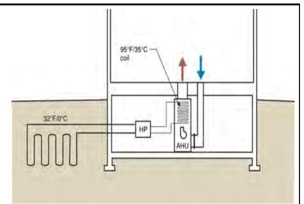

Mechanical Basics

Outline

- functions of HVAC systems
- Role of temperature in system choice and efficiency
- Some common piece of equipment
- Generic systems

HVAC Objectives

- Health
- Safety
- Comfort
  - Temperature, humidity, air speed, noise, light
- Reliability
  - Long term performance, maintainable
- Efficiency
  - Meet the needs imposed by occupants and enclosure with a minimum of additional energy

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Common Problems

- Poor comfort
  - Poor control of temperature and humidity,
  - Noise, drafts from high velocity air
- Health
  - Air based systems act as distribution for outdoor pollutants, mold grown in coils/ducts
  - Chilled water pipes collect condensation leading to mold
  - Insufficient ventilation/mixing common issue
- Energy
  - Systems are often very inefficient
- Maintainability / Controllability
  - Systems are complex, difficult to trouble shoot, maintain etc

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Functions

- Five Critical functions are needed
- Ventilation
  - "fresh air"
  - Dilute / flush pollutants
- Heating
- Cooling
- Humidity Control
- Air filtration / pollutant Removal
  - Remove particles from inside and outside air
  - Remove pollutants in special systems

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Physical Systems & Components

- Components
  - Heat production (including cooling)
  - Heat rejection / collection
  - Heat/Cold Distribution
  - Ventilation air supply/exhaust
  - Ventilation Air Distribution Air Filtration
  - Humidification/ Dehumidification
- Confusion arises when functions are combined across different components in different systems

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Thermodynamics 101

- Heat (Thermal energy) is measured by temperature
- Can produce heat by converting chemical, physical, electrical, radiation, or nuclear energy sources
  - Some heat can be produced at nearly 100%
- Cannot destroy heat, only move it around
  - Heat pumps move thermal energy from
- Cold is a relative term = "less heat"

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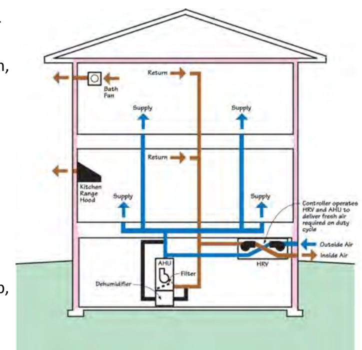
BSI-022: Housing

Ducts shared for ventilation, dehumidification, cooling heating



Heat or cold can be by heat pump, furnace, ground water, solar, wood, etc

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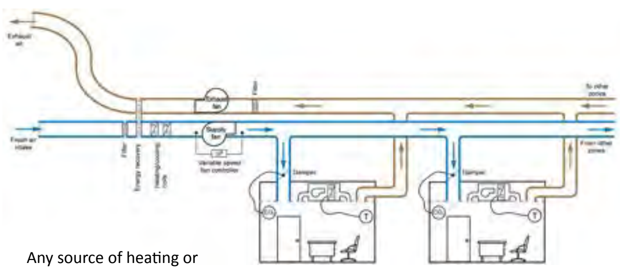
BSI-022 Perfect HVAC



Any source of heating or cooling
Combined ventilation/ humdity control

Heating & Cooling 101

- We produce heat to increase temperature
- We remove heat to lower temperature
- Heat/cool Equipment has <u>three stages</u>
  1. Heat production
  2. Distribution (optional)
  3. Heat rejection
- Can mix and match most of different technologies for each stage

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Heat Production

- Boilers : heat to water
  - Old types heated water to steam and distributed
  - Modern heat water to 35C (95F) to 85C (190 F) and pump water using small electric pumps
- Furnace: heat to air
  - Air is heated to min 40 C (110 F) and usually 60+ (150)
  - Electric fan is used to move air
- Both heat exchanger between <u>flame to fluid</u>
- Fuel sources
  - Nat gas, oil, propane, wood, electric, etc.

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Heating

- Need hot air and hot water
- Can combine one source for two uses
  - Makes sense for small efficient buildings
- This can be a combo fancoil or radiators or radiant slabs
- DHW should be heated to 130 F to kill Legionnaires bacteria

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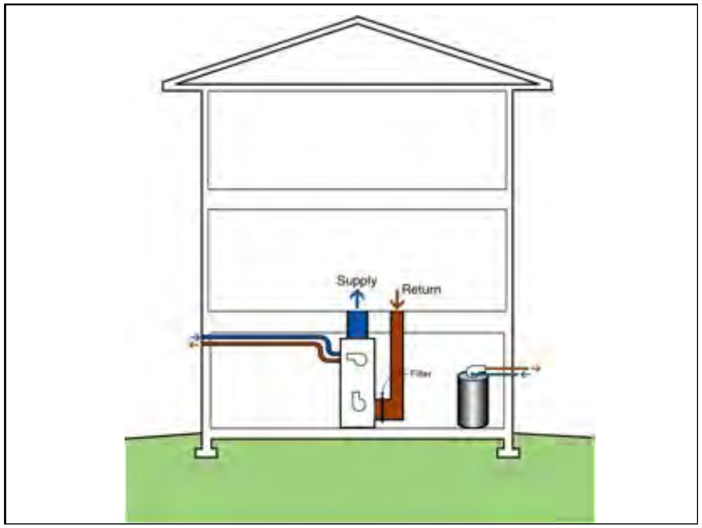

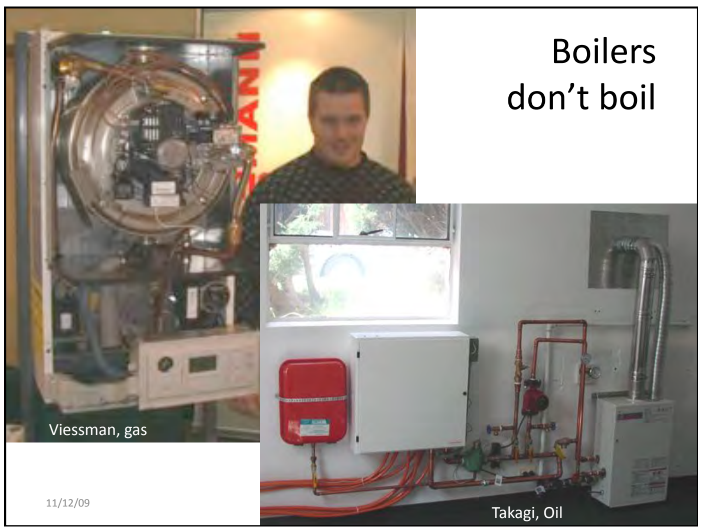

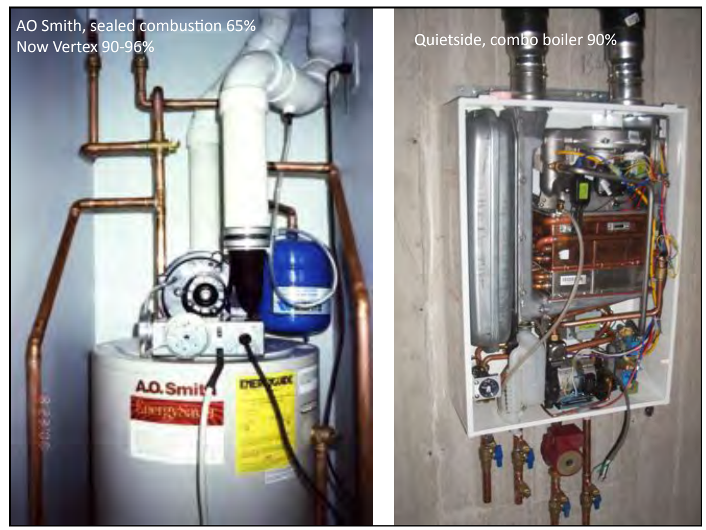

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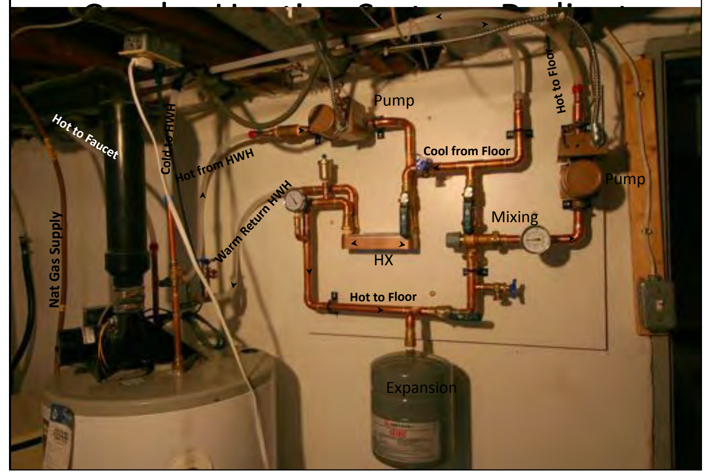
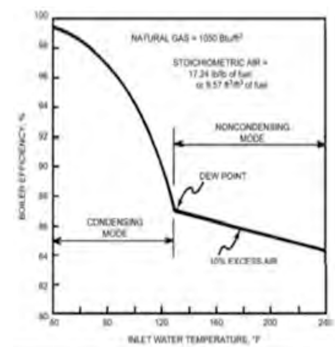


Boiler Combustion Efficiency

- Most combustion is >99.9% efficient
- Equipment varies on ability to extract useful heat from combustion via HX
- Heat exchanger size is important
- Temperature of entering fluid is also critical
  - Condensing furnace (72 F / 22 C)
  - Condensing boiler >90% (<110 F / 45 C)
  - Normal boiler <85% (>130 F/ 55 C)

Condensation % Efficiency

- Depends on return temperature
- Terminal equipment that can return low temps aid efficiency
- Target 95-110 F (35-43 C)



ASHRAE Systems Handbook 2000.

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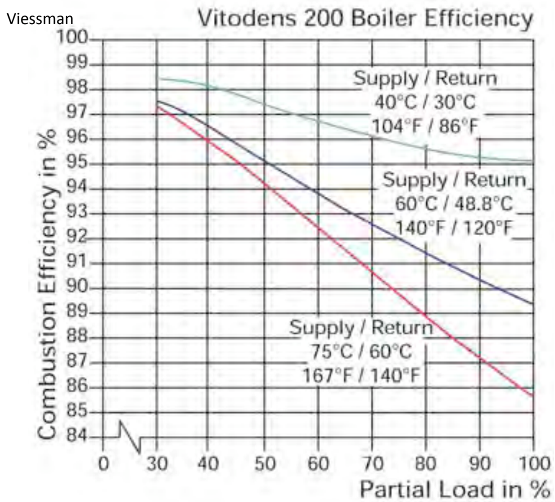

Consequence

- Furnaces: return air temperatures = room temperature (70 F/21C)
  - Hence, condensing, 95%+ efficiency practical
- Boilers: depends on system design/operation
  - Radiant panels: 90-120 F / 32-48 C
  - Fan Coils: 100-180 F /40-80 C
    - Will not condense if T > 135F/55C
  - Baseboards: 120-180F+

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Heat Pumps

- Neither create or destroy heat, but move it around
- Require input energy just like any other pump
- Need
  - **Source** of thermal energy
  - **Sink** of thermal energy
- Sources (inside=cooling, outside=heating)
  - Air ("Air source")
  - Ground ("ground source")
    - Soil, Groundwater, or Surface water (eg lake)
  - Wasteheat in building via exhaust air or drain water

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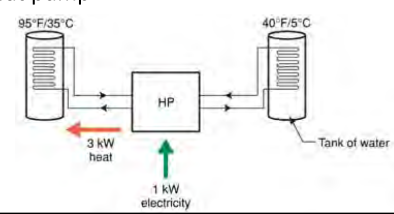
Heat Pumps

- Use compressors, and refrigerant ("Freon")
- All use *internal heat exchangers* to transfer hot or cold refrigerant to water or air
- Terminology
  - "Air to air heat pump" = "air-source"
  - "Water-to-water heat pump"
  - "air conditioning"
  - Water to air
  - Ground source
  - "Geothermal"



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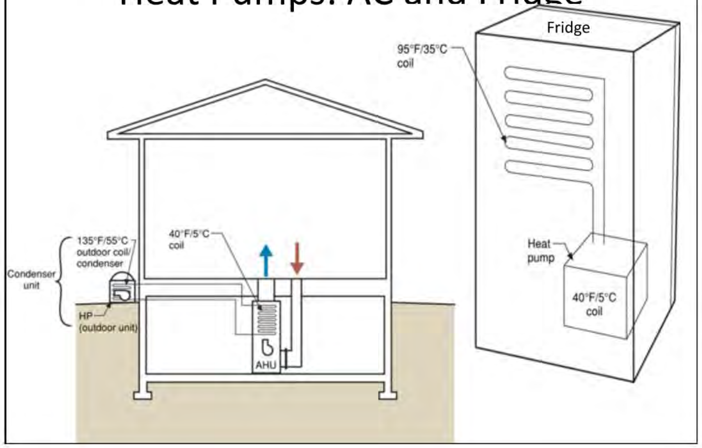
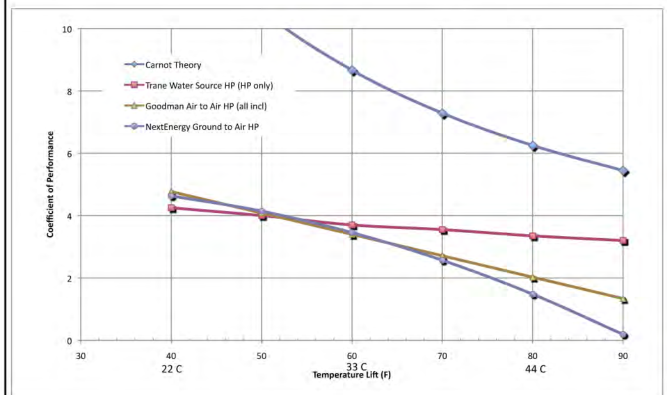
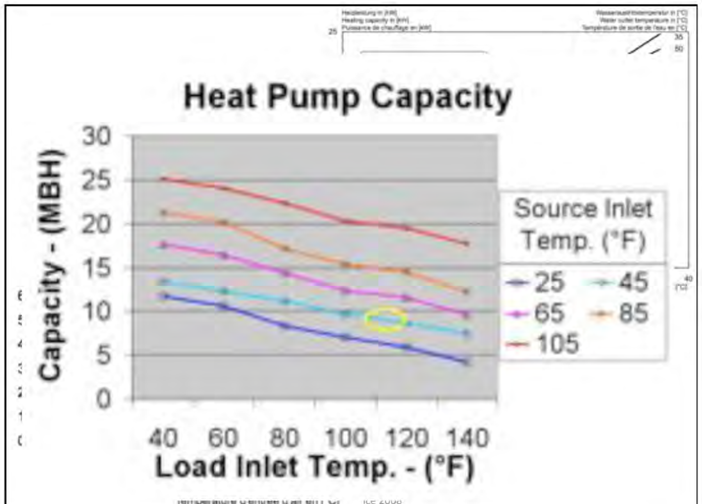
Heat Pumps: AC and Fridge



Heat Pump Efficiency vs Lift





Cooling

- Most cooling equipment is a heat pump
  - uses the interior as a source (collection) and
  - Outside as the sink (rejection)
- Other mechanical cooling systems (all described later)
  - Evaporative cooling
  - “Free cooling”
    - Use a source of cold air or water to absorb (collect) heat and remove to the exterior
    - Air-side economizer
    - Water-side economizer

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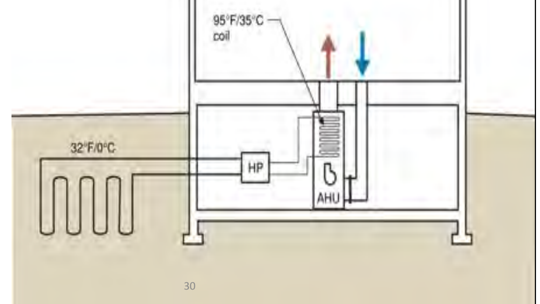
Heat Pump and Reject/Collect in same box

- Compressor, and DX coils in one enclosure

Ground Source Heat Pump

- A water to air or water to water heat pump with with collection / rejection in ground



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Terminal Units

- Terminal= end of line
- One end to dump heat in heating systems
- Two ends of heat pump systems

Differ in terms of amount of heat transferred by convection or radiation

Low Temperature Supply

- Need larger fan coils, radiant panels, base boards etc
- Most manuf rate equipment at high (eg 180 F / 80C) temperatures
- Size for units at 110 F leaving water is about 3 times for baseboard, 1.5x for fan coils

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Extended Surface Heat Exchanger

- Coils: Many many fins of conductive aluminum attached to copper pipes
  - Filled with refrigerant or water
  - Direct Expansion of refrigerant= DX

Coils: increase heat transfer area in a small space & require fans

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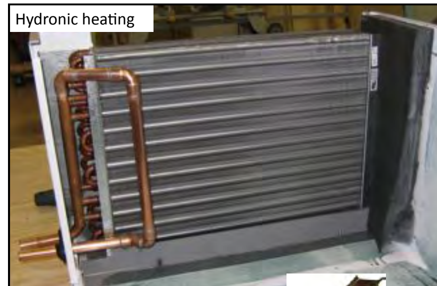
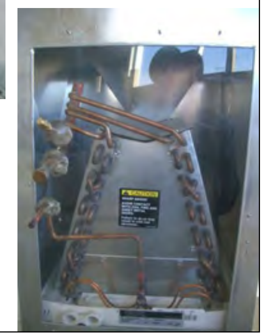

Hydronic heating


Refrigerant DX heating

Coils: increase heat transfer area in a small space & require fans

Refrigerant DX A-coil cooling

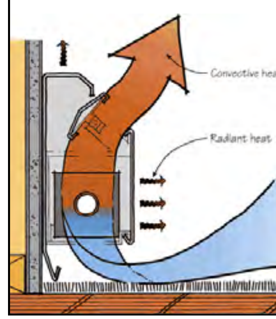


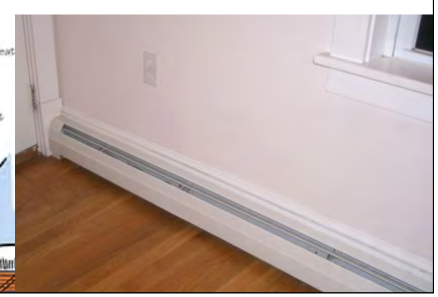
Convector / Radiator

- Hydronic terminal units
  - no energy required at unit

Convector / Radiant

- Usually only for heating
  - large Delta T (140 F) need to drive buoyancy





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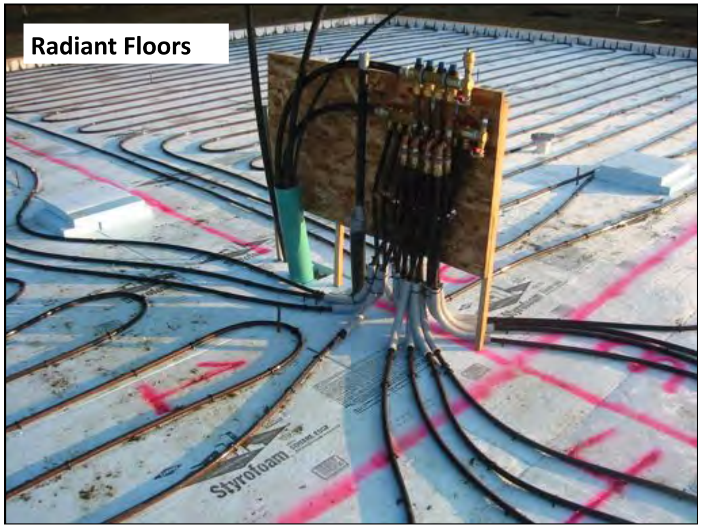
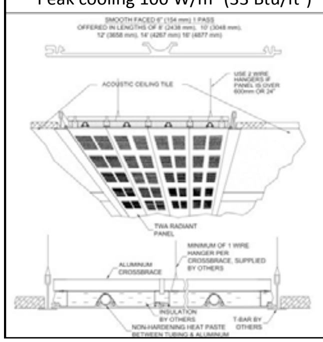
Radiant Floors

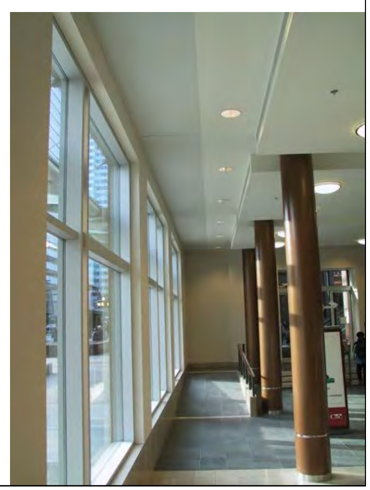


Emission plates under wood

Radiant Panels

- Smaller area → higher deltaT
- About 50/50 radiant/convective
- Peak heating 150 W/m^2 (50 Btu/ft^2)
- Peak cooling 100 W/m^2 (33 Btu/ft^2)





Terminal Units: Radiant Heating / Cooling

- Large heat transfer areas and/or low temperature fluids result in higher *potential* <u>*equipment*</u> efficiencies
- Full floor or ceiling coverage can heat low E buildings with small 5 F/3 C surface temperature difference
- Smaller areas (furniture) or small panels require larger temperature differences require larger Delta T
- In cooling, panels may cause condensation: in climates with humid summers, humidity control is required!
- Large surface temperature differences can be uncomfortable (eg cooling > 25 F or 10C)

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Heat Exchange from Surfaces

- Example: 80F(27C) floor, 72F (22C) room air
  - 15.2 Btu/hr/ft²/F heating
- Example: 60F (15.5C) ceiling, 74F (23C) room air
  - 26.6 Btu/hr/ft²/F cooling

	heating		cooling	
	Btu/hr/ft²/F	W/m² K	Btu/hr/ft²/F	W/m² K
floor	1.9	11	1.2	7
wall	1.4	8	1.4	8
ceiling	1.1	6	1.9	11

Radiant Floor "Self-control"

- With small Delta T terminal units, there is a degree of self control
- *Huge* practical control and comfort benefit in <u>low</u> flux radiant floor and ceilings

Average Heating Load Flux W/m²	Required Floor Temperature (at 20°C [68°F] Room Temperature) °C (°F)	Average Temperature of Heating Medium		% Decrease of Heat Output by 1 K (1.8°F) Increase of Room Temperature Reference Temperature		
		Tile 0.02 m²-K/W, °C (°F)	Carpet 0.1 m²-K/W, °C (°F)	Floor Surface %	Water Tile %	Water Carpet %
80	27.3 (81.1)	31.9 (89.4)	38.4 (101.2)	14	8	5
40	23.9 (75.0)	26.2 (79.2)	29.4 (84.9)	26	16	11
20	22.1 (71.8)	23.3 (73.9)	24.9 (76.8)	48	30	20
10	21.1 (70.0)	21.7 (71.1)	22.5 (72.5)	91	59	40

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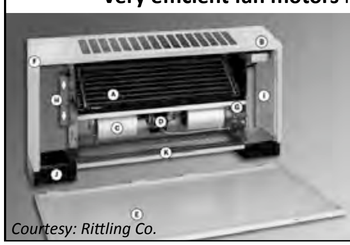
Terminal Unit: Fan coils

- Use fans to below room air over coils
  - Fan-driven air movement = distribution / mixing within a space
  - Noise, maintenance issues
- Fans require electricity
  - Many existing FC are inefficient and noisy
  - **Very efficient fan motors** now available


Courtesy: Rittling Co.

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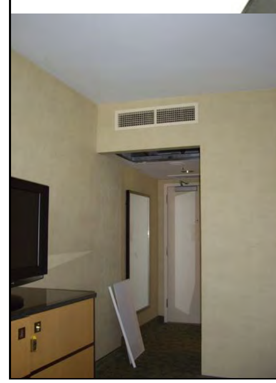

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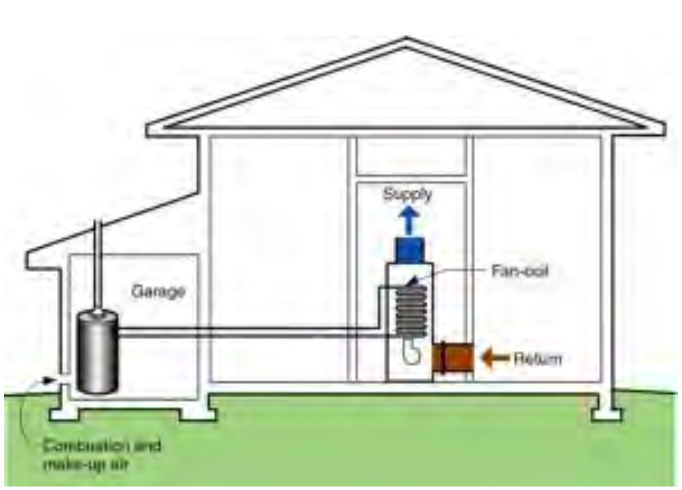

Air-based Energy Delivery

- Heat Capacity: Energy required to raise the temperature or released when a material is cooled
  - Air heat capacity: 0.240 Btu/lb/F.
  - Air density: 0.074 lbs/cf @ room temp = 0.018 Btu/cf/F
  - 1 cfm = 60 cubic feet per hour
  - So… heat delivered per cfm
  - = 60 × 0.018 ≈ **1.1 Btuh/cfm/F (1.2 W/lps/C)**

Air-based 2

- Cooling air supply 55 F, and room air 75 F
  - 1.1 (75-55) = 22 Btu/hr/cfm
  - Need more flow for cooling than heating
- Heating return 70 F
  - Furnace 130 F: 1.1*60= 66 Btu /hr/cfm
  - Heat pump 100 F: 1.1*30 = 33 Btu/hr/cfm
  - Therefore need 2X airflow for low temp sources like heat pump and GSHP

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Fans

- Efficiency
  - Rating: Watt per cfm (or cfm per Watt)
  - Higher pressure = higher power requirement
  - Power (W) = Flow rate * Δpressure / efficiency
  - HP = cfm * Inch Water / (6356 * eff)
  - Efficiency: 0.4 (good) to 0.65 (best)
- Energy: 0.25 to 1.5 W/cfm for ducted systems
- Reduce pressure or flow required = direct energy savings

Fan Laws

1. Increase RPM = direct CFM increase
2. Static Pressure increases RPM^2
3. Horsepower increases with RPM^3

- Double pressure means 1.41 times RPM
- Requires 2.8 times horsepower

- **Energy saving designs uses**
  low CFM *and/or* Low ΔP

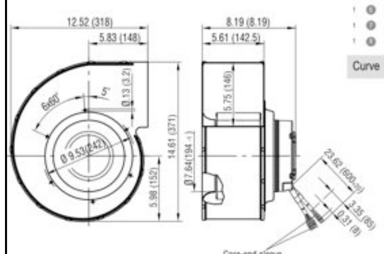
Fan Efficiency Examples

- Fantech FR125
  - 110 CFM @0.2"wg 19 Watts → <0.2 W/cfm
  - Low pressure required
- Fantech FX8
  - 400 cfm@ 0.25"wg 115 W → 0.3 W/cfm
- Furnace fans, fancoil fans (often 1-3 W/cfm)
  - Can be less than 1 Watt/cfm on full speed
  - ECM can be 0.1-0.5 Watt/cfm

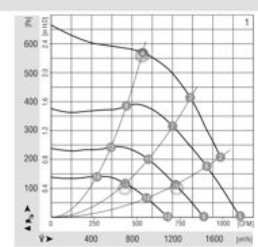
Eg Fan EBM Papst

10. 0.30 Watt/cfm
4. 0.55 Watt/cfm
15. 0.20 Watt/cfm

n [RPM]	P_1 [W]	I [A]	η_L [%]	Lp_A [dBA]	n [RPM]	P_1 [W]	I [A]	η_L [%]	Lp_A [dBA]
—	—	—	—	—	1300	290	1.70	—	71
1750	560	3.30	51	75	1300	225	1.40	51	66
1830	475	2.80	60	73	1300	170	1.10	60	63
1970	335	2.10	59	72	1300	108	0.70	59	61
1610	570	3.40	—	76	1000	140	0.90	—	64
1610	430	2.50	51	72	1000	105	0.70	51	60
1610	325	1.90	60	69	1000	84	0.60	60	56
1610	195	1.20	59	66	1000	55	0.40	59	54



Curve



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Energy of distribution

- Furnace: 1000 cfm
  - Fan 300-800W (=1000-2700 Btu/hr)
  - 1.5 to 4% of energy delivered
- Heat Pump
  - Fan 600-1600 W (3 to 8%)
- Radiant floor
  - Pump 85W (0.4%)
- ***Distribution energy can vary by 5X to 15X***

Distribution

- Voids for ducts can be built into structure
- Voids for pipes require less, but some, planning

Air Terminal Units: Diffusers

- Air-based heating/cooling systems need to manage airflow paths *in the space served*
- Flow can be managed by velocity and surface temperatures
- Supply high velocity to ensure good throw
  - 500 fpm is not too loud but will throw a long way
  - Lower velocity OK if little mixing needed

Terminal Units

- Sensible+ latent (VAV/CAV)
  - Local fancoil w/drainpan
  - Central coils with drain pans
- Sensible
  - Chilled panels, beams
  - Chilled structure
  - Dry fan coils
  - Central dry coils

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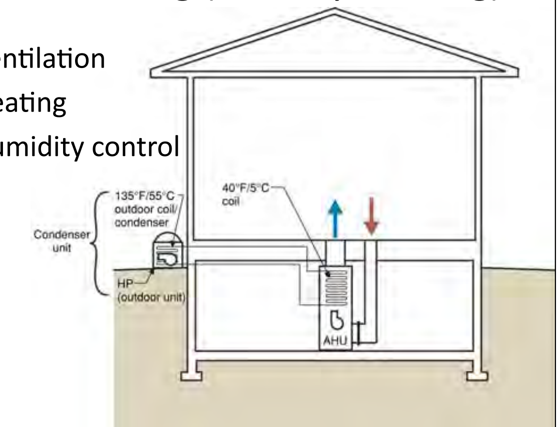
Systems

Heat Production
Rejection / Collection
Distribution

Air Conditioning (actually, cooling)

- No ventilation
- No heating
- No humidity control



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Small Residential HVAC

- Cooling DOES NOT mean humidity control
- Energy removal for lowering temperature:
  - Sensible energy
- Energy removal to condense water vapor:
  - Latent Energy
- Ratio of Sensible Heat Ratio =SHR
  - Normal cooling equipment 65% sensible
  - As enclosures become energy efficient the required SHR drops and latent becomes more important!

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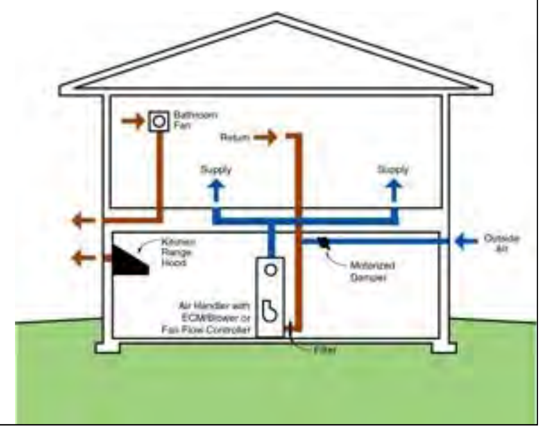
Heating Cooling + Ventilation



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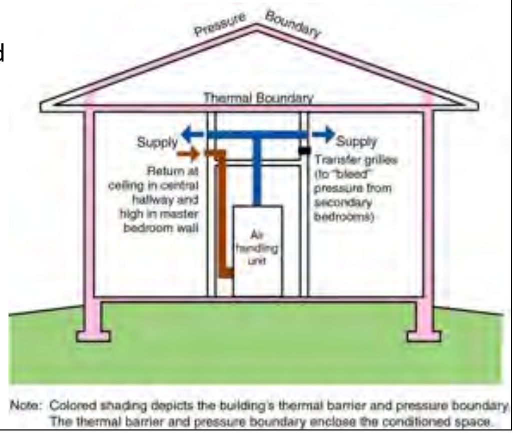
Heating Cooling (and mixing)

- Need good windows



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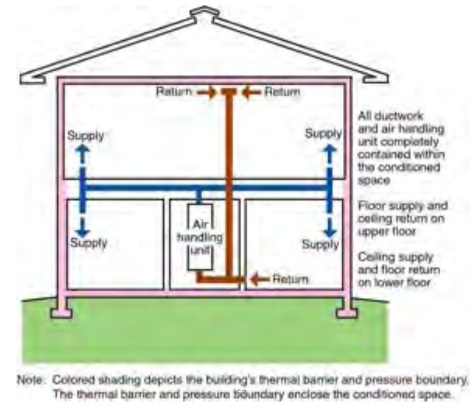
Two Storey Distribution



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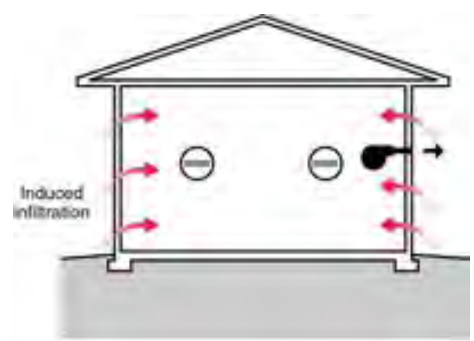
Types of Controlled Ventilation Systems

Exhaust Ventilation
Supply Ventilation
Balanced Ventilation

Exhaust Only: Depressurize



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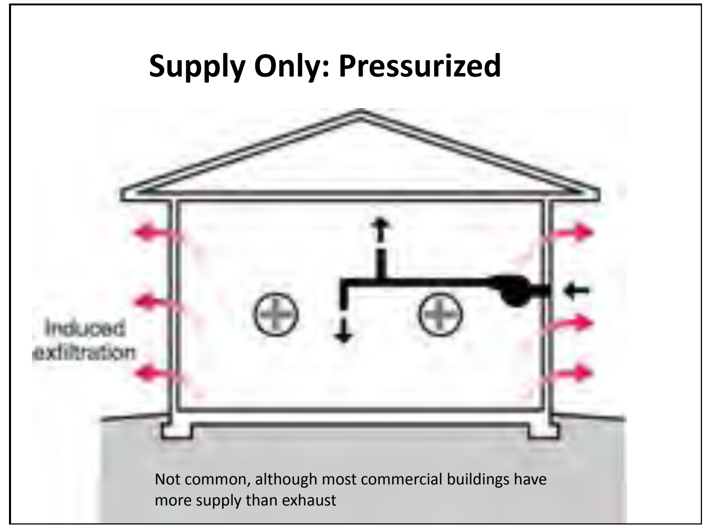
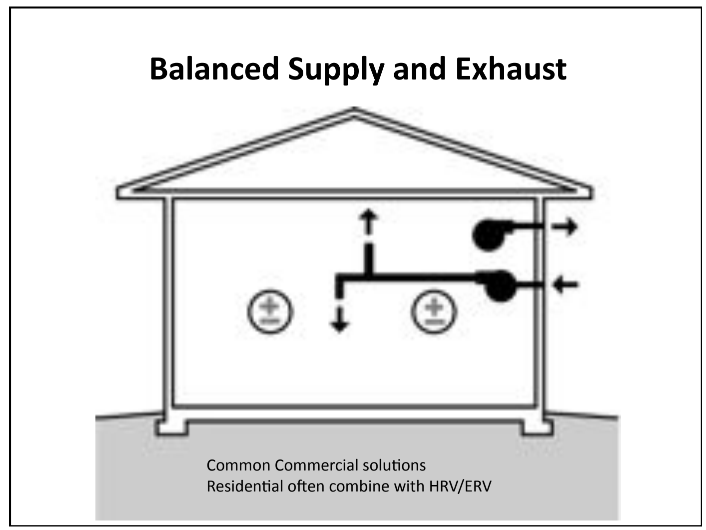
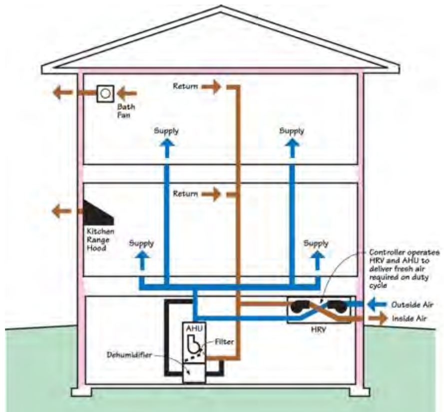

Supply Only: Pressurized
Induced exfiltration
Not common, although most commercial buildings have more supply than exhaust


Balanced Supply and Exhaust
Common Commercial solutions
Residential often combine with HRV/ERV

BSI-022: Housing

Ducts shared for ventilation, dehumidification, cooling heating



Heat or cold can be by heat pump, furnace, ground water, solar, wood, etc

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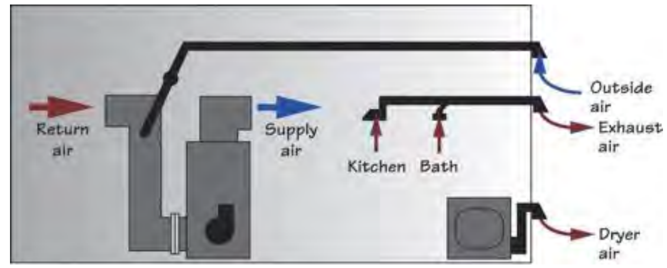
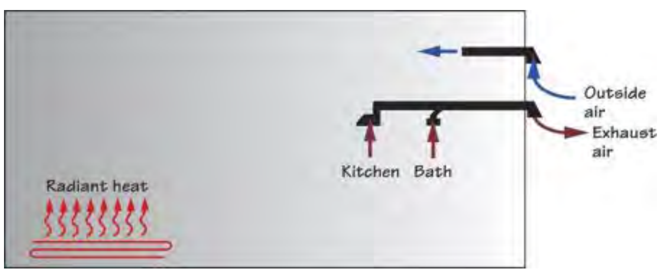
- Point Exhaust, intermittently operated
- Supply via air handler heating/cooling, intermittently operated



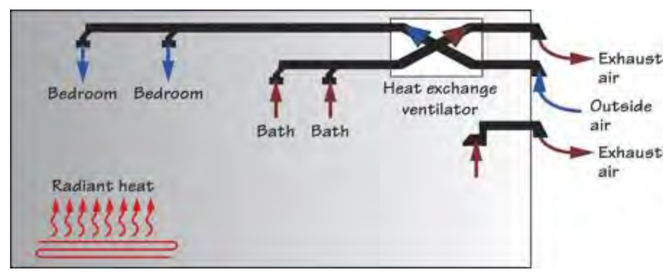
Heating & Cooling can use many sources (hydronic, furnace, split AC or HP)

- Point supply, often continuously operated, may be passive opening
- Point exhaust, intermittently operated



No Cooling. Radiant heat usually from a source of hotwater

- Multi-point supply, often continuously operated
- Multi-Point exhaust, often continuously operated
- Heat recovery of moisture and heat in air add on



No Cooling. Radiant heat usually from a source of hotwater

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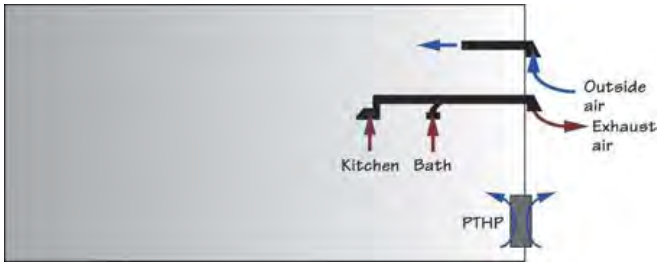
•Point supply, often continuously operated, may be passive opening
•Point exhaust, intermittently operated



Primary Terminal Heat Pump could be Ductless Mini-split

Ductless Mini-split

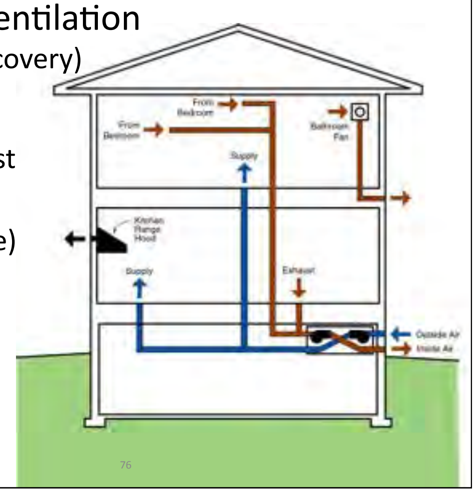
Ductless Mini-split

- Many systems now variable speed to match load, increase dehumidification, and reduce energy use

Systems with SEER26 and HSPF=11 available

Balanced Ventilation
(with Heat Recovery)

- HRV/ERV
- Point exhaust
- Fully ducted (need not be)



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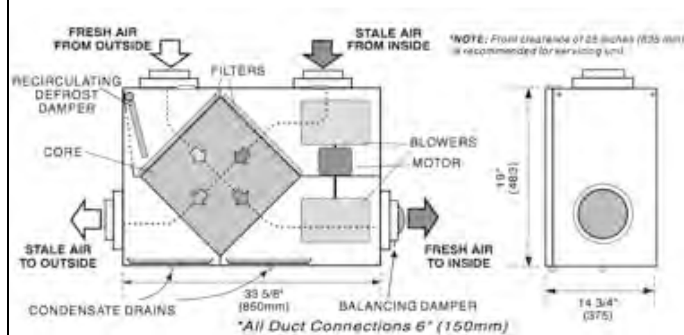
e.g. NuTech 155 ECM



HRV/ERV

- Heat Recovery Ventilation
  - This is a ventilation system that recovers heat from the exhaust air and transfers to incoming air
- Enthalpy/Energy Recovery Ventilator
  - Transfer heat and humidity from incoming to exhaust
- Both, beware poor electric motor efficiency
  - Aim for less than 1 W/cfm

Air-side Economizer

- Through-wall paddle fans can deliver air at very high efficiencies (10-25 cfm/Watt)
- E.g., If t_{out} = 65F & t_{in} = 74 F
  - @1.1 Btu/cfm/F & Δ9F = 10 Btu cooling / cfm
  - 15 cfm/Watt→ 150 Btu /Watt fan
  - EER of 150 = COP= 44!!
- If only 1 cfm/Watt VAV → COP= 2.9
  - AC or water side economizer will be better!!

Natural ventilation

- Airflow driven by natural forces
  - Wind
  - Buoyancy (hot air rises, cold air falls)
- Avoids fan energy
- Can be used for ventilation
  - Lower flows, risk of insufficient air= bad IAQ
- Cooling
  - Higher flows, only risk is occasional overheating

Natural ventilation cooling

- Airside Economizer using natural pressures
  - Large airflows needed as T_{out}> 65 F
- Must throttle airflow as T_{out}<60 F for comfort
- Little airflow possible when T_{out}<40F
  - Frost, comfort problems
- Most low energy buildings have low cooling loads, most internally generated

Conclusions

- Lots of choices, lots of room for improvement

HVAC by the numbers

- Typical office AC required: 400 sf/ton (sensible+latent)
- Typical office AC airflow: 400 cfm/ton
  - Thus about 1 cfm/sf
- Office fresh air req't: 0.1-0.2 cfm/sf
  - Thus 5x to 10x less than cooling
- Classroom fresh air: 0.5 cfm/sf
- Coil velocity: 300-500 fpm
  - Thus, 400 fpm=400 cfm/sf coil, 1 sq ft coil/ton AC
- Typical duct velocity: 600-1500 fpm (noise!)
  - 0.30 to 0.70 sf duct per ton AC
- 200 cfm of hot-humid ventilation= 1 ton AC

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