Overview

- System Description
- Secondary HVAC Systems
  - Air distribution
    - Room diffusers and air terminals
    - Duct Design
    - Fan characteristics
    - Air Handling Units
  - Water distribution
    - Cooling coils
    - Pipes and pumps
- Primary HVAC Systems
  - Electric chillers
    - Air and water cooled
    - Compressor technologies
    - Performance
  - Thermal chillers
    - Absorption
    - Engine-driven
  - Cooling towers
- Overall Design Process
System Overview

- Core Objectives: healthy, productive, comfortable indoor environment
  - Heating to perimeter spaces
  - Cooling to perimeter and core spaces
  - Humidification or dehumidification as needed
  - Ventilation to occupied spaces
- Deliver over time and space

Time and Space

- HVAC needs in each room change over day and over year
- At any time, may need heating and cooling in different rooms of building
  - Core needs cooling even in winter
- HVAC system must meet simultaneous diverse loads
System Options

- Separate HVAC system for every zone
  - Residential
  - Motel
  - Strip mall
- One HVAC system for entire building
  - Distribute heating, cooling, ventilation to individual zones

Typical Home System
Typical Large Commercial System

Distributed HVAC Systems

- Packaged terminal air conditioner (PTAC)
- Water loop heat pump (WLHP)
- Packaged rooftop unit (RTU)
Slab Installation with Side Discharge

Typical Small Commercial System With “Split System”
Water Loop Heat Pump System

System Characteristics

- Rooftop Units (RTU) or Split Systems
- One unit each “zone”
- Refrigerant in cooling coil
- Ventilation
- Ceiling diffusers and ductwork
- Simple controls – one thermostat per zone
- Separate billing for each tenant
- Sometimes separate boiler and radiators
Zoning

- One thermostat per zone
- Rooms with similar load profiles
  - Good: offices on same side of building
  - Bad: exterior office and interior conf. rm.
- Proximity (one thermostat!)
- Air communication allows larger zones
- Recognize local loads in large spaces

Central HVAC System

- Terminal devices
- Fan coil units
- Air and water distribution systems
- Heat exchangers
- Central heating and cooling sources
Typical Central System

Packaged Central System
Large Central System Equipment

Typical Large Central System
## Benefits of Central and Distributed System Designs

<table>
<thead>
<tr>
<th>Central</th>
<th>Distributed</th>
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<tbody>
<tr>
<td>- Large equipment has higher quality, efficiency, and durability</td>
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<tr>
<td>- Maintenance is concentrated</td>
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<td>- Noise is removed from zone</td>
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<td>- Diversity allows lower installed capacity</td>
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<tr>
<td>- Can use thermal storage</td>
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<tr>
<td>- Easy to provide zoning</td>
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<td>- Direct control by occupants</td>
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<td>- Easier independent scheduling for energy savings</td>
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<tr>
<td>- Generally lower capital costs and shorter lead time for equipment</td>
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<tr>
<td>- Don’t need dedicated maintenance staff, use service contract</td>
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<tr>
<td>- Can often install on roof, less useable space for equipment</td>
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## Typical Design Approach

- Start at the zone and work out
  - Loads
  - Air diffusers and zone terminals
  - Air distribution system
  - Air handlers
  - Chilled water distribution
  - Central cooling and heat rejection
Meeting Zone Loads

\[
Q_{tot} = \dot{m}_{SA} (h_{RA} - h_{SA})
\]

\[
Q_{sen} = \dot{m}_{SA} c_p (T_{RA} - T_{SA})
\]

Given controlled room air temperature, can control airflow or supply temperature to meet changing sensible loads.

Air Handling Systems (All Air)

- Constant air volume (CAV) systems
  - Constant zone airflow
  - Meet varying loads with varying supply air temperature
- Variable air volume (VAV) systems
  - Constant zone supply air temperature
  - Meet varying loads with varying supply airflow
Air Handling Systems (cont.)

- Dual duct (DD) systems
  - Mix hot and cold air at each zone
  - Use constant or variable supply airflow
- Multizone (MZ) system
  - Mix hot and cold air for each zone at the air handler

Typical CAV AHU System
Typical VAV AHU System

Typical Dual Duct System
Typical Multizone System

Air-Water Systems

- Use combination of conditioned air and zone water coils
- Ventilation requires air
- Zone heating and cooling loads can be met with fan coils
Fan Coil

- One or two coils (use seasonal valves if one coil for both hot and cold water)
- Thermostat controls water flow
- Ventilation must be met with conditioned or unconditioned outdoor air

Fan Coil System: 4 Pipe
Fan Coil System: 2 Pipe

Integrated With Central System
General System Classification

- **Secondary HVAC Equipment and Systems**
  - Generally in the building
  - Air distribution
  - Water distribution
  - Air handlers and fan coils

- **Primary HVAC Equipment and Systems**
  - Primary sources of heating and cooling
  - Chillers and heat rejection
  - Boilers
  - Engines and generators
  - Thermal Storage

Air Delivery to Zone

- **Fully mixed zone**
  - Supply air is mixed uniformly with room air
  - Air can be introduced at ceiling, walls, floor

- **Displacement ventilation**
  - Supply air is slowly introduced at floor
  - Air rises, absorbing heat and pollutants
Mixed vs. Displacement

Typical Diffusers
Diffuser Selection

- Mix air without causing draft, quietly, with low pressure drop
- Velocities less than 50 fpm (0.25 m/s) in occupied zone
- Diffuser manufacturers report *throw*: distance till velocity is reduced to specified level
- Beware of change in throw at reduced airflow

Air Terminals

- Control supply airflow entering zone (VAV)
- Control supply air temperature (CAV & VAV)
- Interact with zone thermostat
Alternative Air Terminals

- Single-Duct Unit with Hot Water Coil
- Dual-Duct Terminal Unit
- Series Fan-Powered Unit Cooling Only
- Parallel Fan-Powered Unit with Hot Water Coil

Parallel Fan Power Mixing Box

- Modulate VAV airflow for cooling
- Draw warm air from plenum and add heat as necessary
- Maintains higher air velocity in heating to overcome stratification
Duct Design

- Optimization of initial cost with operating costs
  - Larger ducts have lower velocity, pressure drop, and fan energy
  - Small ducts reduce ducting costs and save building space
  - Double duct size reduces fan power by factor of 32!
- Typically use sizing heuristics

Air Handling Units (AHU)

- Delivers air to zones
- Heats and cools air
- Often integrates ventilation
AHU Configurations

1 — Vertical Draw-Thru Air-Handling Unit

2 — Horizontal Draw-Thru Air-Handling Unit with Return Fan Economizer

3 — Horizontal Draw-Thru Air-Handling Unit with External Face-and-Bypass Configuration

4 — Horizontal Draw-Thru Air-Handling Unit

5 — MultiZone Air-Handling Unit

6 — Horizontal Blow-Thru Air-Handling Unit with Final Filtration

Fans

Centrifugal Fan

Axial Fan
Coils

Filtration
Mixing Dampers

- Control airflow rates of outdoor and recirculated air
- Mix air streams
  - Uniform temperature
  - Uniform concentration
- Pressure Control

Hot and Cold Water Distribution

- Deliver heat to the AHUs
- Remove heat from the AHUs
Hot and Cold Water Distribution

System Configuration
Pumps

Energy Efficient Design

- Low pressure drop in piping and fittings
- High efficiency motors and pumps
- Variable speed pumping
- Properly sized two-way valves
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Central HVAC Plants
Chillers in Central HVAC Plants

Chillers

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Michael Brandemuehl
University of Colorado
Electric Chillers

- Expansion Valve
- Evaporator
- Condenser
  - Air cooled
  - Water cooled
- Compressor
  - Reciprocating
  - Scroll
  - Screw
  - Centrifugal

Evaporator

- Refrigerant to water heat exchanger
- Typically water in tubes, refrigerant on shell-side
- Usually designed for constant water flow
Condensers

- Air cooled
  - Plate fin heat exchanger
  - Multiple fans for capacity control
- Water cooled
  - Shell and tube heat exchanger
  - Cooling tower

Reciprocating Chiller

- Used to be common at relatively small capacities
- More recently displaced by scroll and screw compressors
- Control capacity with cylinder unloading
Scroll Chiller

- Small capacities < 50 tons
- Most common in smaller air conditioners and packaged unitary equipment
- Typically no capacity modulation

Screw Chiller

- Medium capacities, 30-500 tons
- Relatively low speed, direct drive
- Capacity modulation using slide valve or variable speed drive
Centrifugal Chiller

- Large capacities, 200-2500 tons
- Highest efficiencies
- Often improved cycle efficiencies
- Capacity control with inlet vanes or VSD

Chiller Performance

- Larger chillers are more efficient
- Capacity and efficiency increase when compressor *lift* (pressure differential) is reduced
  - Higher evaporator temperature
  - Lower condenser temperature
Part Load Performance

Absorption Chillers

- Compressor replaced by pump
- Absorb refrigerant in other liquid
- Pump liquid to higher pressure
- Use heat to drive refrigerant from solution
Absorption Chillers

- No fluorocarbons
- Energy source can be waste heat
- Relatively low efficiency, COP = 0.6
- Risk of crystallizing solution

Cooling Tower
Cooling Tower Types

Open tower
- Use tower water in condenser
- Water treatment
- Closest approach

Closed tower
- Closed condenser water loop with heat exchanger
- Less maintenance

Cooling Tower

Reject heat from warm condenser water to outdoor air using evaporation
Cooling Tower Concepts

- Evaporative process allows heat rejection to temperature below outdoor dry bulb
- Condenser return water approaches outdoor wet bulb
- Approach = $T_{cw, out} - T_{wb}$
- Range = $T_{cw, in} - T_{cw, out}$

Energy Efficient HVAC Design

- High efficiency components
  - Chiller
  - Tower Fans
  - Pumps
  - Motors
- Design for part load conditions
  - Multiple chillers, towers, pumps
  - Variable speed drives
  - Control system to monitor and adjust operation
- Question heuristic design criteria