HVAC Systems

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

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

 © buildingscience.com

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

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

Thermodynamics 101

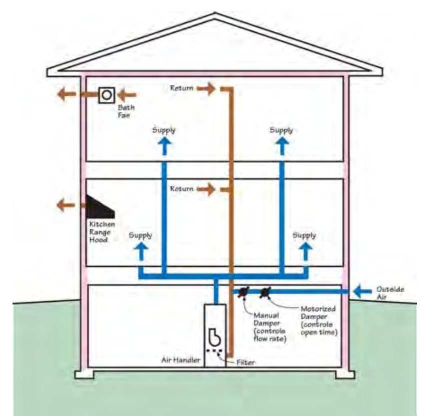
- Heat (Thermal energy) is measured by temperature
- Can produce heat by converting chemical, physical, electrical, radiation, or nuclear energy sources
  - Some heat can be produced at nearly 100%
- Cannot destroy heat, only move it around
  - Heat pumps move thermal energy from
- Cold is a relative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

Minimum "Good" System

Ducts shared for ventilation, dehumidification, cooling heating

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

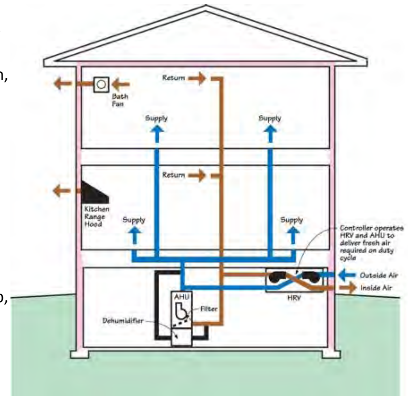
FanCycler ensures fresh air or required amount delivered to each room



© buildingscience.com

Best Affordable

Ducts shared for ventilation, dehumidification, cooling heating

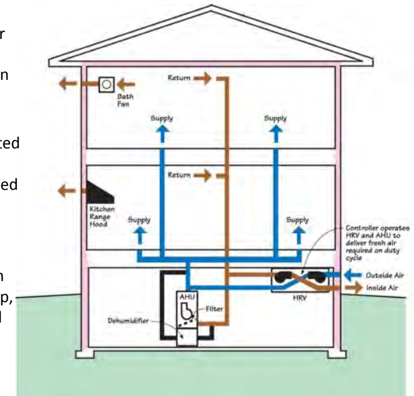


Heat or cold can be by heat pump, furnace, ground water, solar, wood, etc

Ultimate System

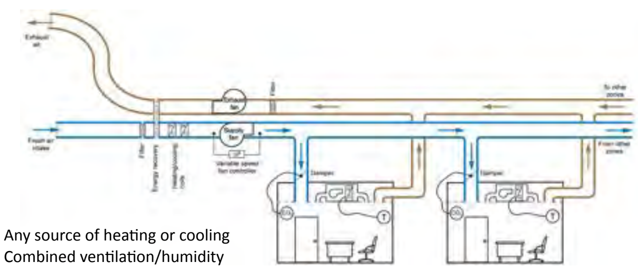
Ducts shared for ventilation, dehumidification

Radiantly heated floors
Radiantly cooled ceilings



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

BSI-022 Perfect HVAC



Any source of heating or cooling
Combined ventilation/humidity control

Terminal units can be fan coils, PTAC, AHU, radiant panels, etc.

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

11/14/09 12

© buildingscience.com

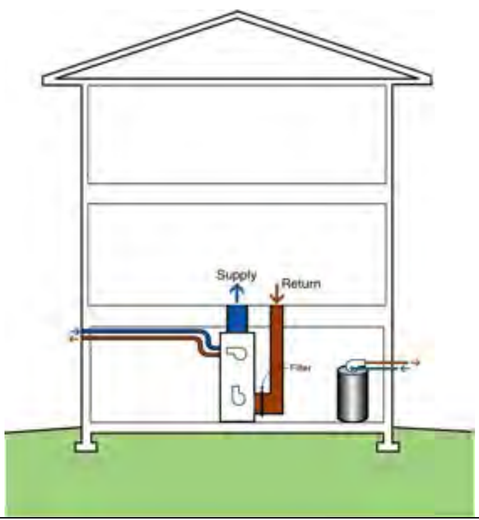
Heat Production

- 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 flame to fluid
- Fuel sources
  - Nat gas, oil, propane, wood, electric, etc.

11/14/09 13

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



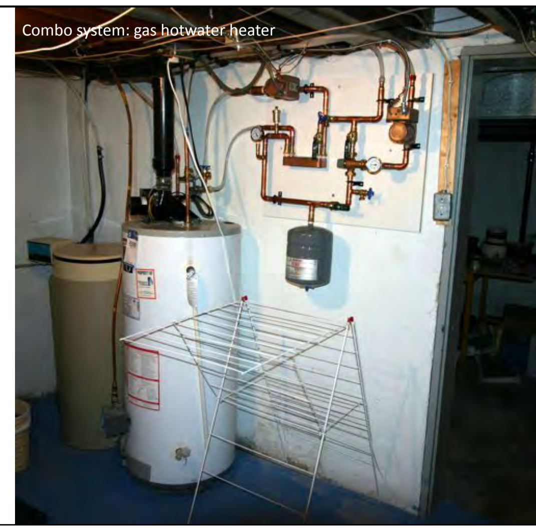
Modern Boilers: small, quiet efficient

Boilers don't boil

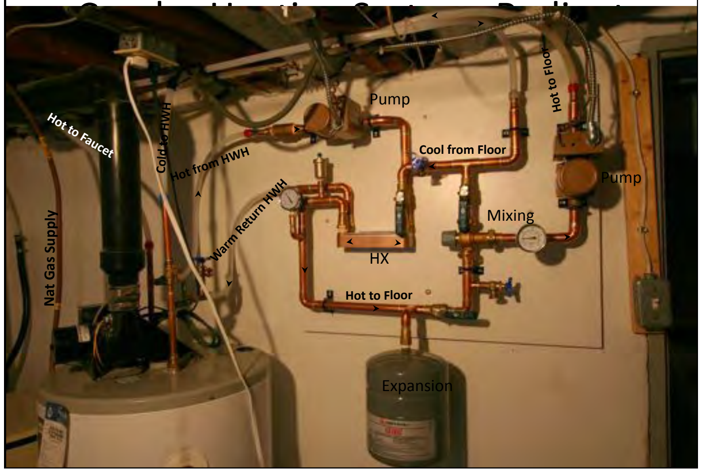
11/14/09

- Navien combo 98%+
- Microstorage
- 10:1 turndown
- 4 - 5 GPM
- US$1875 SRP

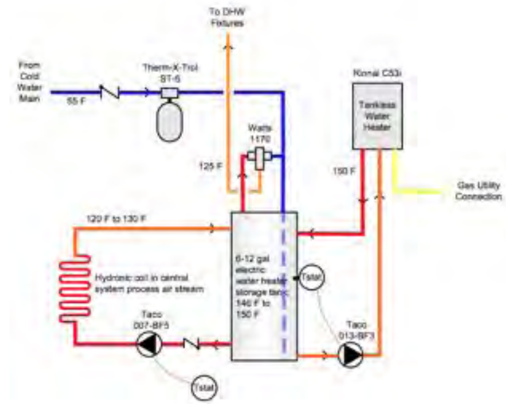
Item		CR-180, CR-180A, CC-180, CC-180A
Heat Capacity (Input)	Natural Gas	Min: 15,000 Btu/h Max: 150,000 Btu/h
	LP Gas	Min: 15,000 Btu/h Max: 150,000 Btu/h
Thermal Efficiency		98.8 %
Energy Factor (DOE)		0.98
Dimensions		W17" x H28" x D10"
Weight	CR/CC-A	77 lbs
	CR/CC	67 lbs



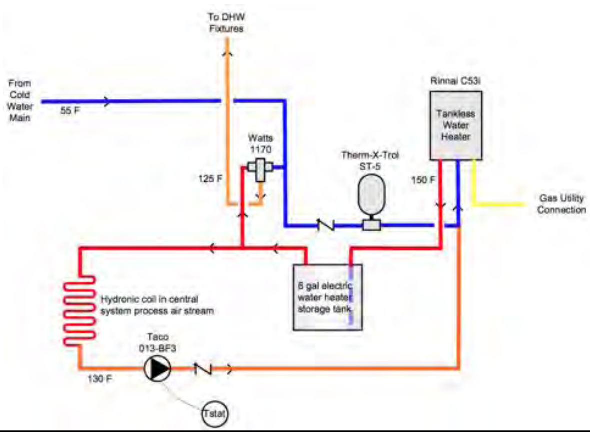
© buildingscience.com



Tankless heaters need tanks



Tankless heaters need tanks



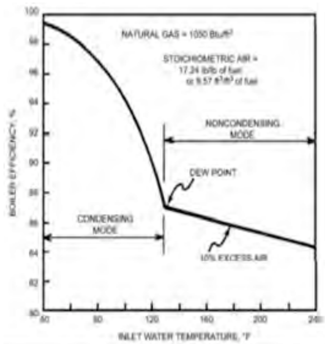
Boiler Combustion Efficiency

- 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)

 © buildingscience.com

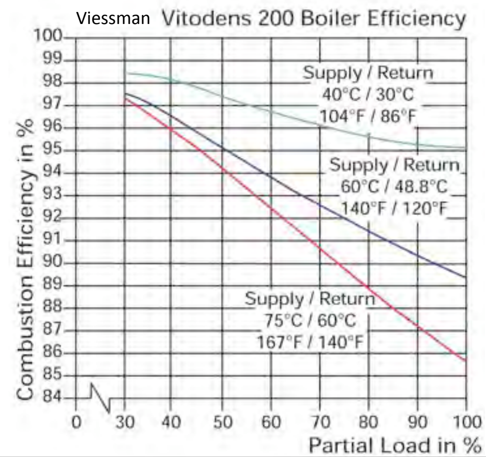
Condensation % Efficiency

- Depends on return temperature
- Terminal equipment that can return low temps aid efficiency
- Target 95-110 F (35-43 C) for condensing
- Target > 130 to protect non-condensing



ASHRAE Systems Handbook 2000.

DHW inlet temperature is usually 55—60 F (10-15C) so great efficiency



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+

Building Science 2008

Heat Pumps

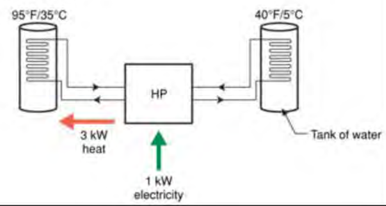
- Neither create or destroy heat, but move it around
- Require input energy just like any other pump
- Need
  - **Source** of thermal energy
  - **Sink** of thermal energy
- Sources (inside=cooling, outside=heating)
  - Air ("Air source")
  - Ground ("ground source")
    - Soil, Groundwater, or Surface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

11/14/09 28

© buildingscience.com

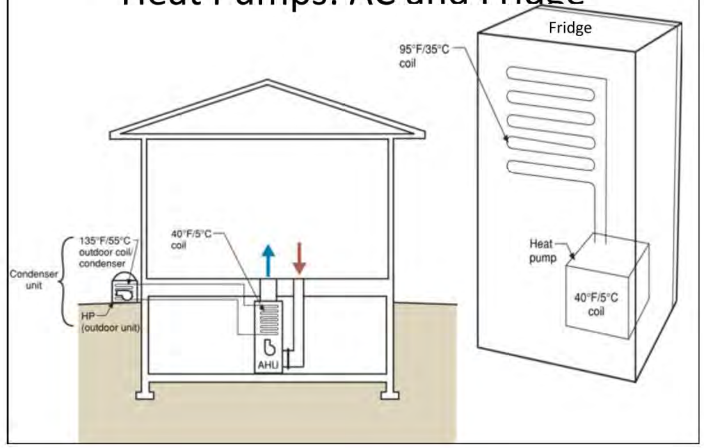
Heat Pumps

- 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"

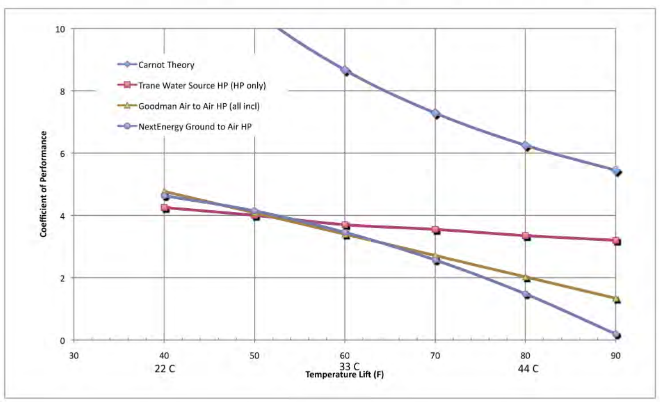


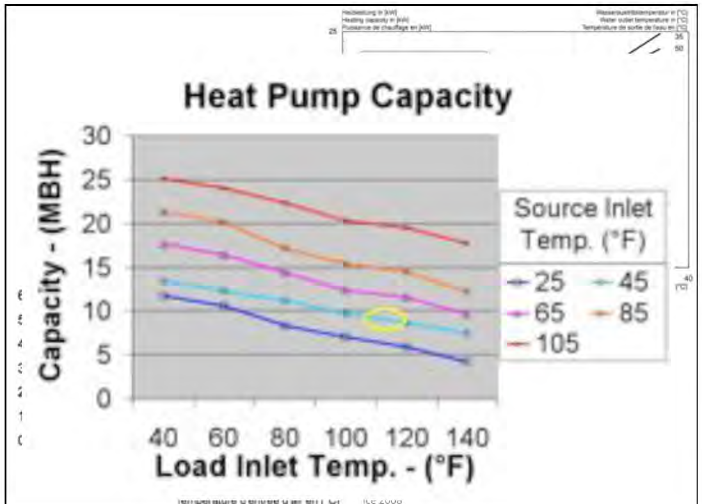
11/14/09

Heat Pumps: AC and Fridge



Heat Pump Efficiency vs Lift





 © buildingscience.com

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

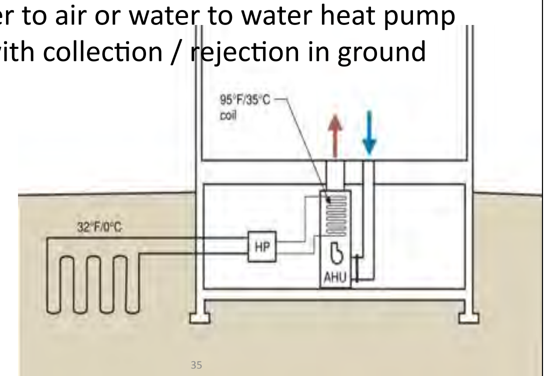
11/14/09 33

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



11/14/09 35

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

© buildingscience.com

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

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

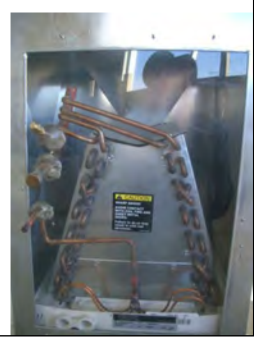
Coils: increase heat transfer area in a small space & require fans


Hydronic heating

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


Refrigerant DX heating

Refrigerant DX A-coil cooling

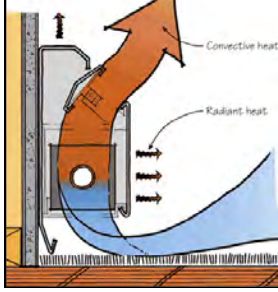


Convector / Radiator

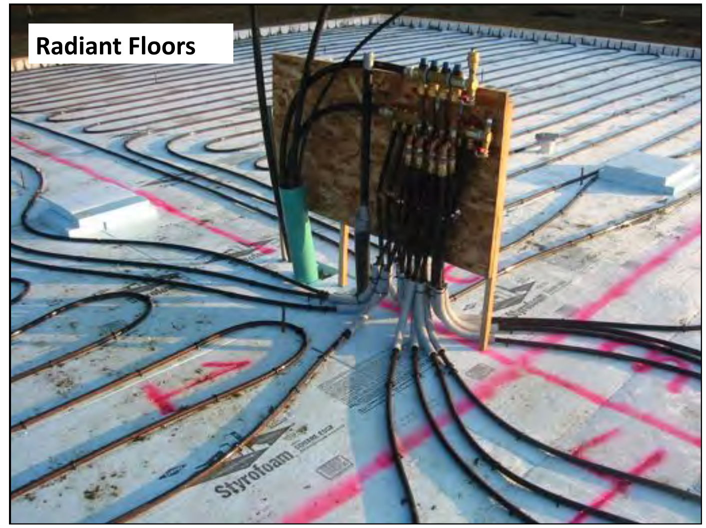
- Hydronic terminal units
  - no energy required at unit


Convector / Radiant

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



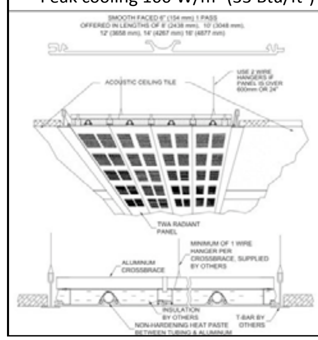
Radiant Floors

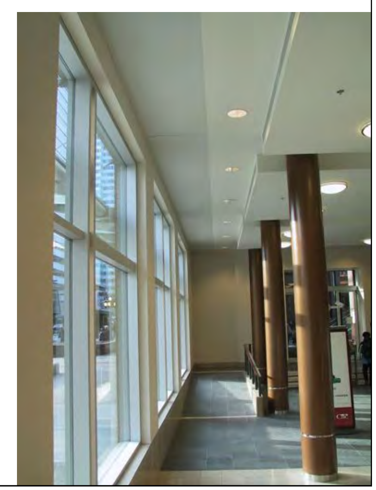


Emission plates under wood

Radiant Panels

- Smaller area → higher deltaT
- About 50/50 radiant/convective
- Peak heating 150 W/m² (50 Btu/ft²)
- Peak cooling 100 W/m² (33 Btu/ft²)





© buildingscience.com

Terminal Units: Radiant Heating / Cooling

- Large heat transfer areas and/or low temperature fluids result in higher *potential* equipment 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)

11/14/09 45

Heat Exchange from Surfaces

- Example: 80F(27C) floor, 72F (22C) room air
  - 15.2 Btu/hr/ft^2/F heating
- Example: 60F (15.5C) ceiling, 74F (23C) room air
  - 26.6 Btu/hr/ft^2/F cooling

	heating		cooling	
	Btu/hr/ft^2/F	W/m^2 K	Btu/hr/ft^2/F	W/m^2 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"

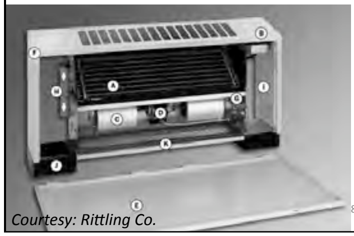
- With small Delta T terminal units, there is a degree of self control
- *Huge* practical control and comfort benefit in low flux radiant floor and ceilings

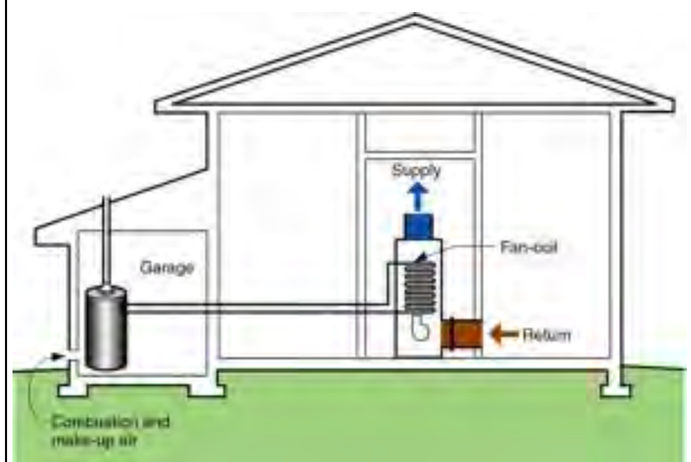
Average Heating Load Flux W/m^2	Required Floor Temperature (at 20°C [68°F] Room Temperature) °C (°F)	Average Temperature of Heating Medium: Tile 0.02 m^2-K/W, °C (°F)	Average Temperature of Heating Medium: Carpet 0.1 m^2-K/W, °C (°F)	% Decrease of Heat Output by 1 K (1.8°F) Increase of Room Temperature Reference Temperature: 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

Building Science

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.



Combo air handler: Built-in pump and ECM fan

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)**

Building Science 2008

© buildingscience.com

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

Building Science 2008

Water Based Systems

- Water moves
  - 500 Btu/hr/GPM/F
  - 375 Btu/hr/GPM/F (Glycol)
  - Radiant panel
    - : 100 F supply 85 return <= 4500 Btu/hr/GPM
- Example: 65000 Btu/hr peak
  - Furnace: @ 66 Btu/hr/cfm → 985 cfm (900W)
  - Heat pump @ 33 Btu/hr/cfm → 1900 cfm (1800W)
  - Radiant 4500 Btu/hr/GPM → 14.4 GPM (85W)

Pump Efficiency Examples

- Grundfos UP15-42B7 1/25 HP Circulator
  - 85 W electrical input
  - 35% eff electric motor 50% eff pump
  - 18% eff pumping
  - 12 GPM at 7 ft head loss
- Gundfos UP26-99BF 1/6 HP (larger)
  - 245 W input, 50% eff motor, 50% pump (25@10)
- Pumps of over 1 hp can be 70% elec eff.

Building Science 2008

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

Building Science 2008

© buildingscience.com

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**

Building Science 2008

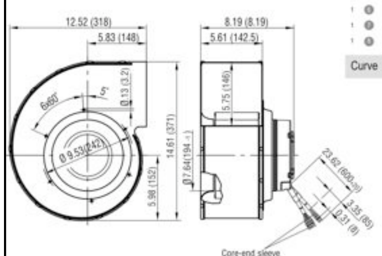
Fan Efficiency Examples

- 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 on low speed

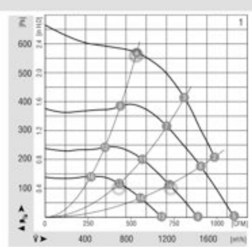
Eg Fan EBM Papst

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

n [RPM]	P1 [W]	I [A]	ηs [%]	LpA [dBA]	n [RPM]	P1 [W]	I [A]	ηs [%]	LpA [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



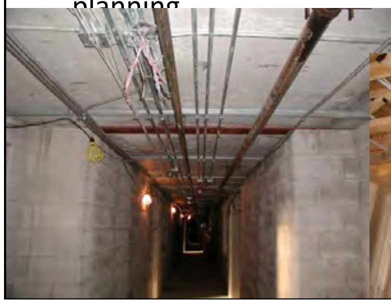
Energy of distribution

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

© buildingscience.com

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

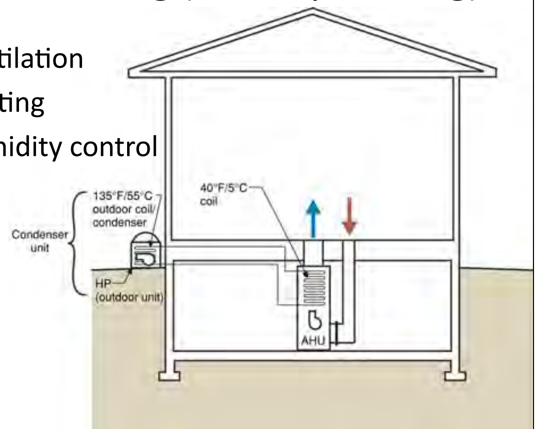
11/14/09 63

Systems

Heat Production
Rejection / Collection
Distribution

Air Conditioning (actually, cooling)

- No ventilation
- No heating
- No humidity control



11/14/09

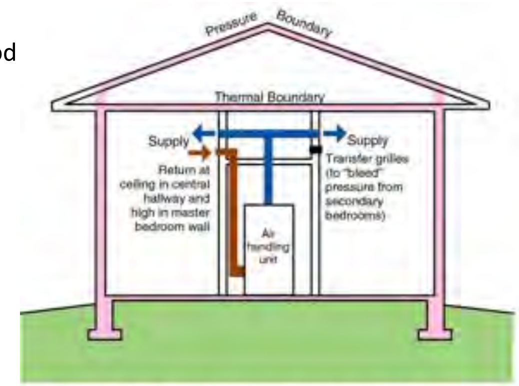
Small Residential HVAC

- 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!

11/14/09 66

Heating Cooling (and mixing)

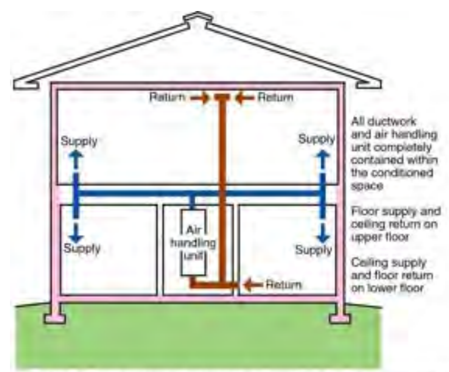
- Need good windows



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

11/14/09

Two Storey Distribution



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

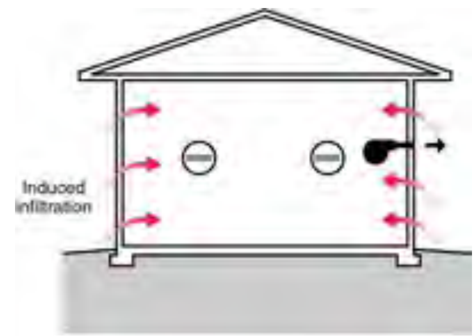
11/14/09

© buildingscience.com

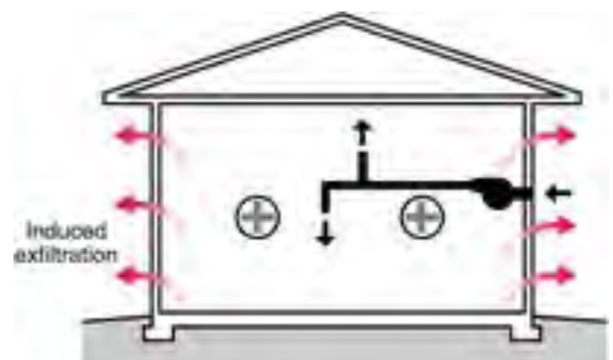
Types of Controlled Ventilation Systems

Exhaust Ventilation
Supply Ventilation
Balanced Ventilation

Exhaust Only: Depressurize

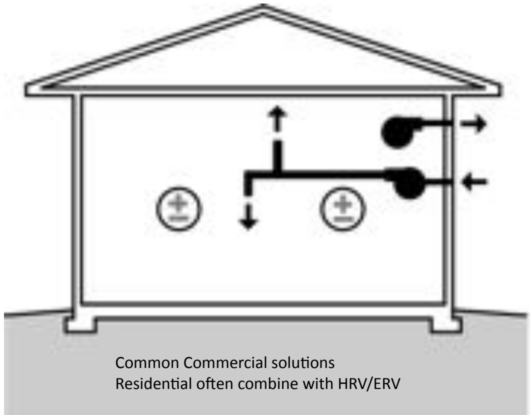


Supply Only: Pressurized



Not common, although most commercial buildings have more supply than exhaust

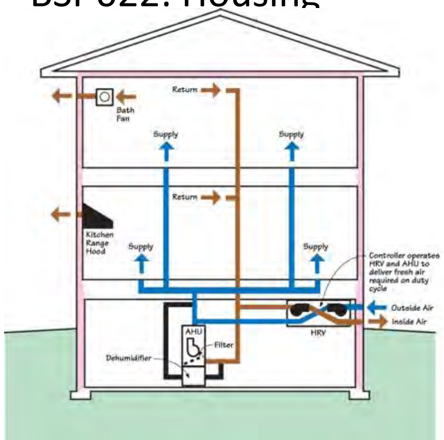
Balanced Supply and Exhaust



Common Commercial solutions
Residential often combine with HRV/ERV

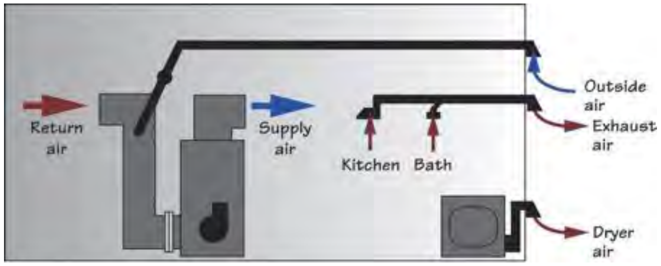
BSI-022: Housing

Ducts shared for ventilation, dehumidification, cooling heating



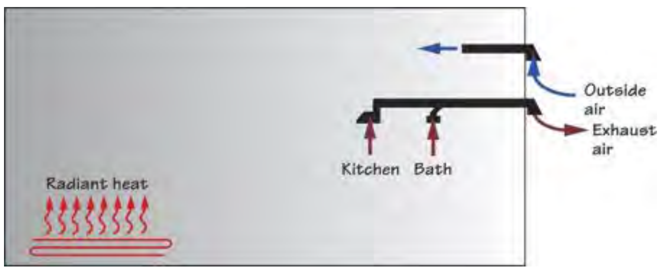
Heat or cold can be by heat pump, furnace, ground water, solar, wood, etc

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



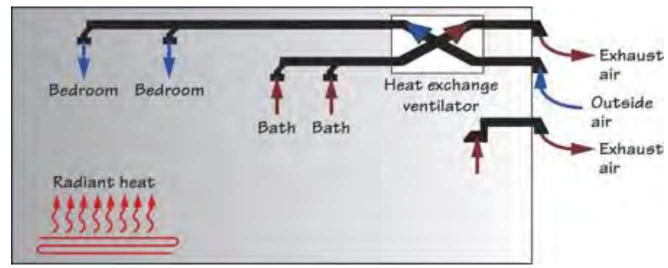
Heating & Cooling can use many sources (hydronic, furnace, split AC or HP)

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



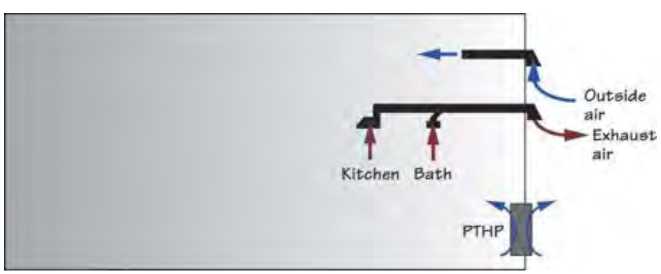
No Cooling. Radiant heat usually from a source of hotwater

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

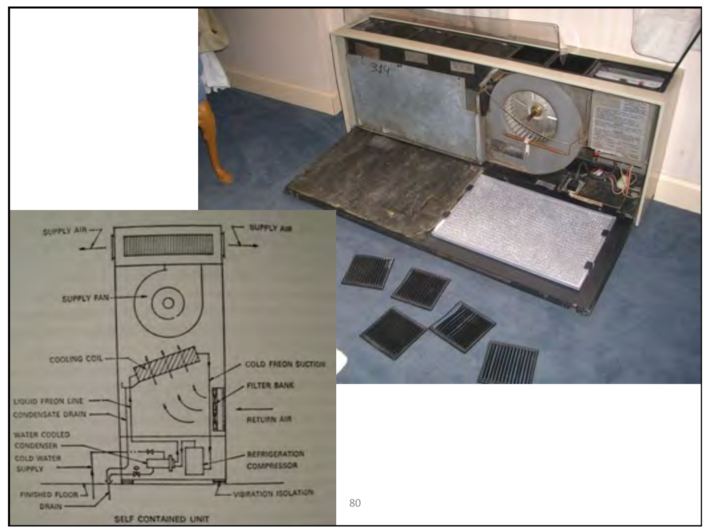


No Cooling. Radiant heat usually from a source of hotwater

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



Primary Terminal Heat Pump could be Ductless Mini-split



80

Ductless Mini-split

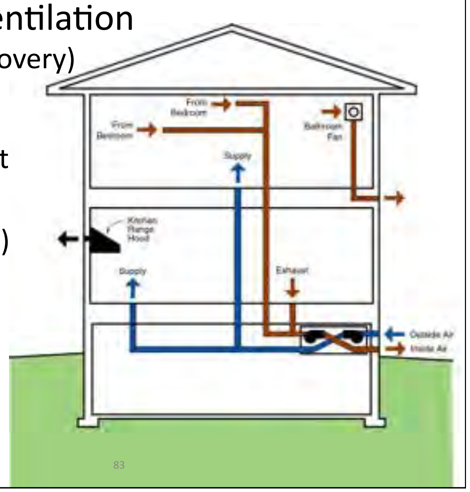
Ductless Mini-split

- 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)

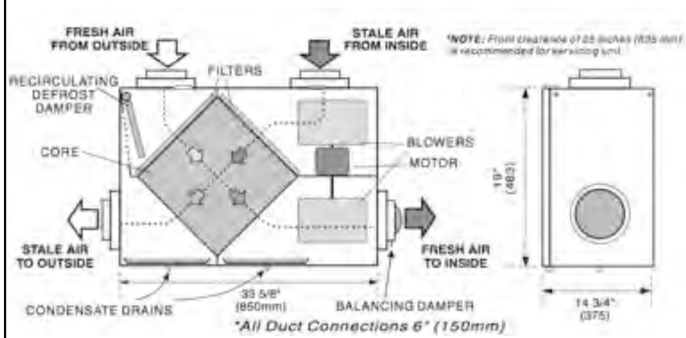
- HRV/ERV
- Point exhaust
- Fully ducted (need not be)



11/14/09 83

© buildingscience.com

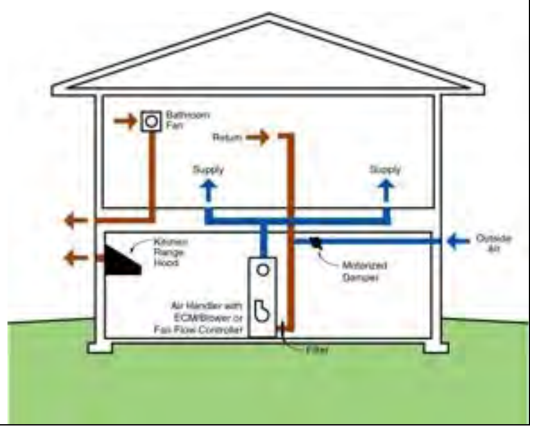
e.g. NuTech 155 ECM



HRV/ERV

- Heat Recovery Ventilator
  - 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

Heating Cooling + Ventilation



11/14/09

© buildingscience.com

Conclusions

- Lots of choices, lots of room for improvement

© buildingscience.com