8:00 - 8:30 1. What is a low-load building?
Dr. Straube will review enclosure specifications including insulation levels, airtightness, windows, and internal gains, and then discuss the approach to determining heating and cooling power densities.

8:30 - 10:00 2. Existing solutions
John will then examine how a typical furnace and air conditioning system should be expected to perform in a low-load enclosure. The relationship between enclosure improvements and mechanical system performance will also be explored for multi-unit residential buildings, including "stacked town houses" (better enclosure, smaller spaces) and large single family homes (better enclosure but may not be low load).

10:00 - 10:15 -- morning break --
10:15 - 12:00 3. Mechanical equipment design choices for heating, ventilation, and hot water
Turning to the mechanical systems, John will review the choices that are available. Systems to be considered will include ground-source heat pumps, air-source heat pumps, ductless mini-splits, ducted mini-splits, air-to-water heat pumps, combo (or combi) systems, and solar hot water systems. The pros and cons of each will be considered. The important of looking at domestic hot water will be emphasized.

12:00 - 1:00 -- break for lunch
1:00 - 2:30 Systems design: equipment, distribution, installation concerns
The review of mechanical system options will continue in the afternoon session.

2:30 - 2:45 -- afternoon break --
2:45 - 3:30 Some commercial building applications
Some commercial and industrial buildings can be approached in the same way. John will conclude the seminar by discussing the applicability of the previous discussion to these building types.

3:30 - 4:00 Closing Remarks

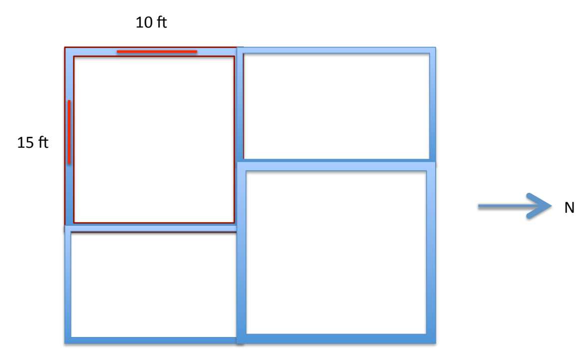
HVAC for Low-load houses

The New World

- Heating / cooling loads shrinking!
  - Better insulation, airtightness, windows
  - Smaller homes, townhomes
  - Multi-unit = small exterior enclosure area
  - New programs: NZE, PH, E-Star V3+
- DHW can be larger energy demand
  - Only efficient appliances can reduce DHW use

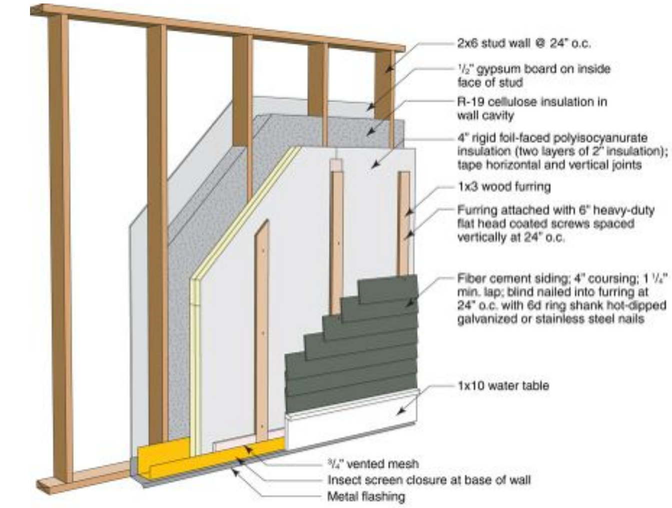
Zones and rooms

- R30 wall R60 roof R4 window

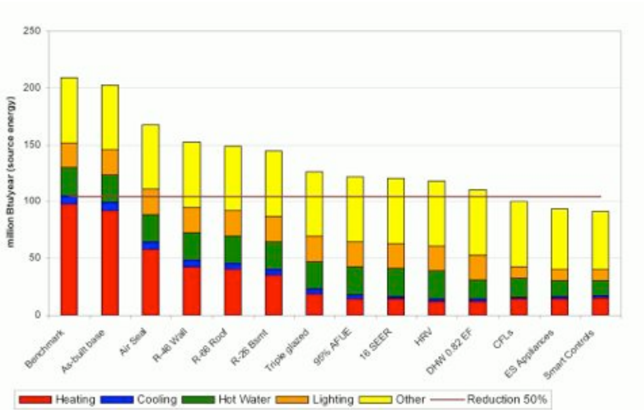


Room/zone

- (15+10) * 9 ft high = 175 sf
- If 5x5 and 5x6 windows = 25+30 = 55 sf
- So 120 sf wall, 150 sf roof
- Heat loss (0F outdoors, Delta=70F)
- Wall 120 / 30 * 70 = 280 Btu/hr
- Windows 55/4 *70= 960/hr
- Roof 150 / 60 *(70) = 175 Btu/hr
- Total skin loss =1415 (20 cfm air @ 135F)



Example Energy



Multi-unit Examples

- 20 x 30 ft = 600 sf 1 BDR interior apartment
  - 20*9 ft height = 180 sq ft enclosure area
  - 40% windows = 72 sq ft
- R20 wall, R4 window, 20 F outdoor temp.
  - (108/20+72/4) * (70-20) = (23.4) * 50
  - **1170 Btu/hr conduction** losses (!)
- Achieve 0.40 cfm/sq ft @75 Pa airtightness
  - 18 cfm leakage natural = **950 Btu/hr air leakage** loss
- Ventilation (New World needs it)
  - 30 cfm w/66%HRV = **1500/500 Btu/hr ventilation**

One therm = 29.3 kWh

Simple Heating Analysis Apartment

- Peak design load: 2.5-3.5 kBtu/hr (<1 kW)
  - Corner apartment up to 4-5 kBtu/hr (1.5 kW) ....
- Heat loss coefficient 50-70 Btu/F/hr
- If we use HDD65 = 4500
  - (50 to 70)*24*4500 = 54-75 therms < $100/yr
  - 1465-2200 kWh/yr <$160/yr
- If we use HDD50=1229 .... Negligible
- If 2.5 kBtu/hr, airflow= 50 cfm @DT=50

Low-load -1

- Peak heating loads in the range of 15-30000 Btu/hr
- Or peak heating power density of 10 to 15 Btu/hr/ft^2
- DHW load often exceeds space heating load
- Mechanical ventilation almost always required due well-built airtightness

Low-Load -2

- Peak design loads are smaller than smallest *commodity* central units
  - Eg 25-30 kBtu/hr furnace
  - 1.5/2 ton AC (18-24 kBtu/hr)
    - 2 ton is the smallest efficient model
- Large sprawling houses

Distance of heat/cool/ventilate unit to the farthest point

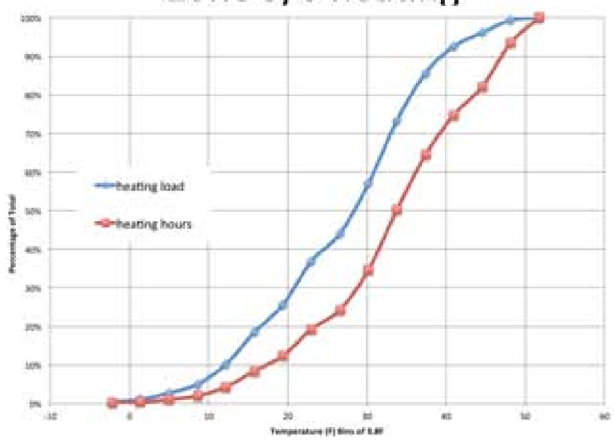
Low Load -3

- Internal / solar gains have a BIG impact on space temperature
  - Eg. SHGC (g)=0.60
  - 6'x6'8" patio door with 80% glass
  - 6000 Btu/hr in bright sun! (1/2 ton AC in one room)
- Better zoning may be needed
  - Room by room
  - Mixing between rooms
  - Or better enclosure? (lower SHGC glazing)

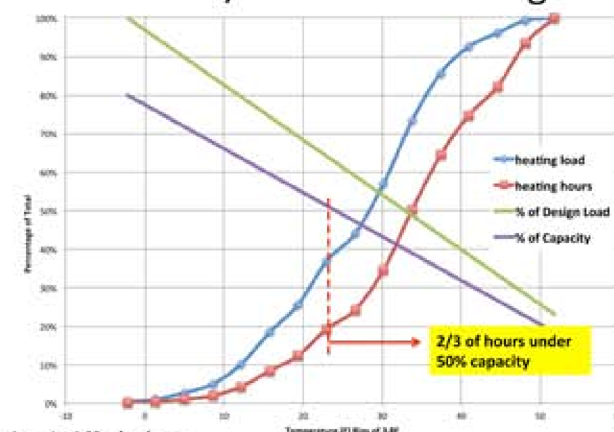
So what's the problem

- Smallest condensing furnaces are 40 kBu/hr
- Two-stage furnaces allow for low stage fire at 30 kBtu/hr
- But most hours are at fractions of peak design
- How does the system work with a hourly heat loss of 5 to 10 kBtu/hr?
  - Runs for 10 to 20 min/hour (two fires/hour?)
  - Short cycling (wear & tear, inefficiency)
  - But must provide ductwork for 30 kBtu/hr

Zone 5/6 heating



Zone 5/6 Climate Heating



Assuming 1.25 safety factor

So what's the problem

- If capacity >> demand
  - Short-cycling kills AC durability and efficiency
  - Overshoot temperatures, too hot in heating, too cold in cooling
  - Need modulation or thermal mass (water)
- Min. monthly charges of two utilities
  - Can dramatically increase cost
- Cannot save money due to small size
  - Ductwork still largish (eg, say 1000 cfm)

Some Goals limit solutions

- Electric consumption is easy to measure
- Net Zero Energy houses: PV is hence preferred for on-site generation
  - Solar thermal may be as expensive per Btu!
  - Small wind turbines often more expensive power
  - Drives solutions to all-electric
- Passive House
  - arbitrary supply temperature limits
  - Calculation tool that encourages high solar gain

Domestic Hot Water

- DHW > Space heating in efficient apartments
- DHW approaches space in efficient small house
- Typical US household (census data)
  - 4000 kWh demand +/- (136 therm)
  - National *consumption* 5600 kWh (192 therm)
- Typical 5 unit + building. Use /unit
  - 2500 kWh demand (86 therm)
  - 3575 kWh/yr estimated *use* (122 therm)

HVAC for Low-Load Houses

Introduction

- No perfect solution
- Depends on building size, shape, etc.
- New or retrofit?
- Gas available or all-electric?
- Trades and equipment availability
- Money available

HVAC

- People want comfort
  - Surface temperatures, humidity
  - Heat, cool, humidity
- People assume health
  - Require fresh air = require ventilation
- Don't want to pay too much
- Don't want to do maintenance

HVAC 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

12-12-06 23

HVAC Constraints

- Safety
  - Combustion, explosion, scalding
- Health
- Comfort
  - Temperature, humidity, air speed, noise, light
- Reliability
  - Maintainable, long term performance,
- Efficiency
  - minimum of additional energy
- Economy
  - Builder can afford

12-12-06 24

Interactions Interactions

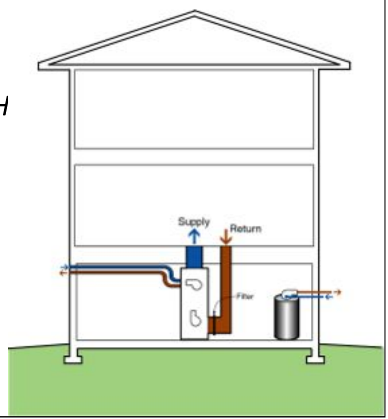
- BEWARE:
- “Perfect” solution for heating may not solve cooling
- “Perfect” cooling solution may not solve DHW supply
- Perfect heating+cooling+DHW may do nothing for ventilation!
- We need
  – heat+ cool + DHW + vent + filtration + humdity

Ratings game

- EER
  – BTU/hr output to W input
  – 95F outdoor, 80F return
- SEER
  – Seasonal EER
  – 82F outdoor, 80F return
- COP
  – Watts out to Watts in

Simple Single Zone Residential

- All rooms the same
- No *ventilation*
- *In AC, accidental RH control*



NOT acceptable for high-performance homes

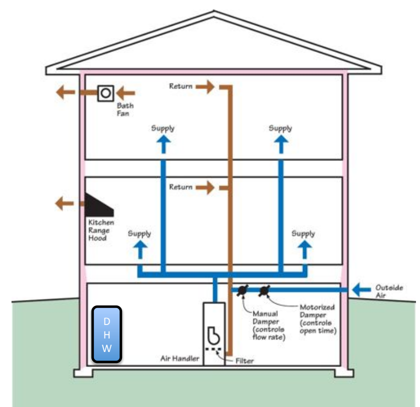
12-12-06

Minimum “Good” System

Ducts shared for ventilation, dehumidification, cooling heating

Heat or cold can be
•heat pump,
•furnace,
•solar
•wood, etc

FanCycler ensures fresh air or required amount delivered to each room



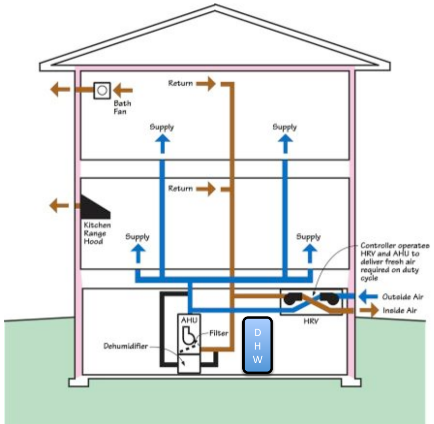
BSI-022: Housing

Lowest cost, high performance solution

Ducts shared for ventilation, dehumidification, cooling, heating

Highest performance separates all functions

Heat or cold can be
•heat pump,
•furnace,
•solar
•wood, etc



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!

12-12-06 30

Heat / Cool Production

Heat Production

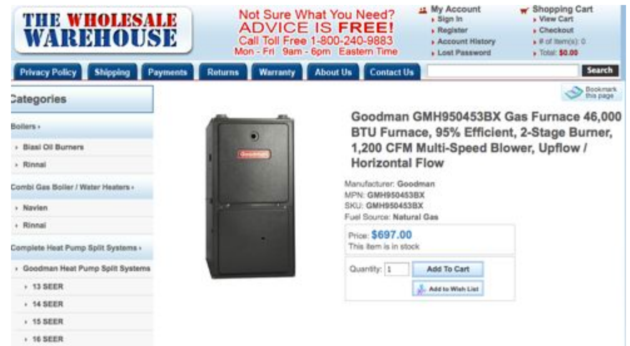
- Boilers : heat to water
  - Old types heated water to steam and distributed
  - Modern heat water to 35C (95F) to 85C (190 F) and pump water using small electric pumps
- Furnace: heat to air
  - Air is heated to min 40 C (110 F) and usually 50(130F)
  - Electric fan is used to move air
- Both heat exchanger between flame to fluid
- Fuel sources
  - Nat gas, oil, propane, wood, electric, etc.

12-12-06 32

Condensing Furnace

- Simple, reliable, lots of service available
- Cheap
- Usually works at near rating condition
- Eg 95% efficiency
- Spec efficient fans

Efficiency is expensive?



Small furnaces

- Most products output 40 kBtu/hr or more
  - 40 kBtu= 750 cfm @ 50F temperature rise
- Some modulating products have lower outputs, e.g.
  - York YP9C (20KBtu) $2500
  - Trane XC95M (23 kBtu) $3000
  - Carrier 58MVC, Rheem RGGE, Lennox SLP98DFV
- Small multi-stage can be better
  - Goodman GMH90-45 (30 kBtu) $900
- Modulating furnaces cant "lock out" high output – require duct sizing for 65-70 kBtu!

Fully-modulating Trane Furnace

95%+
<600 cfm
<90W
130F/54C supply

But.....
Min 24 kBtu/hr
+ expensive

MODEL	TUHMB060ACV3VA
TYPE	Upflow/ Horizontal Left
RATINGS ②	
40% (low) heat Input BTUH	24,000
40% (low) heat Capacity BTUH (ICS) ③	23,000
100% (high) heat Input BTUH	60,000
100% (high) heat Capacity BTUH (ICS) ③	57,000
Temp. rise (Min.-Max.) °F.	35 - 65
AFUE	95.0

*UHMB060ACV3VA** Furnace Heating Airflow (CFM) and Power (watts) vs. External Static Pressure With Filter

Heating	Airflow Setting	Target Airflow (See Note 5)		External Static Pressure 0.1	0.3	0.5	0.7	0.9
40% (low) Heat	Low	465	CFM	393	504	512	546	560
			Temp. Rise	73	57	56	53	51
			Watts	43	81	112	142	140
	Medium Low	504	CFM	435	541	549	580	593
			Temp. Rise	66	53	52	50	49
			Watts	46	86	119	150	148
	Medium**	538	CFM	472	573	580	609	621
			Temp. Rise	61	50	50	47	46
			Watts	50	[illegible]	125	159	155
	High	605	CFM	545	636	644	667	676
			Temp. Rise	53	45	45	43	43
			Watts	60	103	141	177	169
65% (medium) Heat	Low	623	CFM	565	653	660	682	691
			Temp. Rise	68	59	58	57	56
			Watts	64	107	145	182	172
	Medium Low	675	CFM	622	703	710	727	734
			Temp. Rise	62	55	54	53	53
			Watts	75	120	161	199	183
	Medium**	720	CFM	671	745	752	766	771
			Temp. Rise	58	52	51	50	50
			Watts	86	133	175	215	192
	High	810	CFM	769	831	837	843	846
			Temp. Rise	50	46	46	46	46
			Watts	114	164	210	250	211
100% (high) Heat	Low	830	CFM	791	849	856	861	862
			Temp. Rise	65	61	60	60	60
			Watts	121	171	219	258	215
	Medium Low	900	CFM	867	916	922	921	920
			Temp. Rise	59	56	56	56	56
			Watts	148	201	251	290	230
	Medium**	960	CFM	932	972	979	973	970
			Temp. Rise	55	53	53	53	53
			Watts	174	229	282	319	243
	High	1080	CFM	1063	1086	1092	1076	1069
			Temp. Rise	48	47	47	48	48
			Watts	236	295	353	384	268

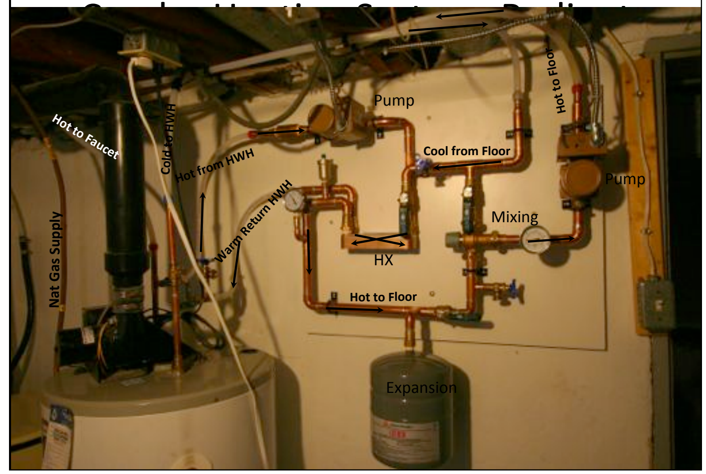
Modern Boilers: small, quiet efficient

Boilers don’t boil

12-12-06

- 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



Condensing Boilers

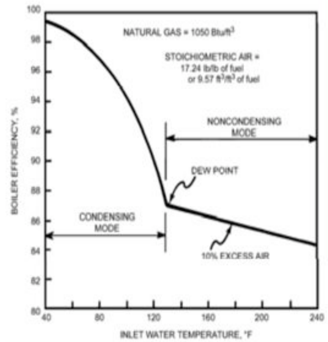
- Supply temperatures of max 140F (60C) under design conditions
  - ensures return temperature low enough to get condensing (=efficiency)
- Lower is better!
  - Outdoor reset
  - Variable speed pump + Delta T controller
  - Varibale speed pump +

Boiler Combustion Efficiency

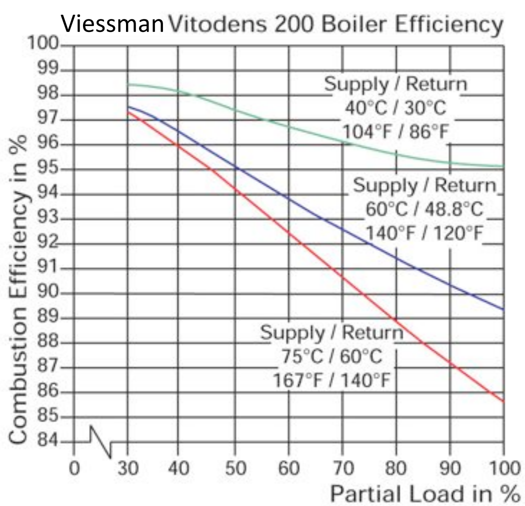
- Most combustion is >99.9% efficient
- Equipment varies on ability to extract useful heat from combustion via HX
- Heat exchanger size is important
- Temperature of entering fluid is also critical
  - Condensing furnace (72 F / 22 C)
  - Condensing boiler >90% (<110 F / 45 C)
  - Normal boiler <85%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



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+ supply

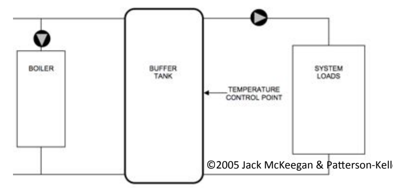
Building Science 2008

Combo Systems

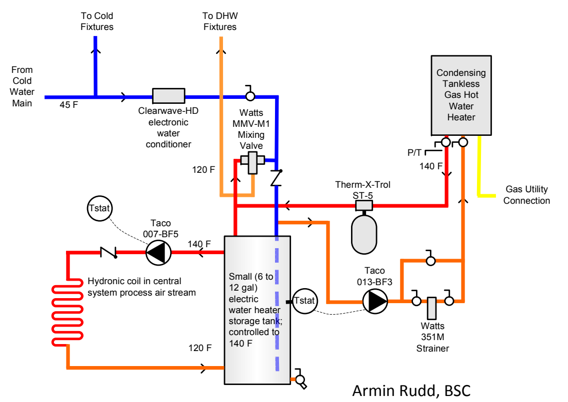
- Condensing Tankless heaters
  - Beware minimum output
  - Most units are 15 to 35 kBtu/hr minimum
  - Eg. no lower than a furnace
- Unless storage is provided, min output equals min output of heating system
  - This means duct sizes, coils, etc.

Combo System Warning

- Provide buffer capacity, eg a storage tank
- Limits short-cycling when loads are small (eg 10-30% of min. boiler output)
  - Allows for very small demand systems
- Buffer tank avoids cold slug complaints



Condensing Tankless Gas Hot Water Heater Application
In Combination Space and Domestic Hot Water Heating System

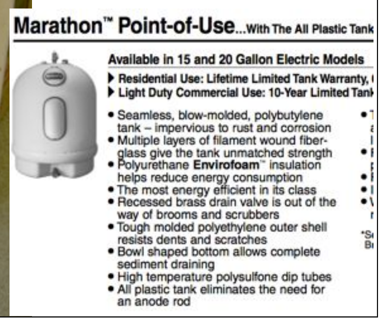


Armin Rudd, BSC
RR-1009 Space Conditioning ...

Combi

- small buffer tank
- Adds some standby losses

Low standby loss



Newer Condensing Tanked systems

Allows for direct connection to air handler.

No additional controls or plumbing

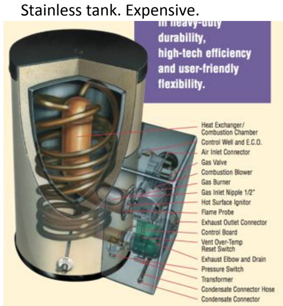
May be lowest cost solution for pretty high efficiency in small apartments, homes, with few cooling needs.

State Force 90

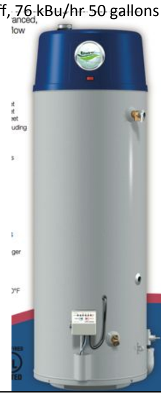
Condensing tanked

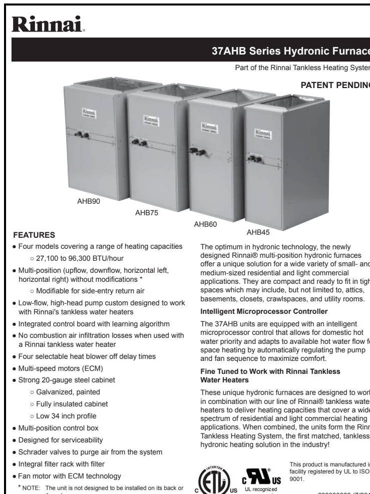
- several suppliers

Rheem Rudd Advantage Plus
95% eff 100 kBtu/hr 45 gallons
Stainless tank. Expensive.



GSW James Wood Envirosense
90% eff, 76 kBu/hr 50 gallons





Fan coils

- Operate at over 100F (38C) air temperatures to avoid “cold blow” drafts
- Ensure low return (under 120F) to get condensation in condensing boilers
- Lower speed jet (200 fpm), high supply location recommended
  - Higher supply temperatures if you don’t do this

Combo air handler: Built-in pump and ECM fan

ECM motor + low flow = very low electrical draw, and very quiet

Low-speed fan setting & lower water temperature (120 F /49C) allows for whole house heating of homes with just 8-15 kBtu/hr peak (e.g. at 300 cfm)

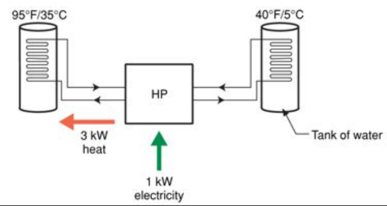
Heat Pumps

- 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

12-12-06 60

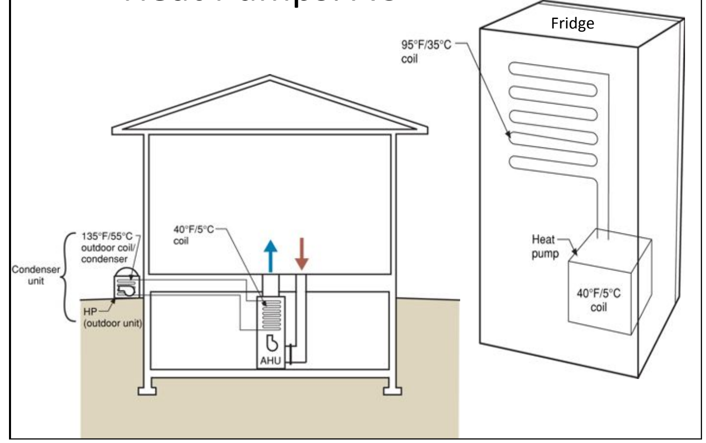
Heat Pumps

- 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"

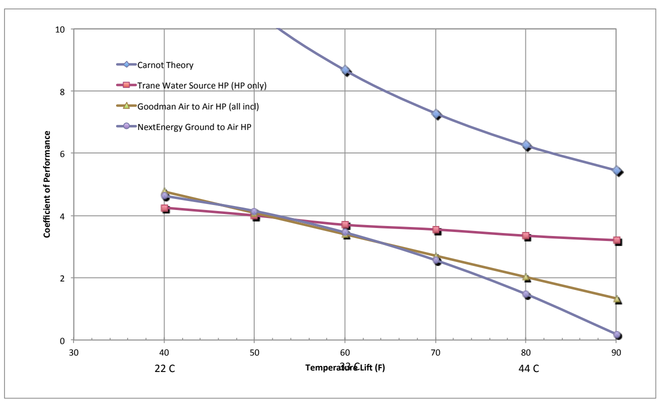


12-12-06

Heat Pumps: AC and Fridge



Heat Pump Efficiency vs Lift



Split System Heat Pump and Reject/ Collect in same box

- Compressor, and DX coils in one enclosure

Cooling

- Most cooling equipment is a heat pump
  - uses the interior as a source (collection) and
  - Outside as the sink (rejection)
- Heat pumps do cooling and heating
- Challenge to get single speed units to be appropriate for both

Dehumidification

- Cooling will often require supplemental dehumidification
- This requires cold surface: eg fan coils, not radiant ceilings/floors!
- Separate dehumidifer is common
- Multi-speed AC may be sufficient in marginal cases (including mini-split)

Heat pumps in heating mode

- Major reduction in heat output as outdoor temperature drops
- COP drops as outdoor temperature drops
- Typically designed for a “balance point” and then used electric “strip” heat
- Modern design avoids strip heat

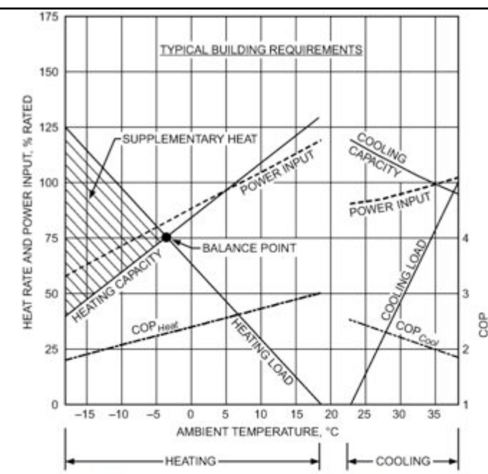


Fig. 11 Operating Characteristics of Single-Stage Unmodulated Heat Pump

Heat+cool: Ducts provides distribution, can add ventilation, no DHW

Split Heat Pumps

- An option for Zone 3-4?
  - Eg Portland Seattle Tacoma 20 F *design* temp
- 2 ton HP produce about 16 kBtu/hr @20F

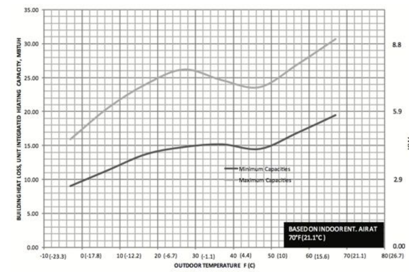
SSZ160241A* / CA*F3636*6A* + TXV / MBE1600-1** **e.g., Goodman SEER16 model**

	Outdoor Ambient Temperature															
	65	60	55	50	47	45	40	35	30	25	20	17	15	10	5	0
MBh	30.2	28.6	26.9	25.1	24.0	23.3	21.6	19.9	18.7	17.3	15.9	15.0	14.4	13.0	11.5	10.0
ΔT	31.9	30.2	28.4	26.6	25.4	24.6	22.9	21.1	19.8	18.3	16.8	15.9	15.3	13.7	12.2	10.6
kW	1.79	1.75	1.72	1.68	1.7	1.65	1.62	1.58	1.68	1.64	1.60	1.58	1.56	1.52	1.48	1.45
Amps	8.4	7.8	7.3	6.9	6.7	6.6	6.2	5.9	5.7	5.4	5.2	5.1	5.0	4.7	4.4	4.2
COP	4.93	4.76	4.57	4.37	4.22	4.13	3.91	3.69	3.26	3.08	2.91	2.79	2.71	2.49	2.27	2.03
EER	16.9	16.3	15.6	14.9	14.4	14.1	13.4	12.6	11.2	10.5	9.9	9.5	9.3	8.5	7.7	6.9
Hi PR	349	334	322	307	300	295	283	272	260	249	239	233	229	220	212	203
Lo PR	144	133	125	115	108	104	96	85	77	69	60	56	54	46	40	33

Seasonal COP 3-3.5, cooling included, standard equipment, <<$3000

Some split-systems might work

INFINITY SYSTEM



EVAP. AIR	CONDENSER ENTERING AIR											
	75 (23.9)				85 (29.4)				95 (35)			
EWB °F (°C)	ID SCFM	Capacity MBtuh Total	Capacity MBtuh Sens‡	Total Sys. KW	ID SCFM	Capacity MBtuh Total	Capacity MBtuh Sens‡	Total Sys. KW	ID SCFM	Capacity MBtuh Total	Capacity MBtuh Sens‡	Total Sys. KW
25VNA024A**30 Outdoor Section With FE4AN												
57 (13.9)		15.41	15.41	0.58		14.77	14.77	0.70		14.10	14.10	0.84
62 (16.7)		15.43	15.43	0.58		14.80	14.80	0.70		14.12	14.12	0.84
63 (17.2)††	500	15.55	11.42	0.57	500	14.74	11.10	0.70	500	13.86	10.76	0.85
67 (19.4)		16.90	11.97	0.56		16.04	11.65	0.68		15.13	11.32	0.82
72 (22.2)		18.84	9.56	0.51		17.90	9.25	0.64		16.92	8.93	0.79

Expensive. Min. cooling capacity of about 14 kBtu/hr
Min heat output of about 10-15 kBtu/hr @ cold temperatures

Ductless Mini-split

Modulating= follows load profile
Available in small sizes
BUT, don't provide ventilation or DHW

Measured Mini-split performance

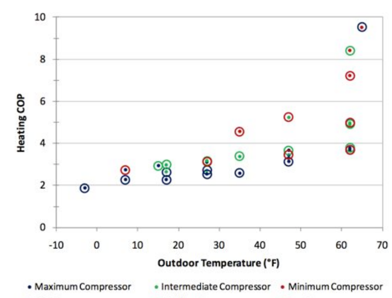
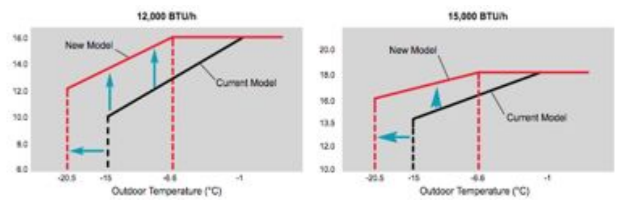


Figure 5. Fujitsu 12RLS steady-state heating COP (70°F return temperature)

Winkler, J. Laboratory Test Report for Fujitsu 12RLS and Mitsubishi FE12NA Mini-Split Heat Pumps, NREL, Golden, CO. 2011.

Modulating / staged heat pump

- Loose less output as temperature drops
- Always loose efficiency (COP drops)
- Usually avoid electric heat, or supplement it



Example: Fujitsu 12RLS2

Example

■ MODEL: ASU9RLS2

AFR	500

		°FDB	Indoor temperature 60		65		70	
	°FDB	°FWB	TC	IP	TC	IP	TC	IP
Outdoor temperature	-5	-7	14.7	1.97	14.3	2.01	14.0	2.05
	5	3	16.1	1.98	15.7	2.02	15.4	2.06
	14	12	16.8	1.91	16.4	1.95	16.0	1.99
	23	19	18.3	1.84	17.9	1.88	17.5	1.92
	32	28	18.8	1.78	18.4	1.82	17.9	1.85
	41	37	21.3	1.85	20.8	1.89	20.3	1.93
	47	43	23.1	1.91	22.6	1.95	22.0	1.99
	50	47	25.5	1.94	24.9	1.98	24.3	2.02
	59	50	26.5	1.95	25.8	1.99	25.2	2.03

AFR : Air Flow Rate (CFM)
TC : Total Capacity (kBtu/h)
IP : Input Power (kW)

16 kBtu/hr output @14F and COP=2.4

Mini-split distribution

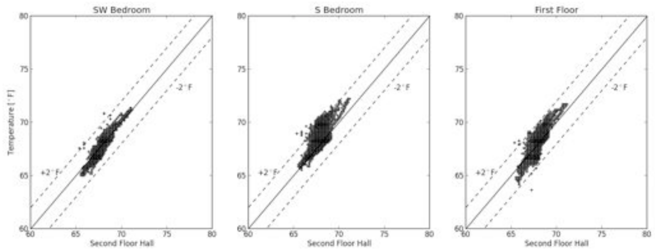
- Heat distribution from 7kBtu/hr head?
- Aesthetics of exposed heads
- Some hidden “slim duct” units exist but efficiency suffer
- Open doors between spaces really helps

Distribution from point sources

- Mini-split first floor only (heating)
- Installed 2nd floor for cooling
- Measured temperature distribution from bedrooms to hallway
- Work by Kohta Ueno / Dan Bergey
- Carter Scott NZEH
- unoccupied

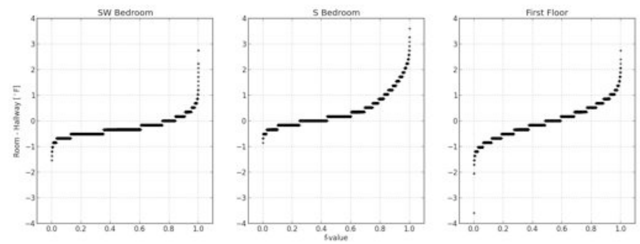
Temperature Distribution

- little temperature variation (+/2F)



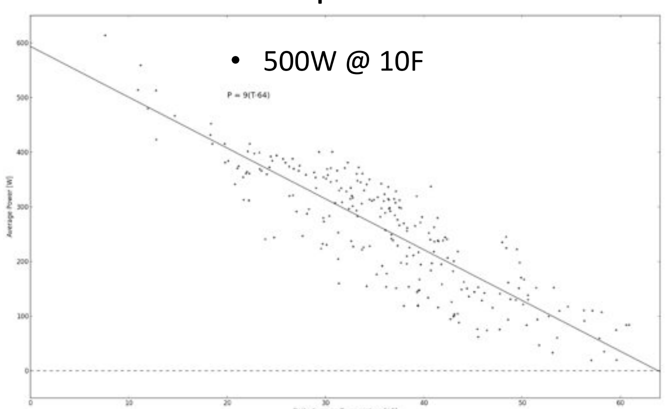
Distribution

- SW/S bedroom was sometimes 2-3F warmer than hall
- Solar heating through SHGC=0.2 windows



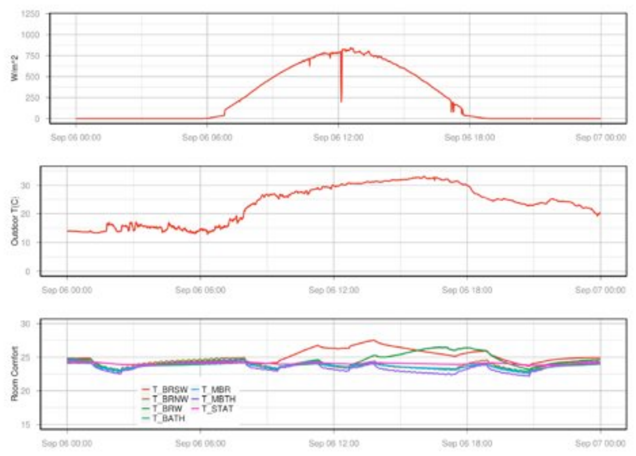
Measured power draw

- 500W @ 10F



More Distribution

- 2400 sf high performance home in Philly
- Sunny day, near peak cooling load
- 2 ton AC (about 2x what is needed)
- Temperature variations exceed 5F/3C from thermostat
- Solar gain in Southwest Bedroom results in peak load



Variable Refrigerant Volume (VRV)

Emerging alternate systems

- Variable speed outdoor unit (VRV) (18 & 24)
- Two-speed indoor fancoil for ducts (ECM fan)
- 18 kBtu/hr model
  - Operates at 600/420 cfm
  - 12 kBtu/hr low speed
  - Up to 20 kBtu/hr heating

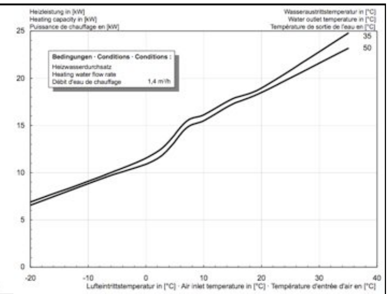
Chillers

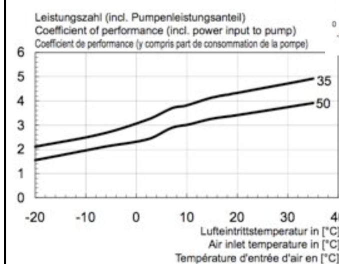
- Air-water heat pumps used for cooling water
- Big units use cooling towers
- Usually large buildings
- "reverse-cycle chiller" is another name for a water-to-air heat pump

Air to water heat pump

- Often need DHW top-up
- Do heat/cooling with AHU

- Air-to-water

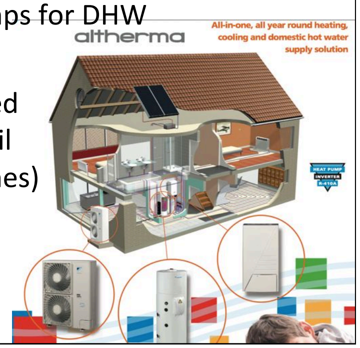




Source: Dimplex.de LA 16AS

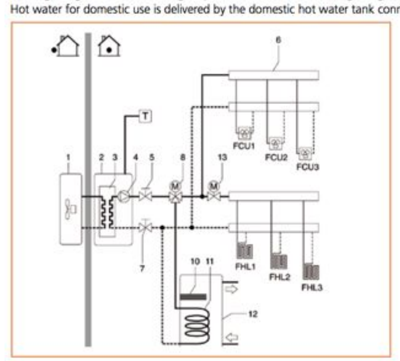
Air-water Altherma

- heats only to 130F
- COP is low at low temps for DHW
- Expensive
- One product if coupled with low-temp fan coil radiant floor (dry climes)



Heat, cool, DHW

3. Application "heating/cooling" via room thermostat and "production of domestic hot water"
Heating using under floor heating loops and fan coil units. Cooling using only the fan coil units.
Hot water for domestic use is delivered by the domestic hot water tank connected to the indoor unit.



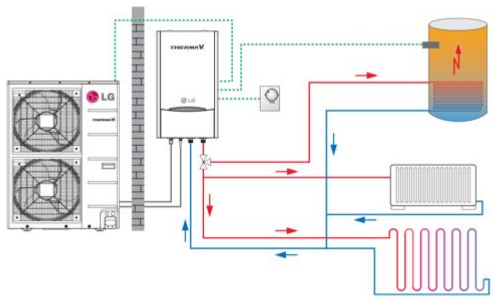
1. Outdoor unit
2. Hydrobox
3. Heat exchanger
4. Pump
5. Valve
6. Manifold (field supply)
7. Valve
8. Motorized 3-way valve
10. Booster heater
11. Heat exchanger spiral
12. Tank for domestic hot water
13. Motorized 2-way valve (field supply)

FCU1...3 Fan coil unit (field supply)
FHL1...3 (Under) floor heating loop (field supply)
T Room thermostat with cooling / heating switch

Numerous systems available

- but not in Canada/US ☹

Therma V + Radiator + Underfloor Heating + Sanitary Tank

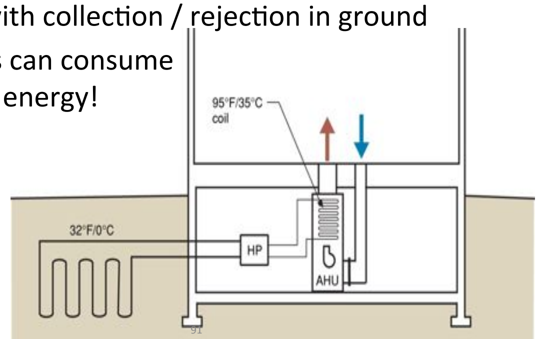


CO2 Refrigerant air-to-water

- allows true hot water (>140F/60C)
- Operates to low (-10F/-25C) temperatures
- Cant buy in north America ☹

Ground Source Heat Pump

- A water-to-air or water-to-water heat pump with with collection / rejection in ground
- Pumps can consume lots of energy!



12-12-06

GSHP Geothermal

- Can buy small capacity systems (eg 1.5 – 2 tons)
- Many benefit for water storage tank
- Cost is challenging: just heat cool but often total system cost of $20K
- Desuperheaters don't help DHW much

Electric Resistance

- Electric heat
  - Cheap to buy, high operating cost, maybe hi GHG
- Baseboard / Cove
  - Impact on space design
- Radiant heat mats (heat does not rise)
  - Floor/ceiling
  - 10-15 W/sf capacity
  - Need 300-600W per room (30-60 sf)

Pellet Boilers

- Can be an option for heating and opt. DHW
- 8-50 kBtu/hr, modulating, some sealed combustion

Domestic Hotwater

Difficult to separate from design of HVAC in low-load *residential* buildings

DHW – Health/Safety

- Require water temps over 120 F (50C)
  - 66 °C (151 °F): Legionellae die within 2 minutes
  - 60 °C (140 °F): Legionellae die within 30 minutes
  - 55 °C (131 °F): Legionellae die within 5 to 6 hours
  - 50 °C (122 °F): They can survive but do not multiply
- Showers are primary indoor residential vector
- Scalding 130F
  - 10 / 30 seconds for child/adult 3rd deg burns

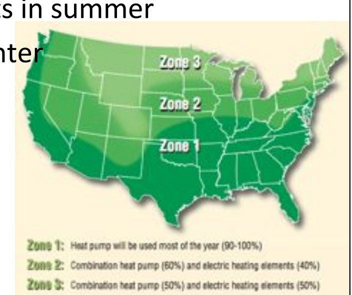
DHW

- Heat pumps
  - difficult to achieve >120F efficiently
  - Need to use R134a/R507 to get hot
- Gas combustion
  - High capacity and >130F easy
- Electric
  - Expensive, lower recovery
  - Point-of-use requires large kW service

Heat-pump water heaters

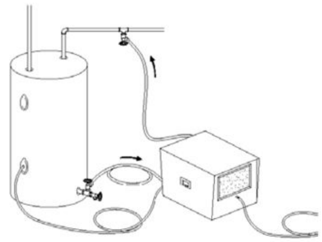
Performance: "depends"

- Work well in warm spaces
  - Eg boiler rooms
- Dehumidify basements in summer
- Cool basements in winter
- Steal heat from house
  - Is free heat available?

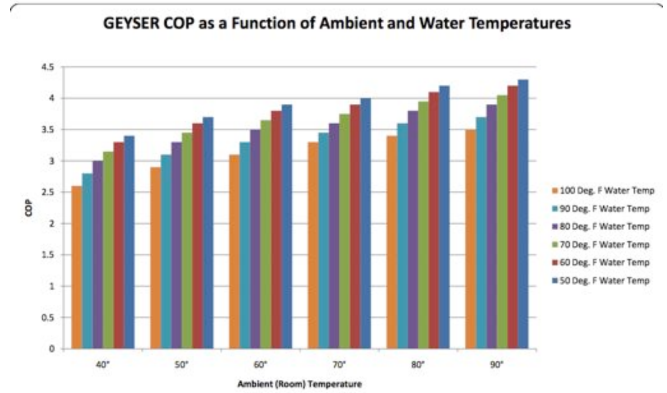


Add-on Heat pump

•



North Road Technologies LLC



DHW efficiency

- Condensing can happen when low entering temperature
- Long pipe runs can eat up energy
  - Small pipes help
- Heat Pump Water Heaters
  - Depend on where you are

Distribution of Thermal Energy

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)**
    - **Usually use 1.05 for cool air, 1.08 for warm air**

Building Science 2008

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 120 F: 1.0*50= 50 Btu /hr/cfm
    - Heat pump 100 F: 1.0*30 = 30 Btu/hr/cfm
    - Therefore need 5/3 more airflow for low temp air

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

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 use low CFM *and/or* Low ΔP**

Building Science 2008

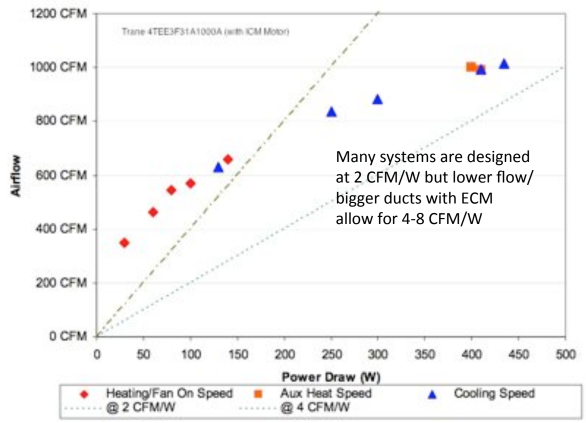


Figure 8: Airflow (CFM) vs. power draw (W) curve of various AHU configurations

$W = 2.6 \cdot 10^{-5}$ CFM^2.4

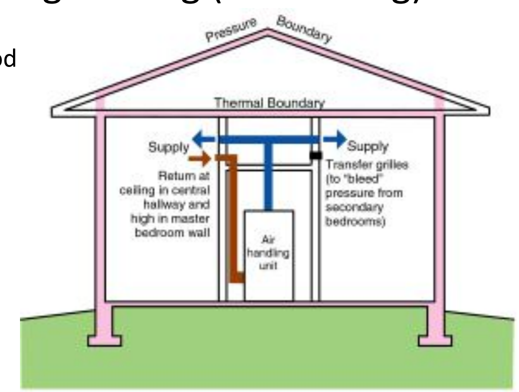
Reducing duct friction

- Reduce velocity
  - Increase duct area!
- Fittings are major source of friction
  - Larger radius bend
- Simplify duct runs if possible

Building Science .com

Heating Cooling (and mixing)

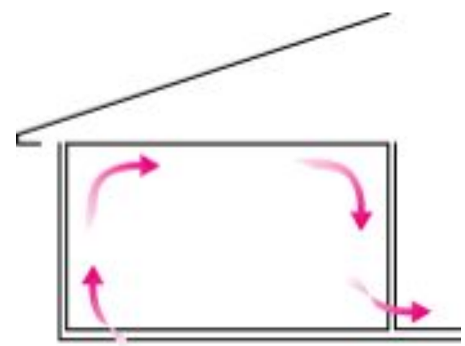
- Need good windows



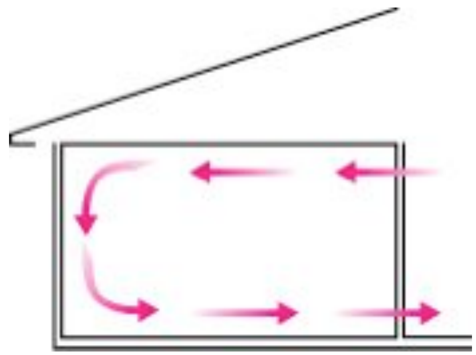
Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

12-12-06

Winter-based old style



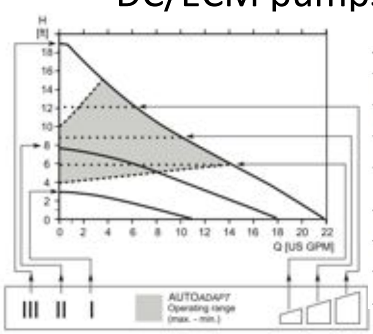
Interior sidewall only



Water-Based Systems

- Water moves…
  - 500 Btu/hr/GPM/F
  - 375 Btu/hr/GPM/F (Glycol)
  - Radiant floor
    - 100 F supply 90 return <= 5000 Btu/hr/GPM
- Example: 30 000 Btu/hr
  - Furnace: @ 50 Btu/hr/cfm → 600 cfm (300W)
  - Heat pump @ 30 Btu/hr/cfm → 1000 cfm (500W)
  - Radiant 5000 Btu/hr/GPM → 6 GPM (40W)
- But, good design/spec can deliver 600 cfm@150W

DC/ECM pumps+controls



Speed setting		Min.	Max.
High fixed speed	III	39W	45W
Medium fixed speed	II	15W	30W
Low fixed speed	I	5W	8W
Constant pressure		8W	45W
Constant pressure		14W	45W
Constant pressure		22W	45W

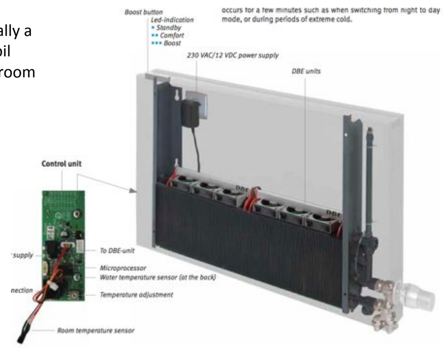
New variable speed pumps offer remarkably low Watt/GPM, and built in controls to allow for fixed flow or fixed pressure

Energy of distribution

- Furnace: 1000 cfm 60 000 Btu/hr
  - Fan 300-800W (=1000-2700 Btu/hr)
  - 1.5 to % of energy delivered
- Heat Pump 1000 cfm 30 000 Btu/hr
  - Fan 300-800 W (4 to 9%)
- Radiant floor
  - Pump 85W 10 GPM 50 000 Btu/hr (0.6%)
- ***Distribution energy can vary by 5X to 15X***

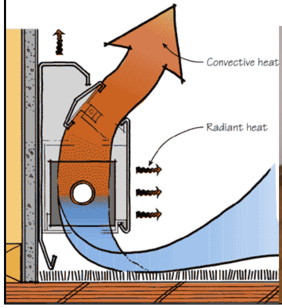
Euro-models

Jaga : basically a small fan-coil exposed in room



Convector / Radiant

- Usually only for heating
  - larger Delta T need to drive buoyancy



Convector / Radiator

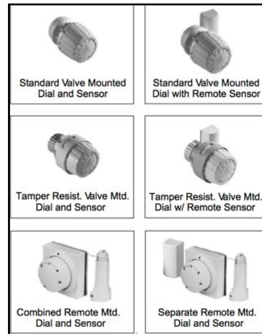
- Hydronic terminal units
  - no energy required at unit

Low-temperature baseboard

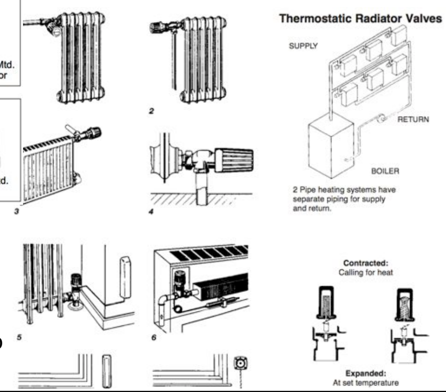
- Typical convectors
  - rated at 180F / 80C (mean or supply)
  - return temperatures >160F /70C
- Want to supply with lower temperature!
  - Condensing boilers and heat pumps only work with supply temperatures under 140F/60C
- Must increase SIZE of convector to reflect lower supply water temperature

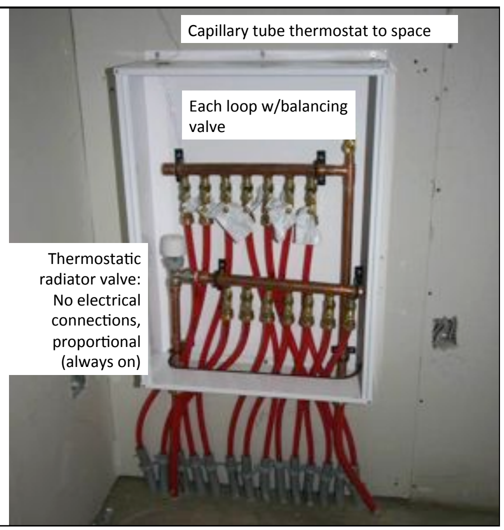
Convector retrofit- see TRV

TRV (very simple)



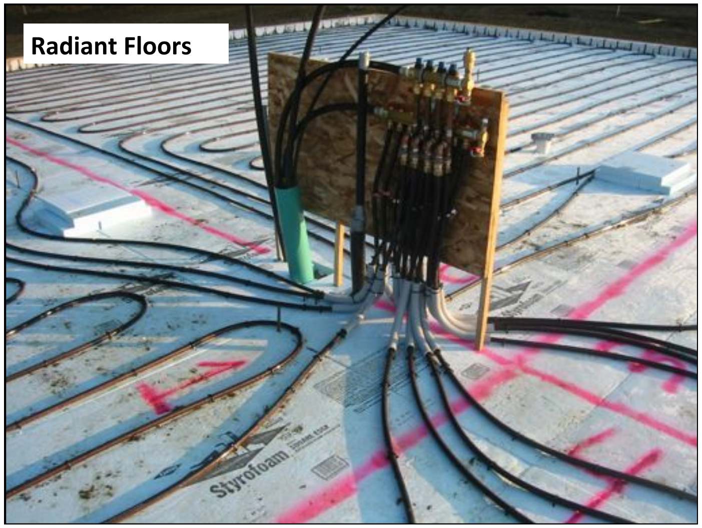
- Thermostatic Radiator Valves
- Automatically open and close to meet setpoint temperature with no power required





Radiant floors in low-load houses

- Radiant floors wont heat up enough to be noticed
  - This is not barefoot friendly
- Still, zero-noise, no maintenance



Emission plates under wood

- Not as effective as topping.
  Requires higher water temperatures.

Heat Exchange from Surfaces

- Example: 80F (27C) floor, 72F (22C) room air
  - 15.2 Btu/hr/ft² heating
- Example: 60F (15.5C) ceiling, 74F (23C) room air
  - 26.6 Btu/hr/ft² cooling (500 sf/ton)
- Example: 68F floor, 74F air (1500 sf/ton)

	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"

- Low temperature radiant has some self control
- *Huge* practical control and comfort benefit in <u>low</u> heat flux radiant floor and ceilings
- If room rises 1F @ low load, heat output drops 38%!

Heating Power Btu/hr/ft2	W/m2	Room 70F Floor Temperature (F)	21.1C Celsius	Power output change for 1F/C room temperature Btu/hr/ft2	W/m2	Percentage change Output
5	15.8	72.6	22.5	1.9	11	38%
10	31.5	75.3	24.0	1.9	11	19%
15	47.3	77.9	25.4	1.9	11	13%

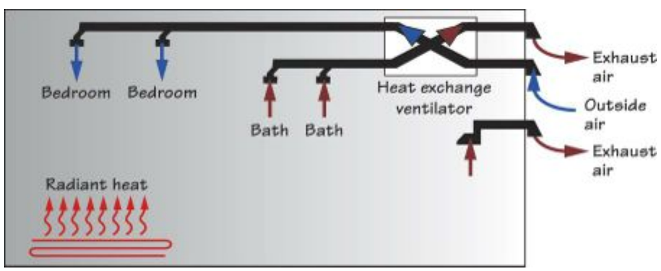
Building Science

Ventilation

Intro

- Require fresh air for health and humidity
- ASHRAE 62.2 latest
  - 7.5 cfm/person + 0.03 /sf
- Therefore
  - 3 BDR / 2000 sf = 90 cfm
  - Was 50 cfm until recently

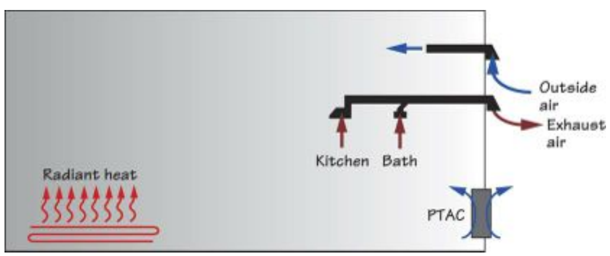
•Multi-point supply, often continuously operated
•Multi-Point exhaust, often continuously operated
•Heat recovery of moisture and heat in air add on



No Cooling. Radiant heat usually from a source of hotwater

Exhaust fans with passive unconditioned make up PTAC cooling and radiant heating

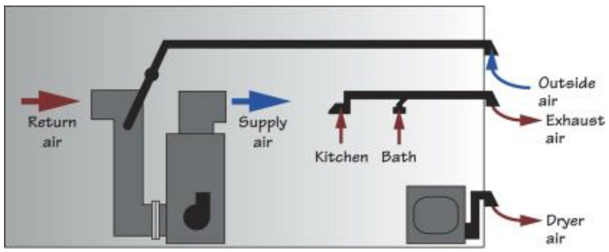
Ventilation distribution?



132 12-12-06 John Straube

Point intermittent exhaust
Air-based heat-cool system with make-up ventilation

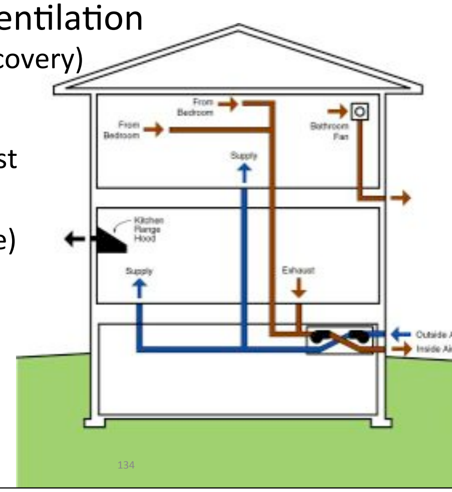
Possible VTAC applications



133 12-12-06 John Straube

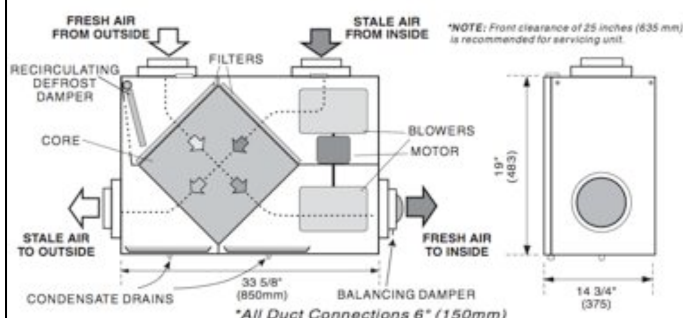
Balanced Ventilation
(with Heat Recovery)

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



12-12-06 134

e.g. NuTech 155 ECM

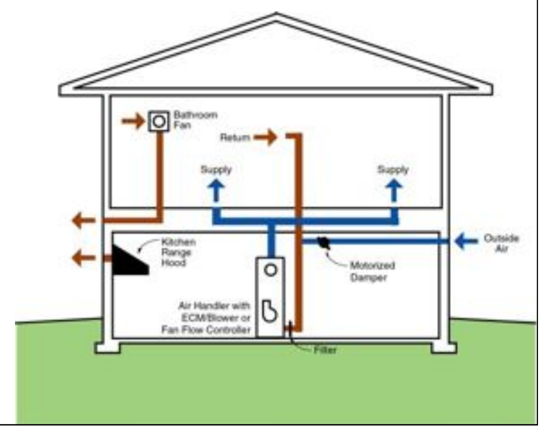


- Mid-scale HRV
- Emerging tech
- 200-600 cfm
- Need to watch fan energy!

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



12-12-06

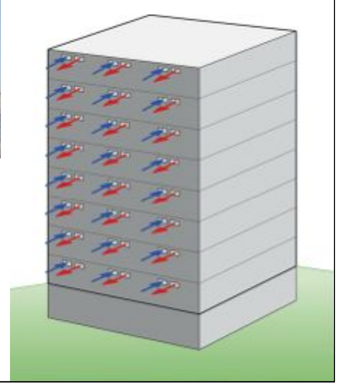
Multi-unit Issues

- Metering: per suite or per building
- Fuel-Source: Gas or all-electric
  - Carbon? Dollars? Energy?
- DHW or just space heat?
- Is Cooling necessary?
- Grouping: Central, unit, or mix?
- Equipment owned per suite or per building?
- Perceived access to apt issues?

Central vs Distributed

- Central systems often
  - reduce capital cost per unit output of *plant*
  - Increase distribution costs dramatically
  - Increase distribution energy losses
  - Decrease redundancy
  - Increase complexity
  - Make sub-metering expensive/difficult
  - Take advantage of load diversity

Suite by Suite supply and exhaust



Ganged sealed combustion – penetrations! Separation (10ft)

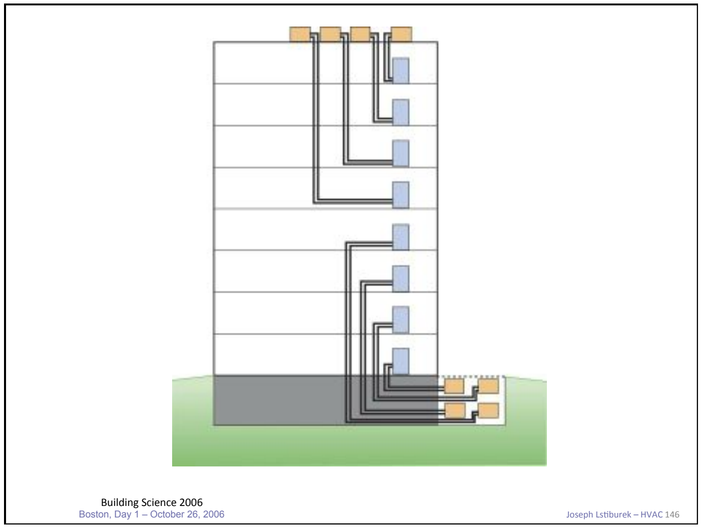
143

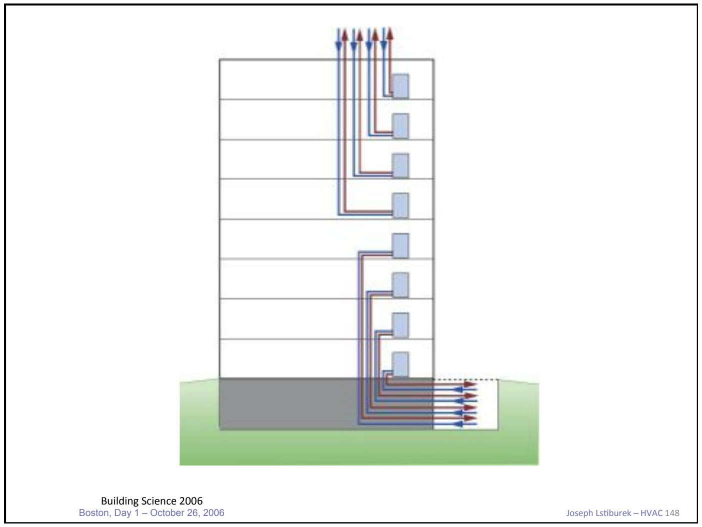
12-12-06

Dual boilers and pumps, quick change out possible, battery operation possible

DHW Distribution

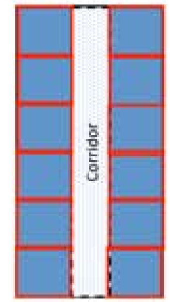
- Distribution losses
  - Can be significant for long runs
  - Recirculation pumps
  - Large pipe diameters store lots of water





Schools

- E.g Double-loaded corridor or exterior corridor
- One wall + roof exposed/class
- Small systems work well per class
  - mini-split + HRV
  - Ventilation control / class
  - Individual control of temperature!
  - Lots of redundancy, easy to maintain



Conclusions

- This is still complex
- No simple or easy solutions

Choices

- Furnace is still a good choice if you have natural gas and loads over 20 kBtu/hr
  - Choose smallest condensing unit, lock out high fire
- Combo Systems
  - Use high-efficiency DHW system to provide heating
  - Space heat can be fan coil, radiator, floor
  - Can be integrated into ventilation, filtration
  - Add cooling coil
- Size of duct/coil often fixed by cooling system

Cooling

- Need variable speed / staged small units
  – Ductless mini-split on upper floor only?
- Separate dehumidifier likely required
  – Could be DHW heat pump!