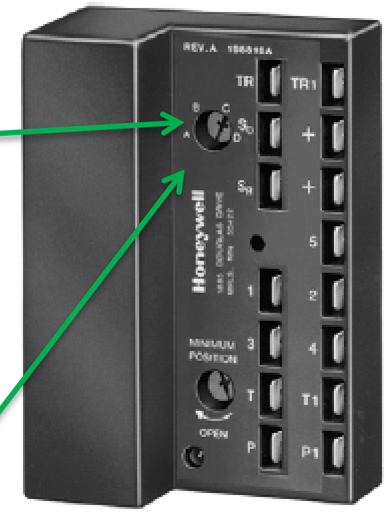


Fig. 17. C7650A Solid State Temperature Sensor output current vs. temperature.



Source: https://customer.honeywell.com/en-US/Pages/Category.aspx?cat=HonECC+Catalog&category=W7459&catpath=1.1.2.1.14

High Limit Set per table C403.3.1.1.3(2) for climate zone

Source: http://www.zipeconomizer.com/

New 2015 IECC Fault Detection & Diagnostic (FDD) Requirements: (C403.2.4.7) Sensors; faults & setup.

The controller above does <u>not</u> meet the new requirements.

https://buildingcontrols.honeywell.com/products/Jade-Economizer

Top of the Charts

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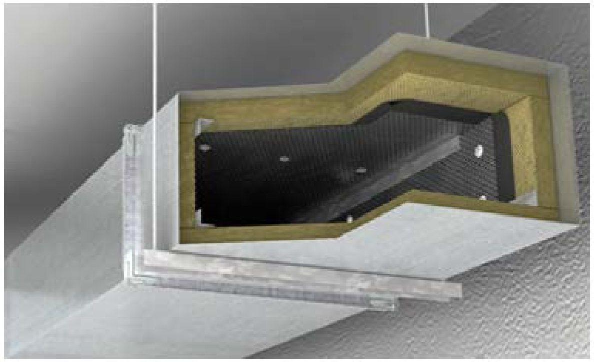

http://www.rockwoolasia.com/products+and+solutions/u/2011.construction/9794/HVAC/Internal+duct+liner

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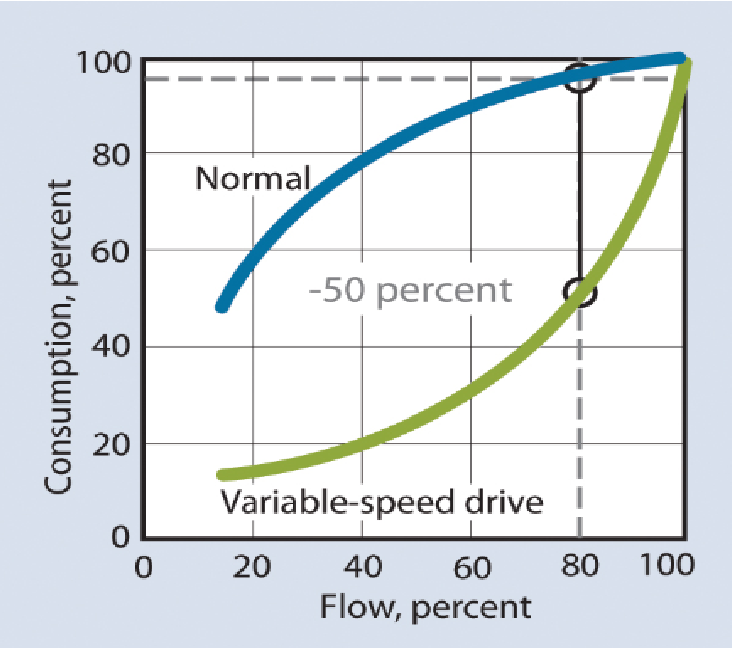
  - Exterior ductwork insulation (C403.2.9)
  - Fan power within limits
  - Proper equipment sizing

Ductwork in attics or outside the building (exposed on the roof) requires more insulation:

R-8 in CZ 1-4
R-12 in CZ 5-8

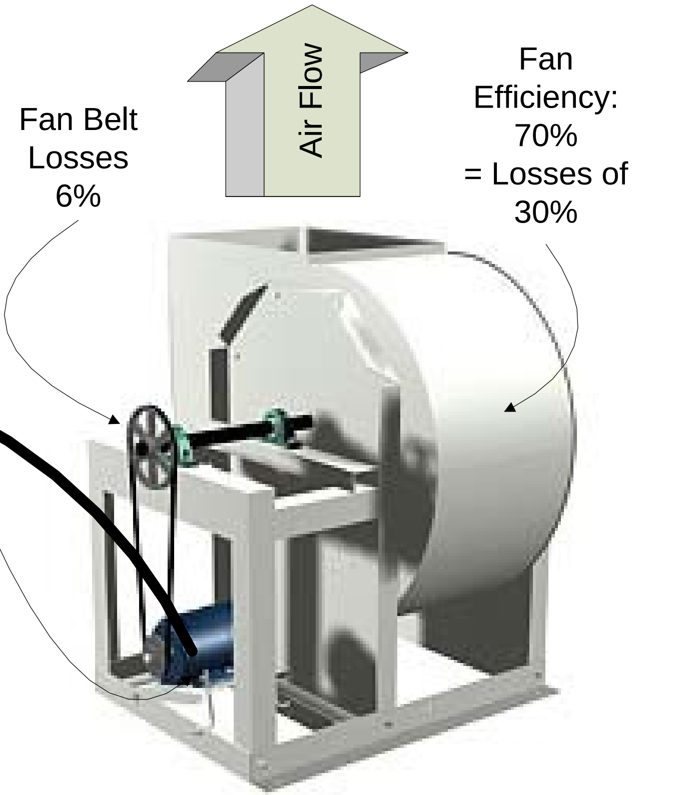
*Rosenberg, M., Hart, R., Athalye, R., Zhang, J., Wang, W., and Liu, B. (2016). "An Approach to Assessing Potential Energy Cost Savings from Increased Energy Code Compliance in Commercial Buildings." PNNL for USDOE. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24979.pdf

Fan Energy Limits



Overall Fan System Efficiency
Multiple Conversions = Multiple Losses

Losses occur for each conversion of energy



	Efficiency	Loss	kW	
Meter			**9.65**	Meter kW
Wire		2%	9.46	Motor Input kW
Motor	80%	20%	7.57	Motor Shaft kW
Belt		6%	7.14	Fan Shaft kW
Fan	70%	30%	**5.00**	Air kW = Work
System	52%	48%	4.65	Losses

Overall system efficiency =

[5.0 kW work] / [9.65 kW in] = 52%

The energy code manages overall large fan efficiency by limiting nameplate motor hp or fan bhp per cfm of airflow supplied.

Fan Power Limit

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- HVAC systems with total fan motor nameplate hp >5hp
  - Either meet nameplate horsepower or fan bhp (C403.2.12.1)
  - Based on supply cfm with pressure adjustments

TABLE C403.2.12.1(1)
FAN POWER LIMITATION

	LIMIT	CONSTANT VOLUME	VARIABLE VOLUME
Option 1: Fan system motor nameplate hp	Allowable nameplate motor hp	$hp \leq CFM_S \cdot 0.0011$	$hp \leq CFM_S \cdot 0.0015$
Option 2: Fan system bhp	Allowable fan system bhp	$bhp \leq CFM_S \cdot 0.00094 + A$	$bhp \leq CFM_S \cdot 0.0013 + A$

For SI: 1 bhp = 735.5 W, 1 hp = 745.5 W, 1 cfm = 0.4719 L/s.

where:

CFM_S = The maximum design supply airflow rate to conditioned spaces served by the system in cubic feet per minute.

hp = The maximum combined motor nameplate horsepower.

Bhp = The maximum combined fan brake horsepower.

A = Sum of $[PD \times CFM_D / 4131]$

where:

PD = Each applicable pressure drop adjustment from Table C403.2.12.1(2) in. w.c.

CFM_D = The design airflow through each applicable device from Table C403.2.12.1(2) in cubic feet per minute.

TABLE C403.2.12.1(2)
FAN POWER LIMITATION PRESSURE DROP ADJUSTMENT

DEVICE	ADJUSTMENT
Credits	
Fully ducted return and/or exhaust air systems	0.5 inch w.c. (2.15 in w.c. for laboratory and vivarium systems)
Return and/or exhaust airflow control devices	0.5 inch w.c.
Exhaust filters, scrubbers or other exhaust treatment	The pressure drop of device calculated at fan system design condition
Particulate filtration credit: MERV 9 thru 12	0.5 inch w.c.

COMcheck: Mechanical - Fan Systems

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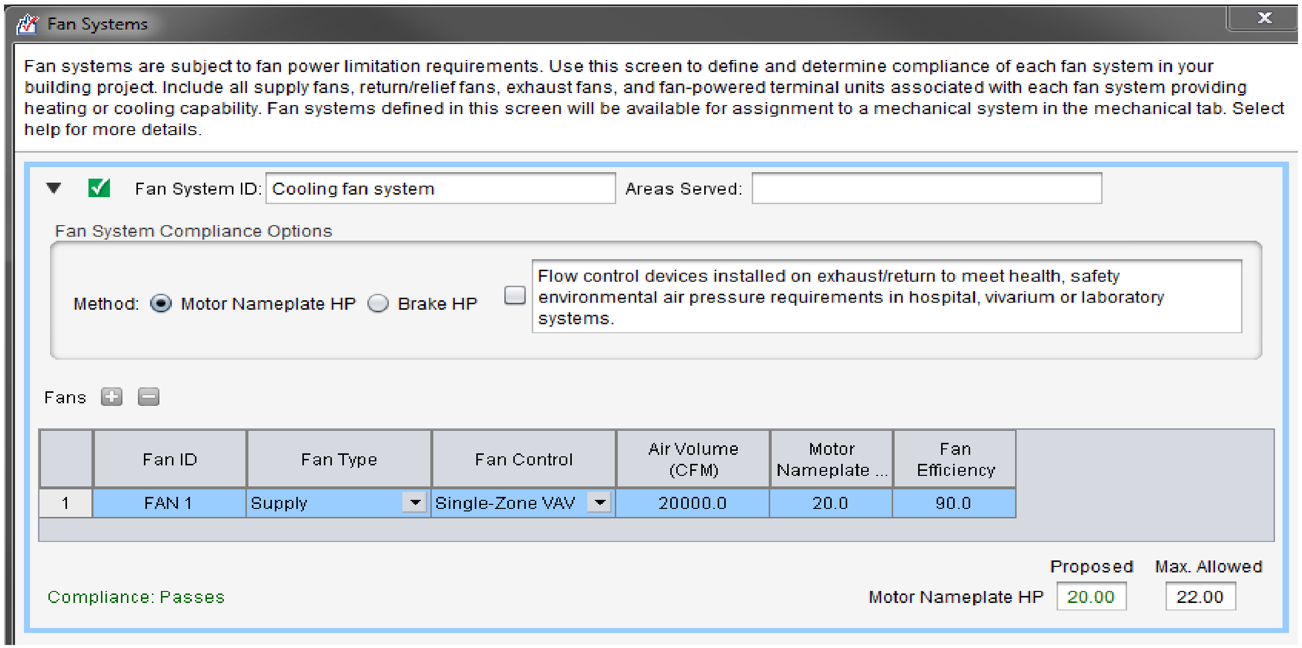
- Determines Fan Power Limitations compliance for each fan system
- Motor nameplate HP and brake HP
  - Brake HP includes pressure drop credits as applicable



- Include all supply, return and exhaust fans in each system
  - May have to allocate partial exhaust to each system
  - Do not need to enter duplicate systems repetitively

Variable Speed Drives

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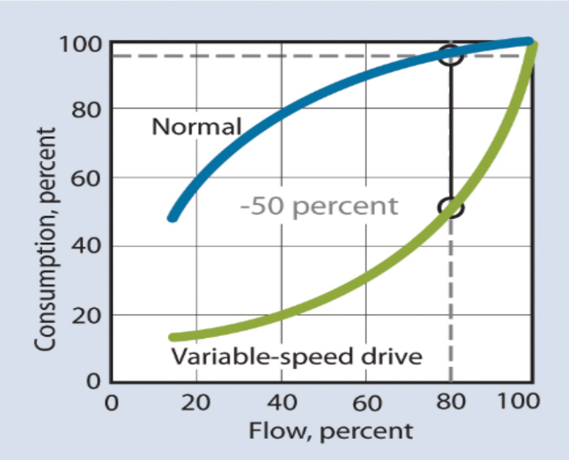
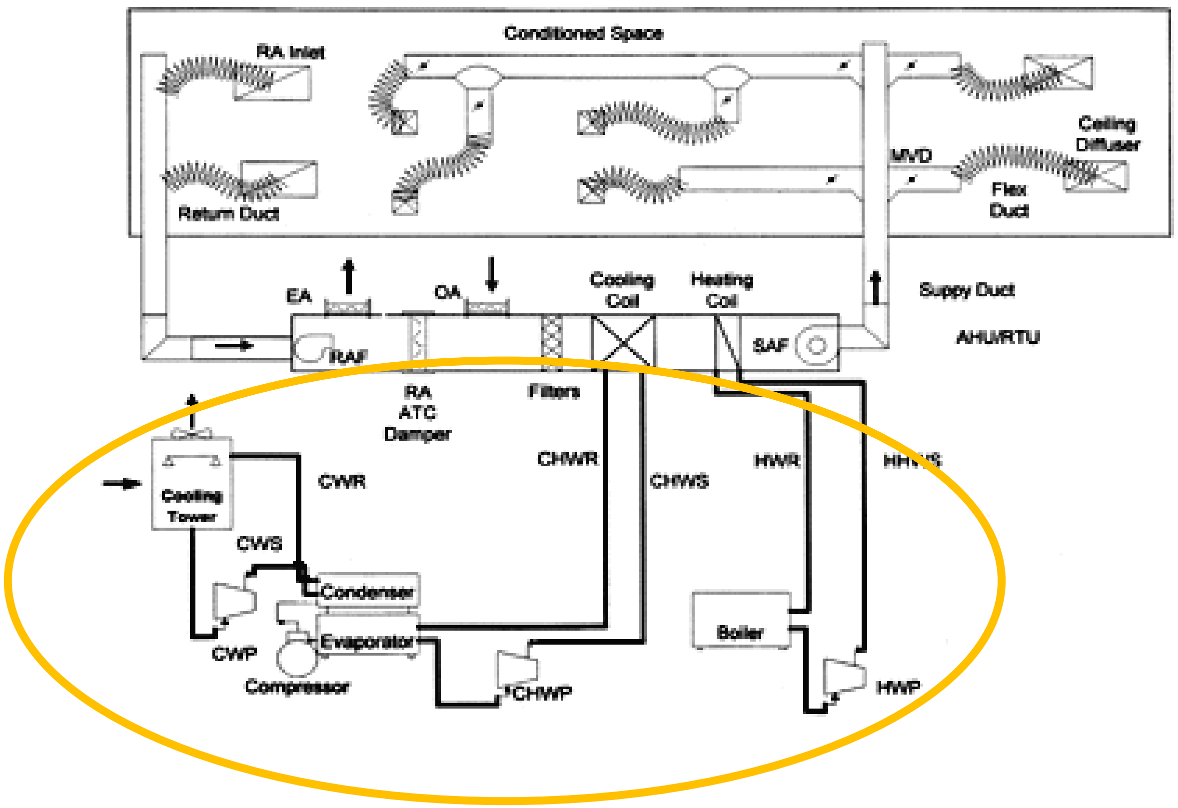
- Reducing fan or pump speed saves energy at partial flow
- Fans in hydronic and multiple zone systems must be variable flow (C403.4.1)
  - Dx 65 MBH or more: 2-speed
  - CHW > ¼ HP: VSD
- So most chilled water (CHW) fans must have variable speed drives
  - For example, 80% flow results in a 50% power reduction
- A variable speed drive should be evident at the site or on the specifications



Source: https://en.wikipedia.org/wiki/Variable-frequency_drive

Complex Systems: Central Plant



Source: http://affordablehousinginstitute.org/blogs/us/2014/08/thats-rich-harbor-towers-part-8-the-hvac-replacement-a-certain-godlike-remoteness.html

Complex Building Energy Use - HVAC

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- Categories of HVAC systems:
  - Central Plant
    - Boilers, chillers, cooling towers
    - A few pieces of large equipment
  - Distribution Systems
    - Pumps
    - Pipe and control valves
    - Ductwork, diffusers and registers
  - Secondary & Zonal HVAC Systems
    - Air handlers, with coils & economizers
    - Fan coils, VAV boxes
- Selected based on:
  - Space temperature and humidity requirements
  - First cost, operating cost, and maintenance cost
  - Spatial constraints
  - Redundancy

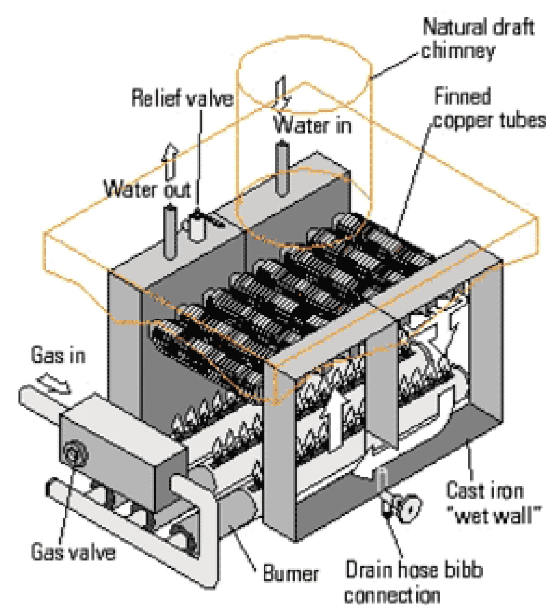
Chiller

Heating and Cooling

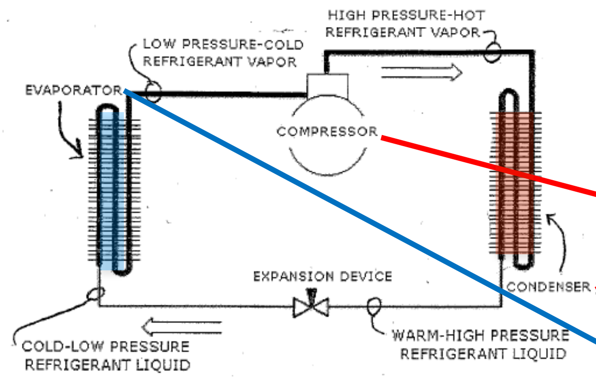
- Heating
  - Typical fuels are electricity and natural gas
  - Efficiency matters:
    - Electricity is 100% efficient
      - E.g., 1,000 W hair dryer heats the room by 1,000 W
      - But what's the source efficiency? Coal-fired power plants are typically only 35% efficient
    - A heat pump is much more efficient than resistance heat; typically :
      - @ 47F: 330% or COP = 3.3 / 17F: 225% or COP = 2.25 / HSPF = 6.8
    - Natural gas typically is 80% efficient
      - E.g., 100,000 Btu/h gas input to a furnace may yield 80,000 Btu/h of heating
      - A condensing boiler or furnace has higher efficiency; exceeding 90%
- Cooling
  - Central chiller
  - Water cooled or air cooled
  - Water cooled requires cooling tower or heat rejection

Central Plant: Boilers

- Hot water or steam boilers are typical
  - Hot water more common for smaller buildings
  - Usually natural gas, but sometimes electric or oil

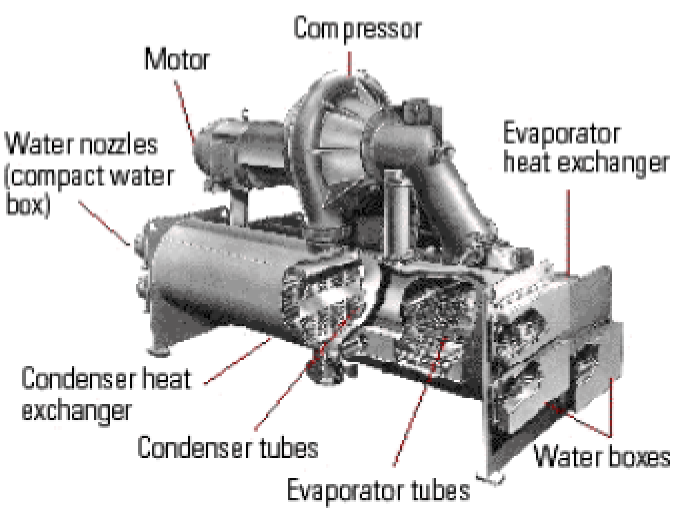


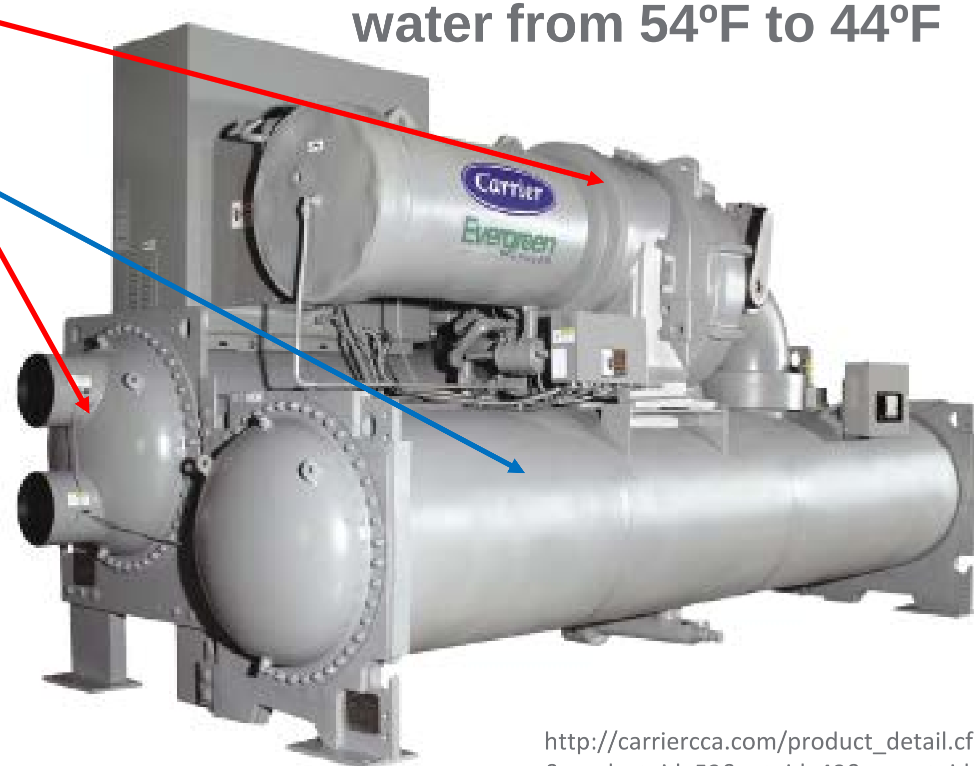
Central Plant: Chillers



Chillers use electricity to remove heat from the chilled water loop (and thus the building)

e.g., cool the chilled water from 54ºF to 44ºF





http://carriercca.com/product_detail.cfm?ln=en&product_id=53&cat_id=48&parent_id=7

http://energy-models.com/hvac-centrifugal-chillers

Central plant: Cooling tower

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Rejects heat from the chiller (transfers it outdoors).

e.g., cool the condenser water (water from the chiller) from 85ºF to 75ºF.

Water-cooled chiller is more efficient than air-cooled chiller due to evaporative cooling

Things to Check in the Energy Code

- Equipment Efficiency
  - 2015 IECC Tables in C403.2.3
  - Boiler efficiency
  - Chiller efficiency
    - Path A or Path B
    - Meet both Full Load & IPLV
  - Heat rejection (tower) efficiency

TABLE C403.2.3(5)
MINIMUM EFFICIENCY REQUIREMENTS: GAS- AND OIL-FIRED BOILERS

EQUIPMENT TYPE[a]	SUBCATEGORY OR RATING CONDITION	SIZE CATEGORY (INPUT)	MINIMUM EFFICIENCY[d, e]	TEST PROCEDURE
Boilers, hot water	Gas-fired	< 300,000 Btu/h	80% AFUE	10 CFR Part 430
		≥ 300,000 Btu/h and ≤ 2,500,000 Btu/h[b]	80% E_t	10 CFR Part 431
		> 2,500,000 Btu/h[a]	82% E_c	
	Oil-fired[c]	< 300,000 Btu/h	80% AFUE	10 CFR Part 430
		≥ 300,000 Btu/h and ≤ 2,500,000 Btu/h[b]	82% E_t	10 CFR Part 431
		> 2,500,000 Btu/h[a]	84% E_c	
	Gas-fired	< 300,000 Btu/h	75% AFUE	10 CFR Part 430
	Gas-fired- all, except natural draft	≥ 300,000 Btu/h and ≤ 2,500,000 Btu/h[b]	79% E_t	10 CFR Part 431
		> 2,500,000 Btu/h[a]	79% E_t	

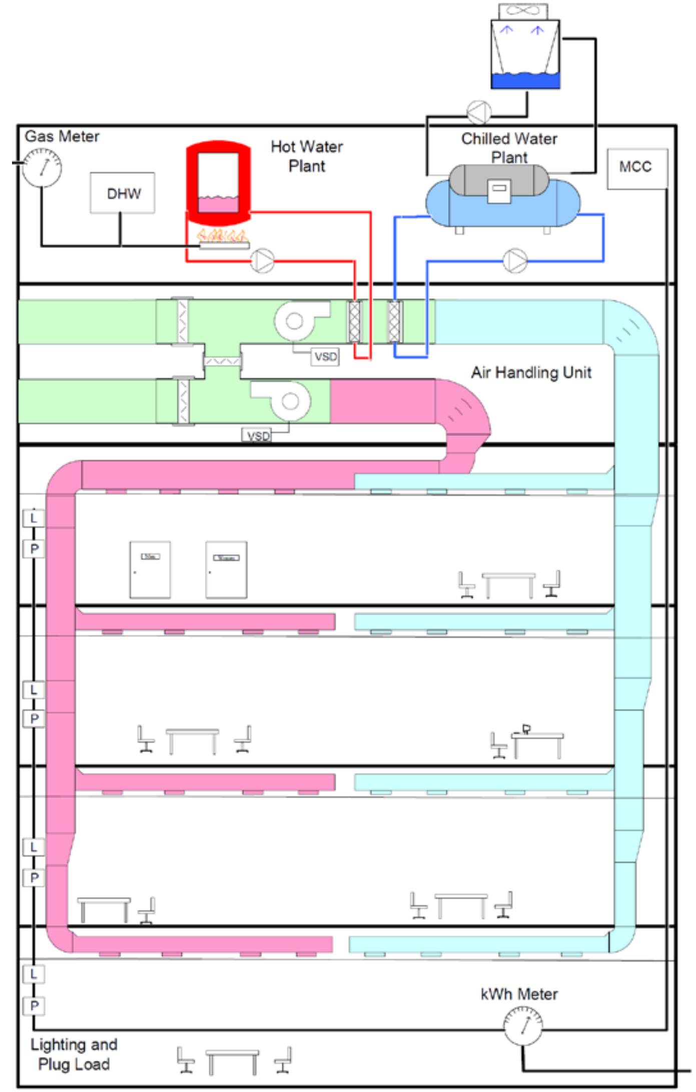
TABLE C403.2.3(7)
WATER CHILLING PACKAGES – EFFICIENCY REQUIREMENTS[a, b, d]

EQUIPMENT TYPE	SIZE CATEGORY	UNITS	BEFORE 1/1/2015		AS OF 1/1/2015		TEST PROCEDURE[e]
			Path A	Path B	Path A	Path B	
Air-cooled chillers	< 159 Tons	EER (Btu/W)	≥ 9.562 FL	NA[c]	≥ 10.100 FL	≥ 9.700 FL	AHRI 550/ 590
			≥ 12.500 IPLV		≥ 13.700 IPLV	≥ 15,800 IPLV	
	≥ 150 Tons		≥ 9.562 FL	NA[c]	≥ 10.100 FL	≥ 9.700 FL	
			≥ 12.500 IPLV		≥ 14.000 IPLV	≥ 16.100 IPLV	
Air cooled without condenser, electrically operated	All capacities	EER (Btu/W)	Air-cooled chillers without condenser shall be rated with matching condensers and complying with air-cooled chiller efficiency requirements.				
Water cooled, electrically operated positive displacement	< 75 Tons	kW/ton	≤ 0.780 FL	≤ 0.800 FL	≤ 0.750 FL	≤ 0.780 FL	
			≤ 0.630 IPLV	≤ 0.600 IPLV	≤ 0.600 IPLV	≤ 0.500 IPLV	
	≥ 75 tons and < 150 tons		≤ 0.775 FL	≤ 0.790 FL	≤ 0.720 FL	≤ 0.750 FL	
			≤ 0.615 IPLV	≤ 0.586 IPLV	≤ 0.560 IPLV	≤ 0.490 IPLV	
	≥ 150 tons and < 300 tons		≤ 0.680 FL	≤ 0.718 FL	≤ 0.660 FL	≤ 0.680 FL	
			≤ 0.580 IPLV	≤ 0.540 IPLV	≤ 0.540 IPLV	≤ 0.440 IPLV	
	≥ 300 tons and < 600 tons		≤ 0.620 FL	≤ 0.639 FL	≤ 0.610 FL	≤ 0.625 FL	
			≤ 0.540 IPLV	≤ 0.490 IPLV	≤ 0.520 IPLV	≤ 0.410 IPLV	
	≥ 600 tons		≤ 0.620 FL	≤ 0.639 FL	≤ 0.560 FL	≤ 0.585 FL	
			≤ 0.540 IPLV	≤ 0.490 IPLV	≤ 0.500 IPLV	≤ 0.380 IPLV	

Air-cooled Chiller

Source: http://www.trane.com/commercial/north-america/us/en/products-systems/equipment/chillers/air-cooled-chillers.html

Complex Systems: Secondary HVAC Systems



Complex Secondary HVAC systems

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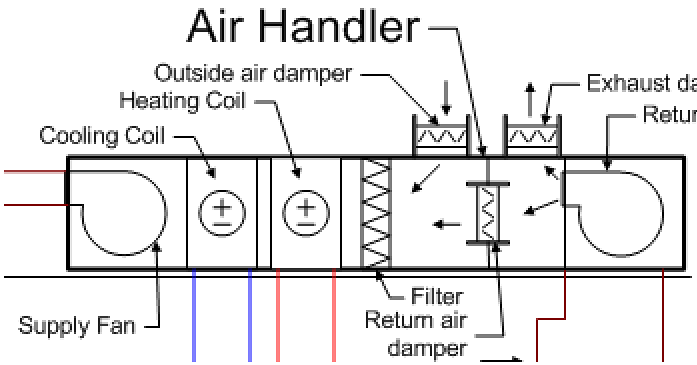
- Similar to residential and small commercial HVAC systems, but bigger
  - Work to maintain comfort conditions in the space
- Complex systems may be more expensive, but are usually more efficient than smaller / simpler systems (depends)
- Usually get heating and cooling energy from a central plant through chilled water and heating water pumped throughout the building
- Some "packaged VAV systems" are unitary, but serve multiple zones

Heat recovery section makes it more efficient. Transfers energy from outgoing to incoming air

'Air handler' has fan and cooling coil, just like in simpler systems

Secondary HVAC System Air handlers



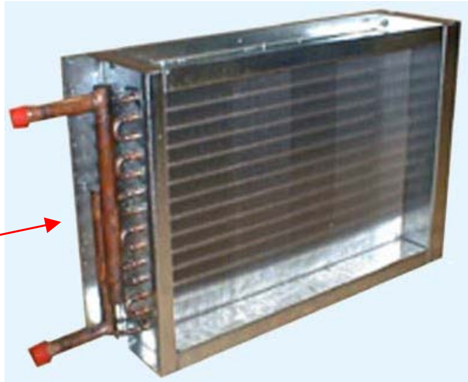
The H, the V, the AC in one piece of equipment.

Uses air dampers, and chilled and heating water from the chiller and the boiler to heat and cool the air.

Also filters the air and draws in outside air.

Distribution: Heating Coils, Radiant Heaters

- Hydronic distribution: Water or steam is heated by the boilers, then delivered to secondary heating units throughout the building
- Various types of heat exchangers:
  - Heating coils in airstreams
    - Air handlers, fan coils (hotels)
  - Radiant heat
    - Baseboard heaters
    - Radiant floor heating
- More about hydronic controls later
- Chilled water distribution is similar; CHW from chiller goes to cooling coils through pipes
- Ductwork is used to distribute heated or cooled air and return or exhaust air



Hot/cold water flows through tubes, air flows across tubes. Heat transfer!

VAV Multiple Zone System Concept

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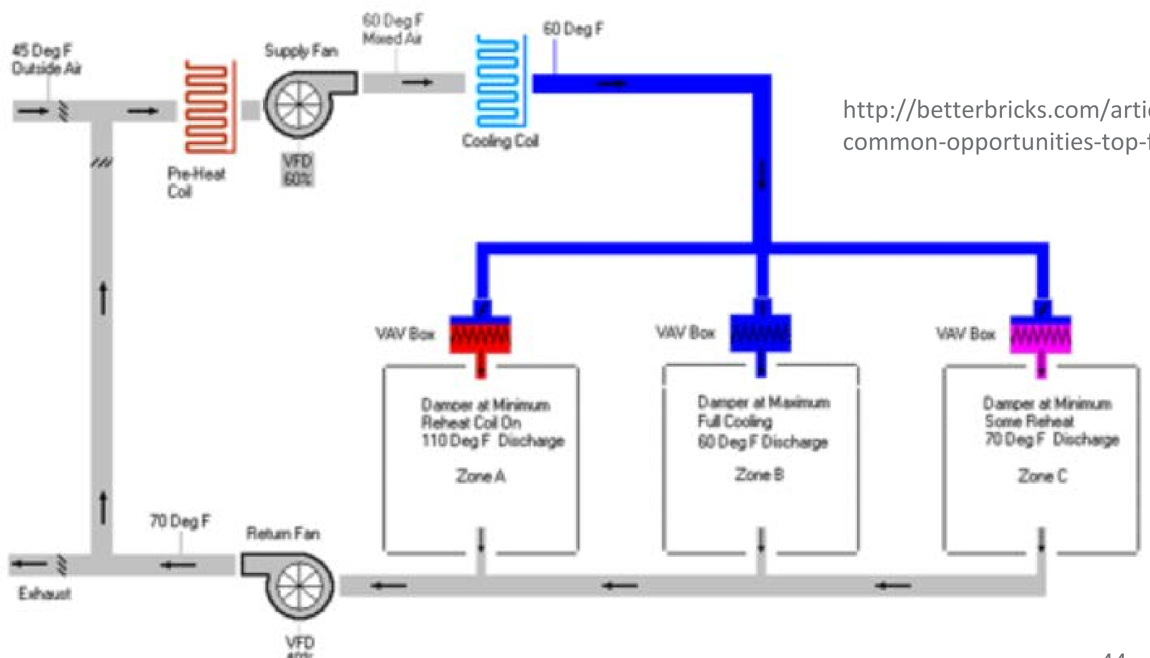
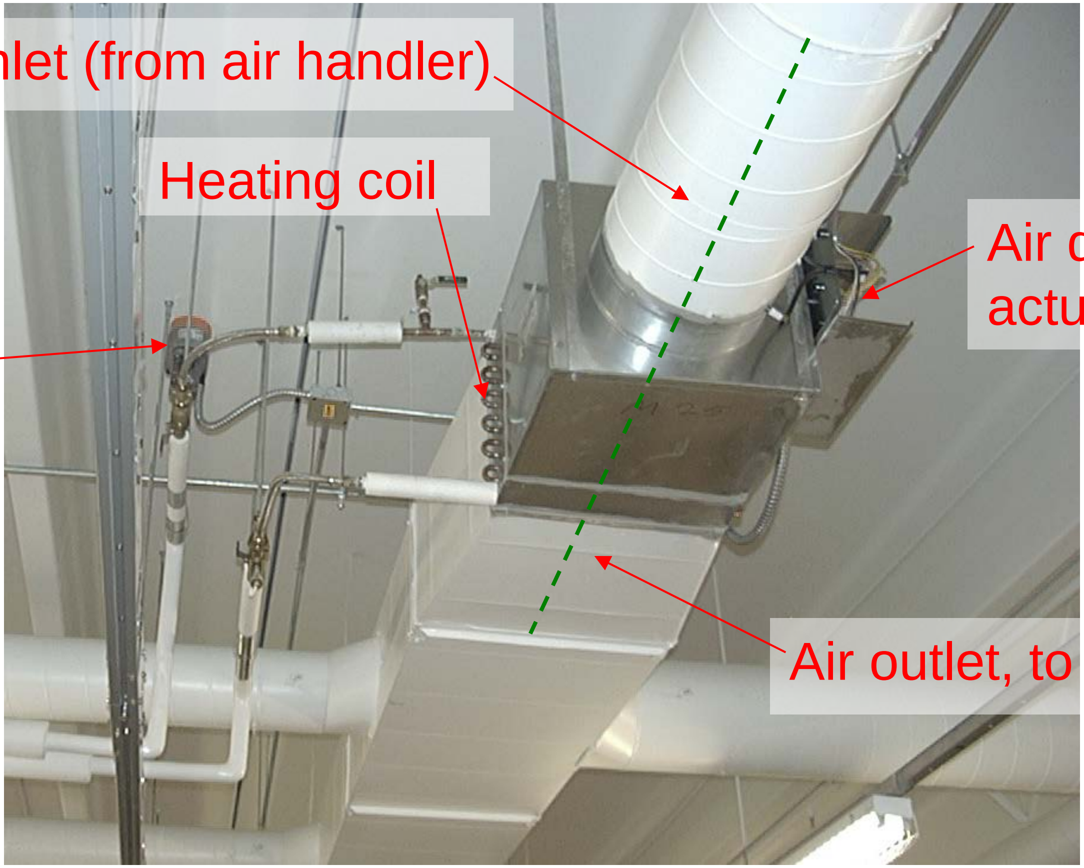
- One variable air volume (VAV) central air system serves several zones
  - The air handling unit (AHU) maintains the desired
    - Primary supply air temperature (SAT)
    - Duct static pressure (SP) using a variable speed drive
    - The setpoints for both SAT & SP can be reset
    - Has preheat capability and may subcool air to reduce humidity
    - Coordinates the OSA economizer with the cooling coil to provide cooling
- Each zone has a VAV box or terminal unit that:
  - Modulates air flow based on cooling load
  - Maintains minimum airflow for ventilation needs
  - Reheats air to meet heating needs



http://betterbricks.com/articles/common-opportunities-top-five

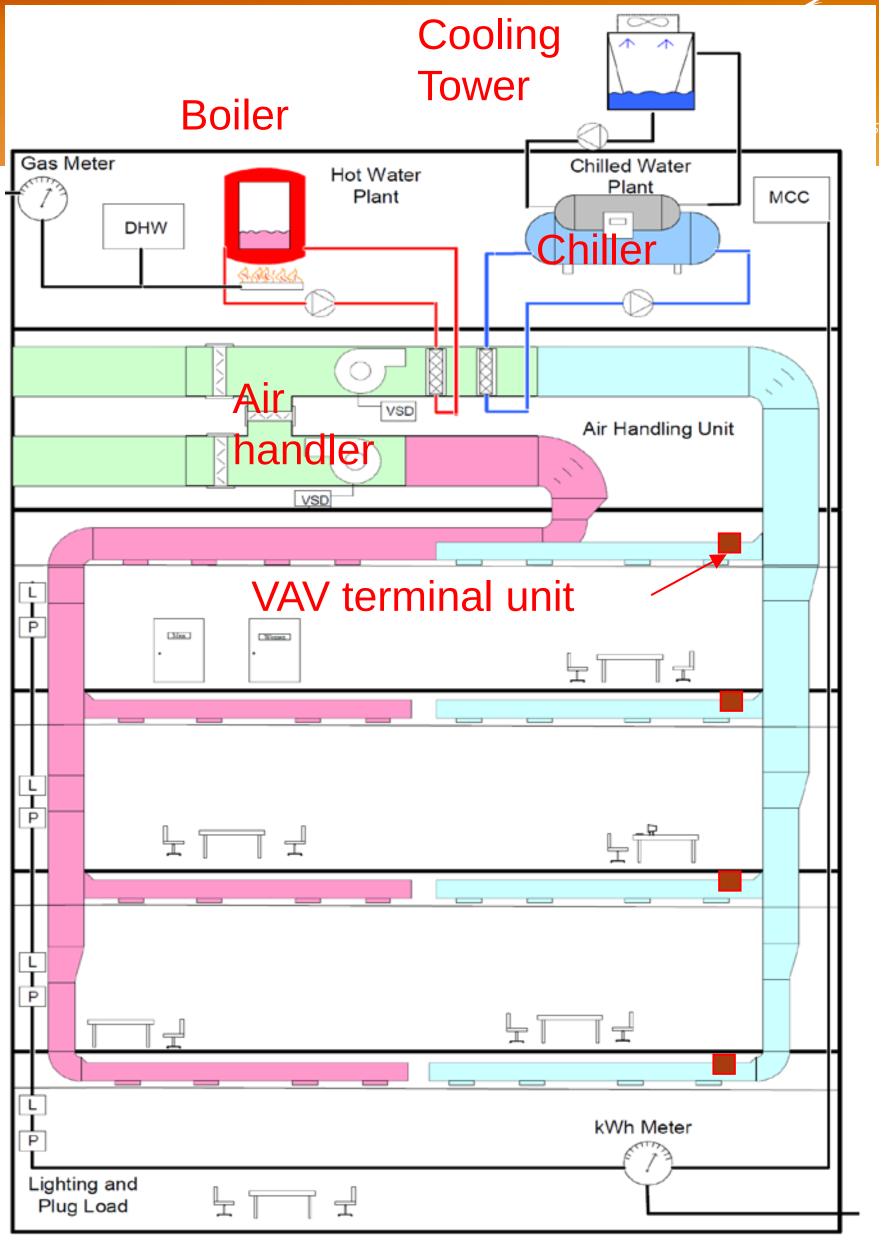
Multiple zone system example: VAV terminal unit (VAV Box)



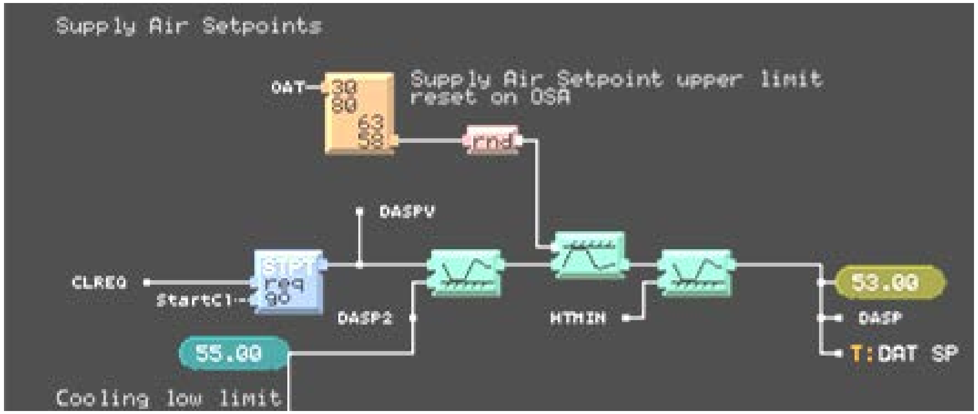
Tying it all Together

A typical large building commercial HVAC system:

- Central plant:
  - Boiler
  - Cooling Tower
  - Chiller
- Distribution
  - Pumps
  - Pipes
  - Control valves
- Secondary System
  - Air handler
  - VAV terminal units



High Energy Impact Complex Controls



Warning! Controls can be complicated!

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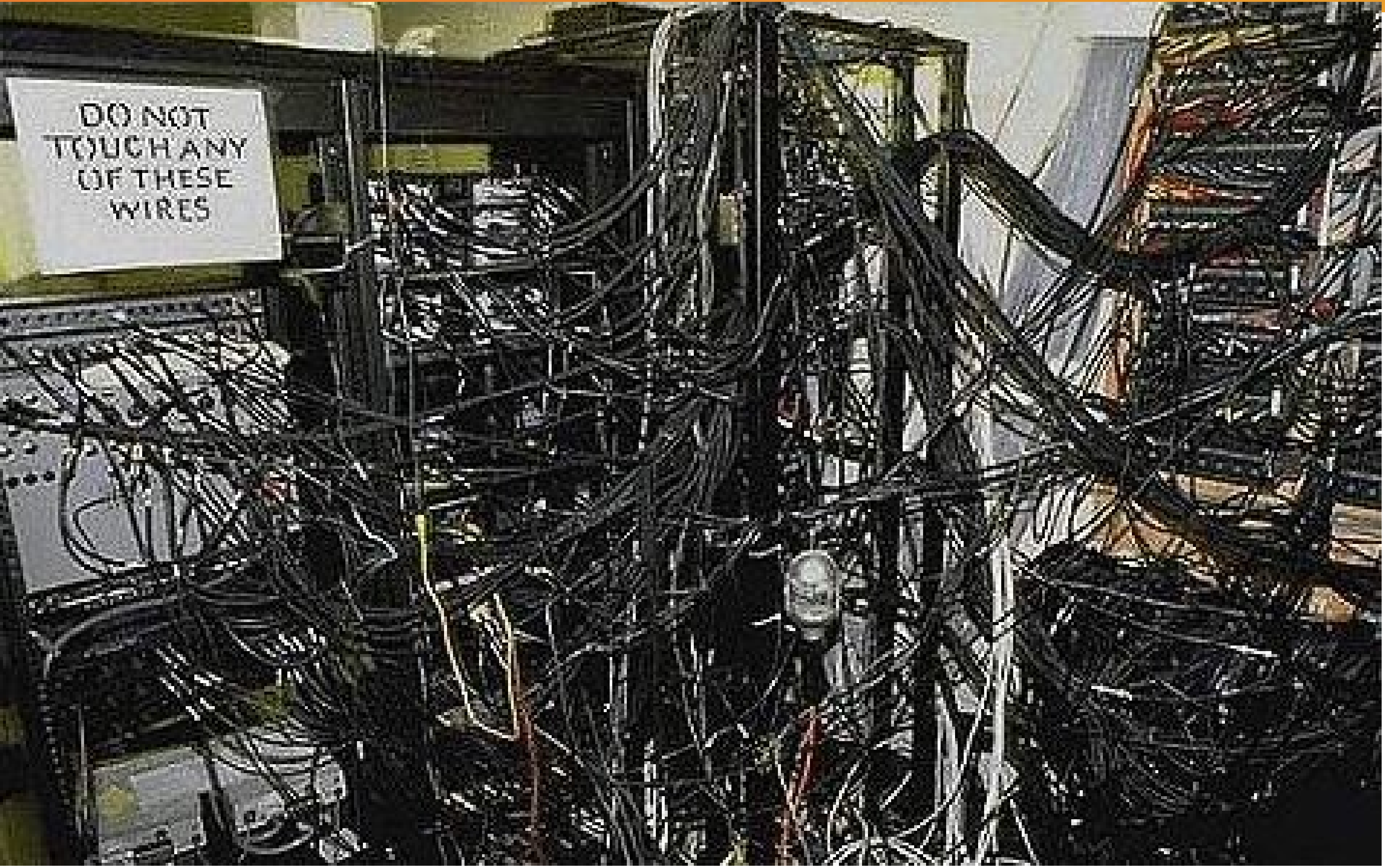
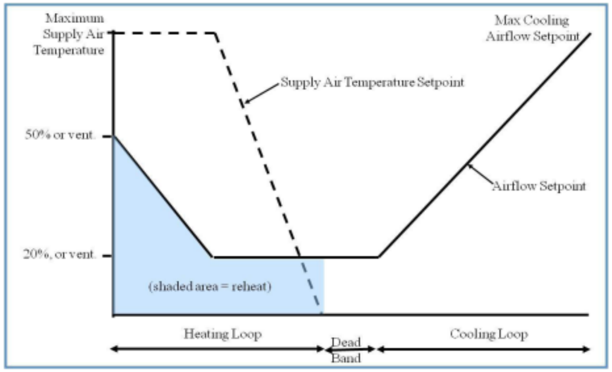


Source: Bob Davis at Ecotope

Top of the Charts

- Most impactful basic HVAC control measures*
  - Snow and ice melt heater control
  - Temperature setback scheduling
  - Full 5 degree thermostat deadband
  - Economizer controls



- Additional impactful complex HVAC control measures
  - Full 5 degree thermostat deadband
  - Limits on simultaneous heating and cooling (VAV reheat)
  - VAV ventilation optimization (C403.4.4.6)
  - Supply air temperature & fan static reset controls
- Other impactful HVAC measures*
  - Exterior ductwork insulation (C403.2.9)
  - Fan power within limits
  - Proper equipment sizing

*Rosenberg, M., Hart, R., Athalye, R., Zhang, J., Wang, W., and Liu, B. (2016). "An Approach to Assessing Potential Energy Cost Savings from Increased Energy Code Compliance in Commercial Buildings." PNNL for USDOE. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24979.pdf

Deadband & Reheat Limit for VAV Boxes

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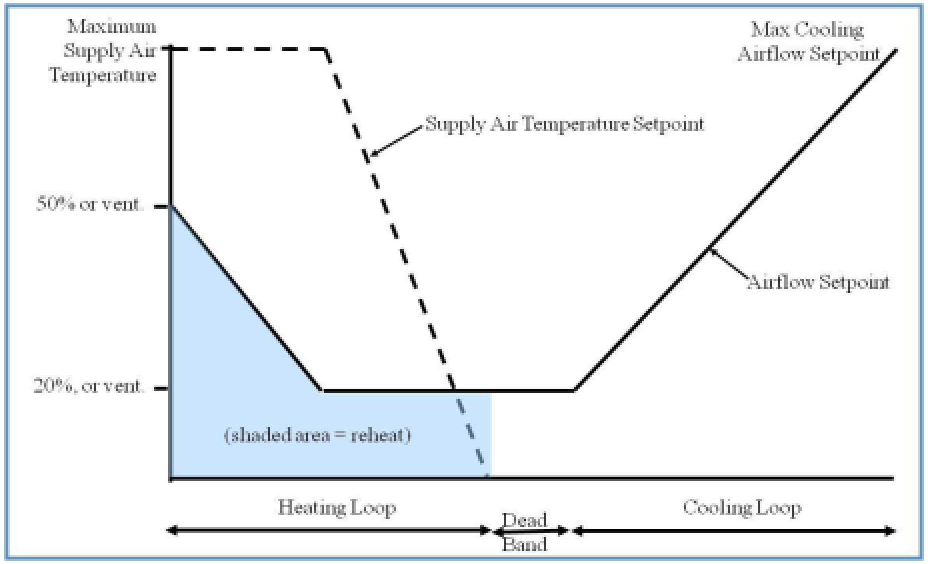
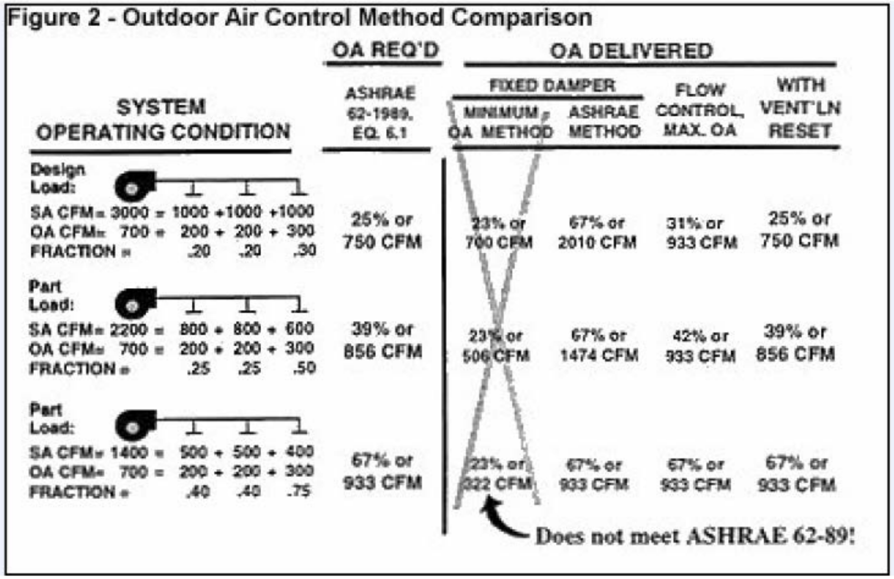
- The deadband requirement applies to VAV boxes too!
  - Just because the lease specification says "temperature shall be maintained at ± 2°F," does not allow a 1°F deadband
  - A 5°F temperature deadband is still required
  - This means separate heating and cooling setpoints are needed
- Between the heating and cooling operation:
  - VAV minimum damper positions shall be maintained
  - The reheat valve is closed
- Minimum ventilation reduces reheat of cooled air
  - 30% of design airflow, or
  - Higher % if saves energy, or
  - Required ventilation



Source: http://energycodeace.com/site/custom/public/reference-ace-2013/index.html#!Documents/56hvaczonelevelsystems.htm

VAV System Ventilation Optimization

- A new requirement in 2015 IECC (C403.4.4.6)
  - Adjusts the primary system outside air rate based on actual box operation
    - Ventilation design is based on VAV boxes at minimum setting
    - When zone supply air is higher than minimum, less outside air is needed at the primary fan to meet ventilation needs in all zones
    - The critical zone for ventilation changes, based on actual cooling loads
- Related to the multi-space ventilation equation in IMC & 62.1
- Significant ventilation air savings at part occupancy loads and higher cooling loads
- *Usually requires commissioning (C408) to verify*



Source: http://internal.trane.com/commercial/uploads/pdf/866/VentilationFanPressureOptimization.pdf

VAV Primary SAT and SP Reset Saves

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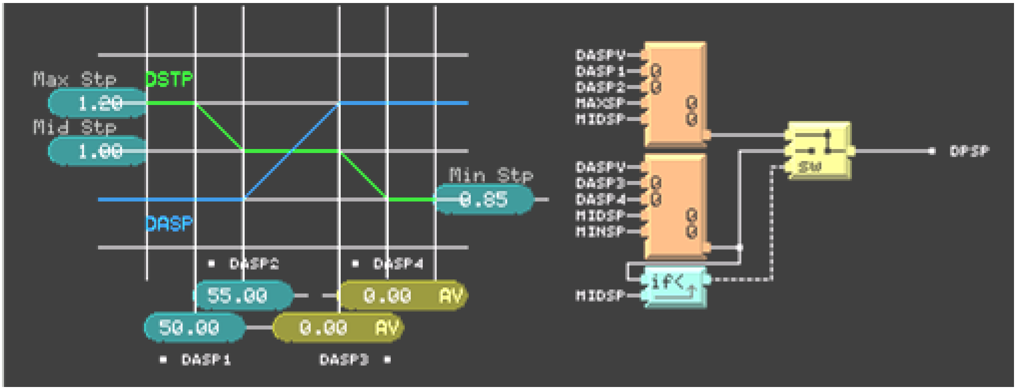
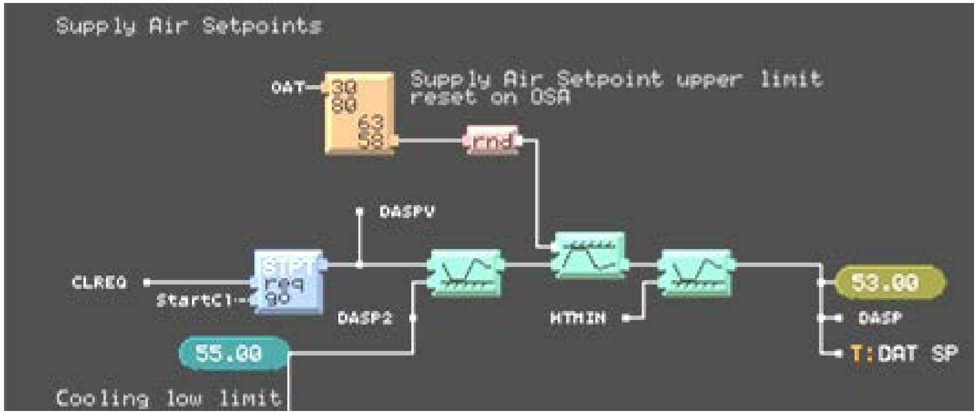
- Reset primary supply air temperature (SAT) (C403.4.4.5)
  - Save with less reheat
  - Tradeoff with fan energy: reduce upper limit when no economizer
  - Improves comfort by reducing terminal gain



- Coordinate with static pressure reset (C403.4.1.3)
  - Saves fan energy
  - Static pressure sensor location near terminal boxes (C403.4.1.2)
- *Usually requires commissioning to verify*



Hydronic System Controls

Hydronic System Purpose & Components

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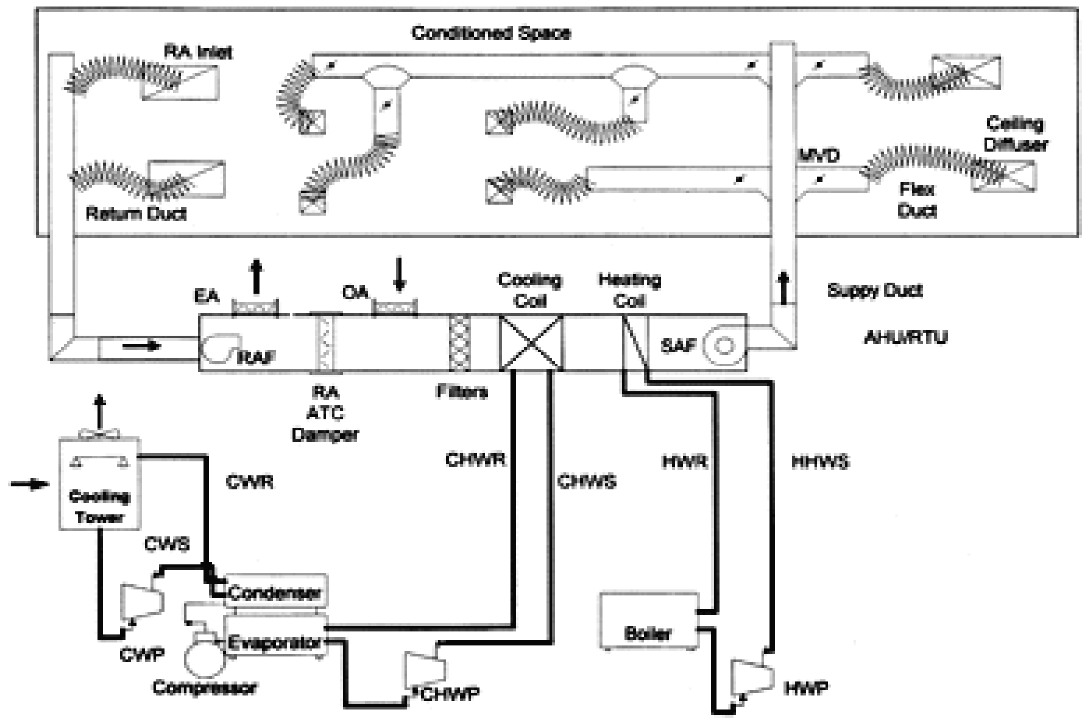
- The hydronic system connects the central plant sources of chilled and heated water to the cooling and heating coils in the secondary HVAC systems
- The system includes
  - Pumps
  - Piping
  - Control valves
  - Heat exchangers (coils)
- Most hydronic systems are required to have variable flow (C403.4.2.4)



Source: http://affordablehousinginstitute.org/blogs/us/2014/08/thats-rich-harbor-towers-part-8-the-hvac-replacement-a-certain-godlike-remoteness.html

Hydronic Flow Requirements for Chillers/Boilers

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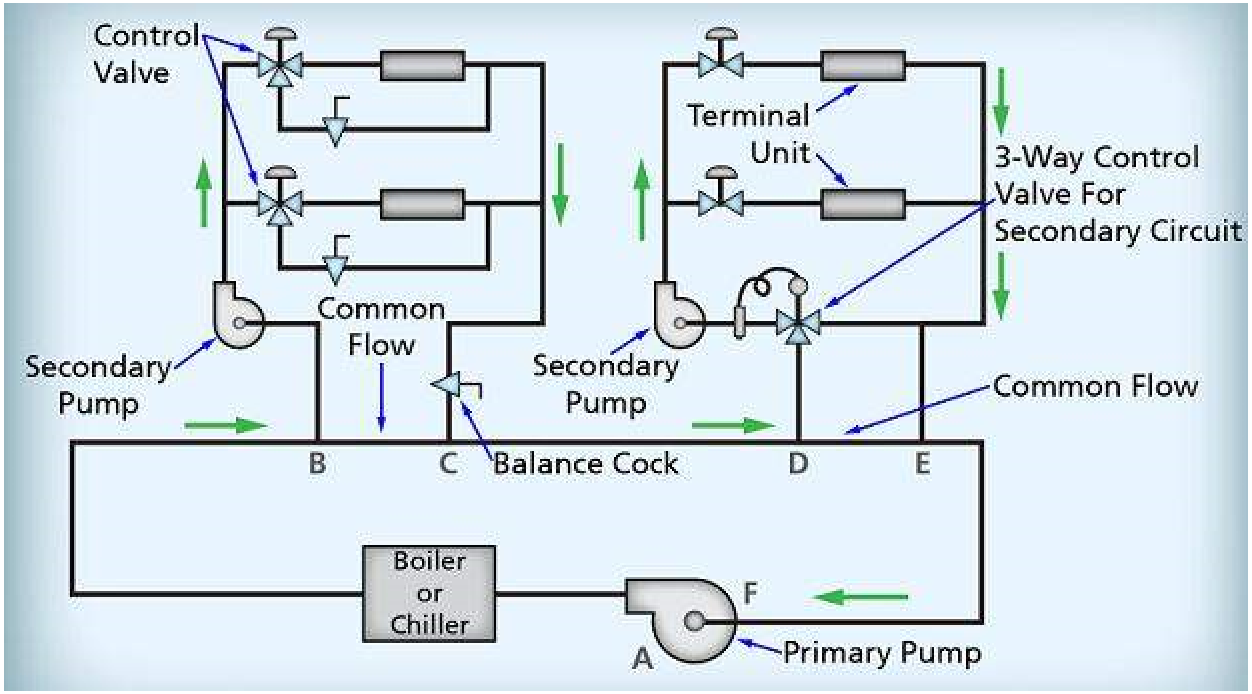
- Hydronic systems have two main flow requirements (C403.4.2.4):
  - Variable flow when total pumping is ≥10 hp and capacity ≥ 500 MBH
    - That means mostly 2-way valves!
  - Isolate large primary equipment when not needed for load
- Verify on plans or in the construction documents

Constant Flow   Variable Flow

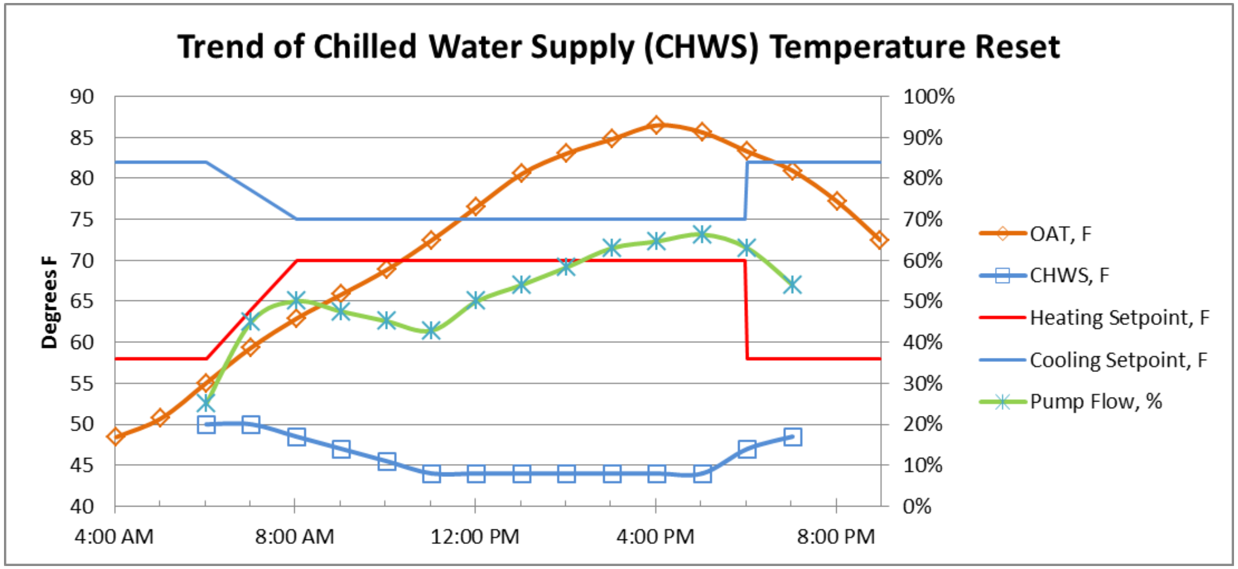


https://www.myodesie.com/wiki/index/returnEntry/id/2990

Source: https://www.belimo.us/americas/ccv.html

Hydronic Temperature Requirements for Chillers/Boilers

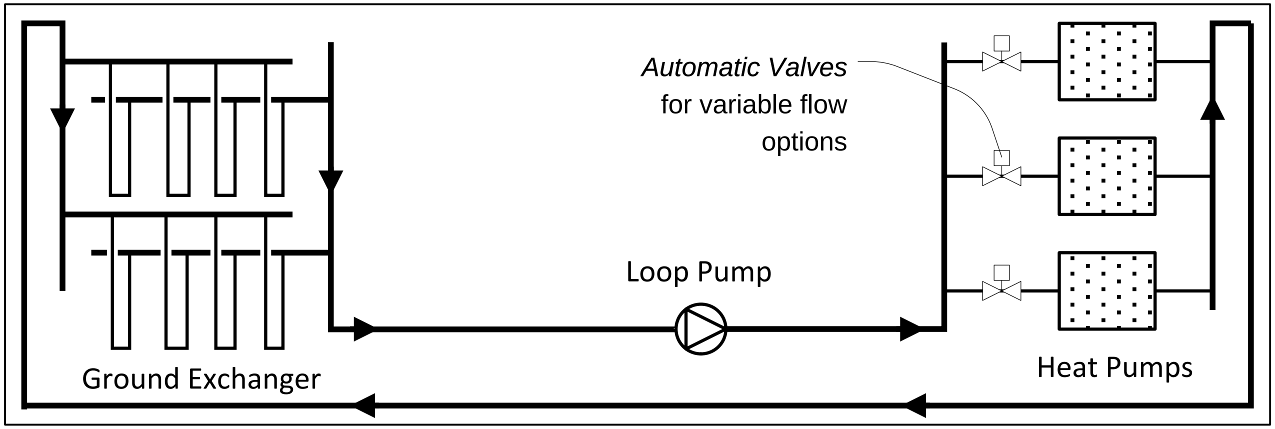
- Automatically reset supply water temperature (C403.4.2.4):
  - Reset by at least 25% of difference between design and return
  - Reset can be based on OSA, return temperature, or zone demand
  - Chilled water reset allows the chiller to operate more efficiently
  - Heating water reset reduces distribution losses
- Verify in the construction documents/control sequences
  - Commissioning report should indicate temperature reset (C408)
  - Can see in trend plot on DDC system



Operating the chiller at a higher CHWS supply temperature than design conditions reduces the lift done by the compressor and saves significant energy.

WSHP Hydronic Requirements

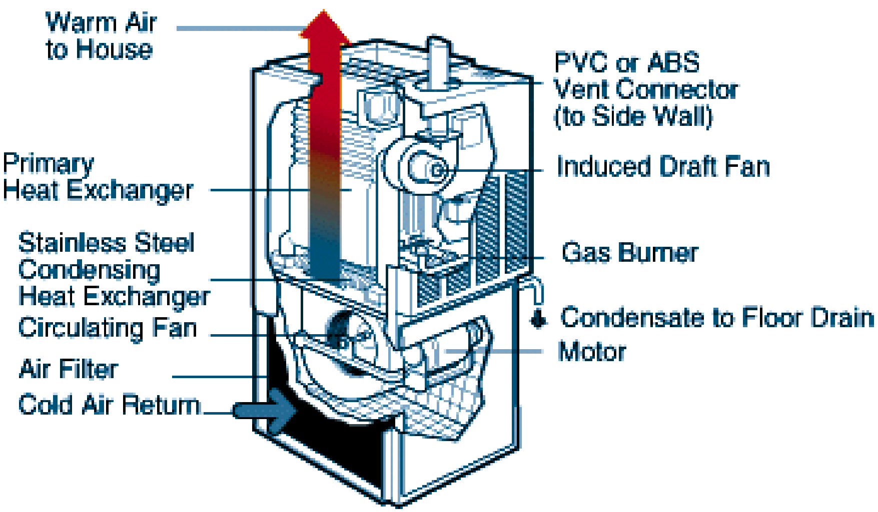
- Water source heat pumps (WSHP) can be:
  - Geothermal
  - Have boiler and heat rejection
- C403.3.2.3



Source: Hart, R & W. Price. 2000. "Improving Heat Pump Efficiency." ACEEE 2000 Summer Study.

- Pumping power can be very large in these systems if uncontrolled
  - Minimum requirement when pump motors total more than 10 HP is for a valve on every heat pump to reduce flow and ride the pump curve
  - Heat rejection isolation based on climate zone
- Important controls:
  - Maintain minimum 20°F deadband between loop heating and cooling for loops with boilers and heat rejection cooling towers

HVAC High Efficiency Option



Condensing Furnace

Source: http://homeenergy.org/show/article/id/1197

High Efficiency HVAC Option (C406.2)

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- All equipment must exceed efficiency requirements by 10%
- Equipment not listed limited to 10% total capacity
  - Electric heat limited; VRF not listed

Examples: Increase heat pump efficiency or chiller/boiler efficiency:

Equipment	Rating Metric	2015 IECC	10% efficiency Improvement
Air-source heat pump, 3Φ 65 to 135 MBH (5.4 – 11.3 tons)	Cooling, EER	11.0	12.1
	Cooling, IEER	12.0	13.2
	Heating, HSPF	8.0	8.8
Chiller efficiency (Path A) Air cooled, ≥ 150 tons	EER	10.1 FL 14.0 IPLV	11.11 FL 15.4 IPLV
Boiler efficiency Gas, 300-2500 MBH	Et	80%	88%

- Package units with furnaces are unlikely to meet extra efficiency requirements
  - Split system with indoor condensing furnace can meet requirement
  - Some gas duct heaters can also meet condensing efficiency requirements
- High efficiency VRF systems reference standard 90.1-2013

Summary: Top of the Charts

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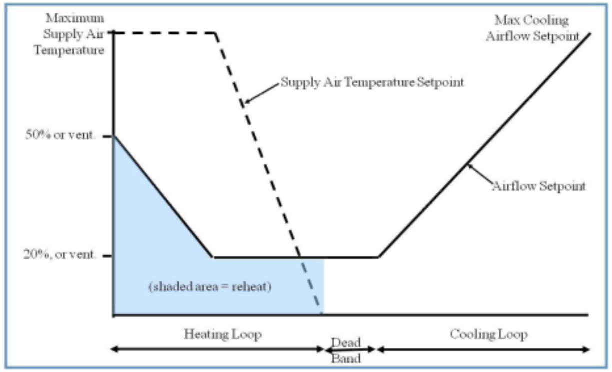

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Conclusion

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- HVAC systems provide the following:
  - Comfort: heating and cooling; humidity control
  - Ventilation, filtration, air movement
- System configurations:
  - Unitary (split and packaged) or small packaged systems for single zones
  - Packaged DX VAV unitary systems serving multiple zones
  - Central plants with secondary and zonal HVAC systems
- Important energy factors are:
  - Controls that save energy: setback, deadband, economizer, resets
  - Fan energy limits, duct insulation, snow melt controls
- Energy codes provide valuable requirements for HVAC savings

U.S. DOE: Building Energy Codes Program Resources

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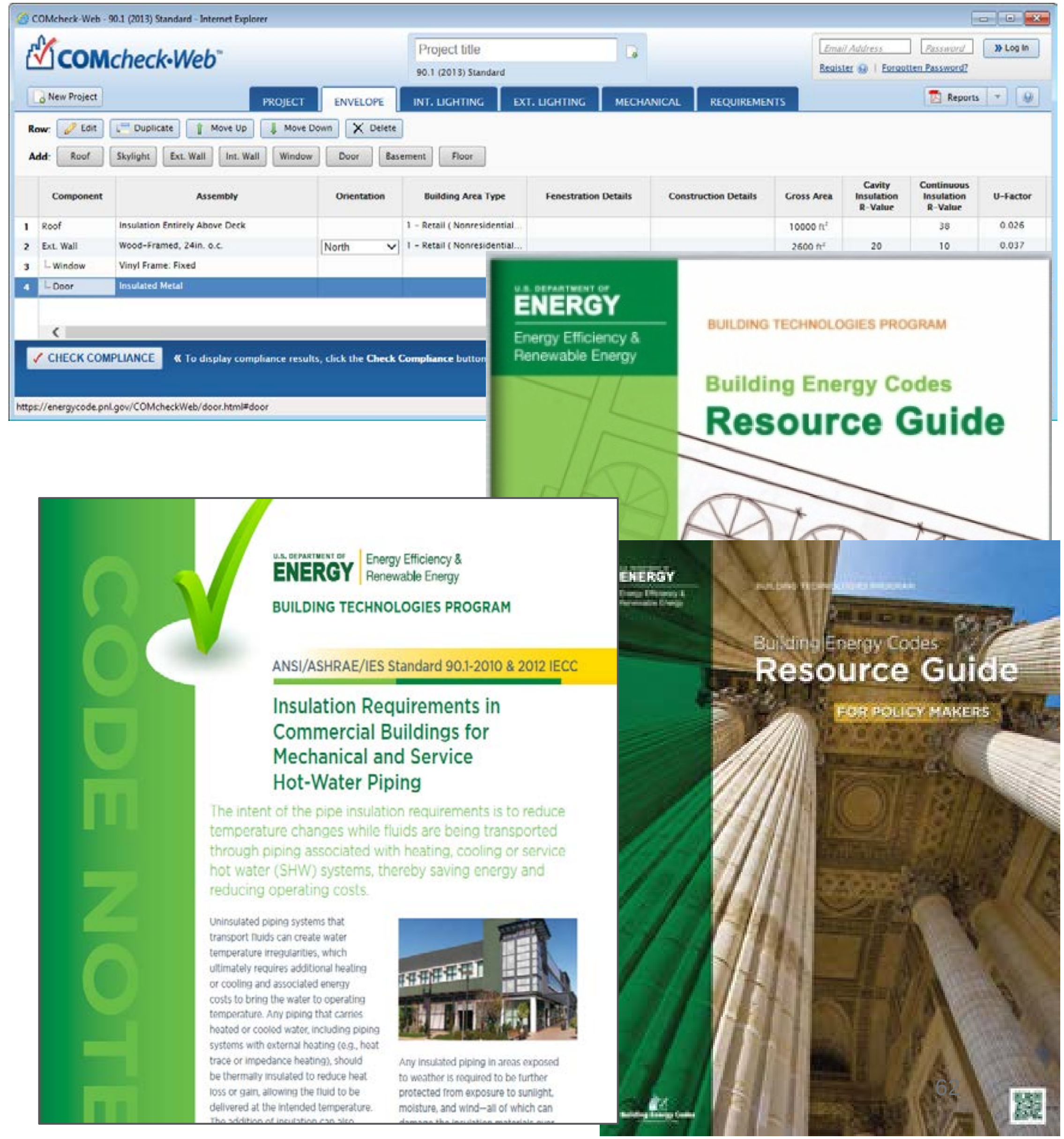
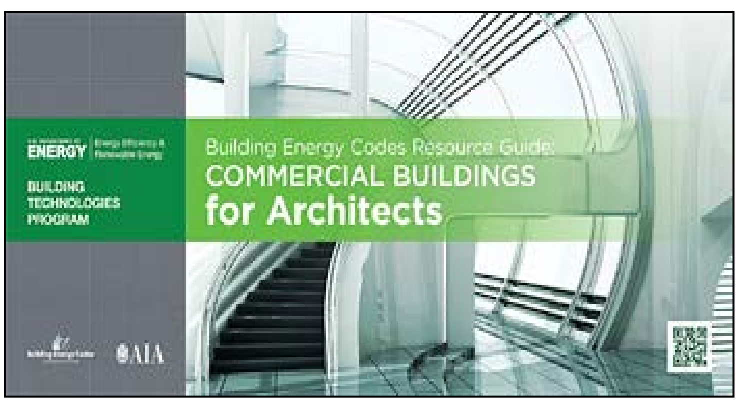
- Compliance software
- Technical support
- Code notes
- Publications
- Resource guides
- Training materials

www.energycodes.gov





THANK YOU!

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Building Energy Codes Program

www.energycodes.gov

BECP help desk

https://www.energycodes.gov/HelpDesk

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