High-Performance Enclosures to Enable Simplified HVAC

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Introduction

- Definitions
  - What is a HP enclosure
  - What is a simple HVAC & why do you want one
- What strategies work

HP Enclosures

- Control energy flow across
  - Minimize need to deliver lots of energy
- Control temperature of inside surfaces
  - Maintain comfort even as air temperature varies
- Durable, control rain, airtight, etc

Simple Mechanicals

- This class: focus on Space Conditioning
  - Heating cooling ventilating
- Simple means
  - you can understand how they work under all conditions
  - They can be understood by repair & maintenance

HP Enclosure Metrics

- Peak heat loss
  - 5 BTU/hr/sf, eg 10 000 BTU/hr for 2000 sf house
  - < 10 in cold climates
- Peak cooling
  - 15 BTU/hr/sf
  - Use thermal mass to reduce this

Functions

Five Critical functions are needed

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

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What do you need to deliver?

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

The New World

- Heating / cooling loads shrinking!
  - Better insulation, airtightness, windows
  - Multi-unit = small exterior enclosure area
- DHW is can be larger energy demand
  - Only efficient appliances can reduce DHW use
- A useful definition of low heating load is a residential building with space heating loads of less than 2 times DHW

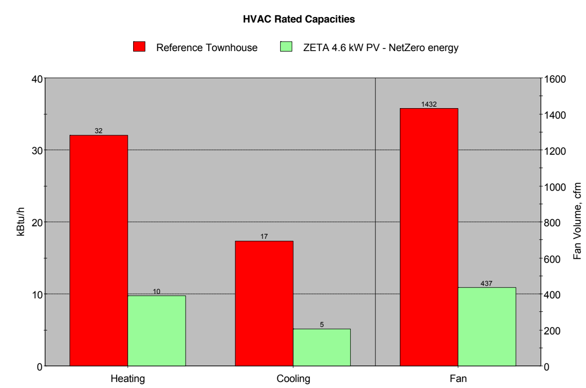
Low-energy houses

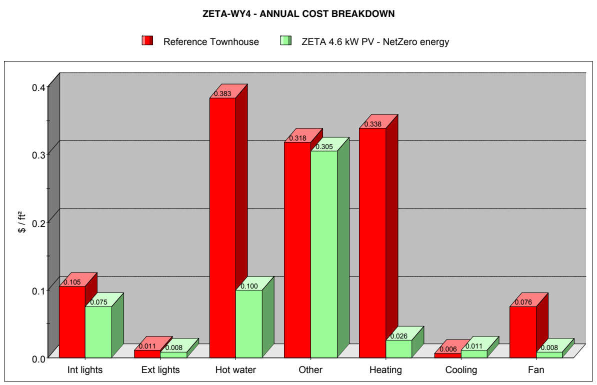
- Peak demand for well-insulated 2000 sf
  - Often 20 kBtu/hr or less, usually under 30
  - Townhouses often under 12 kBtu/hr
- Annual space heating demand usually under 7500 kWh/yr
  - (e.g. 200 therms)
  - High specs, simple buildings gets demand lower

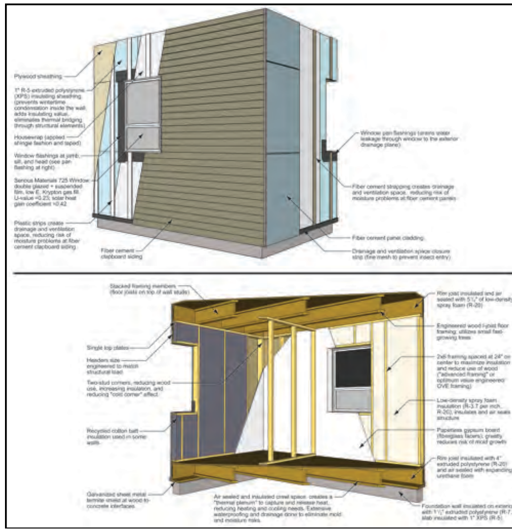
Domestic HotWater

- Typical household
  - 4000 kWh demand +/- (136 therm)
  - National *use* 5600 kWh (192 therm)
- Typical 5 unit + building. Use /unit
  - 2500 kWh demand (86 therm)
  - 3575 kWh/yr estimated *use* (122 therm)

Zeta Homes. Dan Smith Architect. Oakland, CA







Calculations

- Need to see some!
- They don't need to be very precise, just correct
- $Q_{loss/gain} = A \bullet \Delta T / R$
- $Q_{solar} = A \bullet SHGC \bullet I_{solar}$ (I=200-250 Btu/hr/sf)
- $Qair = 1.06 \bullet A \bullet \Delta T$

Basic Assumptions

- Conservation of mass
  - Air in = air out
- Conservation of energy
  - Energy in = energy out (if temperature is to remain constant)
- Perfect mixing of air
  - Injecting heat into a room will mix and become uniform temperature

Examples: SF, 40F outdoors

- 20 x 25 ft = 600 sf 1 BDR interior apartment
  - 20*9 ft height = 180 sq ft enclosure area
  - 40% windows = 72 sq ft
- R15 wall, R3 window, 40 F outdoor temp.
  - (108/15+72/3) * (70-40) = (7.2 + 24) * 30
  - **950 Btu/hr conduction** losses (!)
- Achieve 0.05 cfm/sq ft @5 Pa airtightness
  - 9 cfm leakage 1 * (70-40)= **270 Btu/hr air leakage** loss
- Ventilation (New World needs it)
  - 30 cfm w/66%HRV = **400 Btu/hr ventilation**

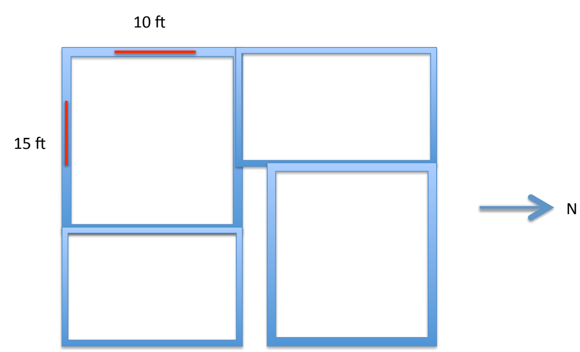
One therm = 29.3 kWh

Example con't

- Peak design load: 1.5 kBtu/hr (<0.5 kW)
  - Corner apartment up to 2.5 kBtu/hr (1 kW) ….
- Heat loss coefficient 30-50 Btu/F/hr
- If we use HDD65 = 2700
  - (30 to 50)*24*2700 = 20-30 therms ($30-$60/yr)
  - 600-1000 kWh/yr <$120-200/yr
- If we use HDD50=117 …. Negligible
- If 2.5 kBtu/hr, airflow= 50 cfm @DT=50

Zones and rooms

- R20 wall R50 roof R3 window



Room/zone

- (15+10) * 9 ft high = 175 sf
- If 5x5 and 5x6 windows = 25+30 = 55 sf
- So 120 sf wall, 150 sf roof
- Heat loss (40F)
- Wall 120 / 20 * 30 = 180 Btu/hr
- Windows 55/3 (30)= 550/hr
- Roof 150 / 50 (30) = 90 Btu/hr
  - Total skin loss = 820 (requires 16 cfm air @ 120F)
- Vent, 15 cfm * 30 = 450 Btu/hr (heat at supply)

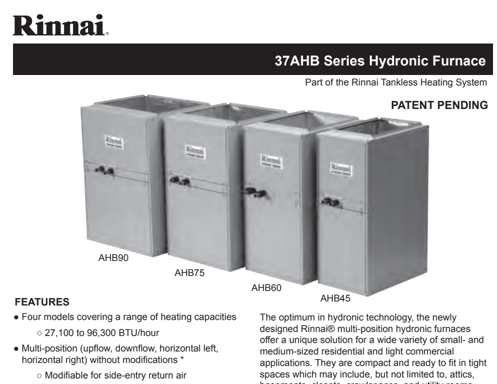
So what's the problem

- 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

Choices

- Furnace is still a good choice if you have natural gas and loads over 10-15 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
- Size of duct/coil often fixed by cooling system

Combo system: gas hotwater heater

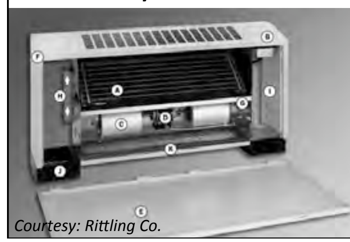


ECM motor + low flow = very low electrical draw

Low speed fan setting and lower water temperature (120 F) allows for whole house heating of space with just 8-15 kBtu/hr peak

Terminal Unit: Fan coils

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



Courtesy: Rittling Co.

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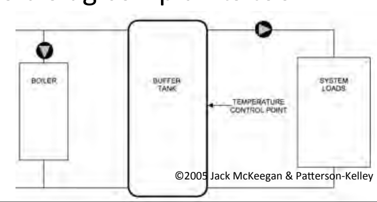
Combo Systems

- Condensing Tankless heaters
  - Beware minimum output
  - Most units are 15 to 35 kBtu/hr minimum
- Unless storage is provided, min output of heating system must min output of boiler
  - 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)
- Buffer tank avoids cold slug complaints too



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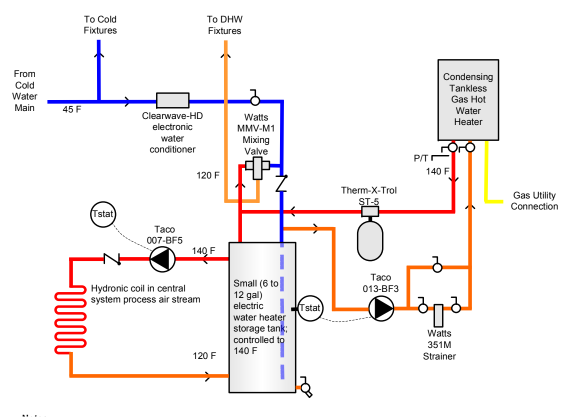
Condensing Tankless Gas Hot Water Heater Application
In Combination Space and Domestic Hot Water Heating System



Newer Condensing Tanked systems

Allows for direct connection to air handler. No additional controls or plumbing. Standard thermostat.

May be lowest cost solution for pretty high efficiency in small apartments, homes, with little cooling needs and gas supply.

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

Split Heat Pumps

- An option for 4?
  - Eg Portland Seattle Tacoma 20 F design temp
- 2 ton HP produce about 16 kBtu/hr @20F
- Or 21.6 kBtu/hr @40 with COP=3.9

SSZ160241A* / CA*F3636*6A* + TXV / MBE1600**-1 Goodman SEER16 model

	Outdoor Ambient Temperature															
	65	60	55	50	47	45	40	35	30	25	20	17	15	10	5	0
MBh	30.2	28.6	26.9	25.1	24.0	23.3	21.6	19.9	18.7	17.3	15.9	15.0	14.4	13.0	11.5	10.0
ΔT	31.9	30.2	28.4	26.6	25.4	24.6	22.9	21.1	19.8	18.3	16.8	15.9	15.3	13.7	12.2	10.6
kW	1.79	1.75	1.72	1.68	1.7	1.65	1.62	1.58	1.68	1.84	1.60	1.59	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	4.78	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

Ductless Mini-split

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

Example

MODEL: ASU9RLS2

AFR	500

Outdoor temperature		Indoor temperature					
	°FDB	60		65		70	
°FDB	°FWB	TC	IP	TC	IP	TC	IP
-5	-7	14.7	1.97	14.3	2.01	14.0	2.05
5	3	[illegible]	1.98	15.7	2.02	15.4	2.06
14	12	16.8	1.81	16.4	1.85	16.0	1.89
23	19	18.3	1.84	17.9	1.88	17.5	1.92
32	28	18.8	1.79	18.4	1.82	17.9	1.88
41	37	21.3	1.85	20.8	1.89	20.3	1.93
47	43	23.1	1.91	22.6	1.95	22.0	1.99
50	47	25.5	1.94	24.9	1.98	24.3	2.02
59	50	26.5	1.92	25.8	1.99	25.2	2.03

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

20 kBtu/hr output @40F, and COP=3.1

Mini-split

- Space distribution from 7kBtu/hr head?
- Aesthetics or exposed heads
- May be excellent point cooling sol'n with combo heating / ventilation

Heat Exchange from Surfaces

- Example: 77 F floor, 72F (22C) room air
  - 9.5 Btu/hr/ft^2/F heating
- Example: 69F ceiling, 74F (23C) room air
  - 9.5 Btu/hr/ft^2/F cooling

	heating		cooling	
	Btu/hr/ft^2/F	W/m^2 K	Btu/hr/ft^2/F	W/m^2 K
floor	1.9	11	1.2	7
wall	1.4	8	1.4	8
ceiling	1.1	6	1.9	11

Radiant heat/cool

- Under most conditions less heat/cool needed
- Example: 72F ceiling, 70F room air
  - = 3.8 Btu/hr/ft^2/F heating
- If room temp drops to 69, and additional 50% heat (1.9) will be added. If room temp rises to 71, 50% less heat added
- "self control" of the temperature w/ thermostat!

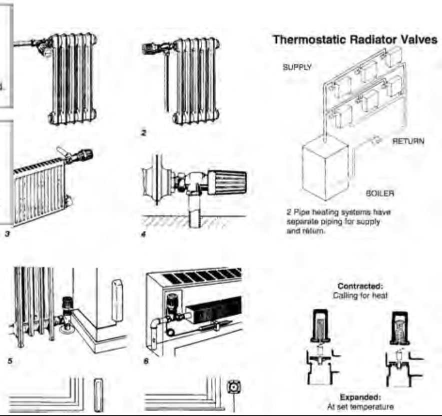
Radiant Floor "Self-control"

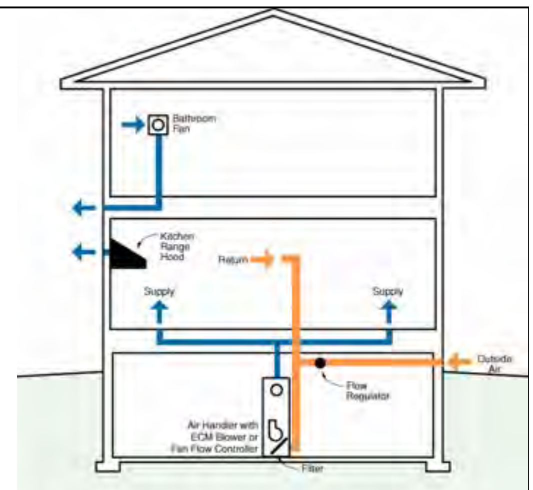
- With small Delta T terminal units, there is a degree of self control
- *Huge* practical control and comfort benefit in low flux (low temp) radiant floor & ceilings

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

Building Science

TRV (very simple)





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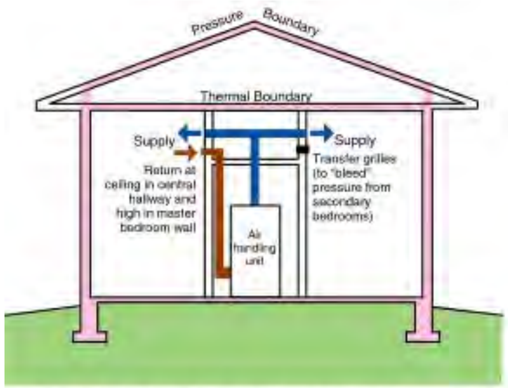
Supply Ventilation System Integrated with Heating and A/C

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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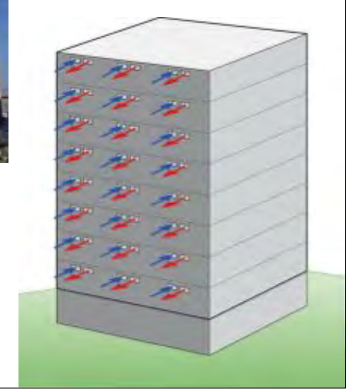
Multi-unit Issues

- 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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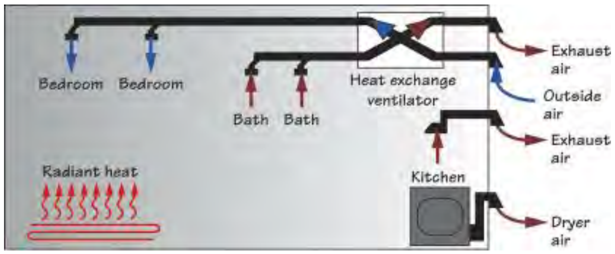
Point intermittent exhaust
Any heat-cool system

Make up air central through corridors or ducts
Forced Ventilation and distribution



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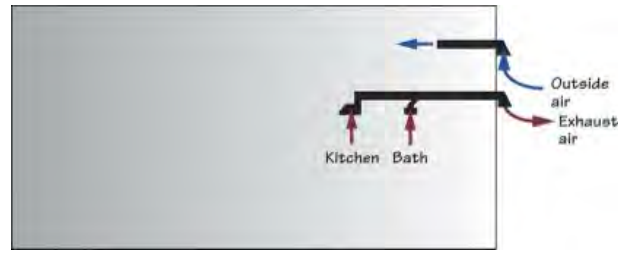
Exhaust fans with passive unconditioned make up
Any cooling and heating strategy

Air distribution? Filtration? Condition fresh?



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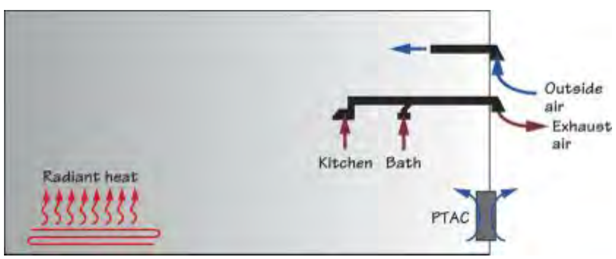
Exhaust fans with passive unconditioned make up
PTAC cooling and radiant heating

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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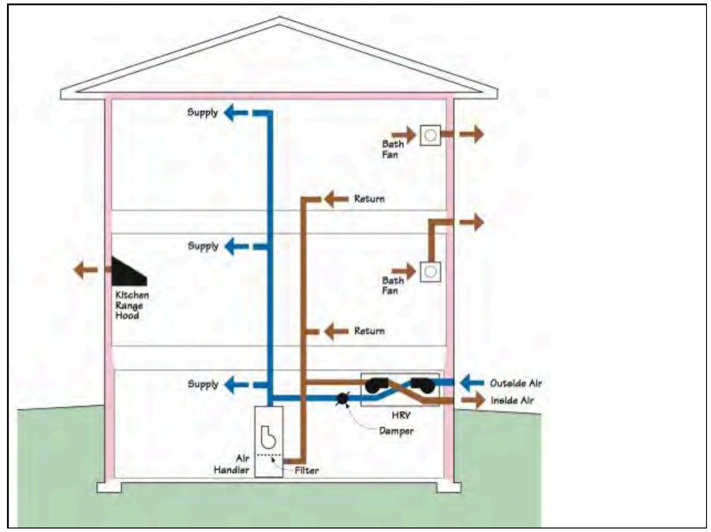
Heat Recovery

- Beware- not always energy saving in mild climates like SF
- Large airflows (commercial) usually worth it
- Include Maintenance access!



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

Common areas

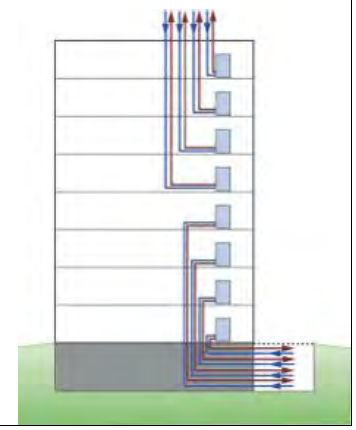
- Simple exhaust
  - Stairs
  - Trash chutes
  - Elevator shafts
  - pools

Supply

- Corridor
- Lobby

Hydronic systems

Heat rejection and Central production



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Floor by Floor

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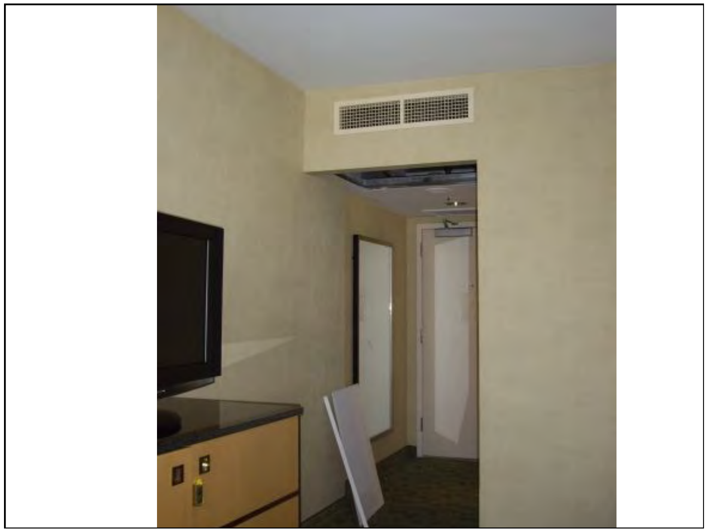

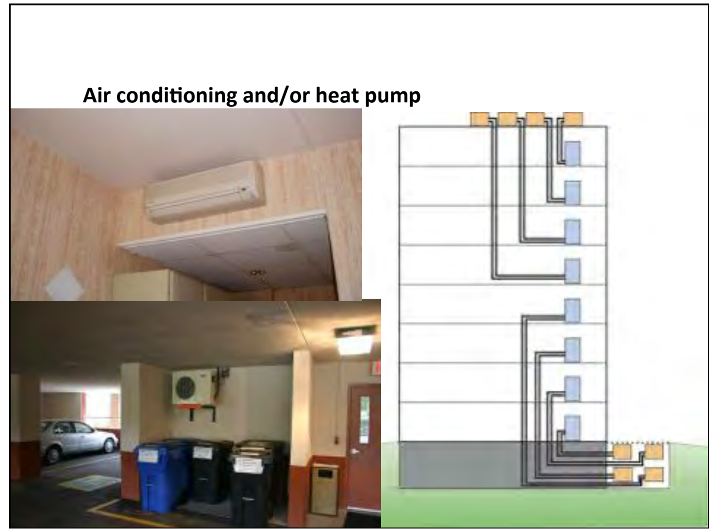
Air conditioning and/or heat pump


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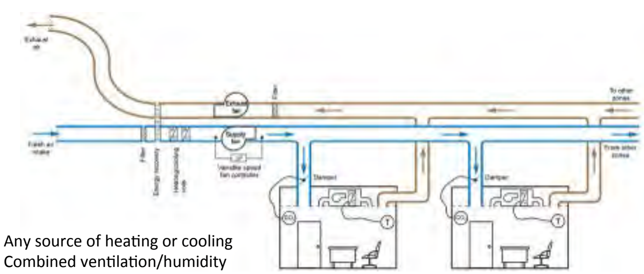
BSI-022 Perfect HVAC

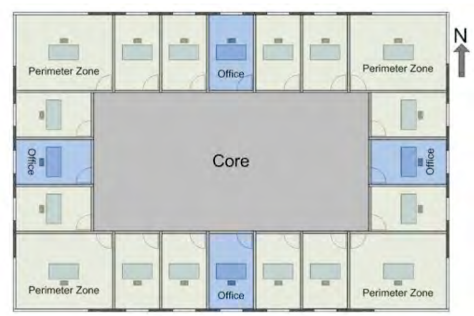


Any source of heating or cooling
Combined ventilation/humidity control

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

Typical office

Modern offices often have small cores to allow more people view and light, and allow for easier ventilation



Typ Problematic Office HVAC

TABLE 26: OFFICE BUILDING ENERGY END USE CONSUMPTION FROM SEVERAL SOURCES

	CEUS, 1997	CEUS, 1999	NRNC, 1999	Bldgs Energy Data book, 2002	Site 1, 2002	Site 2, 2/02 - 1/03	Site 5, 8/99-7/00
Fans ($kWh/ft^2/yr$)	4.0	1.5	2.4	1.5	1.8	1.8	1.6
Cooling ($kWh/ft^2/yr$)	3.2	4.5	2.9	2.7	2.1	1.1	1.3
Heating ($kWh/ft^2/yr$)	n.a.	n.a.	0.4	n.a.	n.a.	n.a.	n.a.
Lighting ($kWh/ft^2/yr$)	4.6	3.7	4.0	8.2	n.a.*	n.a.*	3.6
Misc. ($kWh/ft^2/yr$)	2.4	3.1	5.6	5.9	17.2	16.6	3.5
Total Electricity ($kWh/ft^2/yr$)	14.2	12.7	15.3	18.4	31.1	19.5	10.0
Heating Gas ($kBtu/ft^2/yr$)	22.4	20.6	n.a.	24.3	31.8 9.3	82.5 24.2	18.1 5.3 kWh/sf
HVAC % of Total Electricity	51%	47%	37%	23%	19%	15%	30%
Fans % of HVAC Electricity	56%	25%	45%	36%	47%	61%	56%

* Lighting energy not monitored separately from other misc loads at sites 1 and 2.

Sources.
CEUS 1997. Commercial End-Use Survey, Pacific Gas & Electric Company.
CEUS 1999. Commercial End-Use Survey, Pacific Gas & Electric Company.
NRNC, 1999. Nonresidential New Construction Baseline Study, prepared by RLW Analytics for Southern California Edison.
Buildings Energy Data book, 2002. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.
Site 1. Commercial office building, San Jose, CA. See Appendix for details.
Site 2. Commercial office building, San Jose, CA. See Appendix for details.
Site 5. Public office building, Oakland, CA. See Appendix for details.

From: Taylor Engineering, VAV Design Guide

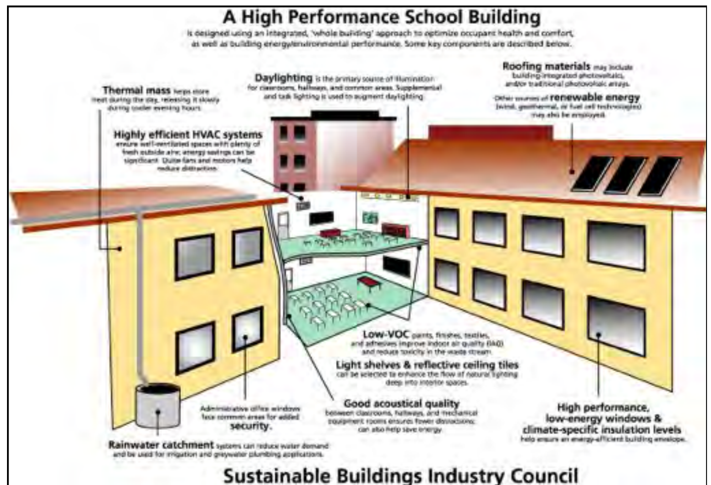
Typ. Bay area offices use a lot of space heating gas!!
Note high fan energy.

Economizers

- Means to blow cool outdoor air into building for cooling
- Requires temperatures below 65F or so
- $Q_{cool,economizer}$ = CFM *($T_{in} - T_{out}$)
- Say 72 indoors, 65 outdoors,
- $Q_{cool,economizer}$ = 7 Btu/hr per CFM
- BUT … requires fan energy, many current designs use poor fans and small ducts

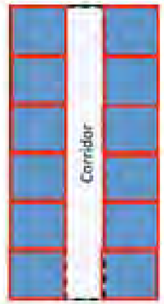
Air-side Economizer

- ASHRAE 90.1-2010 allows VAV fans to use 1.2 W/cfm
- If T_{out} = 65F & T_{in} = 72 F
  - 7 Btu/hr cooling / cfm, but need 1.2 Watts/cfm
  - So EER = 7.5 Btu/hr / 1.2 W = 6.2, COP= 1.8
- A standard AC will deliver better performance
  - E.g., EER of 12, COP=3.5 is common for T_{out}=65
  - When T_{out}=58 F or lower such a systems = AC!
- Through-wall paddle / vane-axial fans can deliver air at very high efficiencies (i.e., < 0.1 W/cfm), COP>20!
  - Provide motorized damper relief and low pressure ducts



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

- When the loads drop due to good enclosures
  - New mechanical options open up
  - Old paradigms no longer valid
- Simpler systems (decouple functions) simpler controls can be designed
- For residential, very small units can be a challenge
- For commercial, use large residential scale

At BuildingScience.com

Core / Perimeter

- Perimeter Zone
  - performance dominated by climate and enclosure
- Core Zone
  - dominated by interior use. Climate/enclosure almost irrelevant
- In most occupancies, core needs cooling and lighting all year long, all day

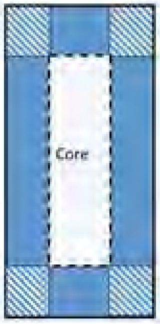
Large Buildings

Many buildings with sizeable core areas require cooling in winter while heating the perimeter

Define "perimeter"

- Maximum distance about 25 ft/ 7.5 m
  - Classrooms often 25-30 ft, open plan office
- Minimum often set by walls/partitions of exterior offices
  - Cellular offices often 15 ft/ 4.5m deep

Skin Dominated Building



- Perimeter Zone over most of building area
- Excellent daylighting and cross ventilation opportunities
- Termed "Skin Dominated"
- Demands good building enclosure