HVAC for Architects

University of Waterloo

bsc Building Science Corporation

Introduction

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Thermodynamics 101

- Heat (thermal energy) is measured by temperature
- Can release heat by converting chemical, physical, electrical, radiation, or nuclear energy sources
- Cannot destroy heat, only move it around
  - Heat pumps move thermal energy from lo to hi
- Cold is a relative term = “less heat”
- Exergy

11-06-02 3

Basic numeracy

- Energy vs Power
  - Energy is measured in Btu, therms, kilowatt-hours or joules
  - Power is *rate* of energy delivery, Btu/hr, kilowatt
- 12000 Btu/hr = one ton
- One kilowatt = 3412 Btu/hr

Numeracy

- One cfm changed 1F = 1.05 Btu/hr
  - 100 cfm * 20 F moves 2,000 Btu/hr
  - 400 cfm * (80F - 50F) moves 12, 000 Btu/hr=1 ton
- One GPM changed 1F = 500 Btu/hr
  - 1 GPM * (55F – 45F) moves 5000 Btu/hr
- 1050 Btu required to dehumidify 1 lb of water

HVAC "Efficiency"

Efficiency = "Energy required to heat, or cool, or ventilate divided by energy consumed"

- Electric heater is 100% efficient
- Nat gas boiler might be 80-95% efficient
- Window air conditioner is 250-300%
  - SEER Btu/hr cooling / Watt of electric
- But all energy sources are not equal
  - Electricity is more expensive and more polluting than natural gas based on heating energy

Example

- A 3 ton Air-Conditioner operates 50% of each hour for 8 hours during the day.
- If the unit has a EER of 10
- how much power is consumed when unit is running?
- How much energy is consumed?

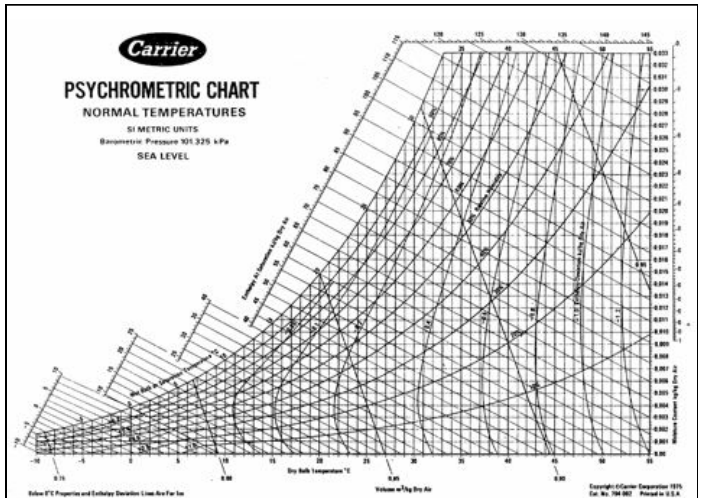
Example

- 3 tons
  = 3*12,000= 36,000 Btu/hr cooling
- EER=10 means,
  - 36,000 Btu/hr/10 = 3600W
- 8 hrs @ 50% operation
  = 8*.5*3600W = 14,400 Watt-hours
  = 14.4 kW-hr

Thus, power draw is 3600W when running and 14.4 kW-hr consumed over the day

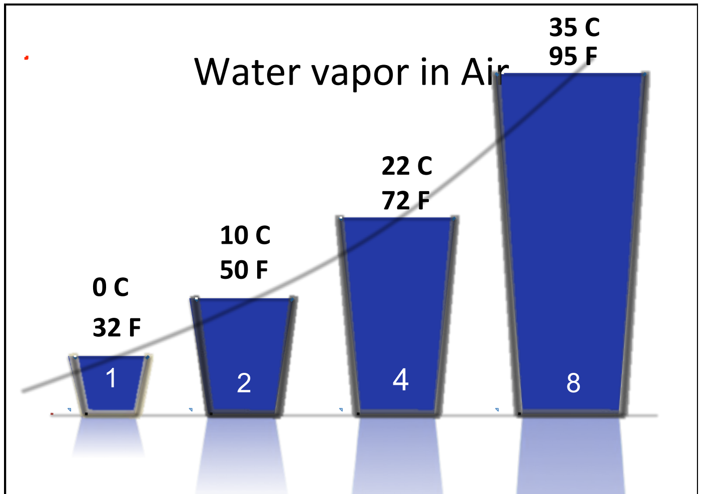
Psychrometrics

- Study of air and its heat and moisture content
- Important to HVAC
- Important to architects to understand temperature and relative humidity



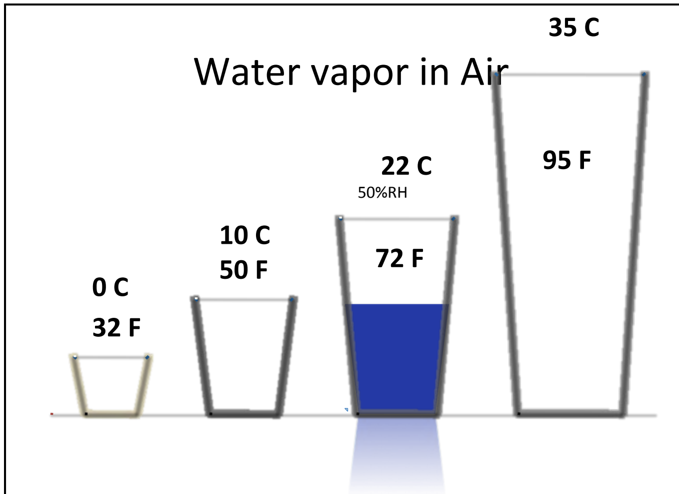
Heat Air and Moisture No.10/78

Water vapor in Air

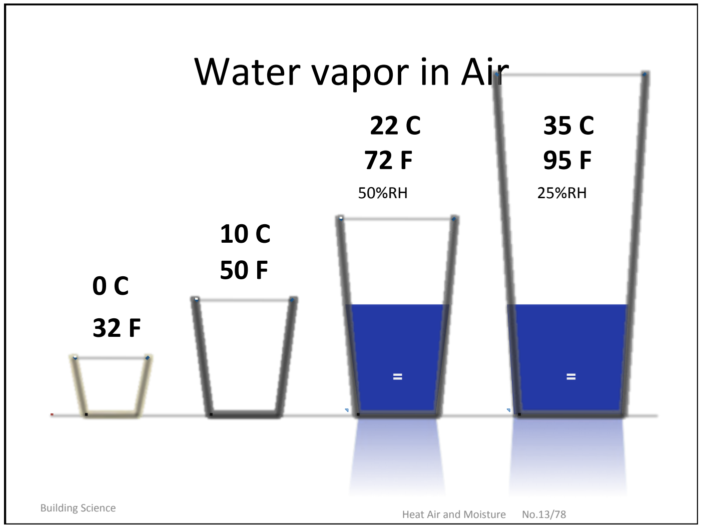


Building Science Heat Air and Moisture No.11/78

Water vapor in Air



Building Science Heat Air and Moisture No.12/78


Water vapor in Air
0 C
32 F
10 C
50 F
22 C
72 F
50%RH
35 C
95 F
25%RH
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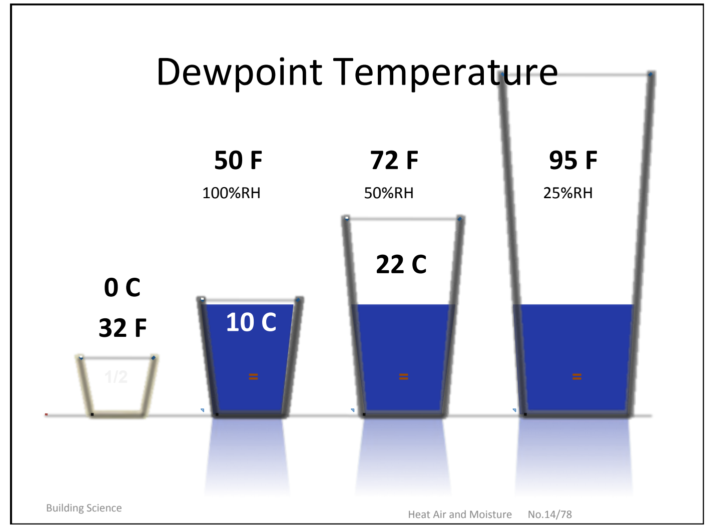
Heat Air and Moisture No.13/78


Dewpoint Temperature
0 C
32 F
50 F
100%RH
10 C
72 F
50%RH
22 C
95 F
25%RH
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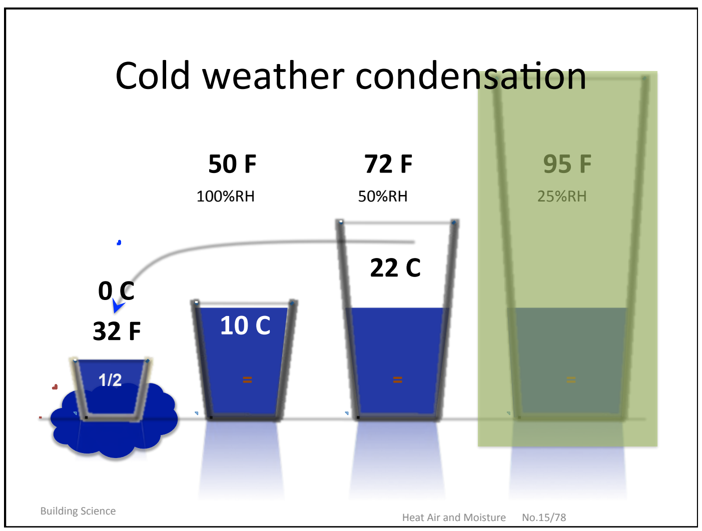
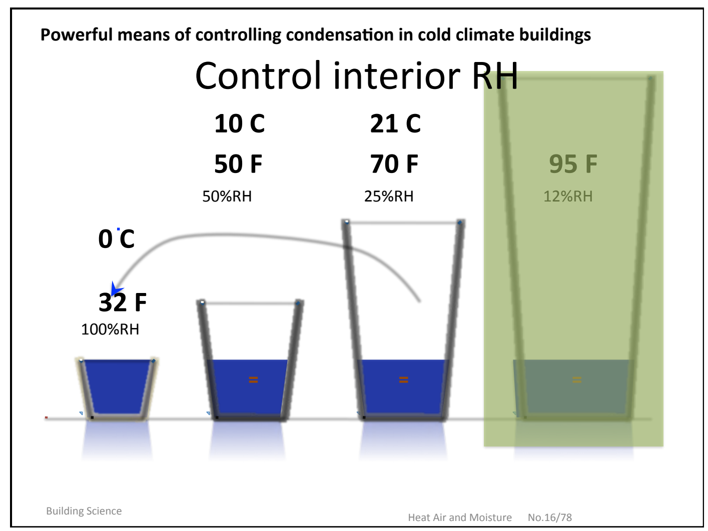
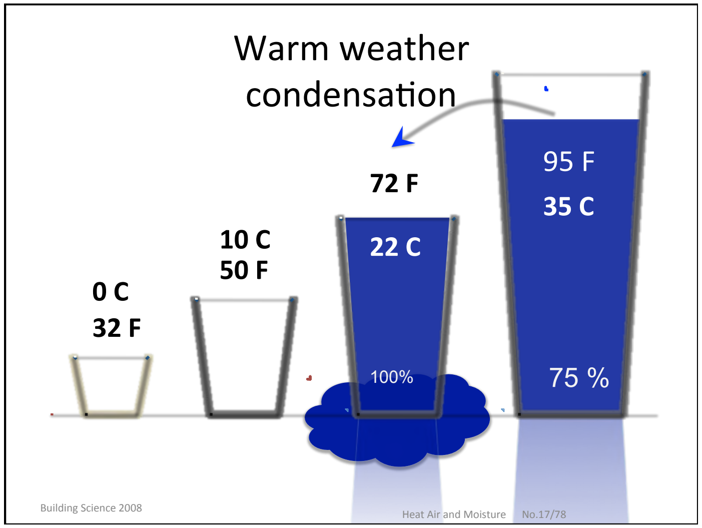
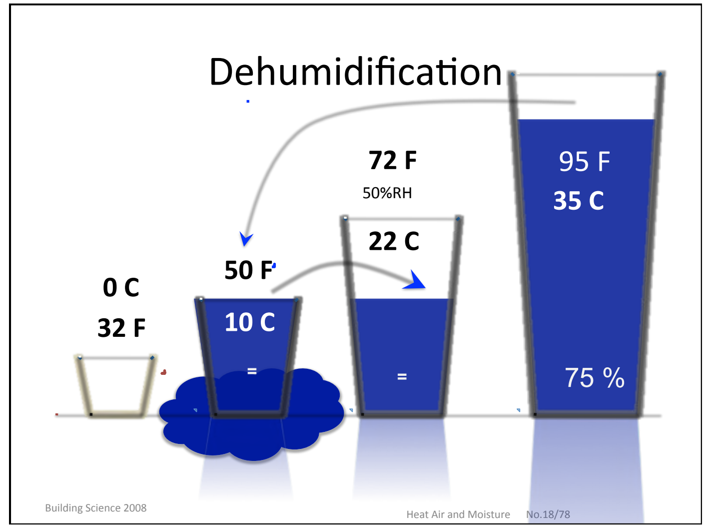
Heat Air and Moisture No.14/78


Cold weather condensation
0 C
32 F
1/2
50 F
100%RH
10 C
72 F
50%RH
22 C
95 F
25%RH
Building Science
Heat Air and Moisture No.15/78


Powerful means of controlling condensation in cold climate buildings
Control interior RH
0 C
32 F
100%RH
10 C
50 F
50%RH
21 C
70 F
25%RH
95 F
12%RH
Building Science
Heat Air and Moisture No.16/78





Human Comfort & Ventilation

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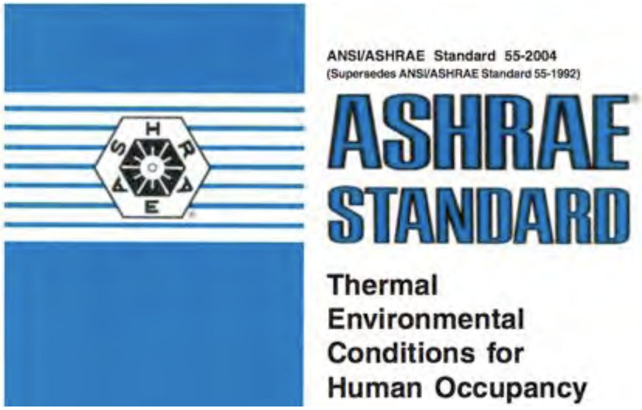
Human comfort

- Energy balance, just like a building
- Interior heat generation – losses = zero
- Humans are very sensitive to inbalances

- All space conditioning is not created equal
- Temperature is not a good measure of comfort



Thermal comfort

Six Primary Thermal Comfort Variables

$PMV = f($ Air temperature,
Radiant temperature,
Air flow velocity,
Relative Humidity,
Clothing Insulation,
Physical activity)

Note: Latent proportion around 50% until work intensity increases

ACTIVITY	HOURLY METABOLIC RATE BTU/HR FOR AVERAGE ADULT @ 79°F-AMBIENT Total	Sensible	Latent	MOISTURE DISSIPATED IN LBS/HR/PERSON
Basal	290	145	145	0.140
Seated – reading aloud	420	225	195	0.183
Light work – standing	490	225	265	0.255
Pool player	680	230	450	0.434
Carpenter	954	307	647	0.623
Bowling	1500	490	1010	0.973
Walking upstairs	4365			
Maximum exertion for different people – 3000 to 4800				

	Extreme Metabolic Rates	Time to Reach Exhaustion
Professional bicyclist	2,100 BTU/hr.	4.37 hrs.
Sculling boat race	4,900 BTU/hr.	0.37 hrs.
Max. effort – bicycle	15,600 BTU/hr.	0.006 hrs.

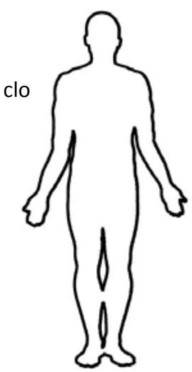
Heat Loss from Human Skin

Clothing Insulation I_{cl}

Unit: R (m^2k/W) or clo

1 clo = 0.155 m^2k/W

1 clo = 0.88 R-value



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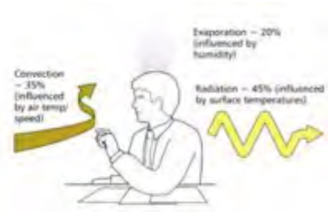
Insulation

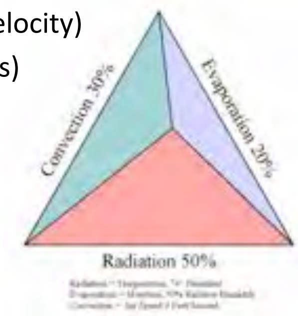
Evaporation

- 60 - 90 g/hr (2-3 ounce) normal conditions
- Evaporation rate depends on
  - Activity level
  - Relative humidity
  - Airflow
- Increasing airflow rate and decreasing RH increases potential for evaporation

Human Cooling Modes

- Convection (air temp/Velocity)
- Radiation (surface temps)
- Evaporation (temp/ RH)





Mean Radiant Temperature

- Area weighted average of all temperatures in the enclosing space seen by occupant
- Asymmetry is uncomfortable
  - Wall at 95F / 35C and ceiling at 68F/20C = bad

Operative Temperature

$$t_{operative} = \frac{t_{ambient} + t_{radiative}}{2}$$

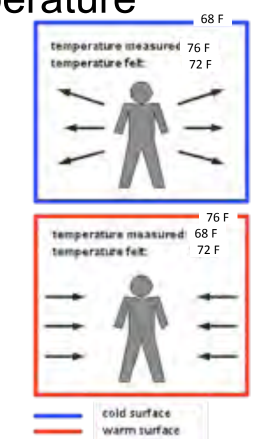
For low airspeeds

t_o = operative temperature [°C/F]

t_a = ambient temperature [°C/F]

t_r = radiative temperature [°C/F]

Ignores evaporation (RH)



Air Movement

- Allows people to cool themselves Convectively/ evaporativel

Example Comfort Conditions

Temperature, °F	Humidity (RH)	Air velocity (fpm)
76	45	20
76	80	250
72	80	20
80	20	20
80	45	500

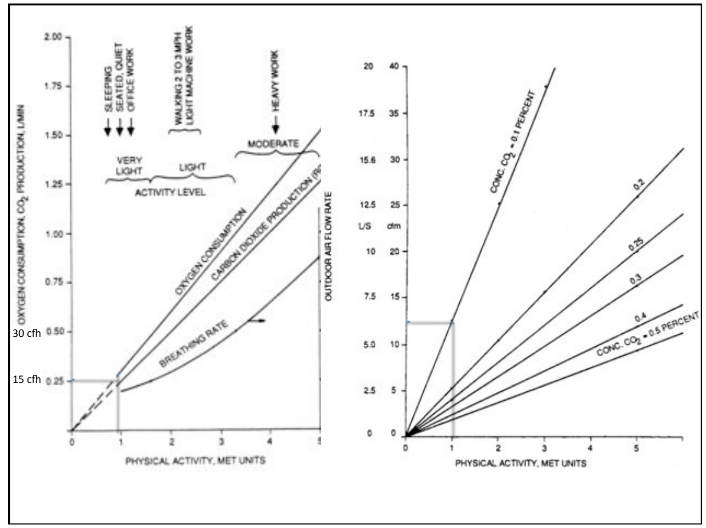
Run	Air Temp.		RH	Radiant Temp.		Air Speed			
#	°F	C	%	°F	C	FPM	m/s	Met.	CLO
1	67.3	19.6	86	67.3	19.6	20	0.10	1.1	1
2	75.0	23.9	66	75.0	23.9	20	0.10	1.1	1
3	78.2	25.7	15	78.2	25.7	20	0.10	1.1	1
4	70.2	21.2	20	70.2	21.2	20	0.10	1.1	1
5	74.5	23.6	67	74.5	23.6	20	0.10	1.1	0.5
6	80.2	26.8	56	80.2	26.8	20	0.10	1.1	0.5
7	82.2	27.9	13	82.2	27.9	20	0.10	1.1	0.5
8	76.5	24.7	16	76.5	24.7	20	0.10	1.1	0.5

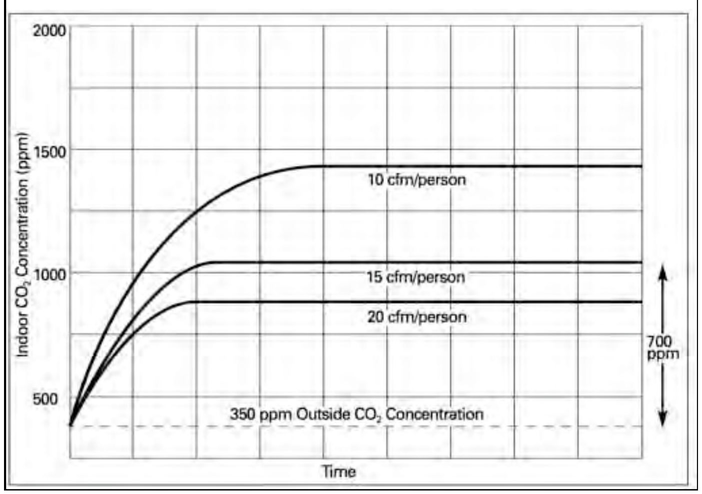
Ventilation

- Oxygen Replacement
  - Very little required (1 cf/h O_2/person) 0.02 cfm
- Pollution Dilution & Removal
  - What pollution is in the space? (x cfm/sf)
- Odor and "stuffiness"
  - How smelly are you?
- ASHRAE 62 provides good guidance

C0$_2$

- Humans generate CO_2 depending on activity
  - Can be a tracer gas for ventilation
- Submarines: target 5 000 – 10 000 ppm
  - Limit is 30 000 ppm
- ASHRAE 62.1-2007 Section 6.2.7
  - Allows ventilation to vary with operating conditions
  - Target is about 1000 ppm, although up to 1500 ppm OK

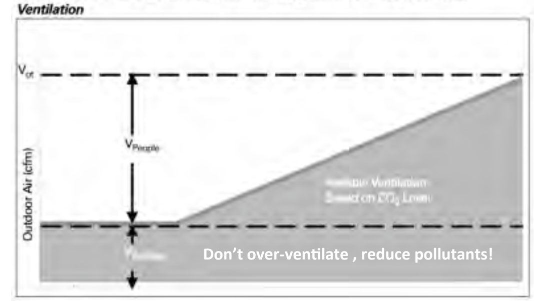




Building Pollution

- Base-level min. building ventilation always needed to remove other pollutants

Figure 10: Minimum Ventilation Rate with CO_2-Based Demand-Controlled Ventilation



Standard Rates

- Housing
  - 7.5 cfm/person + 0.01 cfm/sf
- Office
  - 5 cfm/person + 0.06 cfm/sf
- These are political choices
- Rate human odor and building pollutant differently

ASHRAE 62.1

Zone Air Distribution Effectiveness

	Air Distribution Configuration	E_z
Typical office	Ceiling supply of cool air	1.0
	Ceiling supply of warm air and floor return	1.0
	Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return.	0.8
	Ceiling supply of warm air less than 15°F (8°C) above space temperature and ceiling return provided that the 150 fpm (0.8 m/s) supply air jet reaches to within 4.5 ft (1.4 m) of floor level. **Note**: For lower velocity supply air, E_z = 0.8.	1.0
Typical Underfloor Air	Floor supply of cool air and ceiling return provided that the 150 fpm (0.8 m/s) supply jet reaches 4.5 ft (1.4 m) or more above the floor. **Note**: Most underfloor air distribution systems comply with this proviso.	1.0
Displacement ventilation	Floor supply of cool air and ceiling return, provided low-velocity displacement ventilation achieves unidirectional flow and thermal stratification	1.2
Typical House htg	Floor supply of warm air and floor return	1.0
	Floor supply of warm air and ceiling return	0.7
	Makeup supply drawn in on the opposite side of the room from the exhaust and/or return	0.8
	Makeup supply drawn in near to the exhaust and/or return location	0.5

1. "Cool air" is air cooler than space temperature.
2. "Warm air" is air warmer than space temperature.
3. "Ceiling" includes any point above the breathing zone.
4. "Floor" includes any point below the breathing zone.
5. As an alternative to using the above values, E_z may be regarded as equal to air change effectiveness determined in accordance with ASHRAE Standard 129 [illegible] all air distribution configurations except unidirectional flow.

Conclusions

- Comfort is more complex than thermostat setting
- These complications affect design choices of enclosures, mechanical controls, distribution of air heat and cool, etc.
- Ventilation is more than "fresh air"

HVAC for Architects

HVAC Objectives

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

11-06-01 2

Common Problems

- Poor comfort
  - Poor control of temperature and/or humidity (automation)
  - Noise, drafts from high velocity air (at 55 or 95 F)
  - Lack of RH control
- Health
  - Air based systems act as distribution for outdoor pollutants, mold grown in coils/ducts
  - Chilled water pipes collect condensation leading to mold
  - Insufficient or excess ventilation is common issue
- Energy
  - Systems are often very inefficient
- Maintainability / Controllability
  - Systems are complex, difficult to trouble shoot, maintain etc

11-06-01 3

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

11-06-01 4

What do you need to deliver?

This should be decided upon and written down in programming phase!

Type	Temperature	Humidity	Pressure	Examples
I a	●			Heated house, warehouse
I b	●	○		Heating and normal A/C
I c	●		○	Heating + exhaust fans
I d	●	○	○	Heating+ A/C + exhaust fans
II a	●	●		Museum, fruit storage
II b	●	●	○	Pressurized + controlled
III	●	●	●	Special labs, chip fabrication
IV	●		●	Dust controlled manufacturing
V		●	●	
VI			●	

Note: ● Directly controlled ○ - Incidental Implicit

All require metered deliver of fresh air, and some exhaust of polluted air

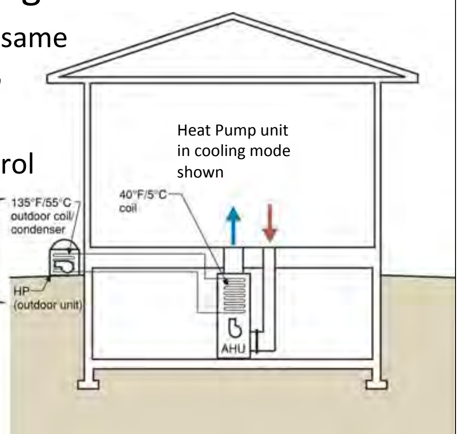
Next Steps

- Analyze a simple residential system
- Look at types of commercial multi-zone

- Revisit details of both

Simple Single Zone Residential

- All rooms the same
- No *ventilation*
- *Accidental* humidity control



Good ventilation, heating, cooling

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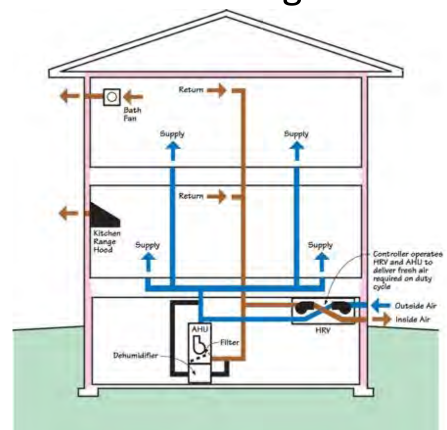
BSI-022: Housing

Ducts shared for ventilation, dehumidification, cooling, heating



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

Large Buildings

- Differences to houses
  - Multiple zones
  - May have high internal heat generation
  - Often with simultaneous heating and cooling
  - Highly-variable ventilation demands over day
  - Large distances to distribute air, heat, cool
- Low-energy buildings with small cores begin to act more like houses

Commercial HVAC & Indoor Air Quality

- Most HVAC re-circulates air
  - This takes pollutants from one space and moves to another
- HVAC can suck in pollutants from outdoors
  - Locate air intakes carefully
- Filters, plenums, duct insulation collect dirt
- If moisture (condensate) contacts, mold can grow
- Air flow distributes the problem smells and spores

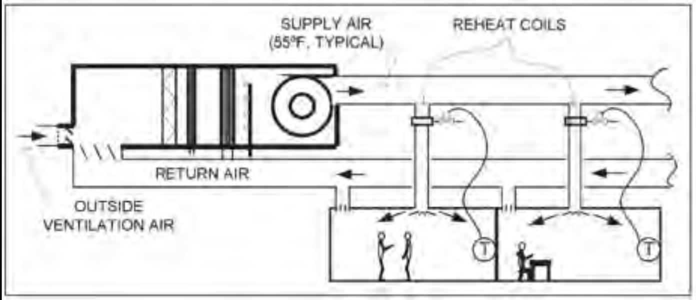
11-06-01 10

Common Air-based Sysems

- CAV systems
  - high energy consumers but provide outdoor air
- VAV
  - decent energy performance, but rarely supply desired ventilation (fresh) air rates
  - Often heat and cool simultaneusly

11-06-01 11

Constant Air Volume



Great RH & T control (Dewpoint of 55 all the time)
Terrible energy performance (reheating almost all the air, all the time)
Often no designed exhaust air: "pressurize" building

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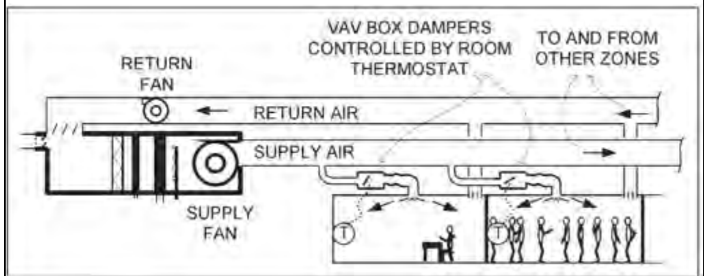
Variable Air Volume



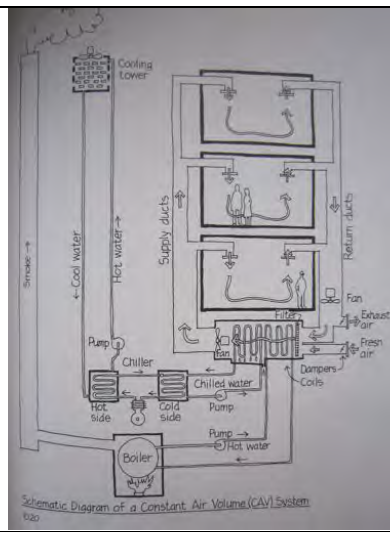
Poor IAQ: ventilation controlled by thermostat
Poor/no RH control: depends on cooling coil operation
Either good energy performance /poor RH, or good RH / poor energy
Often no designed exhaust air: "pressurize" building

11-06-01 13

Variations on VAV

- Spaces with low cooling load often under-ventilated
- Minimum flow setting at box can be imposed by clock or CO_2 and "reset" by temperature
- Reheat at box often needed, can be significant energy
- Outdoor air % can vary with return air CO_2 or clock
- Supply fan can be operated to provide constant static pressure (VFD)
- Flow can be measured at each box, with reheat, connected to central control to guarantee ventilation air (complex, $, works)

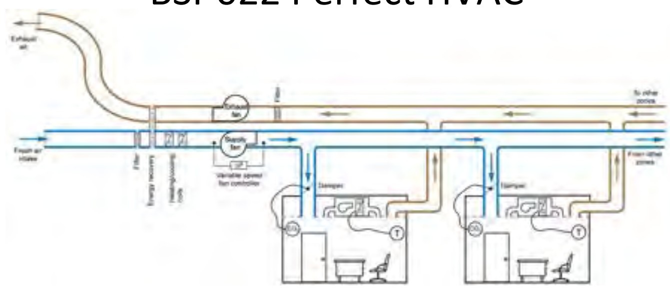
11-06-01 14



Solutions? DOAS

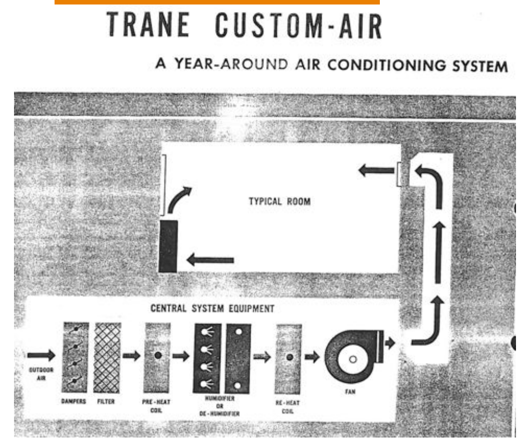
- DOAS: Dedicated Outdoor Air Systems
  - provide Ventilation (+ almost always dehumidification) only
  - separate standard *terminal* equipment does heating and cooling
  - Highest performance, easy to design control & fix
- Integrates energyrecovery

BSI-022 Perfect HVAC



Thermostat controls heating/cooling by zone
Ventilation controlled by occupancy (CO_2)
All air is delivered dry (to provide humdity control)
No recirculated air (improved IAQ / less cross contamination)
No holiday schedule for ventilation. No under/over ventilation.

Not a new idea . . .



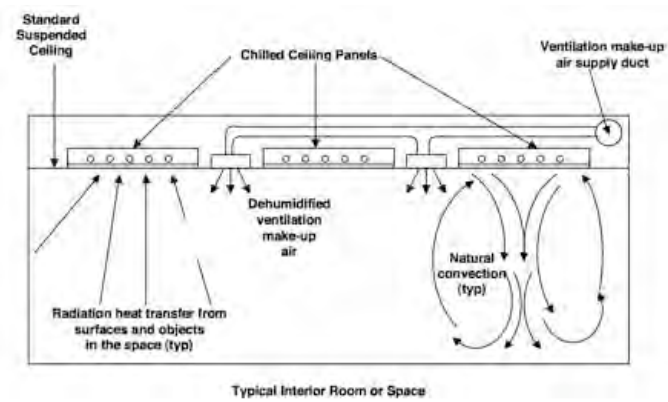
From Trane Co., 1951

DOAS

- Most reliable means of delivering ventilation air to people without over ventilating
- Excellent humidity control, no *extra* reheat
- No cross-contaminated air from different zones
- Small ducts (ventilation only, no cooling)
- Works well with hybrid ventilation
- Disadvantage: economizer flow is limited, so free *air* cooling capacity is limited by 2-3X

Very high efficiency of heating, cooling, etc

DOAS + Radiant Terminal



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 60+ (150)
  - Electric fan is used to move air
- Both heat exchanger between <u>flame to fluid</u>
- Fuel sources
  - Nat gas, oil, propane, wood, electric, etc.

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Modern Boilers: small, quiet efficient

Boilers don't boil

Viessman, gas

Takagi, Oil

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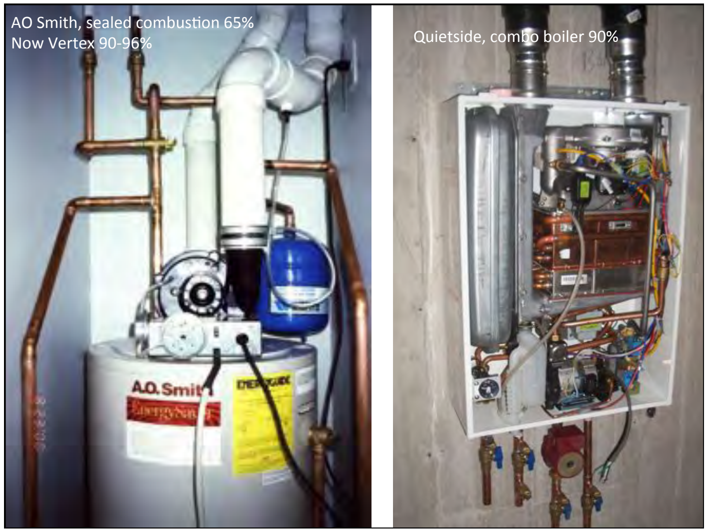
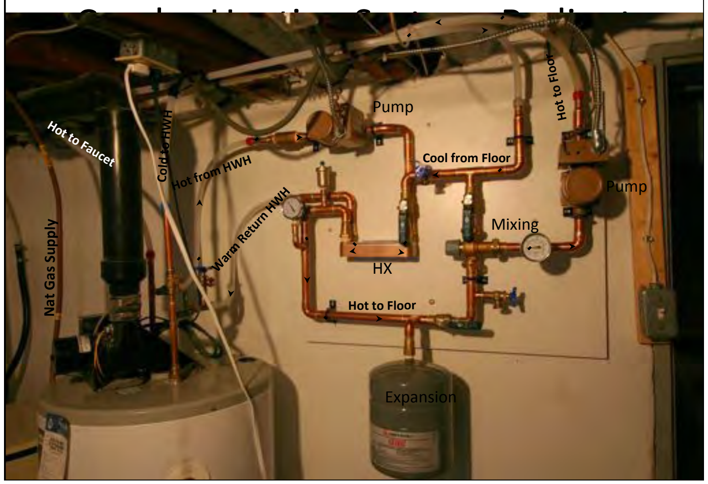
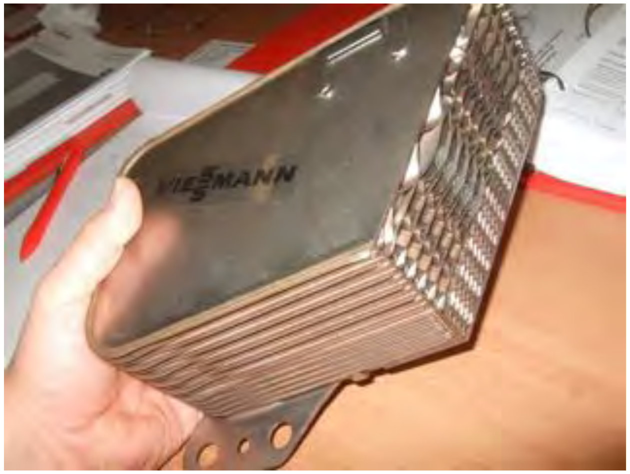




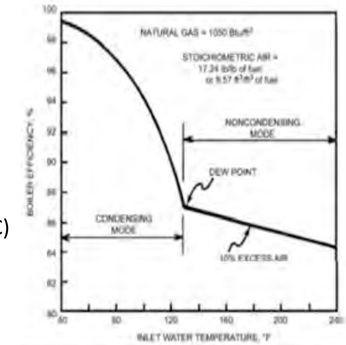
Boiler Combustion Efficiency

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

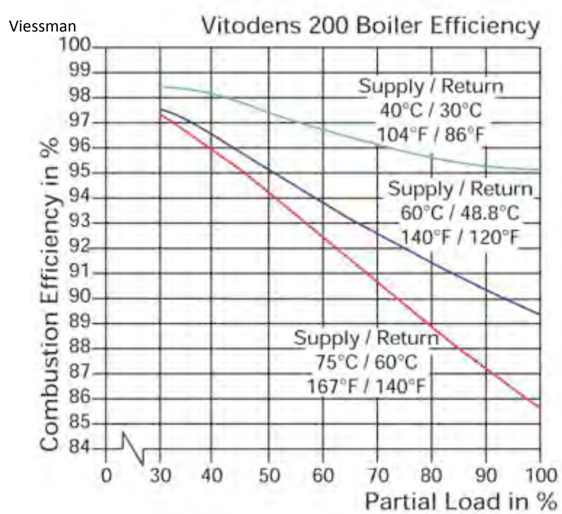


Condensation % Efficiency

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



ASHRAE Systems Handbook 2000.



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

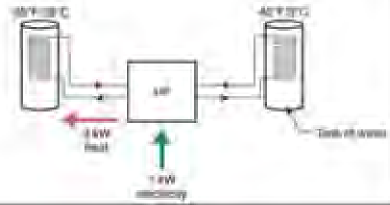
Building Science 2008

Heat Pumps

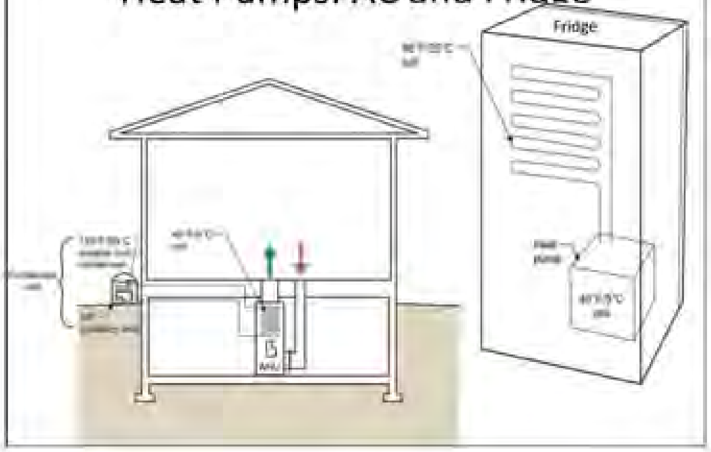
- Neither create or destroy heat, but move it around
- Require input energy just like any other pump
- Need
  - **Source** of thermal energy
  - **Sink** of thermal energy
- Sources (inside=cooling, outside=heating)
  - Air ("Air source")
  - Ground ("ground source")
    - Soil, Groundwater, or Surface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

Heat Pumps

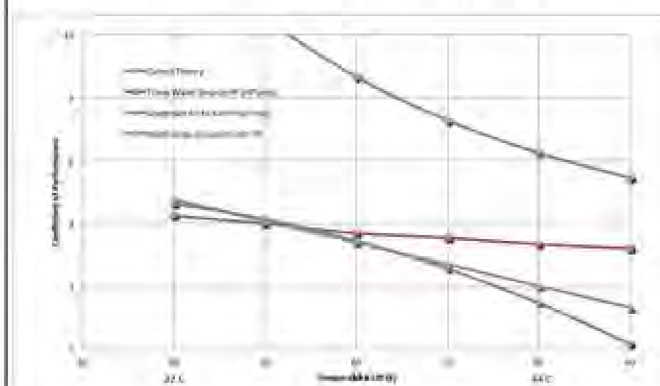
- Use compressors, and refrigerant ("Freon")
- All use *internal heat exchangers* to transfer hot or cold refrigerant to water or air
- Terminology
  - "Air to air heat pump" = "air-source"
  - "Water-to-water heat pump"
  - "air conditioning"
  - Water to air
  - Ground source
  - "Geothermal"



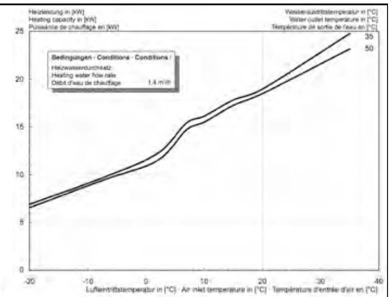
Heat Pumps: AC and Fridge

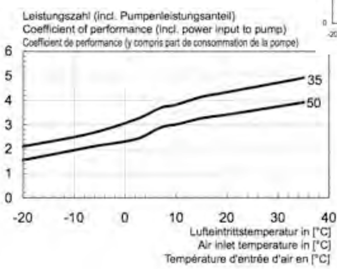


Heat Pump Efficiency vs Lift



- Air-to-water





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Source: Dimplex.de LA 16AS

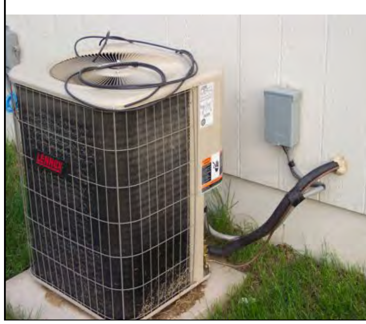
Cooling

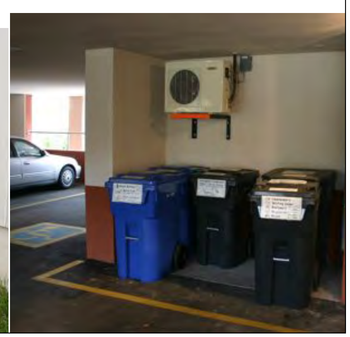
- Most cooling equipment is a heat pump
  - uses the interior as a source (collection) and
  - Outside as the sink (rejection)
- Other mechanical cooling systems (all described later)
  - Evaporative cooling
  - "Free cooling"
    - Use a source of cold air or water to absorb (collect) heat and remove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

11-06-01 38

Heat Pump and Reject/Collect in same box

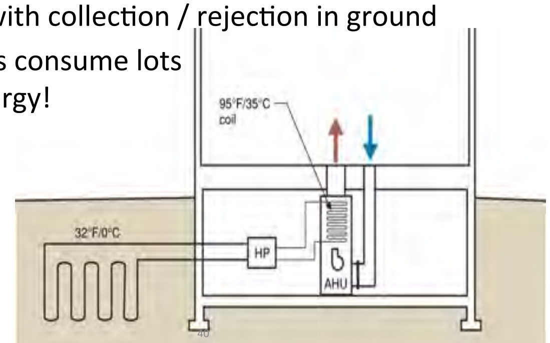
- Compressor, and DX coils in one enclosure





Ground Source Heat Pump

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



11-06-01 40

Chillers

- Air-to-water heat pumps used for cooling
- Usually large buildings
- Very high efficiencies possible with 100-250 ton units

Distribution / Terminal Units

Fans

- Move air through systems
- Typical ducted VAV office systems use 30% of energy running fans

Terminal Units

- Diffusers (ceiling, wall, floor)
- Fancoils
- Radiant panels, floors, beams, walls
- Active beams

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

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

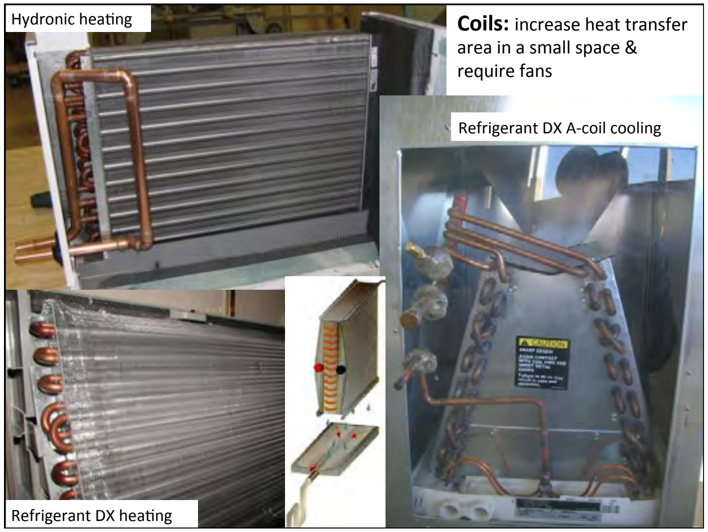
Low Temperature Supply

- 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

48

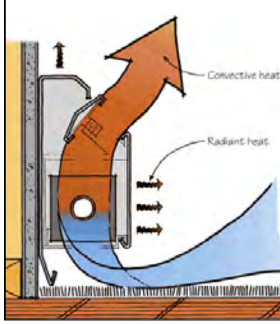


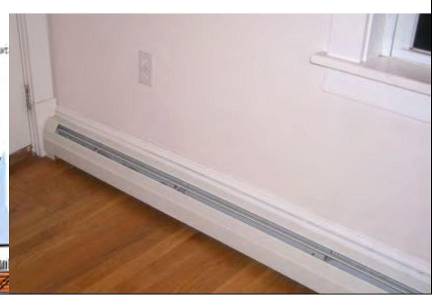
Convector / Radiator

- Hydronic terminal units
  - no energy required at unit

Convector / Radiant

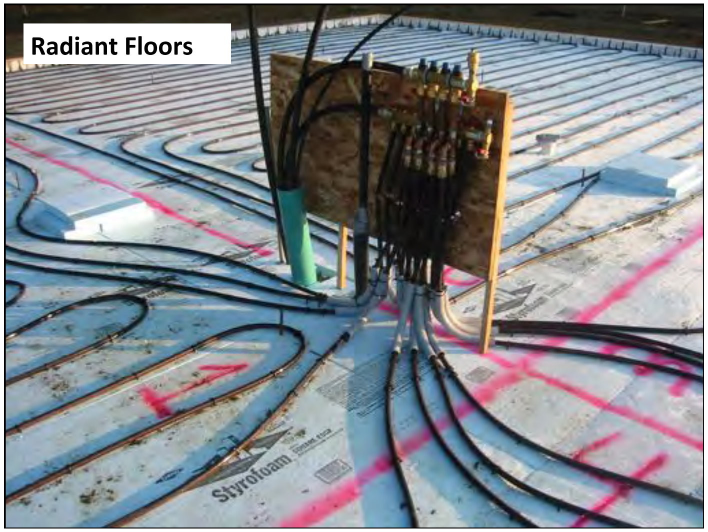
- Usually only for heating
  - large Delta T need to drive bouyancy





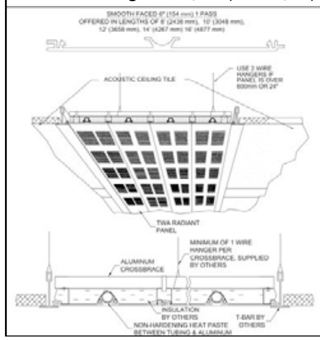
Convector retrofit

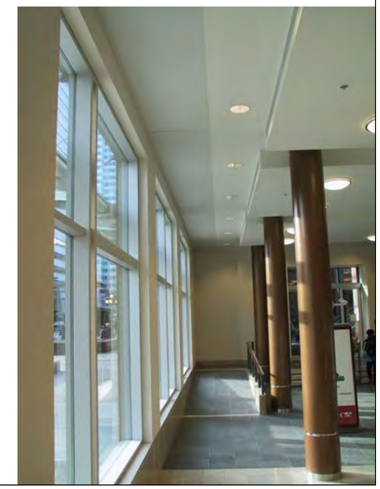
Radiant Floors



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)





Emission plates under wood

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)

11-06-01 56

Heat Exchange from Surfaces

- Example: 80F(27C) floor, 72F (22C) room air
  - 15.2 Btu/hr/ft^2 heating
- Example: 60F (15.5C) ceiling, 74F (23C) room air
  - 26.6 Btu/hr/ft^2 cooling (500 sf/ton)
- Example: 68F floor, 74F air (1500 sf/ton)

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

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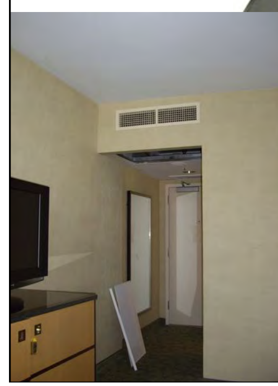
Terminal Unit: Fan coils

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

Courtesy: Rittling Co.

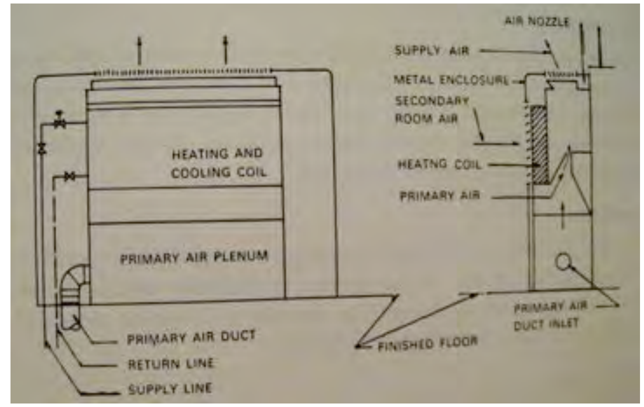
9



60

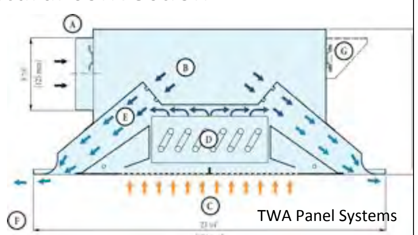
Combo air handler: Built-in pump and ECM fan

Induction Units



Chilled Beams

- Increase the convective component of radiant panels, usually for cooling
- Active CB use mechanically-induced airflow
- Passive CB use natural convection



TWA Panel Systems

Active Chilled Beams

- For the benefits of small ducts in active chilled beams to work, the cooling/heating loads of each space need to be small enough that ventilation air, when cooled to 50 F, can cool the space under design conditions. If not, then more air needs to be delivered, and this will require bigger ducts and some recirculation of air.
- The rate of ventilation air generally should change with occupancy: in an active beam system that means cooling capacity will vary with occupancy (or over ventilation must occur, which uses more energy than saved by using ACB) or changing supply air temp.
- A separate ventilation supply system and separate cooling system allows for the most flexibility but is often at odds with ACB for variable occupancy spaces.
- Passive beams don't have this issue, but they have a lower peak capacity than ACB.

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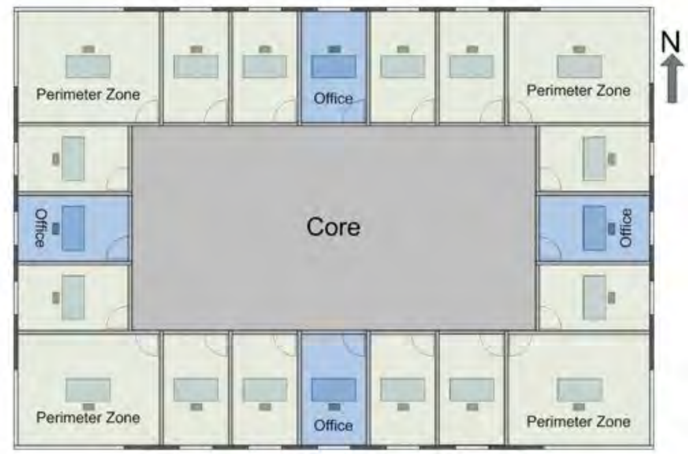
Trox Spandrel unit

- Ventilation, heating, cooling in spandrel

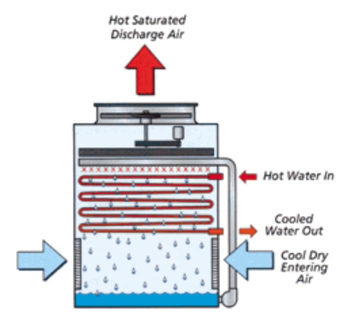


Heat Pump and Reject/Collect in same box

- Compressor, and DX coils in one enclosure

Cooling Tower Rejection

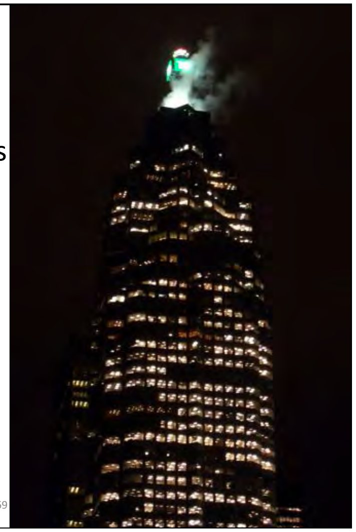
- Cool hot water by spraying through air



Principle of Operation

Cooling Tower

- Many sizes and shapes



69

Pond Heat Collection / Rejection

Distribution

- Water Pipes + pumps (for heat/cool)
- Refrigerant lines + compressors
- Air Ducts + fans
  - Ceiling plenums
  - Floor plenums (Underfloor Air)

Distribution of Air

- Ductwork consumes space, penetrates fire- and noise-rated partitions
- High Speed airflow generates noise
- Moving air uses lots more fan energy than water consumes pump

11-06-01 72

Air Distribution: high- vs low-rise

- Larger distances for conveyance systems
- Larger wind pressures
- Larger stack pressures
- More fire/smoke control requirements
- Often fewer sides of building available for ventilation openings
- Greater variation in occupant loading
  - Meeting room vs. office space
  - CEO office vs call center
- Cooling almost always needed

11-06-01 73

Distribution

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

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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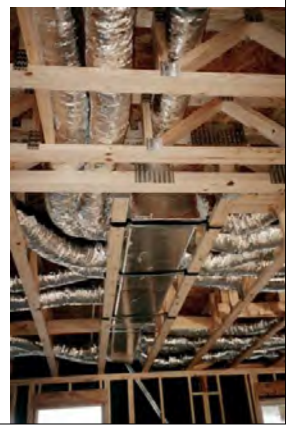
Fittings create friction



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**

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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*60= 60 Btu /hr/cfm
  - Heat pump 100 F: 1.0*30 = 30 Btu/hr/cfm
  - Therefore need 2X airflow for low temp air

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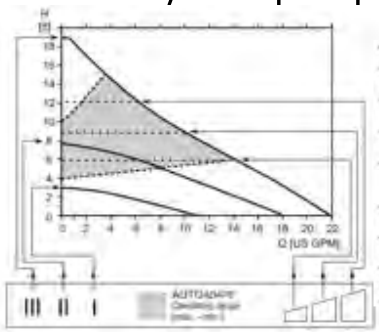
Water Based Systems

- 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: 60 000 Btu/hr
  - Furnace: @ 60 Btu/hr/cfm → 1000 cfm (900W)
  - Heat pump @ 30 Btu/hr/cfm → 2000 cfm (1800W)
  - Radiant 5000 Btu/hr/GPM → 12 GPM (85W)

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

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***

Ductless Mini-split

Variable Refrigerant Volume (VRV)

UFAD

- Confusion about defintions
- Many small details matter to make UFAD work

Underfloor Air Distribution

- A "green" technology. Why?
- Higher temperature air delivery (55F vs 65)
  - High T required for ankle comfort,
  - allows higher chilled water temp (saves energy)
- Large airflow volumes required for cooling
  - More airflow= more fan energy, but . . .
  - Allows economizer at higher outdoor T
  - Requires large "ducts" to reduce fan energy

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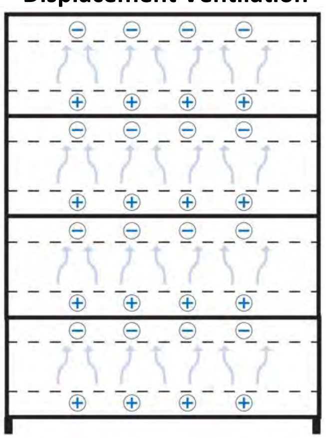
Displacement Ventilation



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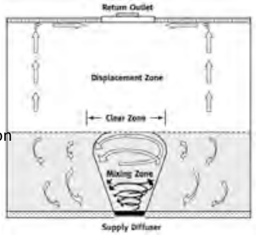
Ventilation

- Displacement (DV) ≠ UFAD
- Many UFAD are not DV
- Low supply Velocity = DV

Swirl diffuser
UFAD ventilation



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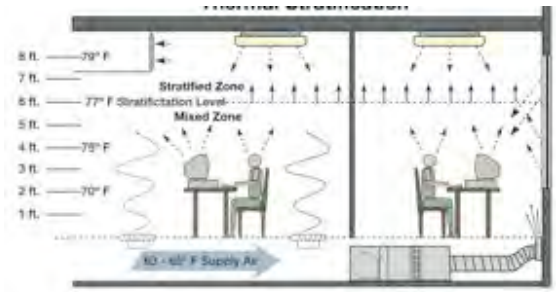
Cooling dominates, not ventilation

- Perimeter zones



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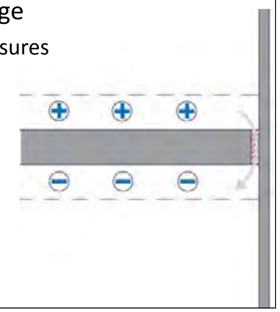
UFAD Leakage

- Underfloor plenum is a duct
  - Ducts leak
  - Field reports of 20-30% leakage
    - Into partitions walls, into enclosures
- Loss of control & cooling



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Building Science 2007 Joseph Lstiburek – Airflow 91

Building Science 2007 Joseph Lstiburek – Airflow 92

Building Science 2007

Joseph Lstiburek – Airflow 93

Other "Issues"

- Dirt Collection & IAQ
  - During construction
  - Operation
- Furniture
  - Need to coordinate heavy furniture with filters, access

Building Science Green Buildings No. 94/51

UFAD + Economizer

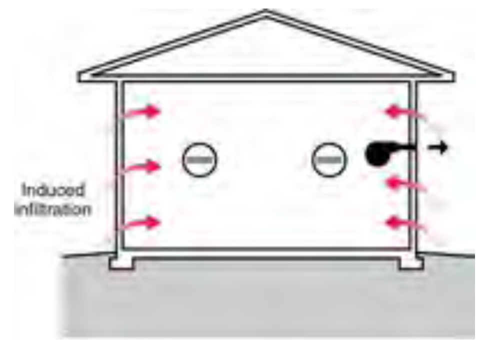
- Bring outdoor air in to cool when it is cooler outdoor than indoor
- Problems:
  - 1. outdoor RH may be too high
  - 2. flows may be too high for ducts and fans
  - 3. Cant blow 30 F air through building (comfort condensation)

Ventilation Approaches

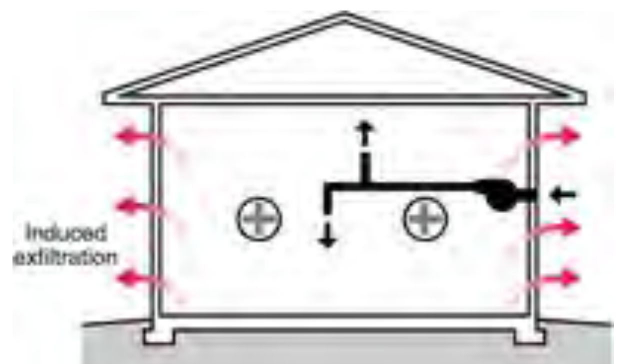
Ventilation

Exhaust Ventilation
Supply Ventilation
Balanced Ventilation

Exhaust Only: Depressurize

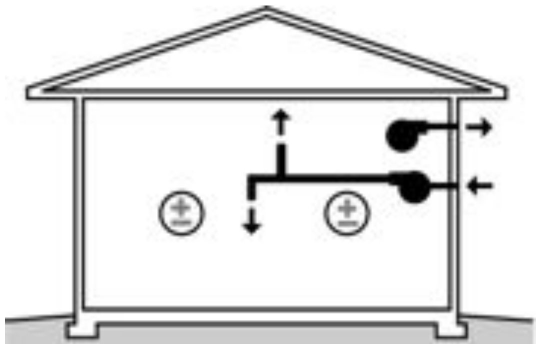


Supply Only: Pressurized



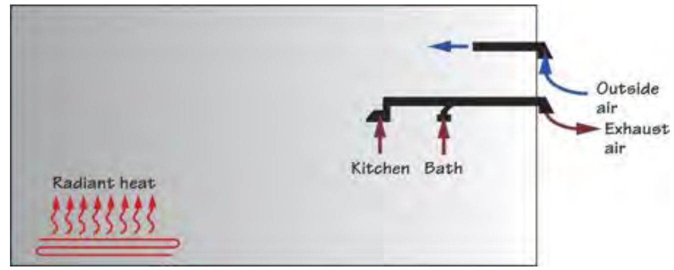
Not common, although most commercial buildings have more supply than exhaust

Balanced Supply and Exhaust



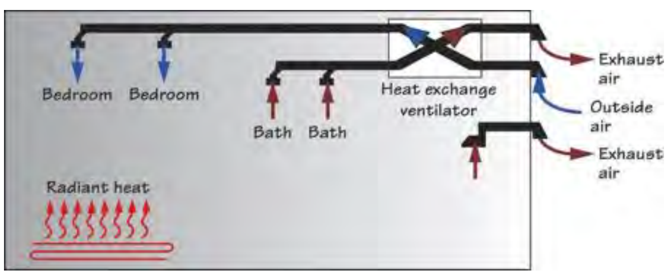
Common Commercial solutions
Residential often combine with HRV/ERV

•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



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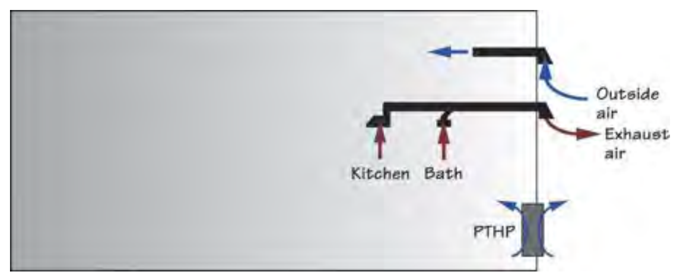
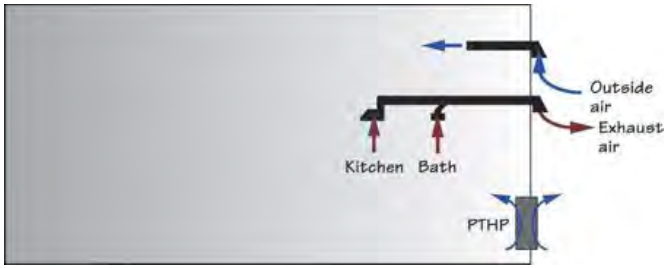


Primary Terminal Heat Pump could be Ductless Mini-split

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



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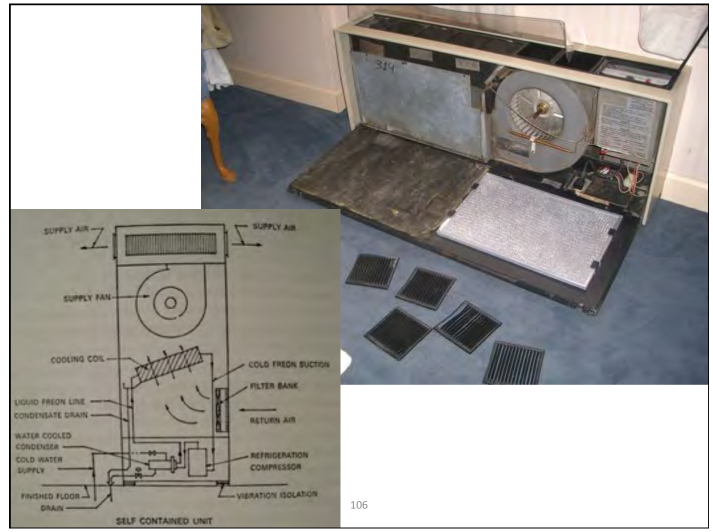


106

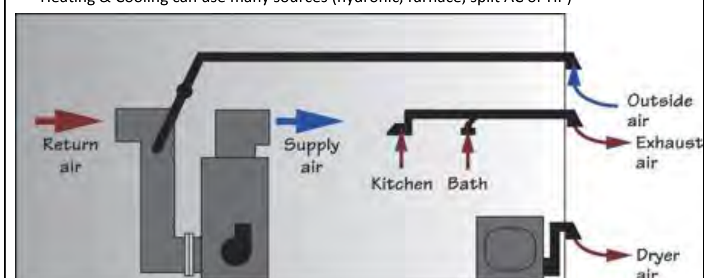
Ductless Mini-split

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

Systems with SEER26 and HSPF=11 available

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

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

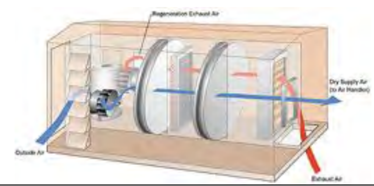


HRV/ERV

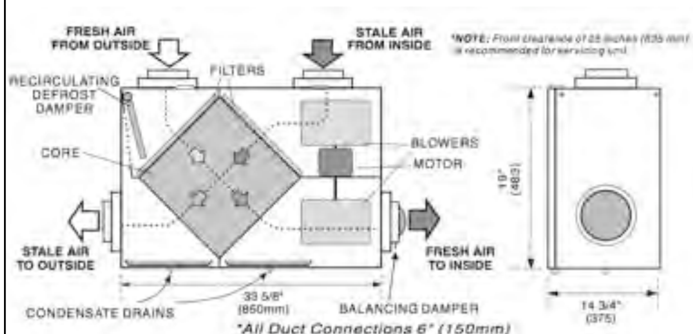
- Heat Recovery Ventilator
  - This is a ventilation system that recovers heat from the exhaust air and transfers to incoming air
- Enthalpy/Energy Recovery Ventilator
  - Transfer heat and humidity from incoming to exhaust
- Both, beware poor electric motor efficiency
  - Aim for less than 1 W/cfm

Energy recovery ventilation

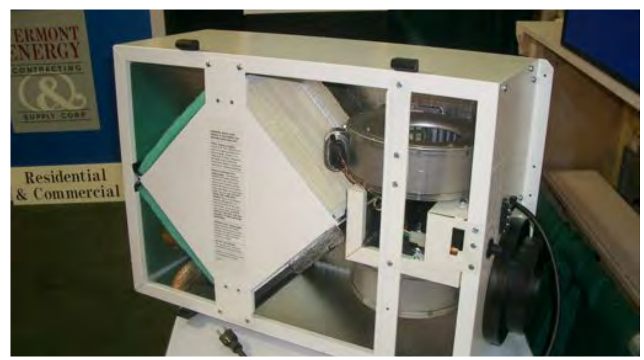
- Reduces equipment peak capacity (saves capital $)
- Reduces load on heating/cooling/ dehumidification (saves energy/operating $)
- Usually makes sense for any large mechanical ventilation flow

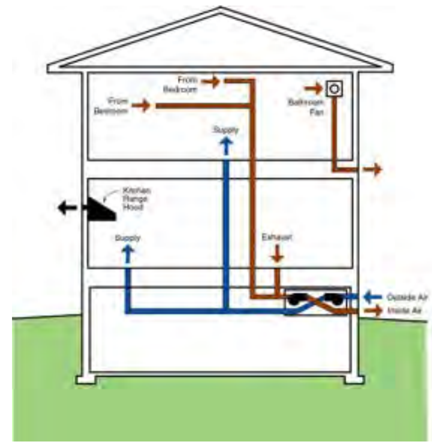


e.g. NuTech 155 ECM

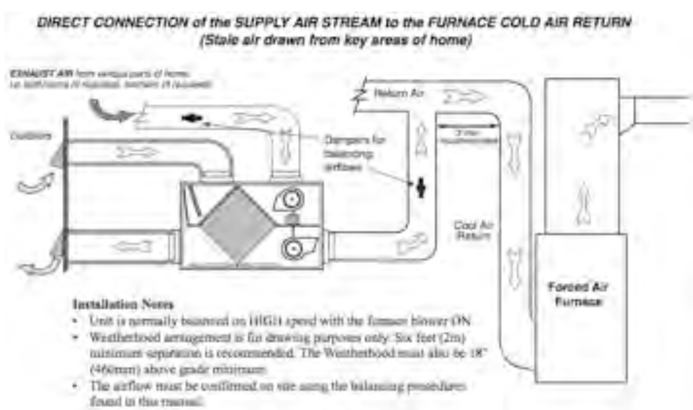


HRV, small, cheap





HRV connections



Economizer aka "Free cooling"

- If it is cooler outside than inside and cooling is desired, blow some outdoor air into building
- This is called "air side economizer"
- *Beware* fan energy consumption- free cooling is not free, esp with long small twisty ducts!
  - Small temperature differences (eg 5F) not enough to cool normally
  - larger temperature differences (eg >10F) work well
  - Cant use air if it is too humid (enthalpy control)
- Water-side may be more efficient in large buildings

11-06-01 116

Natural ventilation

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

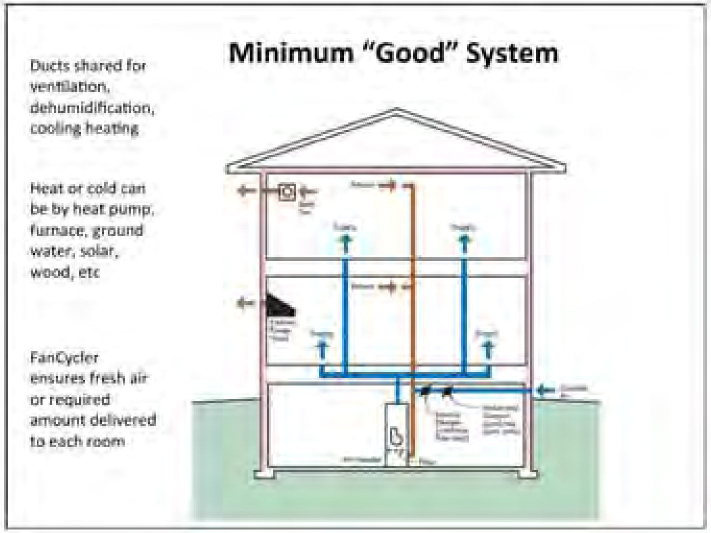
Natural ventilation cooling

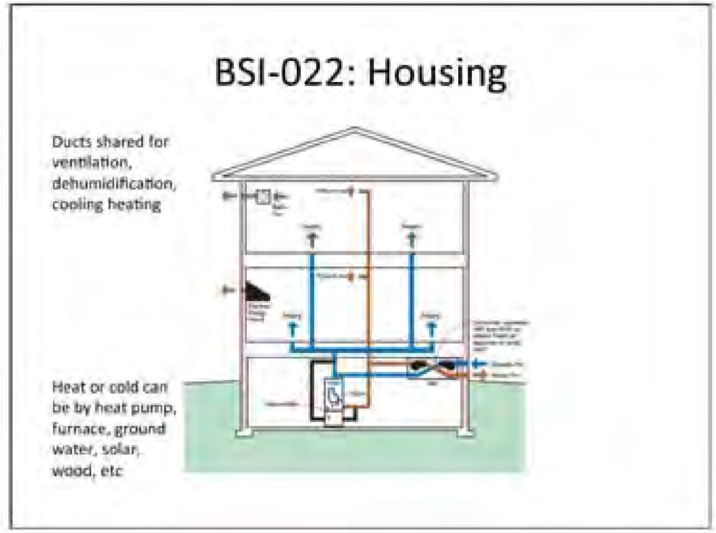
- Basically, Airside Economizer using natural pressures to drive air
  - Large airflows needed at T_{out}> 65 F (18C)
- Must throttle airflow as T_{out}<60 F for comfort
- Little airflow possible when T_{out}<40F (5C)
  - Condensation, comfort problems
- Most low energy buildings have low cooling loads, mostly internally generated

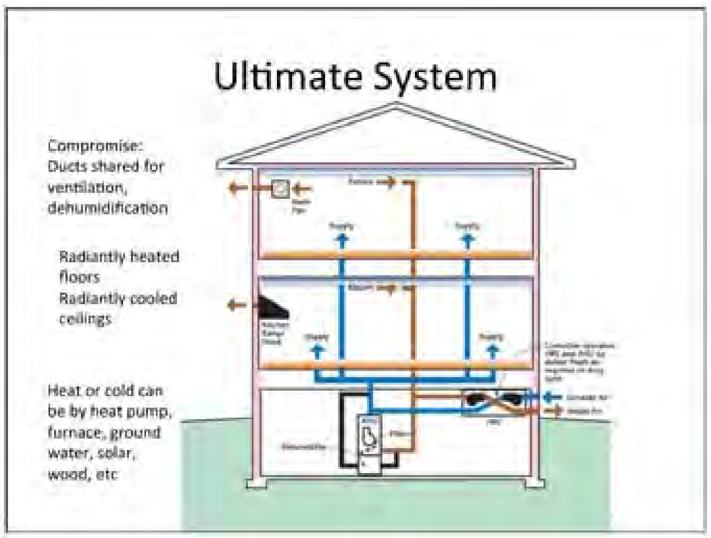
Air-side Economizer

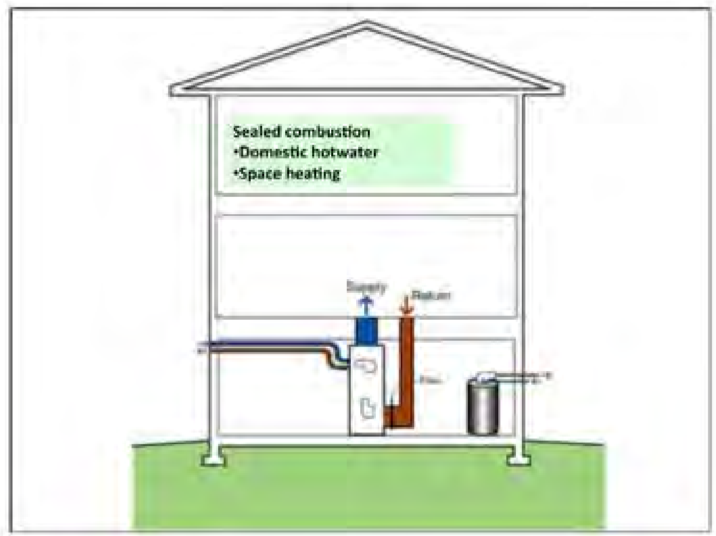
- Through-wall paddle fans can deliver air at very high efficiencies (10-25 cfm/Watt)
- E.g., If t_{out} = 65F & t_{in} = 74 F
  - @1.1 Btu/cfm/F & ΔT 9F = 10 Btu cooling / cfm
  - 15 cfm/Watt→ 150 Btu /Watt fan
  - EER of 150 = COP= 44!!
- If only 1 cfm/Watt VAV → COP= 2.9
  - AC or water side economizer will be better!!

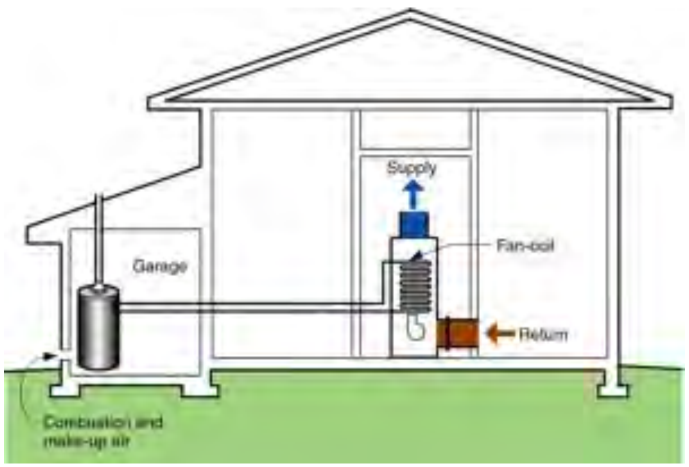
Housing in more depth


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


BSI-022: Housing
Ducts shared for ventilation, dehumidification, cooling heating
Heat or cold can be by heat pump, furnace, ground water, solar, wood, etc


Ultimate System
Compromise: 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


Sealed combustion
•Domestic hotwater
•Space heating
Supply
Return



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!

11-06-01 126