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Passive House Northwest

HVAC for Low-load Buildings

Dr John Straube, P.Eng.

www.BuildingScience.com

University of Waterloo

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

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Course Description

Prof. Straube will define low and ultra-low load buildings and discuss the enclosures that are needed to get there. Next, the implications of these low load enclosures on heating, ventilation, hot water, and other building systems will be explored. Fossil-fueled, electric, solar and biomass will be addressed. This session is intended for designers and builders of ultra-efficient residential (i.e. Passive House, DOE Challenge Home, and similar) and smaller commercial buildings.

PHnw

CONTINUING EDUCATION AIA

Learning Objectives

At the end of the this course, participants will be able to:

1. Define ultra-low load buildings and discuss the enclosures that are needed to get there.

2. Understand the implications of these low-load enclosures on heating, ventilation, hot water, and other building systems. Mechanical equipment design choices for heating, ventilation and hot water will be discussed.

3. Understand the design of the systems, i.e. equipment, distribution, installation, and some of the challenges. Fossil-fueled, electric, solar and biomass based systems will all be addressed.

4. Understand the similarities and differences between small scale commercial and residential applications.

PHnw

Passive House Northwest
AIA CEU Provider

Mechanical Systems For Low-Load Buildings

AIA Course # phnw015

John Straube
April 25, 2013

PHnw

The New World

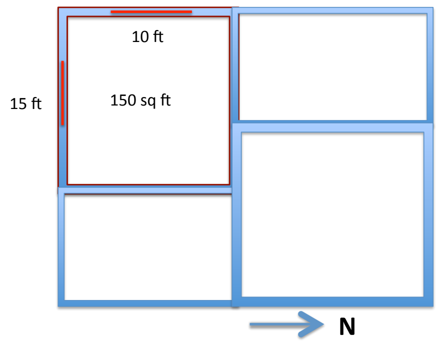
- Heating / cooling loads shrinking!
  - Better insulation, airtightness, windows
  - Smaller homes, townhomes, apartments, seniors
  - Multi-unit = small exterior enclosure area
  - New programs: NZE, PH, E-Star V3+
- DHW often larger energy demand than heat
  - Only efficient appliances can reduce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

Pacific Northwest

- What's special about the PNW?
- Not very extreme cold or hot
  - Design temperatures?
- Moderate summer humidity
- Cheap electricity, cleaner ..

Example: Zones and rooms

- Consider true R30 wall R60 roof R4 window



- What do we need to know?
- Q = U •A •ΔT
- U = 1 / R
- Q_{air}= cfm •ΔT

Room/zone

- (15'+10') * 9 ft high = 175 sf of wall
- If 5'x5' and 5x6 windows = 25+30 = 55 sf windows
- Therefore: 120 sf wall, 150 sf roof, 55 sf window
- Heat loss (ΔT=50 if 20°F outdoors)
- Wall 120 / 30 * 50 = 200 Btu/hr
- Windows 55/4 *50= 687 Btu/hr
- Roof 150 / 60 *50 = 125 Btu/hr
- Total skin loss = 1012 Btu/hr
  - can be met by 17 cfm air @ 130F /54C

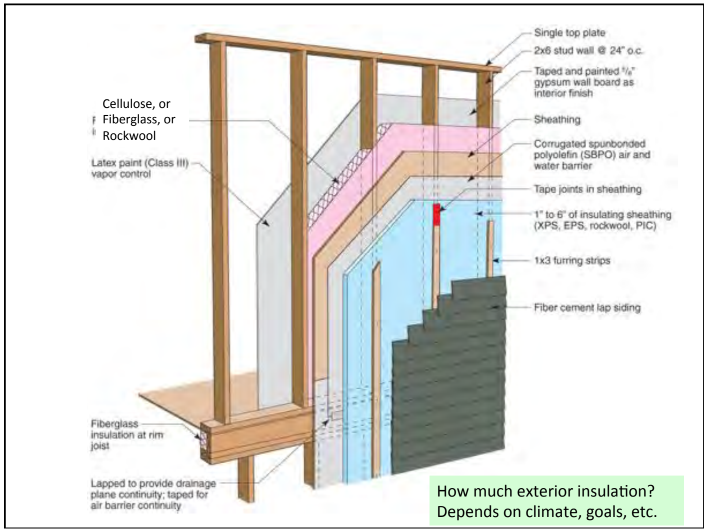
Multi-unit Examples

- 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 total 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**

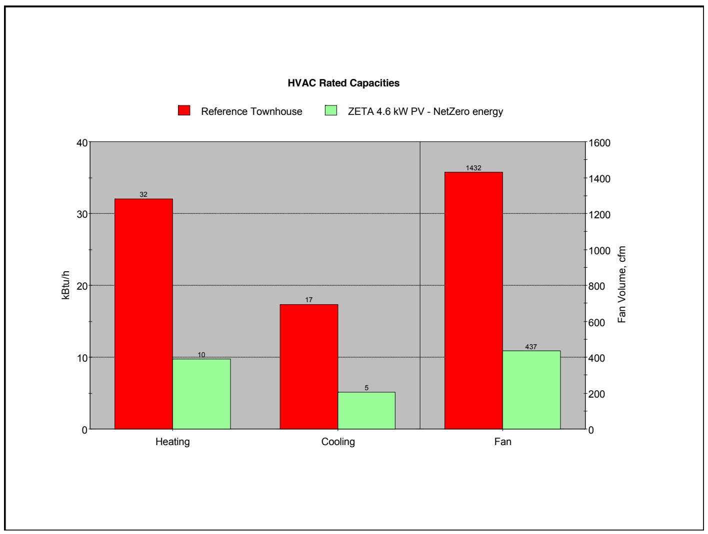
One therm = 29.3 kWh

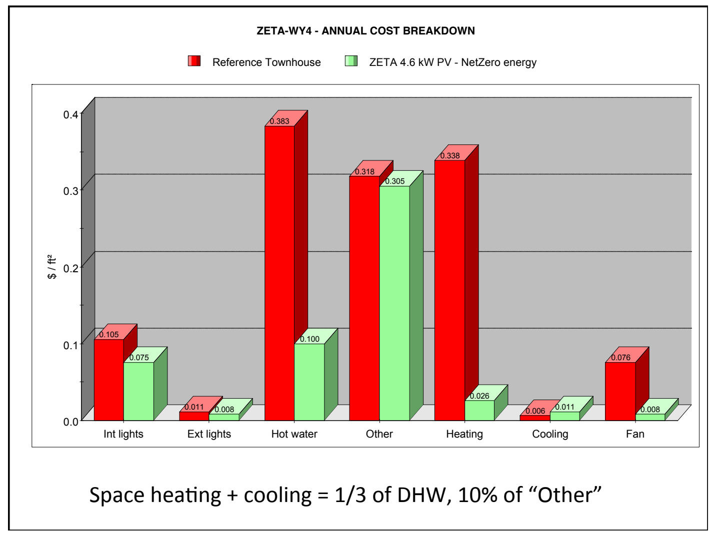
Simple Heating Analysis Apartment

- 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 = 5000
  - (50 to 70)*24*5000 = 54-75 therms < $100/yr
  - 1465-2200 kWh/yr <$160/yr
- If we use HDD50=1500 …. Negligible
- If 2.5 kBtu/hr, airflow= 50 cfm @DT=130F

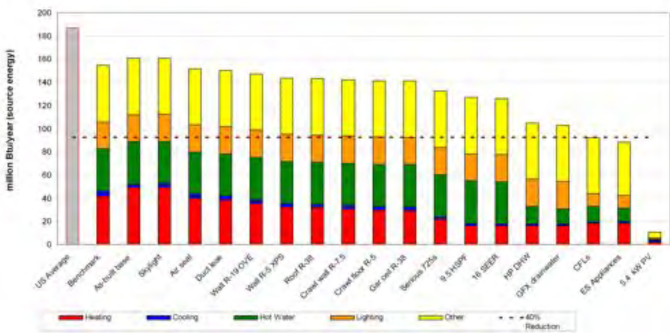

Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted ⅝" gypsum wall board as interior finish
Cellulose, or Fiberglass, or Rockwool
Latex paint (Class III) vapor control
Sheathing
Corrugated spunbonded polyolefin (SBPO) air and water barrier
Tape joints in sheathing
1" to 6" of insulating sheathing (XPS, EPS, rockwool, PIC)
1x3 furring strips
Fiber cement lap siding
Fiberglass insulation at rim joist
Lapped to provide drainage plane continuity; taped for air barrier continuity
How much exterior insulation?
Depends on climate, goals, etc.


Zeta Homes. Dan Smith Architect.
Oakland, CA infill
1560 sq ft + garage


HVAC Rated Capacities
Reference Townhouse
ZETA 4.6 kW PV - NetZero energy
kBtu/h
Fan Volume, cfm
32
10
17
5
1432
437
Heating
Cooling
Fan


ZETA-WY4 - ANNUAL COST BREAKDOWN
Reference Townhouse
ZETA 4.6 kW PV - NetZero energy
$ / ft²
0.105
0.075
0.011
0.008
0.383
0.100
0.318
0.305
0.338
0.026
0.006
0.011
0.076
0.008
Int lights
Ext lights
Hot water
Other
Heating
Cooling
Fan
Space heating + cooling = 1/3 of DHW, 10% of “Other”

Parametric



High-performance Enclosures for PNW

- Specs will change with climate, goals
- Walls?
  - Usually over R20, perhaps as high as R30
- Roofs?
  - Depends on construction. R40-100
- Windows?
  - R4 min, often R5-7
- Airtightness
  - Under 1.5 ACH@50

Low-Load Definition #1

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

Low-load Definition #2

- Peak heating loads in the range of 10-20000 Btu/hr for PNW
- Or… peak heating power density of under 10 Btu/hr/ft^2
  - Typ. house of 1000-2000 sf means …
  - PH 3.15 Btu/hr/ft^2
- DHW load often exceeds space heating load
- Mechanical ventilation almost always required due well-built airtightness

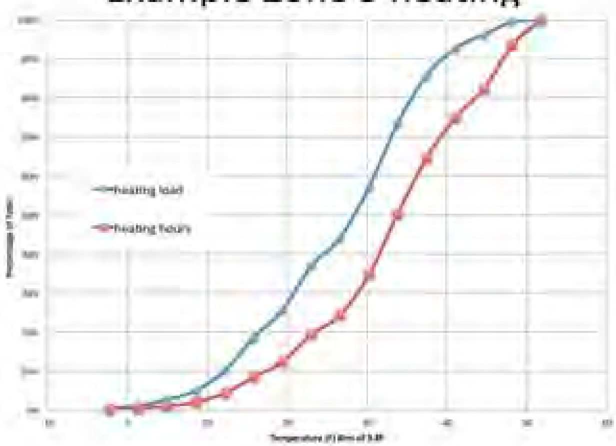
Low Load – more implications

- Internal / solar gains have a BIG impact on space temperature (i.e., Passive gains)
  - Eg. Assume SHGC (g)=0.60
  - 6'x6'8" patio door with 80% glass, 20% frame
  - 6000 Btu/hr in bright sun! (1/2 ton AC in one room)
- Different zoning may be needed
  - Room by room assessment
  - Mixing between rooms can be *more* effective
  - better enclosure for peaks? (e.g.lower SHGC glazing)

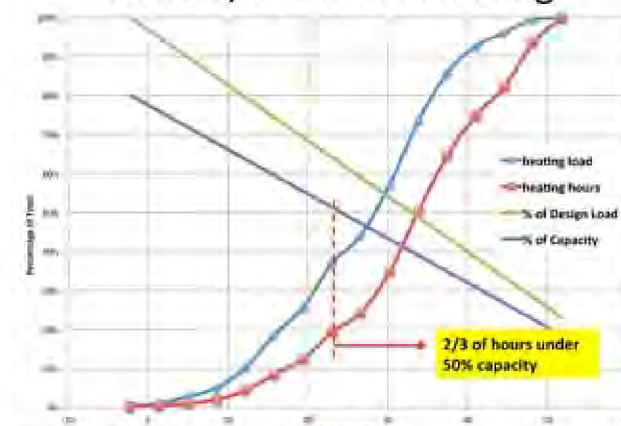
So what's the problem?

- 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

Example Zone 5 heating



Zone 5/6 Climate Heating



Assuming 1.25 safety factor

So what's the problem?

- If capacity >> demand
  - Overshoot temperatures, too hot in heating, too cold in cooling
  - Short-cycling kills AC durability and efficiency
  - Need modulation or thermal mass (or water)
- Cannot save money due to small size
  - Ductwork still largish (eg, say 800 cfm)
- Min. monthly charges of two utilities
  - Can dramatically increase cost

Some Goals Limit solutions

- Net Zero Energy houses: PV is hence preferred for on-site generation
  - Easy measurement and on-site generation drives solutions to all-electric
  - Solar thermal may be as expensive per Btu!
  - Small wind turbines often more expensive
- Passive House
  - Limiting heating demand not strongly correlated to low energy house
  - Calculation tool encourages high solar gain

Domestic Hot Water

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

Summary

- High performance enclosures reduce heating and cooling loads
- Low load means different solutions for HVAC
- DHW remains large
- Must balance
  - HVAC
  - Enclosure
  - Renewable

HVAC for Low-Load Houses

Introduction

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

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

1. Ventilation
   - – "fresh air"
   - – Dilute / flush pollutants
2. Heating
3. Cooling
4. Humidity Control
5. Air filtration / Pollutant Removal
   - – Remove particles from *inside* and outside air
   - – Remove pollutants in special systems

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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/owner can afford

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Interactions Interactions

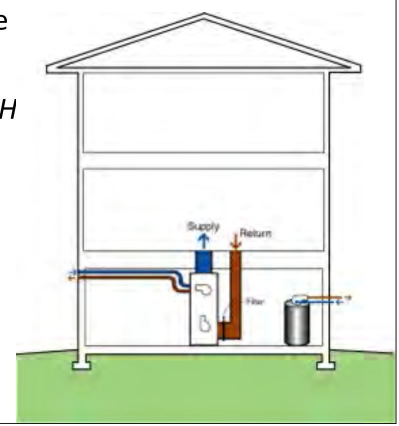
- BEWARE:
- “Perfect” solution for heating may not solve cooling
- “Perfect” cooling solution may not solve DHW supply
- Perfect heating+cooling+DHW may do nothing for ventilation!
- We need
  - heat+ cool + DHW + vent + filtration + humdity

ASIDE: Ratings game

- EER
  - BTU/hr output to W input
  - Conditions: 95F outdoor, 80F return
- SEER
  - Seasonal EER
  - 82F outdoor, 80F return
- COP
  - Watts out to Watts in
  - HSPF (Watts in Btu out @ 47°F)

Simple Single Zone Residential

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



NOT acceptable for high-performance homes

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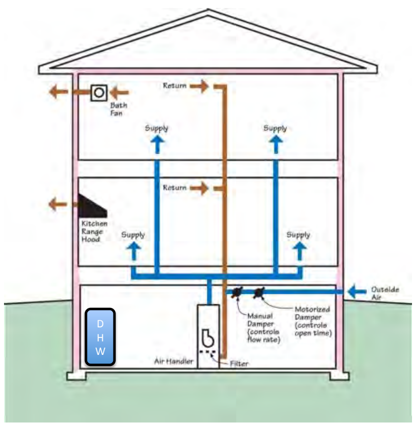
Minimum “Good” System

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



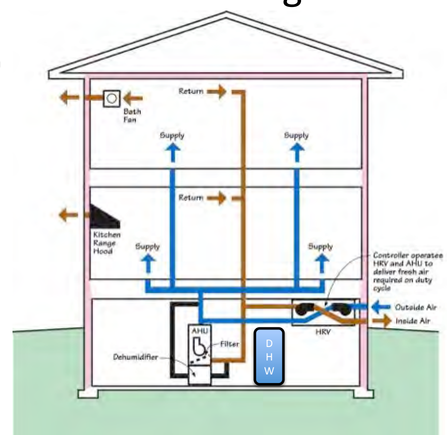
BSI-022: Housing

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



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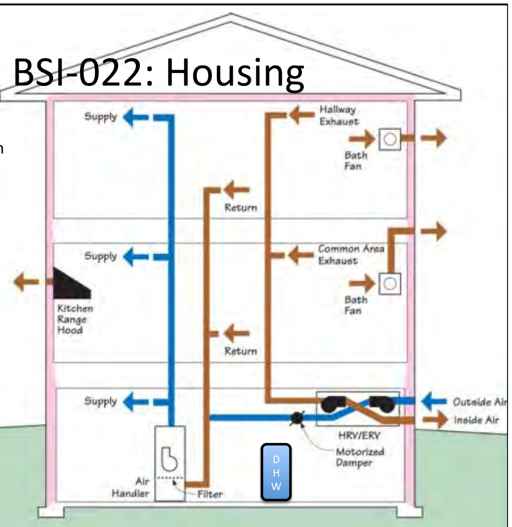
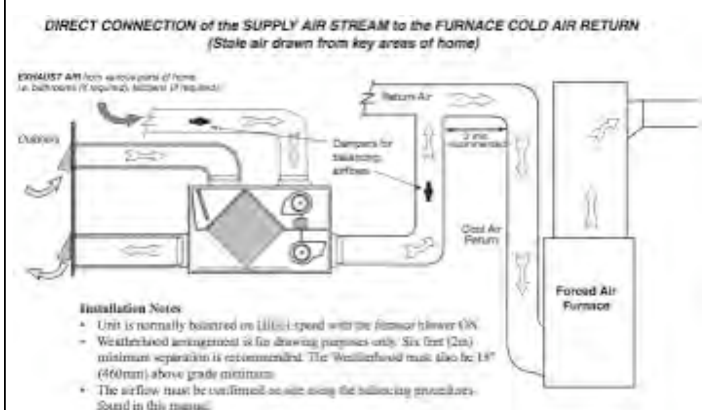


Various HRV connection options



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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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 <u>flame to fluid</u>
- Fuel sources
  - Nat gas, oil, propane, wood, electric, etc.

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Condensing Furnace

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

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 two-stage can be better
  - Goodman GMH90-45 (30/44 kBtu) $<1000
- Modulating furnaces can't "lock out" high output – require duct sizing for 65-70 kBtu!

Fully-modulating Trane Furnace

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

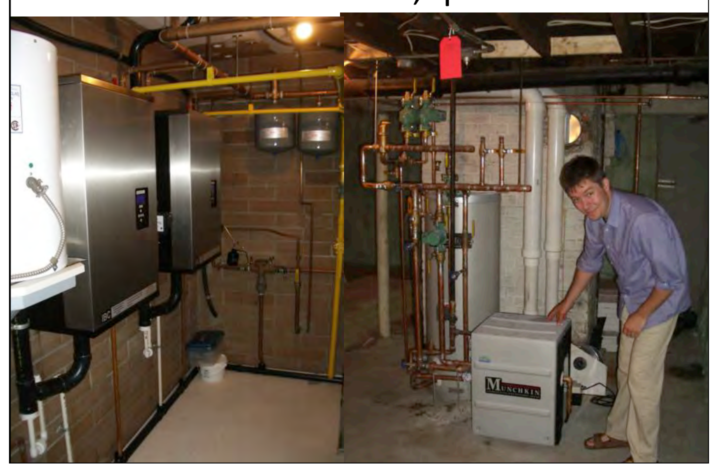
But.....
Min 24 kBtu/hr
+ expensive

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

		Airflow Setting	Target Airflow (See Note 5)		External Static Pressure 0.1	0.3	0.5	0.7	0.9
Heating	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	583
				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	546	636	644	667	676
				Temp. Rise	53	45	45	43	43
				Watts	56	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	789	831	837	843	846
				Temp. Rise	50	46	46	46	46
				Watts	114	164	210	250	211
	100% (high) Heat	Low	830	CFM	721	849	856	861	862
				Temp. Rise	65	61	60	60	60
				Watts	121	171	219	258	215
		Medium Low	905	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


Viessman, gas


Takagi, Oil

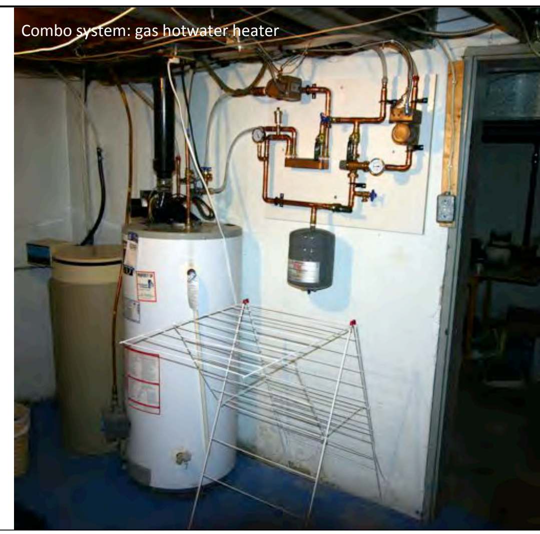
2013-04-29

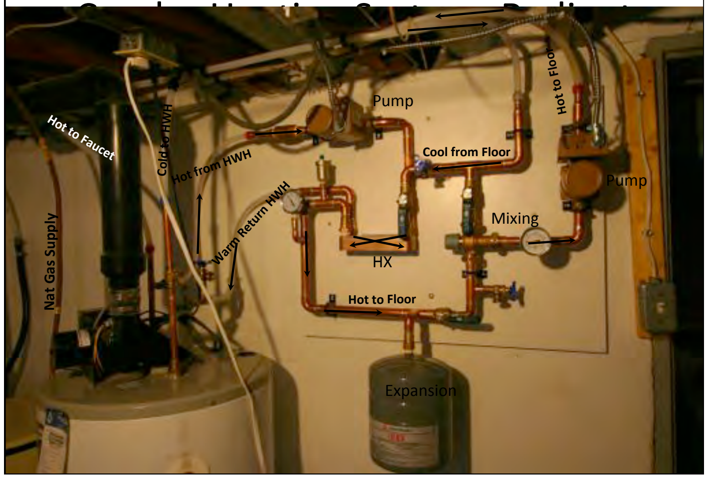

AO Smith, sealed combustion 65%
Now Vertex 90-96%


Quietside, combo boiler 90%

- 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


Combo system: gas hotwater heater



Condensing Boilers

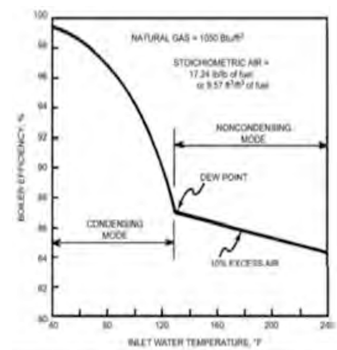
- Supply temperatures of max 140F (60C) under design conditions
  - ensures return temperature low enough to get condensing (=efficiency)
- Lower is better!
  - Outdoor reset
  - Variable speed pump + Delta T controller
  - Varibale speed pump +

Boiler Combustion Efficiency

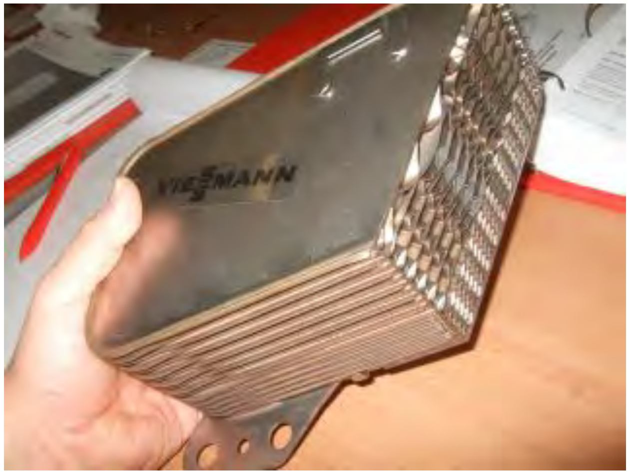
- Most combustion is >99.9% efficient
- Equipment varies on ability to extract useful heat from combustion via HX
- Heat exchanger size is important
- Temperature of entering fluid is also critical
  - Condensing furnace (72 F / 22 C)
  - Condensing boiler >90% (<110 F / 45 C)
  - Normal boiler <85%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

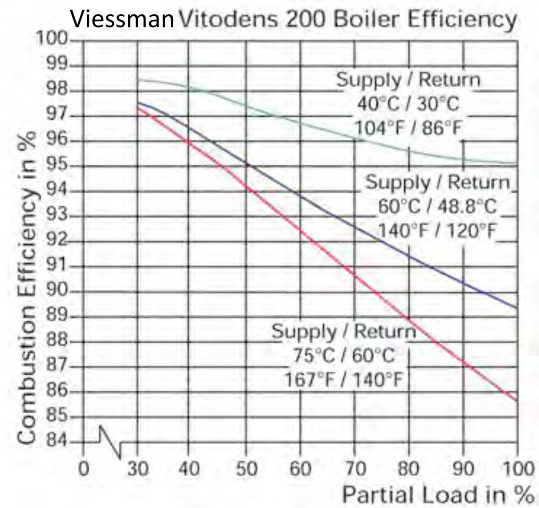
Condensation % Efficiency

- 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

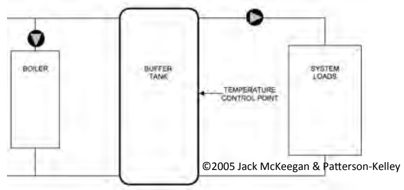
Building Science 2008

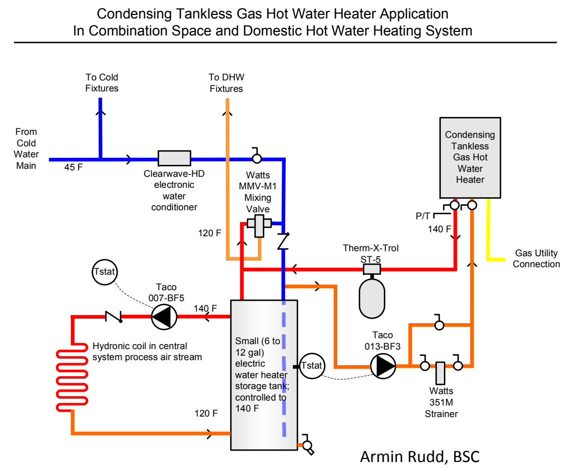
Combo Systems

- 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



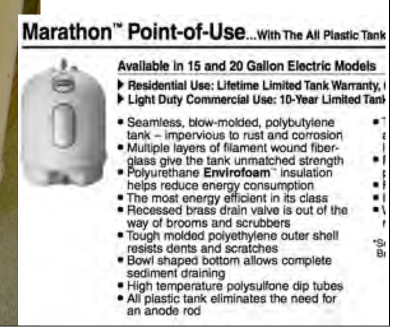


Armin Rudd, BSC
RR-1009 Space Conditioning …

Combi

- small buffer tank
- Adds some standby losses

Low standby loss


Marathon™ Point-of-Use...With The All Plastic Tank

Available in 15 and 20 Gallon Electric Models

- Residential Use: Lifetime Limited Tank Warranty,
- Light Duty Commercial Use: 10-Year Limited Tank

- Seamless, blow-molded, polybutylene tank – impervious to rust and corrosion
- Multiple layers of filament wound fiber-glass give the tank unmatched strength
- Polyurethane Envirofoam™ insulation helps reduce energy consumption
- The most energy efficient in its class
- Recessed brass drain valve is out of the way of brooms and scrubbers
- Tough molded polyethylene outer shell resists dents and scratches
- Bowl shaped bottom allows complete sediment draining
- High temperature polysulfone dip tubes
- All plastic tank eliminates the need for an anode rod

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.
- Spec small pump (<2GPM) and ECM airhandler / radiant

State Force 90

76 Kbtu. Sized to meet DHW.

Condensing tanked

- several suppliers

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

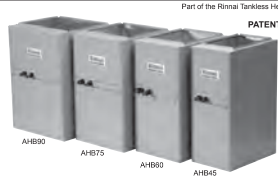
GSW James Wood Envirosense
90% eff, 76 kBu/hr 50 gallons

Rinnai

37AHB Series Hydronic Furnace

Part of the Rinnai Tankless Heating System

PATENT PENDING



FEATURES

- Four models covering a range of heating capacities
  - 27,100 to 96,300 BTU/hour
- Multi-position (upflow, downflow, horizontal left, horizontal right) without modifications *
  - Modifiable for side-entry return air
- Low-flow, high-head pump custom designed to work with Rinnai's tankless water heaters
- Integrated control board with learning algorithm
- No combustion air infiltration losses when used with a Rinnai tankless water heater
- Four selectable heat blower off delay times
- Multi-speed motors (ECM)
- Strong 20-gauge steel cabinet
  - Galvanized, painted
  - Fully insulated cabinet
  - Low 34 inch profile
- Multi-position control box
- Designed for serviceability
- Schrader valves to purge air from the system
- Integral filter rack with filter
- Fan motor with ECM technology

* NOTE: The unit is not designed to be installed on its back or face down.

The optimum in hydronic technology, the newly designed Rinnai® multi-position hydronic furnaces offer a unique solution for a wide variety of small- and medium-sized residential and light commercial applications. They are compact and ready to fit in tight spaces which may include, but not limited to, attics, basements, closets, crawlspaces, and utility rooms.

Intelligent Microprocessor Controller

The 37AHB units are equipped with an intelligent microprocessor control that allows for domestic hot water priority and adapts to available hot water flow for space heating by automatically regulating the pump and fan sequence to maximize comfort.

Fine Tuned to Work with Rinnai Tankless Water Heaters

These unique hydronic furnaces are designed to work in combination with our line of Rinnai® tankless water heaters to deliver heating capacities that cover a wide spectrum of residential and light commercial heating applications. When combined, the units form the Rinnai Tankless Heating System, the first matched, tankless hydronic heating solution in the industry!

UL recognized component

This product is manufactured in a facility registered by UL to ISO 9001.

600000060 (7/2010)

Built-in pump
Ratings are for high supply temps- cut in half or more

Combo Fan coils / Air Handler

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

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

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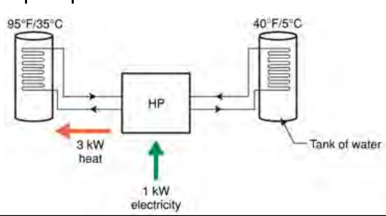
Heat Pumps

- 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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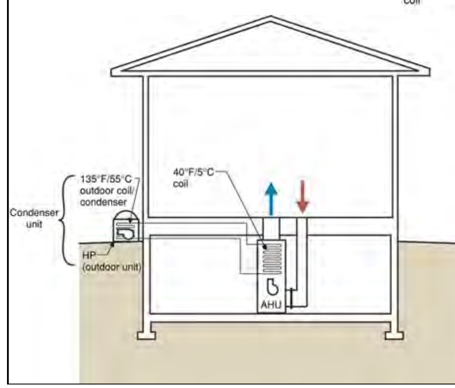
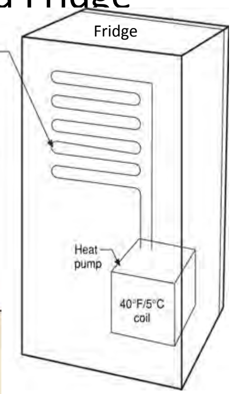
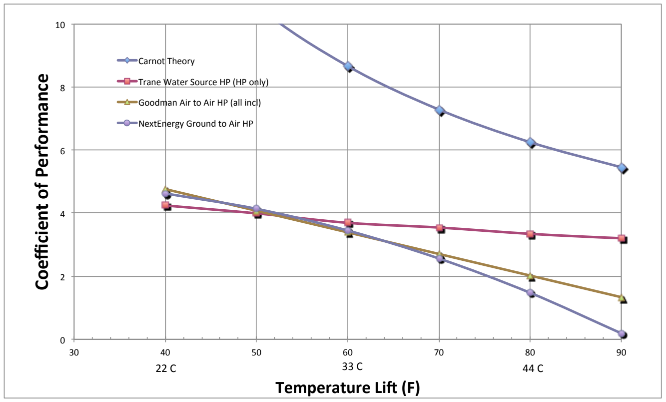
Heat Pumps: AC and Fridge





Heat Pump Efficiency vs Lift



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

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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

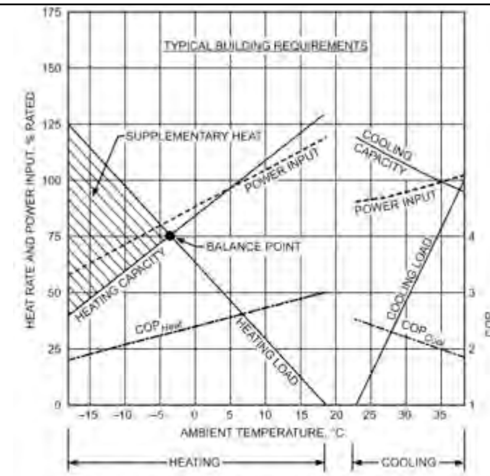


Fig. 11 Operating Characteristics of Single-Stage Unmodulated Heat Pump

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

Split Heat Pumps

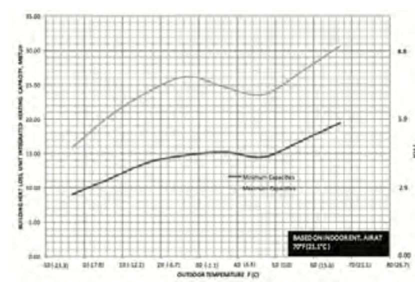
- An option for Zone 3-4?
  - Eg Portland, Seattle, Tacoma 20 F *design* temp
- 2 ton HP produce about 16 kBtu/hr @20F

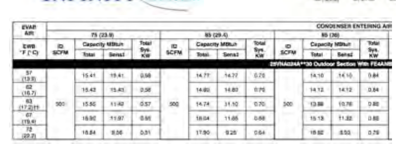
SSZ160241A* / CA*F3636*6A* + TXV / MBE1600-1** **e.g., Goodman SEER16 model**

	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	17.1	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	280	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





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

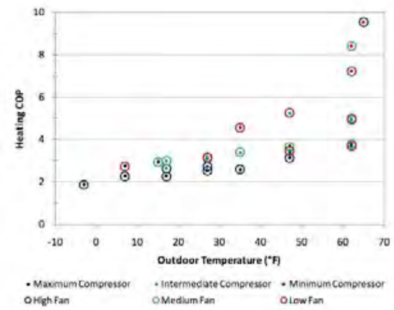
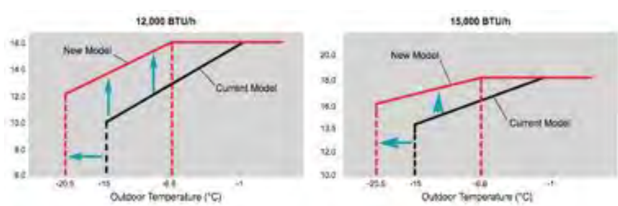


Figure 5. Fujitsu 12RLS steady-state heating COP (70°F return temperature)

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: a SEER27 unit

MODEL: ASU9RLS2

AFR	500

		Indoor temperature	
	°FDB	72	
°FDB	°FWB	TC	IP
-5	-7	14.0	2.06
5	3	15.4	2.06
14	12	16.0	1.99
23	19	17.5	1.92
32	28	17.9	1.68
41	37	20.3	1.93
47	43	22.0	1.99
50	47	24.3	2.02
59	50	25.2	2.03

(Outdoor temperature)

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

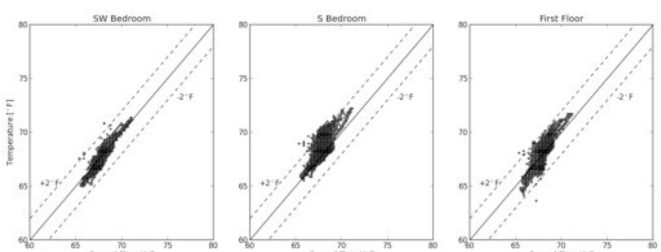
- Heat distribution from single head?
- Aesthetics of exposed heads
- Some hidden "slim duct" units exist but efficiency suffer
- Open doors between spaces really helps

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

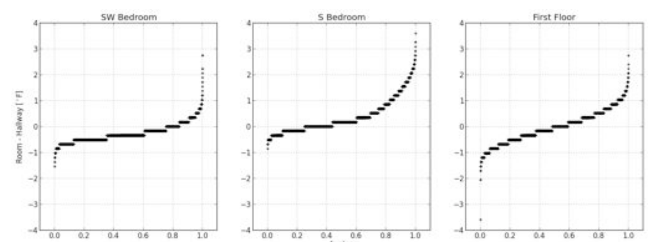
Temperature Distribution

- little temperature variation (+/2F)



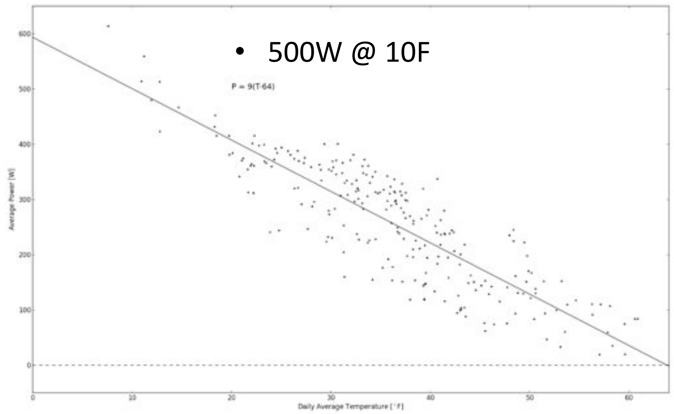
Distribution

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



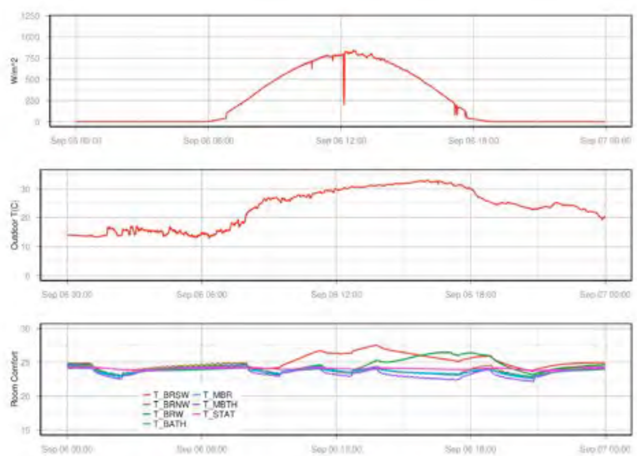
Measured power draw

- 500W @ 10F

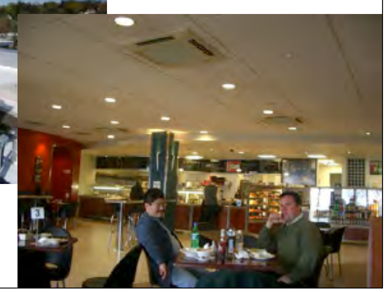


More Distribution examples

- 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

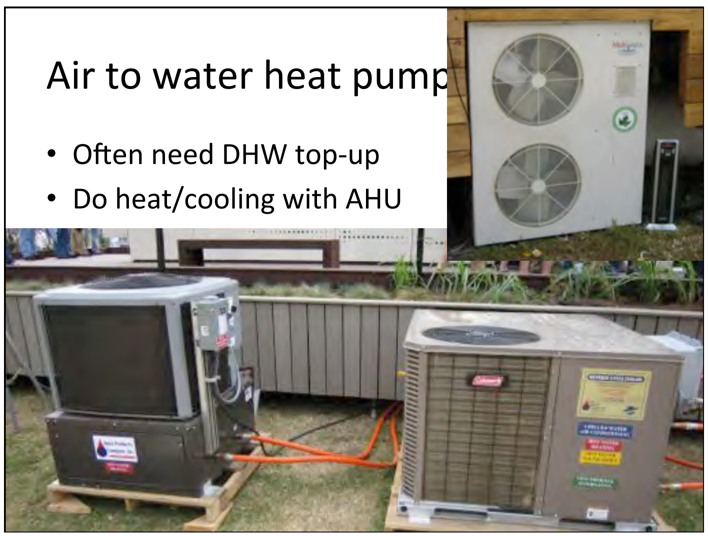
- Variable speed outdoor unit (VRV) (18 & 24)
- Two-speed indoor fancoil for ducts (ECM fan)
- 18 kBtu/hr model
  - Operates at 600/420 cfm
  - 12 kBtu/hr low speed
  - Up to 20 kBtu/hr heating

Chillers

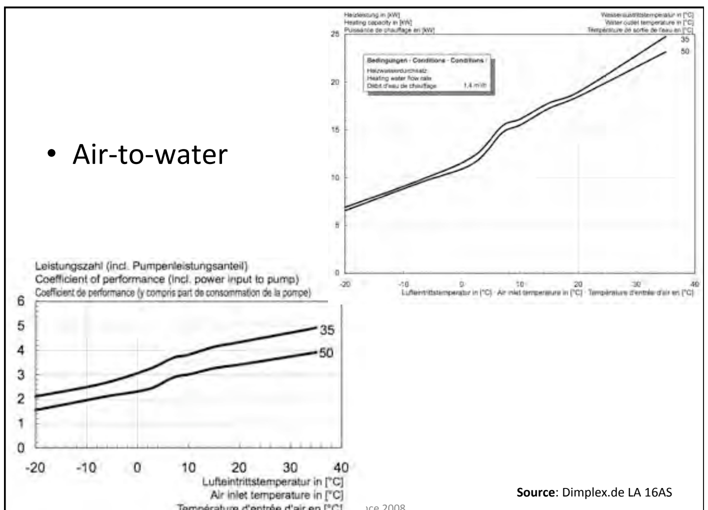
- Air-water heat pumps used for cooling water
- Big units use cooling towers
- Usually large buildings
- “reverse-cycle chiller” is another name for a water-to-air heat pump

Air to water heat pump

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



- Air-to-water

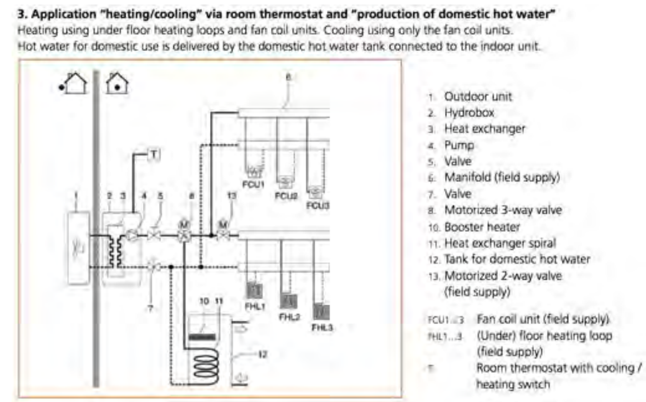


Source: Dimplex.de LA 16AS

Air-water Altherma

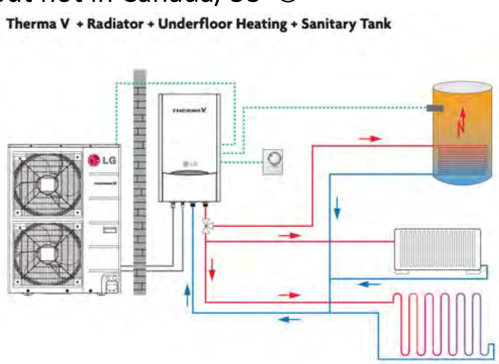
- heats DHW to 130F
- COP is low at low temps for DHW
- Expensive
- One product if coupled with low-temp fan coil or radiant floor (dry climes)

Heat, cool, DHW



Numerous systems available

- but not in Canada/US ☹

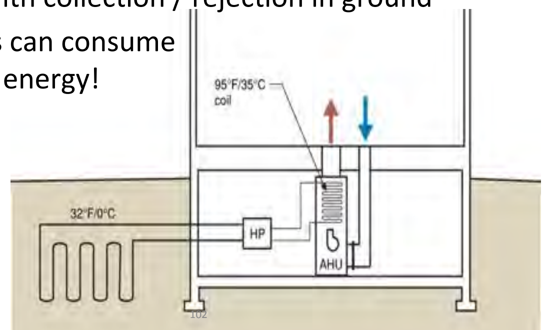


CO2 Refrigerant air-to-water

- 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!



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GSHP Geothermal

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

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

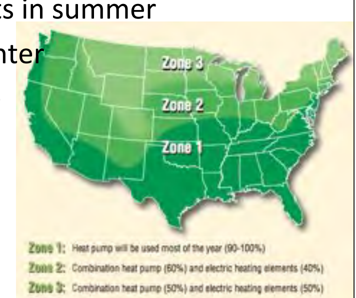
DHW

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

Heat-pump water heaters

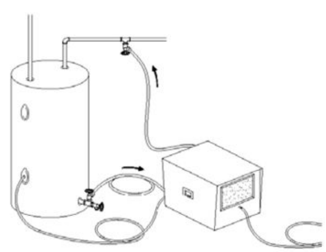
Performance: "depends"

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

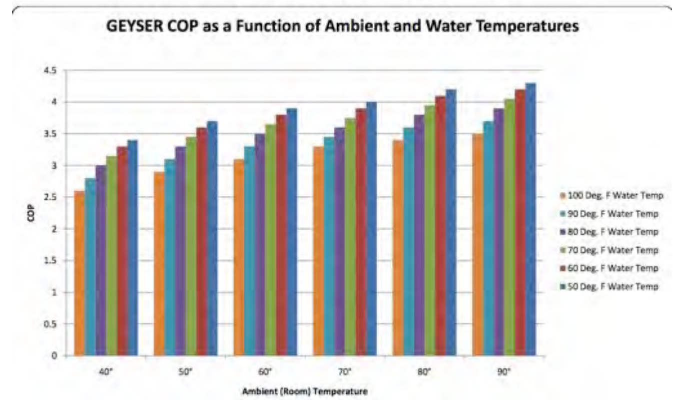


Add-on Heat pump

- eg Geyser. Allows unit location near heat source (fireplace? Sunroom?)



North Road Technologies LLC



DHW efficiency

- Gas Condensing can only happen with 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**

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: 1.0*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

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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

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**

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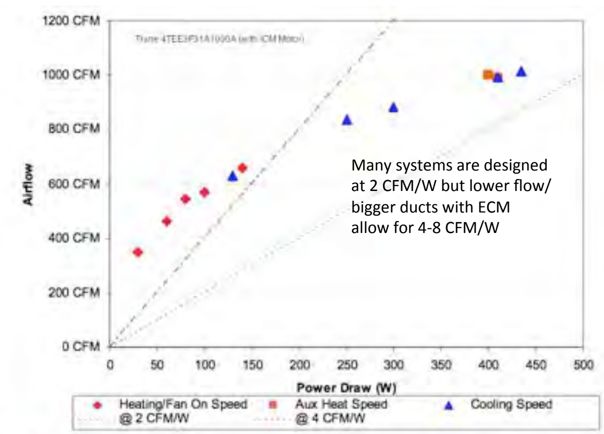

Figure 8: Airflow (CFM) vs. power draw (W) curve of various AHU configurations

W= $2.6*10^{-5}$ 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

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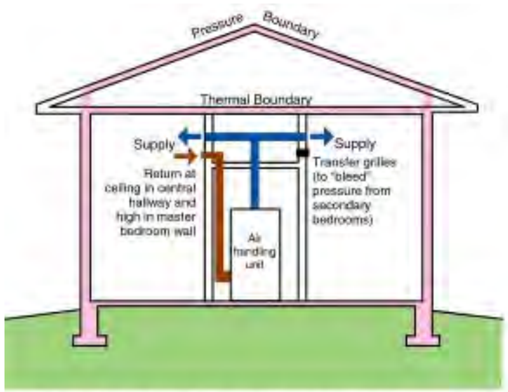
Heating Cooling (and mixing)

- 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.

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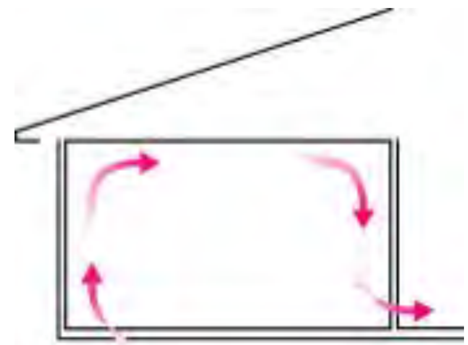
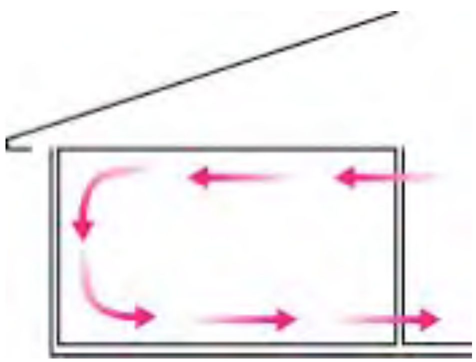
Winter-based old style



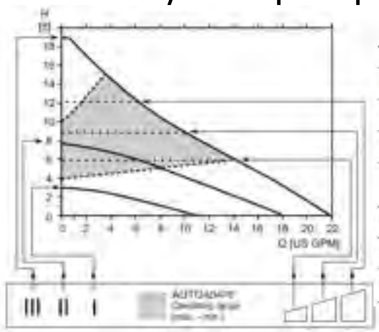
Interior sidewall only



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

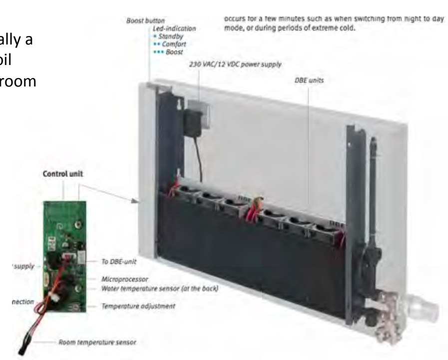
New variable speed pumps offer remarkably low Watt/GPM, and built in controls to allow for fixed flow or fixed pressure

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***

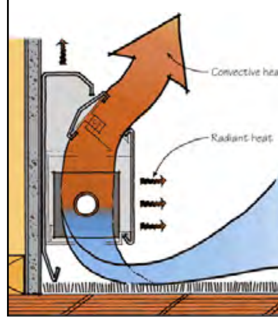
Euro-models

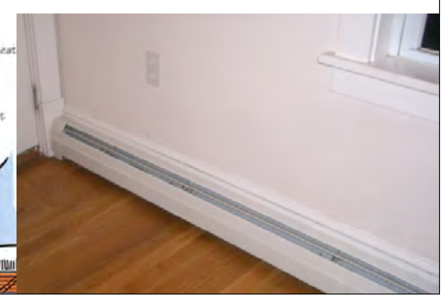
Jaga : basically a small fan-coil exposed in room



Convector / Radiant

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





Convector / Radiator

- Hydronic terminal units
  - no energy required at unit

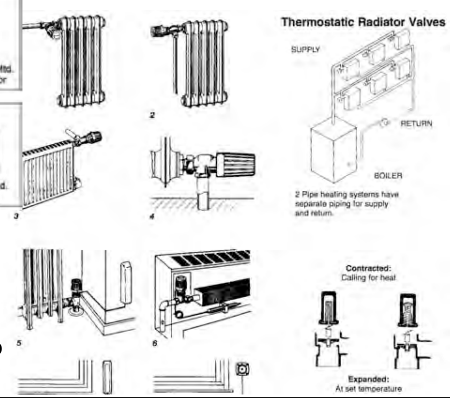
Low-temperature baseboard

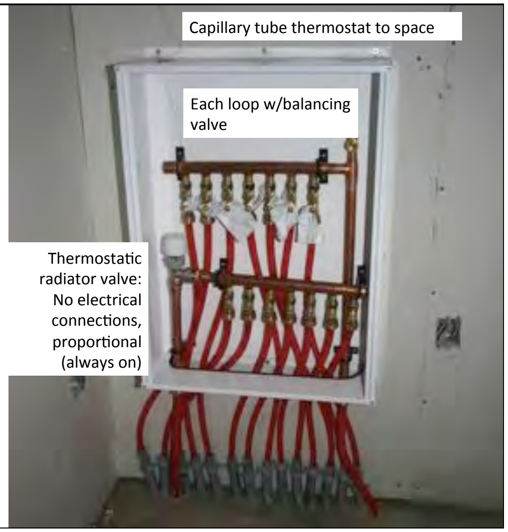
- Typical convectors
  - rated at 180F / 80C (mean or supply)
  - return temperatures >160F /70C
- Want to supply with lower temperature!
  - Condensing boilers and heat pumps only work with supply temperatures under 140F/60C
- Must increase SIZE of convector to reflect lower supply water temperature

Convector retrofit- see TRV

TRV (very simple)

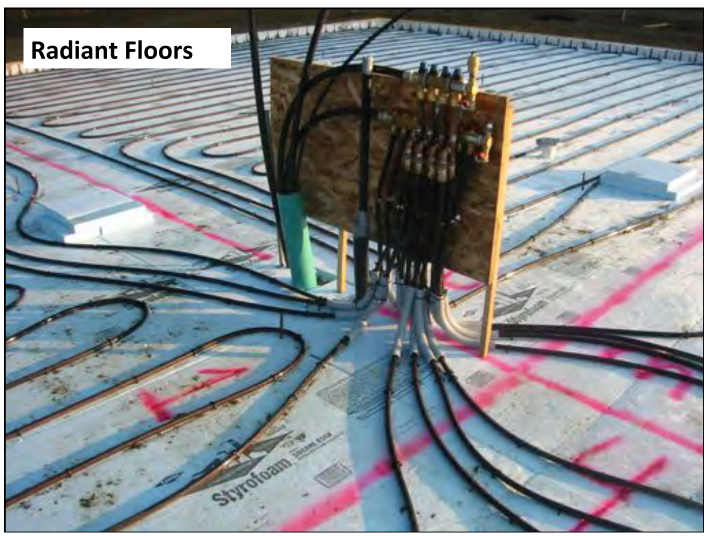
- Thermostatic Radiator Valves
- Automatically open and close to meet setpoint temperature with no power required





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 low 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%

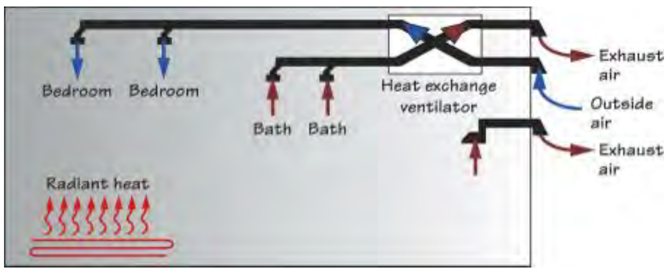
Building Science

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

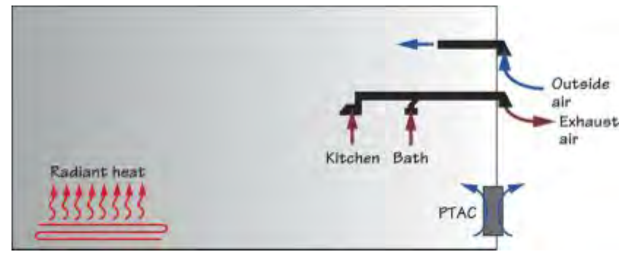
•Multi-point supply, often continuously operated
•Multi-Point exhaust, often continuously operated
•Heat recovery of moisture and heat in air add on



No Cooling. Radiant heat usually from a source of hotwater

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

Ventilation distribution?



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

Possible VTAC applications

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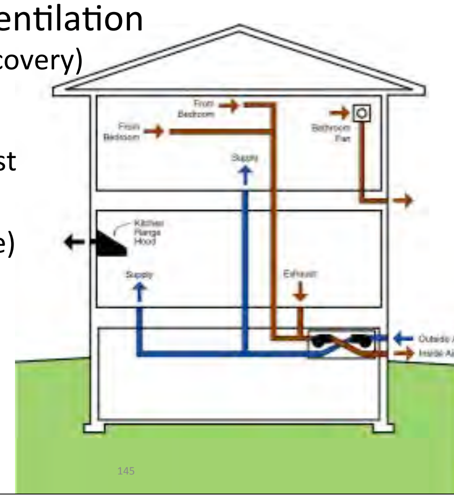
Balanced Ventilation
(with Heat Recovery)

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



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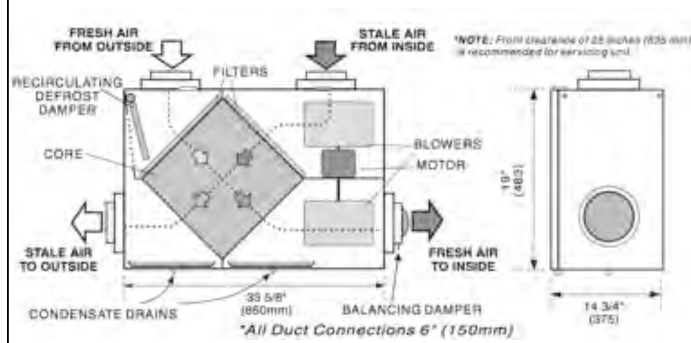
e.g. NuTech 155 ECM



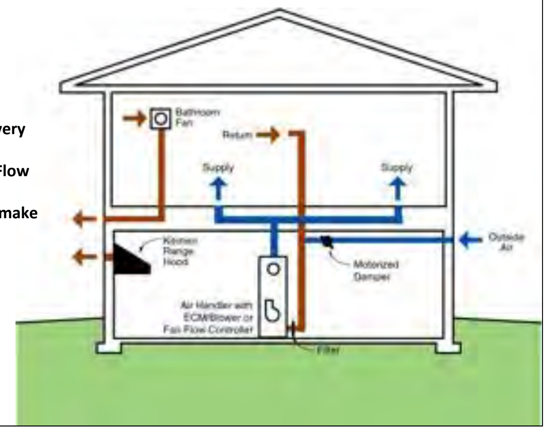
- Mid-scale HRV
- Emerging tech
- 200-600 cfm
- Need to watch fan energy!

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

- **Non-heat-recovery ventilation**
- **Requires a FanFlow Controller and efficient fan to make sense**



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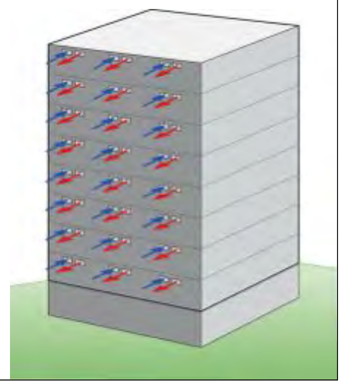
Multi-unit Issues

- 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)

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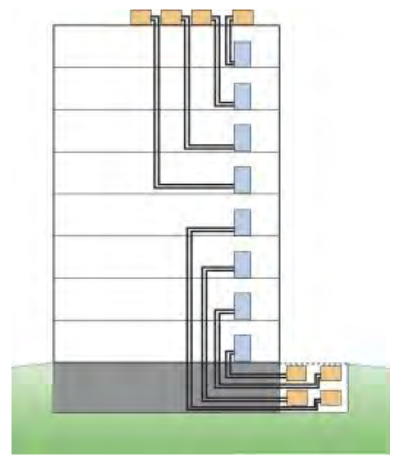
Dual boilers and pumps, quick change out possible, battery operation possible

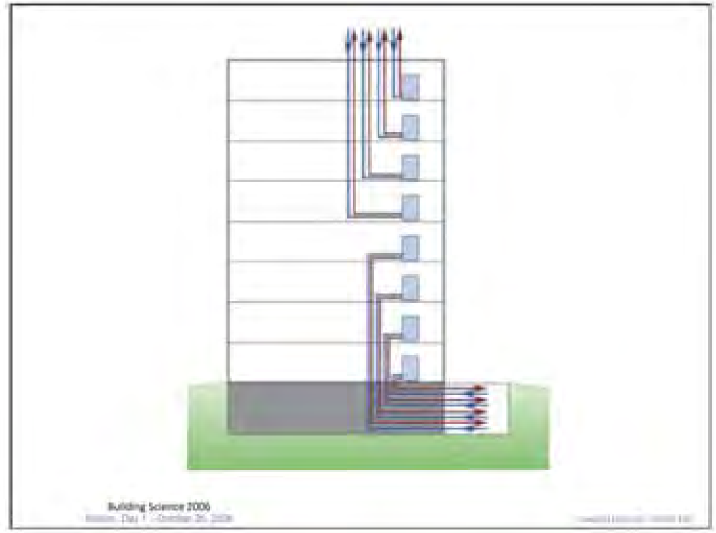
DHW Distribution

- Distribution losses
  - Can be significant for long runs
  - Recirculation pumps increase loss unless controlled
  - Large pipe diameters store lots of water
    - Use smaller pipes



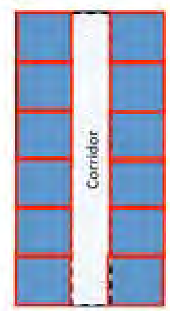
Building Science 2006
Boston, Day 1 – October 26, 2006

Joseph Lstiburek – HVAC 157



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 required in hot-humid weather
  - Could be DHW heat pump!