



Air System Design

Air System Controls



What you will Learn in this Lesson

- Economizer control
- Space temperature control
- Unitary control
- Cooling coil control
- Heating coil control
- Mixed air temperature control
- Air volume control
- Building pressure control
- IAQ control

Control Options

- The number one job of the designer is to maintain an indoor environment suitable for the building owners use
- How that environment is controlled is up to the designer
- Choices available to the designer vary in complexity, performance, and cost

Requirements for Effective Control

- Properly design air distribution to spaces
- Properly design air distribution within spaces
- Properly design and select heating and cooling coils
- Properly locate all sensor elements
- Properly size control valves
- Properly provide effective safeties for heat and cold
- Properly provide good part load modulation
- Properly provide good IAQ management

Properly design air distribution to spaces

- Start with a correct space load
- Choose an appropriate energy distribution
 - All air
 - All water
 - Air-water
- Choose an appropriate ventilation distribution
 - For all air systems you can use full sized ductwork
 - For all water systems you need a local source of fresh air (ex. natural ventilation)
 - For air-water systems you can use a DOAS

Conditioning system options

- Three types of energy delivery

Air-Water

All Air

All Water

All Water Systems

- Heating and/or cooling provided by direct heat transfer between an element and the space air temperature
- Both heating and cooling can be accomplished through convection and radiation with systems such as:
 - Baseboard
 - Radiant panel
 - Radiant floor
 - Induction unit
 - Convector

All Air Systems

- No direct heat transfer between a water heat exchanger and the space air
- Heat transfer occurs using force air at a temperature and humidity appropriate for the space
- There is always at least one fan involved
- There is always at least one conditioning coil involved
- Heat transfer includes the mass transfer of air
 - Central air handling systems

Air-Water Systems

- Air-water systems condition spaces by distributing air and water resources to terminal units installed in habitable space throughout a building
- Terminal unit is sized for the space load
- Terminal unit is controlled by a space sensor
 - Fan coils
 - Induction units
 - Unit ventilators
 - Active chilled beams
 - VAV boxes

Properly Design Air Distribution within Spaces

- Delivering energy to a space is only half the design
- Conditioning the air within the space to acceptable levels uniformly is essential
- The object of air diffusion in warm-air heating, ventilating, and air-conditioning is to create the proper combination of temperature, humidity, and air motion in the occupied zone
- ADPI is the measurement of that diffusion

Air Diffusion Performance Index (ADPI)

- ADPI is based on an empirical analysis that says a high percentage of people are comfortable in sedentary occupations when the effective draft temperature is between -3 and +2°F
- Effective draft temperature

Effective Draft Temperature

- A draft is any localized feeling of coolness or warmth of any portion of the body caused by both air movement and air temperature
- It is measured from a base condition:
 - 76° F db in center of a room, 30 in above the floor at 30 fpm

Effective Draft Temperature

$$\Theta_{ed} = (T_x - T_c) - 0.07(V_x - 30)$$

Where:

Θ_{ed} = effective draft temperature, °F

T_x = local airstream temperature, °F

T_c = average room db temperature, °F

V_x = local airstream velocity, fpm

Air Diffusion Performance Index (ADPI)

- The ADPI is the percentage of test points in a space where the effective draft temperature and velocity meet the criteria:
 - $V \leq 70 \text{ fpm}$
 - $-3^{\circ}\text{F} \leq \Theta \leq 2^{\circ}\text{F}$

Air Diffusion Performance Index (ADPI)

- Average air temperature = 77.8°F
- Average air velocity = 65 fpm
- Number of points:
 - Total 100
 - Within limits 80
- $ADPI = 80/100 = 0.8$

Properly design and select heating and cooling coils

- Coils are selected to meet the required maximum SYSTEM LOAD
- Do not oversize coils to improve controllability
- Use preheat coils when OA needs to rise more than 35°F to reach desired mixed air temperature
- Choose coils with a favorable aspect ratio

Properly locate all sensor elements

- Sensors can be placed in locations that do not represent the average air temperature
- Place room sensors on an inside wall near a return grill
- Place duct temperature and humidity sensors in an unstratified air mixture
- Place air pressure and flow sensors away from immediate fan discharges and provide with capacity tanks where necessary to reduce surges and pulsations.

Properly size control valves

- A common mistake in design is the improper size of control valves and dampers
- Three-way valves have two types:
 - Diverting: common port is inlet
 - Mixing: common port is outlet

Provide Effective Safeties for Heat, Cold and Pressure

- All air systems need some safeties to protect the equipment
 - Protect the coils, drain pans, fans and motors from dirt
 - Protect the coils from freezing
 - Protect the ducts from exploding or collapsing

Provide Good Part Load Modulation

- Air volume control is difficult to control but critical in VAV systems
- Air pressure control is easier
- Low load control can be difficult when control devices are oversized

Provide Good IAQ Management

- Outdoor air flow management has challenges
- Outdoor air volumes depend upon several things
 - Occupancy
 - Building area
 - Air diffusion efficiency
 - Activity

Control Options

- Choice of thermal zones
- Choice of control complexity
- Choice of control accuracy
- Choice of management
- Choice of supervision
- Choice of recordability

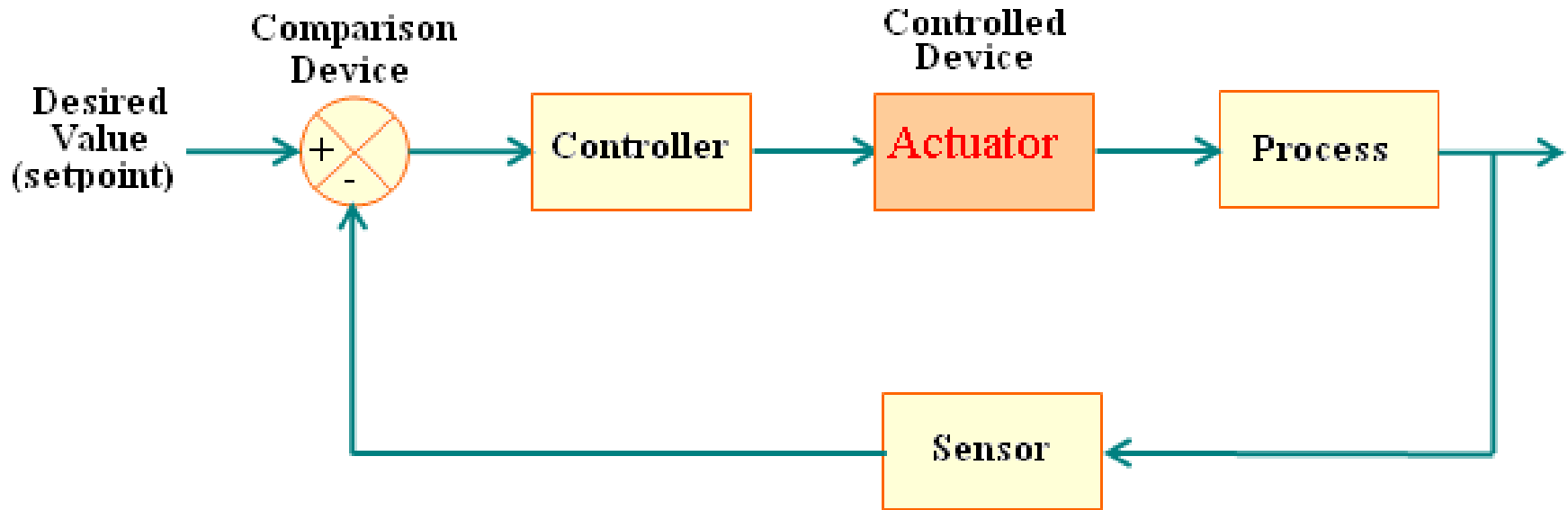
Choice of Thermal Zones

- A thermal zone is any space or combination of spaces that is controlled by a single temperature sensor or thermostat
- Some designs which place an emphasis on economy of initial building construction will limit the number of thermal zones.
- Single zone buildings have the simplest controls

Control Complexity

- The simplest control is a two position switch which starts and stops a fan and/or a coil to heat or cool a space
- The opposite extreme has an enterprise building automation system with trending, recording, remote monitoring, remote control, and multiple schedules and optimization schemes

Control Complexity



Control Loop Diagram

Control Accuracy

- Two position control

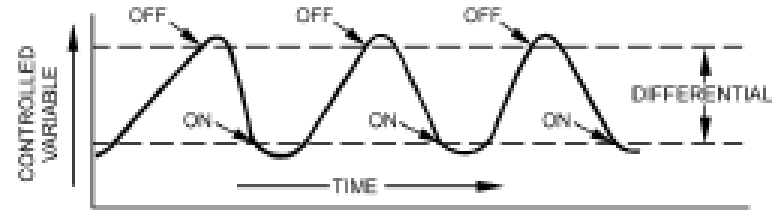


Fig 4 Two-Position Control

- Proportional control

$$V_p = K_p e + V_0$$

- Proportional Integral

$$V_p = K_p e + K_i \int e dt + V_0$$

- PID

$$V_p = K_p e + K_i \int e dt + K_a \frac{de}{dt} + V_0$$

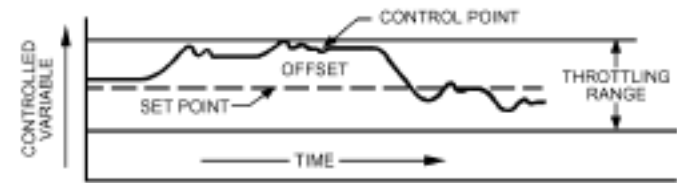


Fig 5 Proportional Control Showing Variations in Controlled Variable as Load Changes

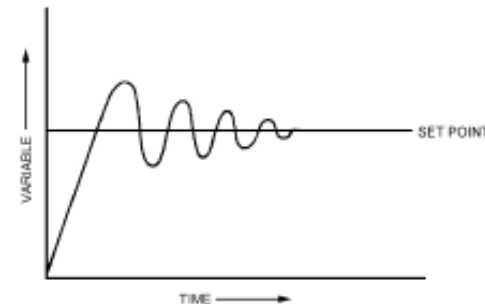


Fig. 6 Proportional plus Integral (PI) Control

Control Accuracy

- Floating point control
- Used with reversible operators
- Uses two digital outputs that drive a control device open or closed
- The operator fails as-is

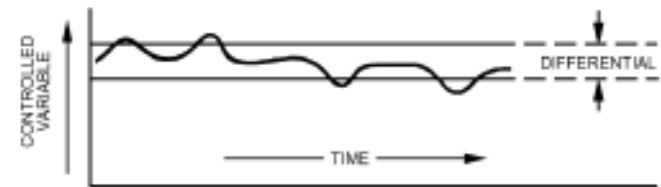


Fig. 7 Floating Control Showing Variations in Controlled Variable as Load Changes

Control Management

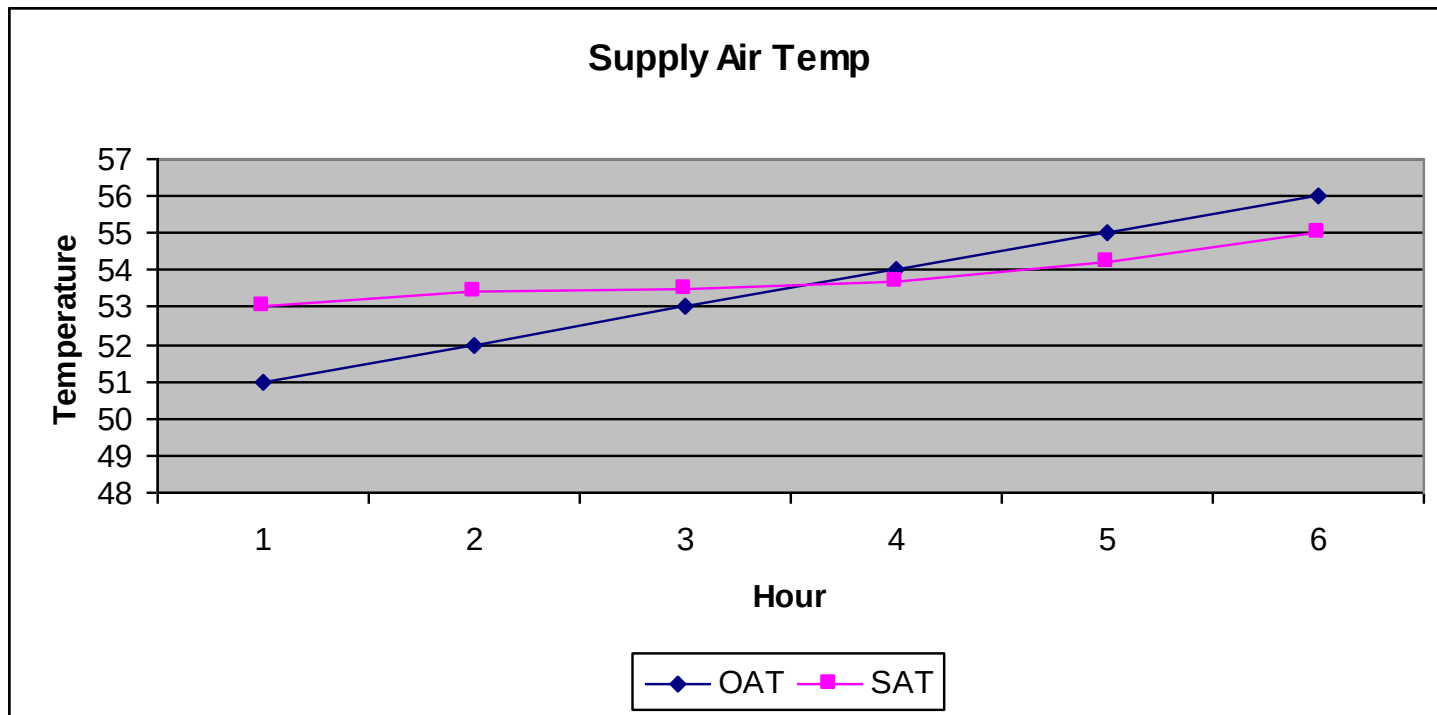
- Temperature control is relatively simple
- Temperature control management is complicated
 - Someone must be responsible
 - That someone must be knowledgeable
 - Someone must have access to the controls
 - Someone must be watching

Control Supervision

- Buildings need to be supervised more or less constantly to perform well
- Supervision can happen by personal inspection or by remote monitoring
- Certain key parameters are watched to judge the performance of each HVAC system
 - Discharge air temperature
 - Chilled water supply temperature
 - Space temperatures
 - Space pressures

Control Recordability

- The most useful tool in the energy managers toolbox is the trend analysis



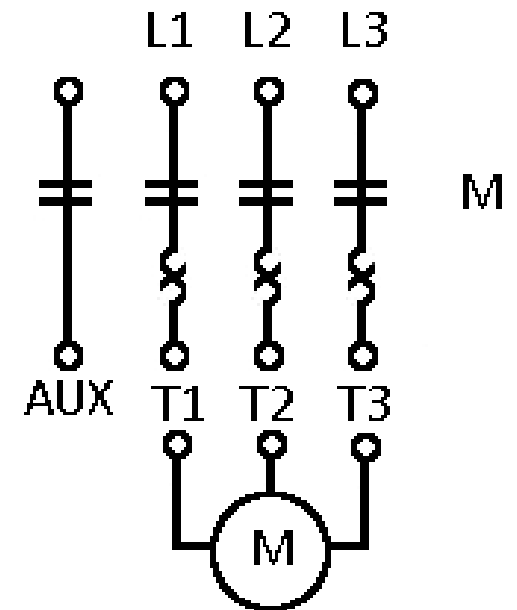
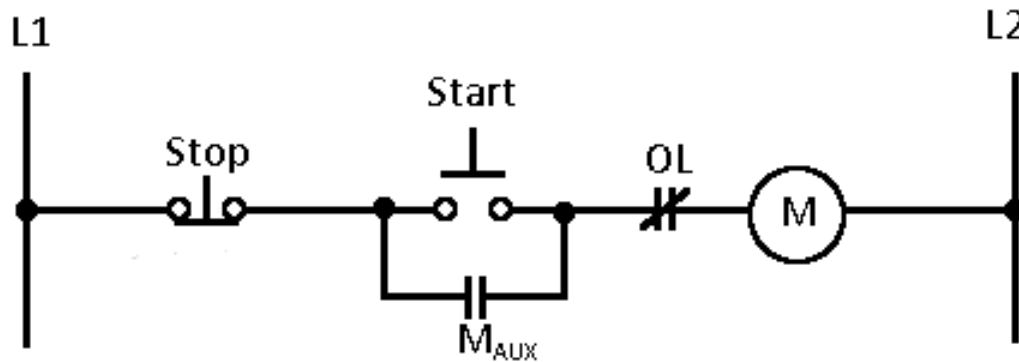
Simple Fan Start/Stop Control

- The most common and simplest control is the starting and stopping of a motor such as a fan
- Two common motor starters are: HOA and push button

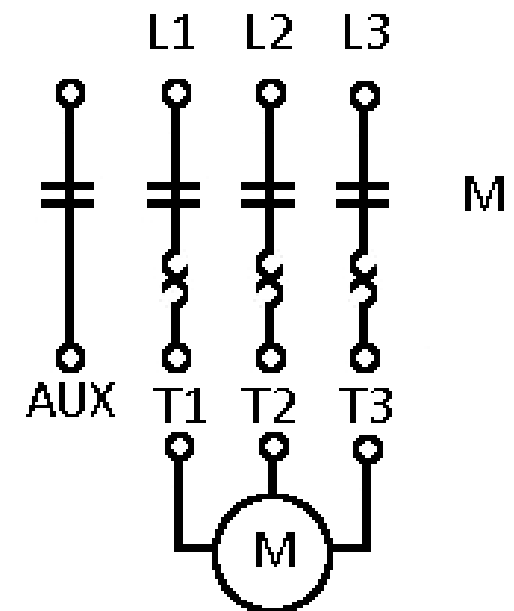
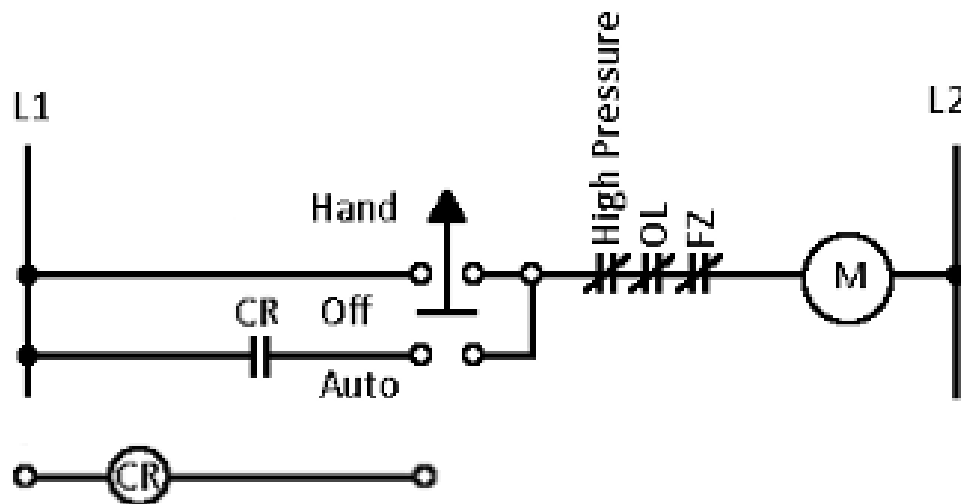
Simple Fan Start/Stop Control

- Simple push button control will start and stop a motor subject only to the control fuse and the safeties on the windings
- HOA (hand-off-auto) will allow a remote control of the motor
- An automation system of any type can command the motor to start

Simple Fan Start/Stop Control



HOA (Hand-Off-Auto)



Simple Fan Start/Stop Control

- Automation examples:
 - Time clock
 - Remote switch
 - Low voltage relay contact
 - Auxiliary contact from another motor starter

Mixed Air (Economizer) Control

- MA control can be very simple or extremely complicated
- The simple control uses a mixed air sensor to operate one actuator which opens or closes two dampers
- A more complicated control adds in the cooling coil in sequence with the dampers. An economizer switch turns off (closes) the OA damper at some fixed set point of outside air temperature or calculated enthalpy

Mixed Air (Economizer) Control

- A special case occurs when the cooling coil is DX rather than chilled water
- Low part loads cause DX compressors to short cycle
- An economizer switch can use one of several types of control:
 - OA dry bulb limit
 - OA enthalpy limit
 - OA & RA dry bulb differential
 - OA & RA enthalpy differential

Space Temperature Control

- Ultimately, HVAC is all about controlling the temperature in an occupied space
- Space temperature control (STC) is the best feedback mechanism to regulate the flow of energy into or out of a space environment
- STC is used in every kind of HVAC system:
 - Unitary
 - Central AHU
 - All Air; All water; and Air-Water
- It can be used to control a single zone AHU

Space Temperature Control

- Simple space temperature control is common in small unitary and single zone rooftop AHUs
- It is used in place of a discharge air control scheme
- In all water and air-water systems the control can get complicated
 - VAV has reheat and minimum air flow requirements
 - Both reheat and baseboard or radiant panel heating is controlled by a single sensor
 - Reheat and baseboard valves must be coordinated

Unitary Control

- Unitary systems are usually very simple
- Thermostats provide on-off control of one or two devices
- Cooling is often on or off
- Heating may be one or two stages using a gas furnace, an electric coil, or a heat pump coil
- Fans may have multiple speeds and are either automatic or manually controlled
- More complicated thermostats will have a dead band between heating and cooling stages

Unitary Control

- A thermostat is often a dial labeled “warmer” and “cooler” without any temperature indication
- Some unitary equipment may offer an option to open an outside air damper for fresh air
- A common element of unitary equipment is the combination of a compressor, evaporator and condenser all in the same cabinet with optional heating coils
- Unitary equipment nearly always comes with factory controls

Cooling Coil Control

- Cooling coils have three types of control:
 - Modulating chilled water
 - 2-position direct expansion
 - Modulating direct expansion
- 2-position DX control can be accomplished with an electric thermostat in the space. No additional controller is needed for a single zone system
- Any modulating control needs some type of controller

Cooling Coil Control: 2-Position

- 2-position control DX
- The liquid line solenoid valve controls the cooling coil
- Timers are needed to protect the compressor from short cycling
- Not recommended for discharge air control

Expansion Valve Control

- The expansion valve on a DX coil is a special case
- This valve modulates to the temperature in the liquid line
- It doesn't sense the air temperature

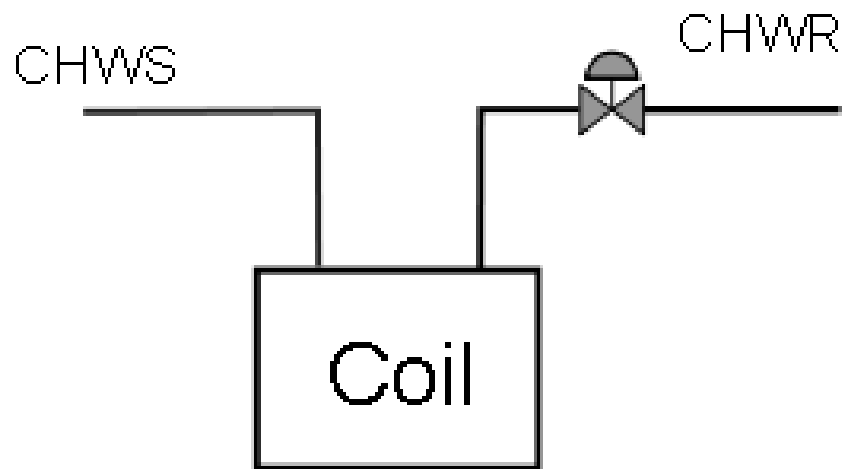
Cooling Coil Control: 2-Position

- A DX system that has multiple stages can make use of a discharge air control
- The DAT must be allowed to drift even with staging of cooling to prevent short cycling.

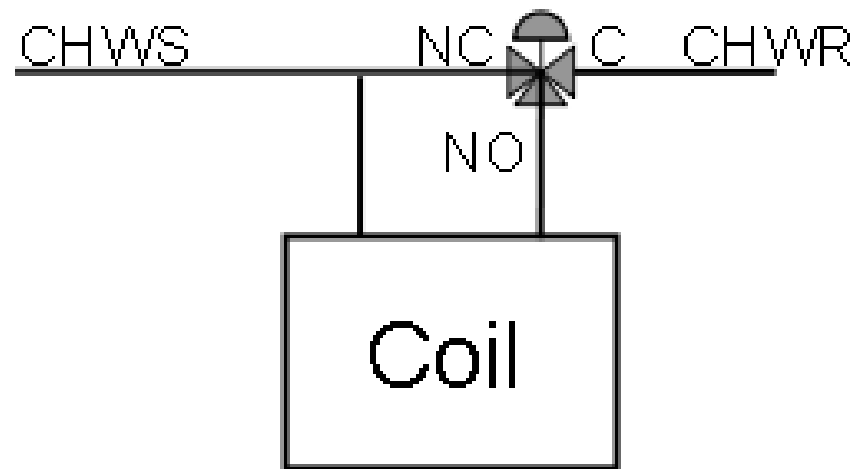
Cooling Coil Control: Modulating

- 1) The DAT is held constant and tightly controlled as long as the chilled water temperature remains at design conditions. Primary water flow is constant and air flow is constant. This design has the highest energy use
- 2) The primary water flow is variable and the DAT is held constant as long as the CHW temperature is at design and the coil is capable of maintaining DAT at reduced air flow

Variable Flow



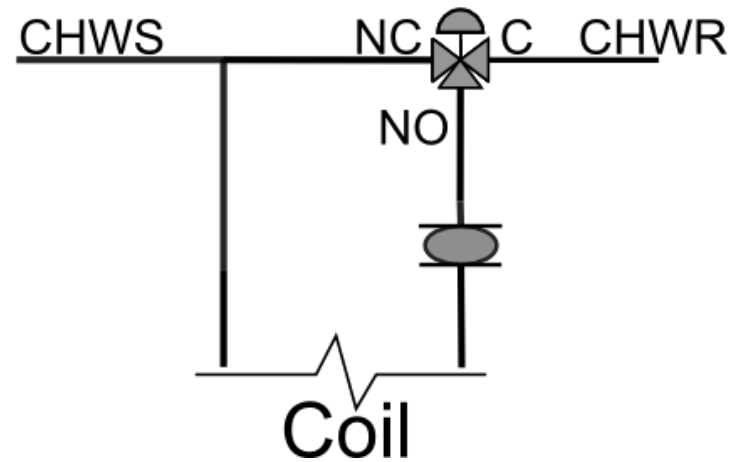
Constant Flow



Cooling Coil Control: Modulating

- 3) Secondary (or tertiary) pumping of cooling coils is done for several reasons
 - A. to ensure a coil receives the full design water flow rate at all times
 - B. to protect the coil from freezing
 - C. to boost the pressure from inadequate water distribution
- The chilled water supply has only one possible path which is through the coil and into the pump suction. The temperature of the water entering the coil will rise as the three-way valve modulates closed. This valve fails to full flow from the primary water. Water flow through the coil remains constant.

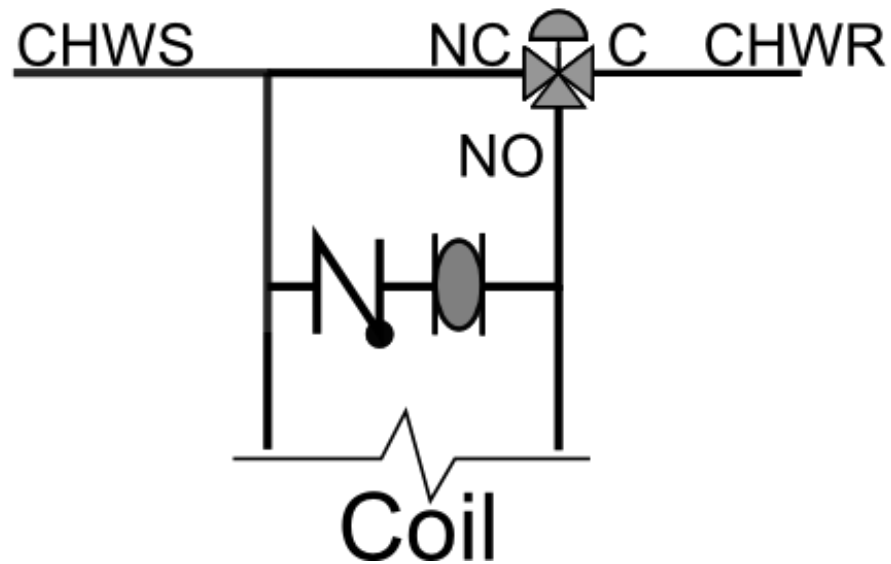
Series Secondary Variable Primary



Cooling Coil Control: Modulating

- 4) Parallel Secondary and Constant Primary piping arrangement takes the pump out of the main flow to the coil. The check valve prevents CHW from by passing the coil. The ports on the 3-way valve must be arranged as shown for this scheme to work. This piping prevents freezing but will work well even if the pump is off

Parallel Secondary Constant Primary



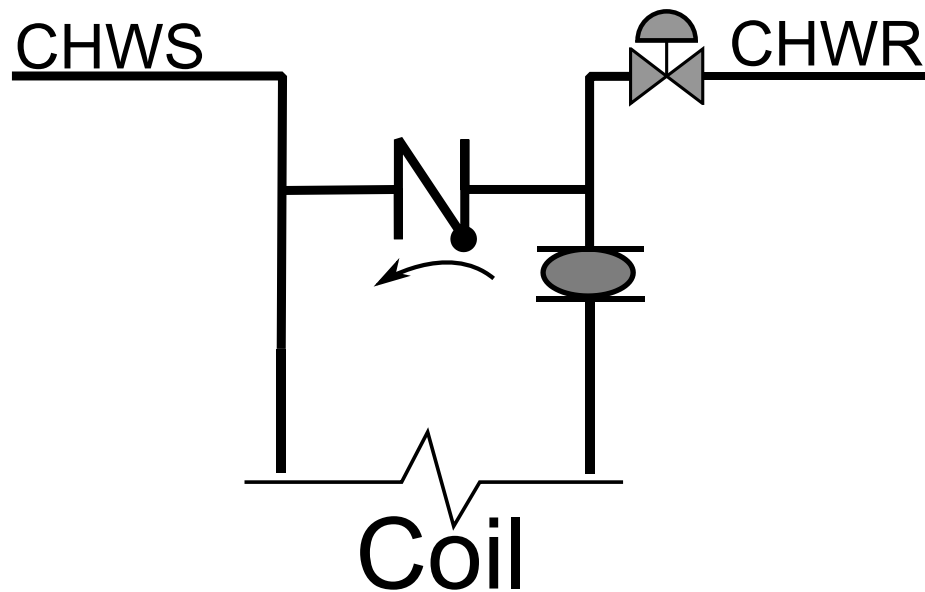
Effect of high Entering Water Temp

- The temperature of the water entering the coil has a large impact on the coils ability to generate a design delta T.

Cooling Coil Control: Modulating

- 5) Series secondary: variable primary is very similar to constant primary except for the control valve is now a 2-way. The secondary pump must always run. As the control valve closes the EWT to the coil increases
- 6) Parallel secondary: variable primary is probably the best piping arrangement of all six. The secondary pump is not in the main flow to the coil and the coil will perform normally without the pump running

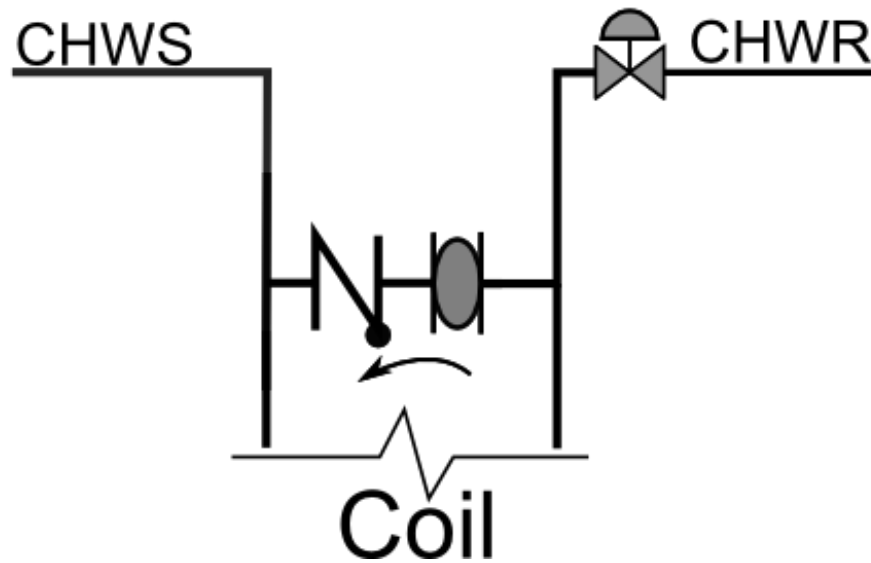
Series Secondary Variable Primary



Cooling Coil Control: Modulating

- Parallel secondary: variable primary is best used when freeze protection is needed in unoccupied times and not needed when occupied. With no secondary pump flow the coil will always receive the lowest possible chilled water temperature. In this scheme the pump does not need to be sized for the full coil flow but can be used for freeze protection only.

Parallel Secondary Variable Primary



Heating Coil Control

- Warm-up cycle
- Preheat
- Face and bypass control
- Steam control
- Hot water control
- Reheat control

Warm-Up Cycle

- Most buildings use a night setback
- A morning set-up will put an instantaneous load on the coil and plant
 - If ΔT changes from 1 to 5°F in a space, that = 80% increase in load

Step increase in heating load

- $Q = 1.08 * \text{CFM} * \Delta T$
- ΔT in the space = Setpoint – Air temperature

Constant Volume Single Zone

- The effect on the coil is the same as the reheat control

Preheat

- In many northern climates a preheat coil is used to temper outside air prior to a cooling coil
- Preheat coils are specially designed to withstand very cold entering air temperatures
- They offset heating requirements associated with ventilation and make-up air; protect the system and building from sub-freezing air.

Preheat Coil IVFB

- Open loop control plus face and by pass control

Reheat Control

- Reheat coils can be used for all or part of the heating load in a space depending upon the climate
- Reheat can also be used in conjunction with baseboard radiation
- The choice of how to divide up the load between reheat coils, air handler coils and baseboard radiation is largely a matter of designer preference

VAV with Reheat

- In VAV with reheat, the load change on the AHU coil is small
- Coil control is by discharge air temp sensor (55°F)

Fan Powered VAV

- FP VAV allows air flow in a space without the AHU running

Air Volume Control

- Variable air volume systems require some type of sensor which will respond to the variation in the cooling load of one or more spaces
- Typically, that sensor is a differential pressure sensor located somewhere in the ductwork downstream from the air handler
- The exact location can't be precisely calculated but it should be somewhere around 2/3 of the way down the critical path
- The setpoint for the sensor is more important

Air Volume Control

- Under design conditions, the set point must be sufficient to push the required volume of air down the critical path to the critical design diffuser.

Noise!

Noise Criteria (NC)									
Inlet Size	cfm	Discharge				Radiated			
		ΔP_s				ΔP_s			
		0.5"	1.0"	2.0"	3.0"	0.5"	1.0"	2.0"	3.0"
12	800	-	-	26		-	22	29	32
	900	-	21	27	29	-	24	30	34
	1000	-	22	28	32	-	25	31	35
	1200	-	24	30	34	21	27	33	37
	1500	20	26	33	36	23	29	36	39
	1800	22	28	34	38	25	31	37	41
	2000	23	29	36	39	26	32	39	42
14	1000	-	-	25	31	-	21	27	30
	1200	-	-	26	31	-	22	28	32
	1500	-	-	26	32	-	25	31	34
	1800	-	20	27	32	21	27	32	36
	2100	-	21	28	32	22	28	34	38
	2400	-	22	29	33	24	30	35	39
	3000	-	24	31	35	26	32	38	41
16	1400	-	-	-	21	-	-	22	25
	1600	-	-	-	23	-	-	24	27
	2000	-	-	23	26	-	22	27	31
	2400	-	21	26	29	-	24	30	34
	2800	-	23	28	31	21	27	33	36
	3200	21	25	30	33	23	29	35	38
	4000	24	28	33	36	27	32	38	42

Controllability

- Manufacturer publishes minimum flows for each size box due to the accuracy of the measuring sensor
- What do you choose for minimum flow?

Box Size	Minimum Flow CFM
12	325
14	450
16	580



Air Volume Control

- An alternative method of controlling a fan speed in a VAV system takes advantage of DDC controls that communicate with each VAV box controller and responds to the actual airflow going through each box

Static Pressure Reset Control

- In DDC, it is possible to send a parameter from the box controller to the BAS that indicates the position of the box damper
- The speed of the fan can be adjusted such that at least one box damper is wide open. This control also needs to look at the error signal from the box controller
- This is accomplished with a reset of the static pressure setpoint

Building Pressure Control

- There are two general methods of building pressure control:
 - Static pressure control relative to outside
 - Air volume control

Building Pressure Control

- Static control senses space pressure relative to the outside and adjusts a relief or return fan

Building Volume Control

- Volume control senses air flow in and out and adjusts a relief or return fan

IAQ Control

- AHU OA percentage reset in VAV
- AHU OA percentage reset for multiple zones
- Demand control ventilation (DCV)

AHU OA Percentage Reset in VAV

- OA volume resets often: upon shutdown, when OAT changes, and when total air volume changes
- Some AHU have simple, one actuator controls

AHU OA Percentage Reset in VAV

- Most AHU have individual actuators
- This arrangement could cause excessive high or low pressure in the AHU if not controlled well.

AHU OA Percentage Reset in VAV

- Modern controllers adjust the dampers to account for reduced total air volume

AHU OA percentage reset for Multiple Zones

- ASHRAE Standard 62.1 allows a reset based on certain changes in the distribution
- Design OAV requirement is based only on design conditions
- Operational OAV can be reset based on
 - Zone airflow
 - Occupancy

AHU OA percentage reset for multiple zones

- Zone airflow
 - In VAV multiple zone systems, the total air delivered to a space varies with the load in the space. The fraction of that air that is OA will adjust upward to deliver the required OA volume
 - Which ever zone has the lowest ratio of actual OA flow delivered to required zone airflow will reset the AHU OA percentage

AHU OA percentage reset for multiple zones

- Occupancy
 - In VAV multiple zone systems, the required OA flow can vary with the number of people in the zone
 - Control methods can count heads in real time, estimate population based on schedule, respond to an occupancy switch (on-off), or use zone level CO₂ sensors as a surrogate for head count

AHU OA percentage reset for multiple zones

- Occupancy
 - CO₂ sensors can be used to estimate occupancy
 - Setpoints for these sensors is more art than science
 - In 1997, when the DCV was first introduced into the standard, the background CO₂ concentration was around 300 ppm, today it is about 380 ppm
 - Setpoints should be made that account for the background. In 1997, 900 ppm was adequate. Today, setpoints can move to 1000 ppm

End of Lesson

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