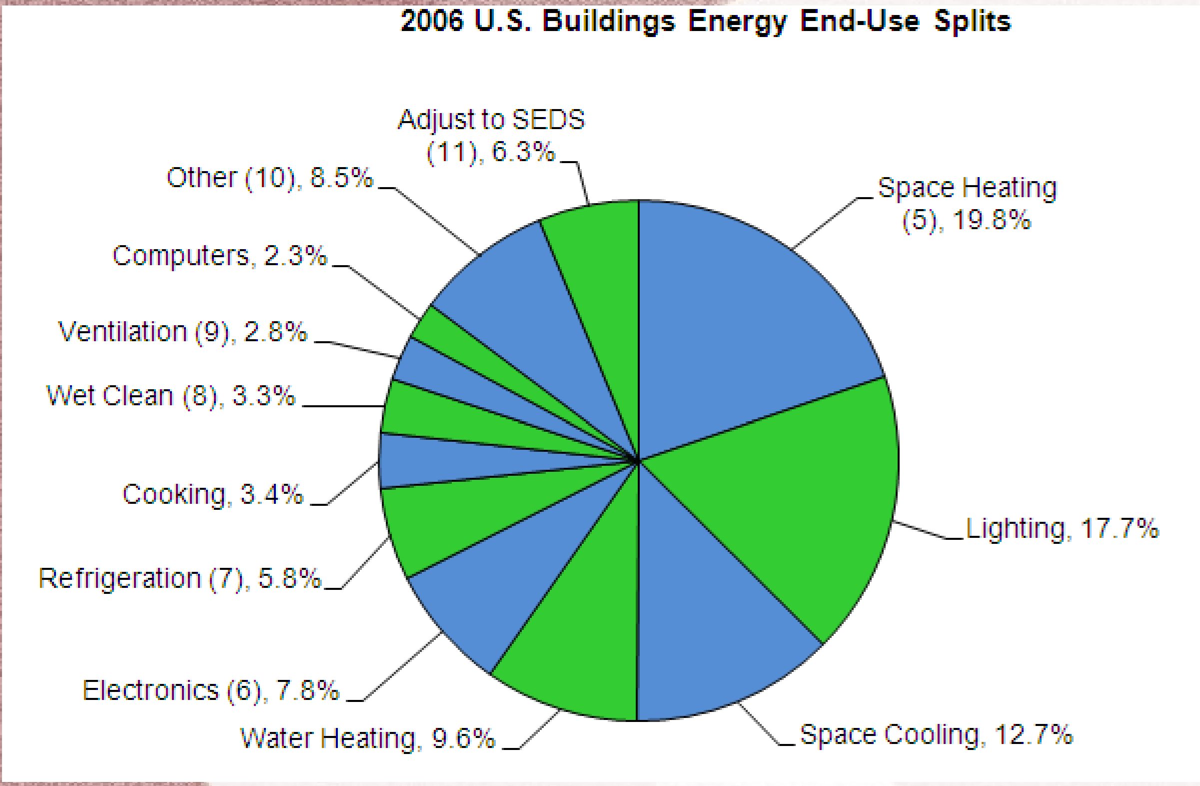
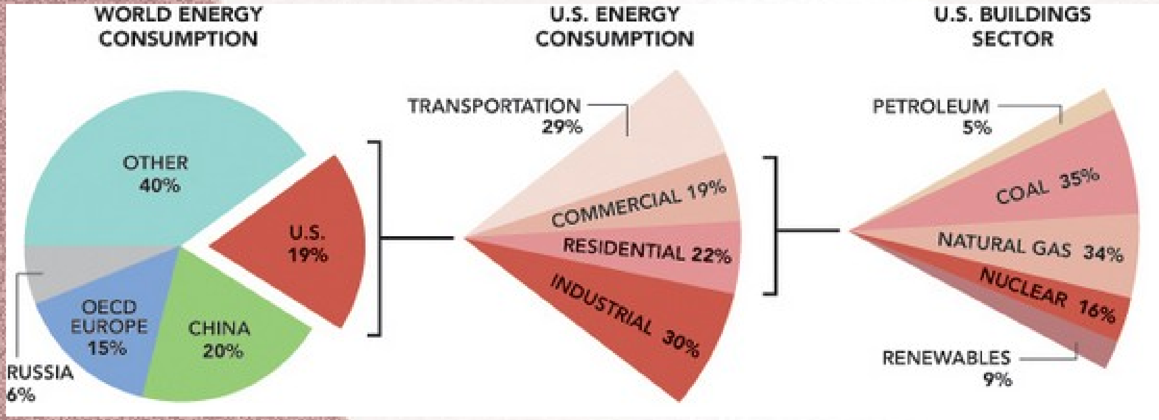
Sustainability in Civil Engineering

VIII. Building

Building energy use





DoE Buildings Energy Data Book (2011)

- 72% of USA electricity and 1/3 of natural gas goes to buildings and appliances (6 kW/residential household; not much change per capita in 30 y)
- Need to do without these fossil fuel requirements
- Renewable drop-in replacements are expensive or unavailable (given intermittency)

Residences

2.1.12 **2005 Residential Delivered Energy Consumption Intensities, by Vintage**

Year	Per Square Foot (thousand Btu)	Per Household (million Btu)	Per Household Member (million Btu)	Percent of Total Consumption
Prior to 1970	49.3	104.2	41.8	46%
1970 to 1979	44.5	82.9	33.3	15%
1980 to 1989	41.3	82.3	32.7	14%
1990 to 1999	38.6	96.5	34.4	16%
2000 to 2005	34.0	96.1	34.8	8%
Average	43.8	95.0	37.0	

Source(s): EIA, A Look at Residential Energy Consumption in 2005, October 2008, Table US-1 part 1.

2.1.5 **2006 Residential Energy End-Use Splits, by Fuel Type (Quadrillion Btu)**

	Natural Gas	Fuel Oil	LPG	Other Fuel(1)	Renw. En.(2)	*Site* Electric	*Site* Total	*Site* Percent	Primary Electric (3)	Primary Total	Primary Percent
Space Heating (4)	3.13	0.60	0.23	0.08	0.41	0.33	4.78	44.3%	1.05	5.51	26.4%
Space Cooling	0.00					0.85	0.85	7.9%	2.70	2.70	13.0%
Water Heating	1.08	0.10	0.06		0.01	0.42	1.67	15.5%	1.34	2.59	12.5%
Lighting						0.76	0.76	7.0%	2.41	2.41	11.6%
Electronics (5)						0.53	0.53	4.9%	1.69	1.69	8.1%
Refrigeration (6)						0.47	0.47	4.4%	1.50	1.50	7.2%
Wet Clean (7)	0.07					0.38	0.46	4.2%	1.22	1.30	6.2%
Cooking	0.22		0.03			0.23	0.48	4.4%	0.72	0.98	4.7%
Computers						0.07	0.07	0.6%	0.21	0.21	1.0%
Other (8)	0.00		0.15		0.00	0.19	0.34	3.2%	0.61	0.76	3.6%
Adjust to SEDS (9)						0.37	0.37	3.5%	1.19	1.19	5.7%
Total	4.50	0.70	0.47	0.08	0.43	4.61	10.79	100%	14.65	20.83	100%

- Efficiency improvements in new construction offset by more space per household (cf. cars)
- Apartments not more energy efficient per unit area, but use less energy per household

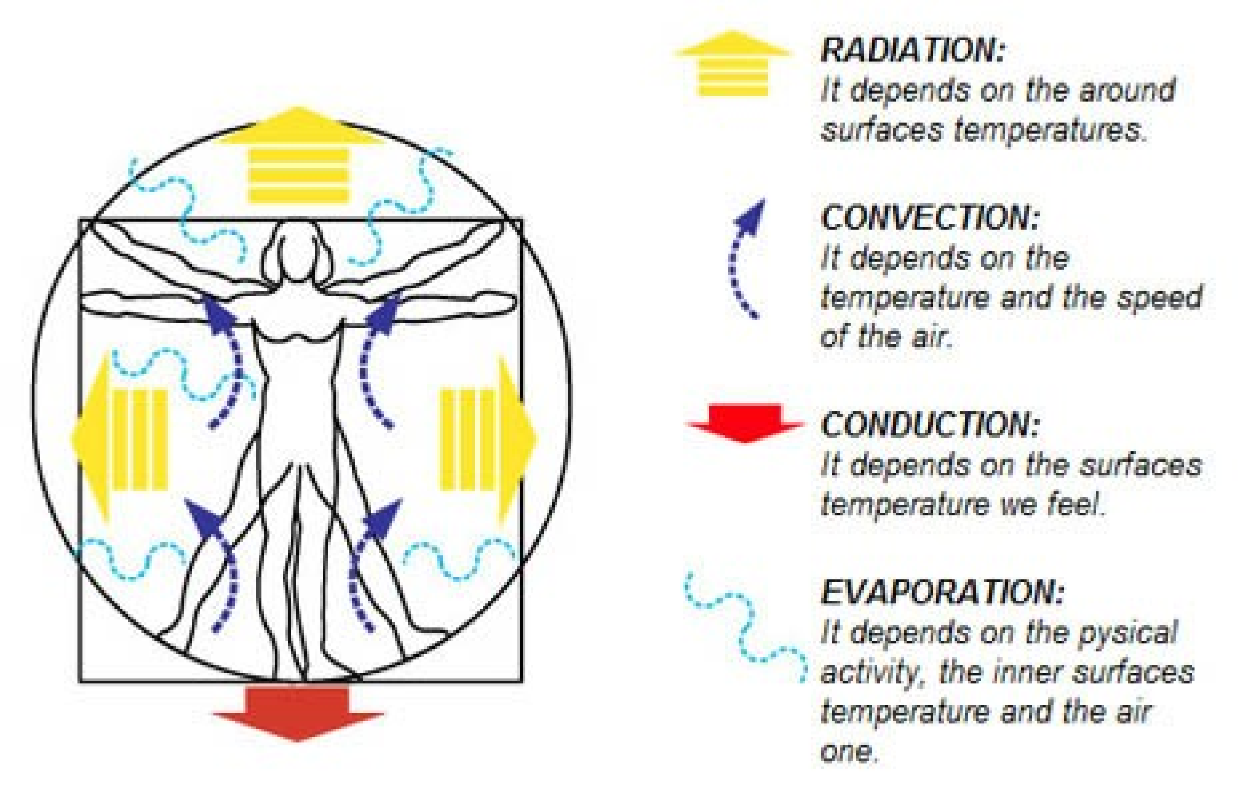
Climate and energy demand

2.1.11 2005 Delivered Energy End-Uses for an Average Household, by Region (Million Btu per Household)

	Northeast	Midwest	South	West	National
Space Heating	71.8	58.4	21.0	26.3	40.5
Space Cooling	4.5	6.2	14.5	7.6	9.6
Water Heating	21.9	20.6	15.8	21.3	19.2
Refrigerator	4.3	4.9	4.8	4.3	4.6
Other Appliances & Lighting	23.0	25.9	25.0	24.1	24.7
Total (1)	122.2	113.5	79.8	77.4	94.9

- Minimizing energy needed for heating and cooling is a good first step...

Thermal comfort



- When the heat we generate can be transferred at the normal body temperature
- Depends on e.g. humidity (sweat evaporation rate) and windspeed (promotes heat transfer) as well as T

- Generally best at 18-25 °C
- NYC day/night: 29°/20° (Jul), 3°/-3° (Jan)
- Aurungabad: 40°/26° (May), 29°/14° (Jan)

New & old sustainable buildings

- Strategies for more self-sufficient buildings are not new
- Technologies like window glass can help make such buildings more comfortable

Where is heat lost/gained?

2.1.14 Aggregate Residential Building Component Loads as of 1998 (1)

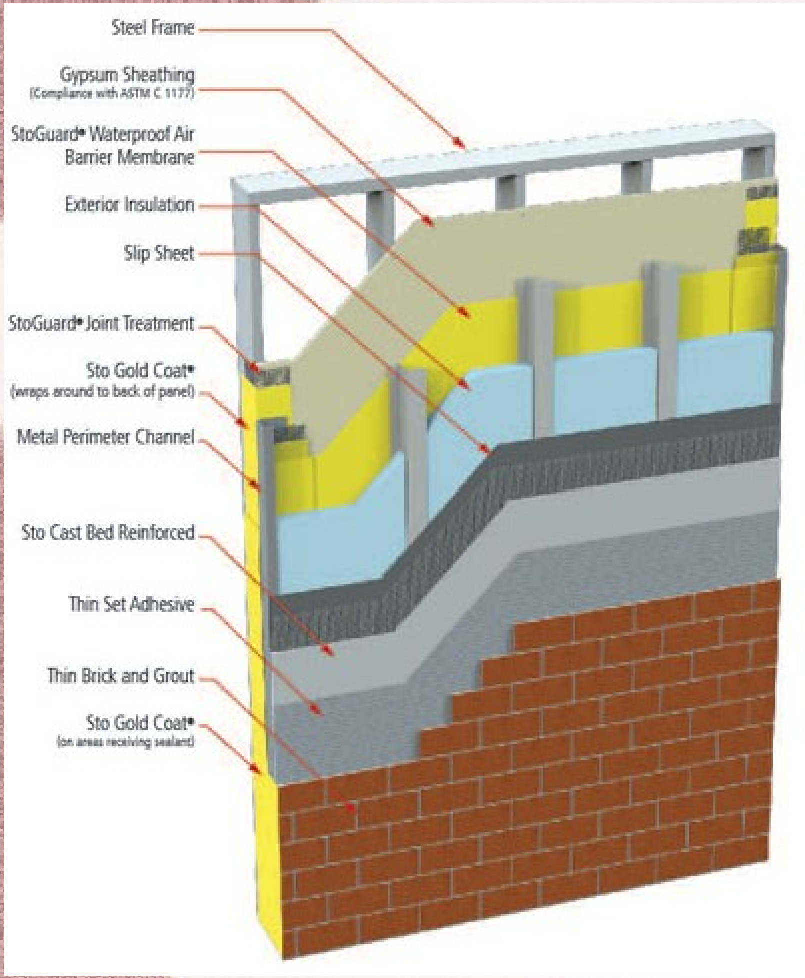
	Loads (quads) and Percent of Total Loads			
Component	Heating		Cooling	
Roof	-0.65	12%	0.16	14%
Walls	-1.00	19%	0.11	10%
Foundation	-0.76	15%	-0.07	-
Infiltration	-1.47	28%	0.19	16%
Windows (conduction)	-1.34	26%	0.01	1%
Windows (solar gain)	0.43	-	0.37	32%
Internal Gains	0.79	-	0.31	27%
Net Load	**-3.99**	100%	**1.08**	100%

Note(s): 1) "Loads" represents the thermal energy losses/gains that when combined will be offset by a building's heating/cooling system to maintain a set interior temperature (which then equals site energy).

Source(s): LBNL, Residential Heating and Cooling Loads Component Analysis, Nov. 1998, Figure P-1, P-1 and Appendix C: Component Loads Data Tables.

- For winter: concentrate on building airtightness, windows, and roof
- For summer: concentrate on window shading, airtightness, and roof

Insulation

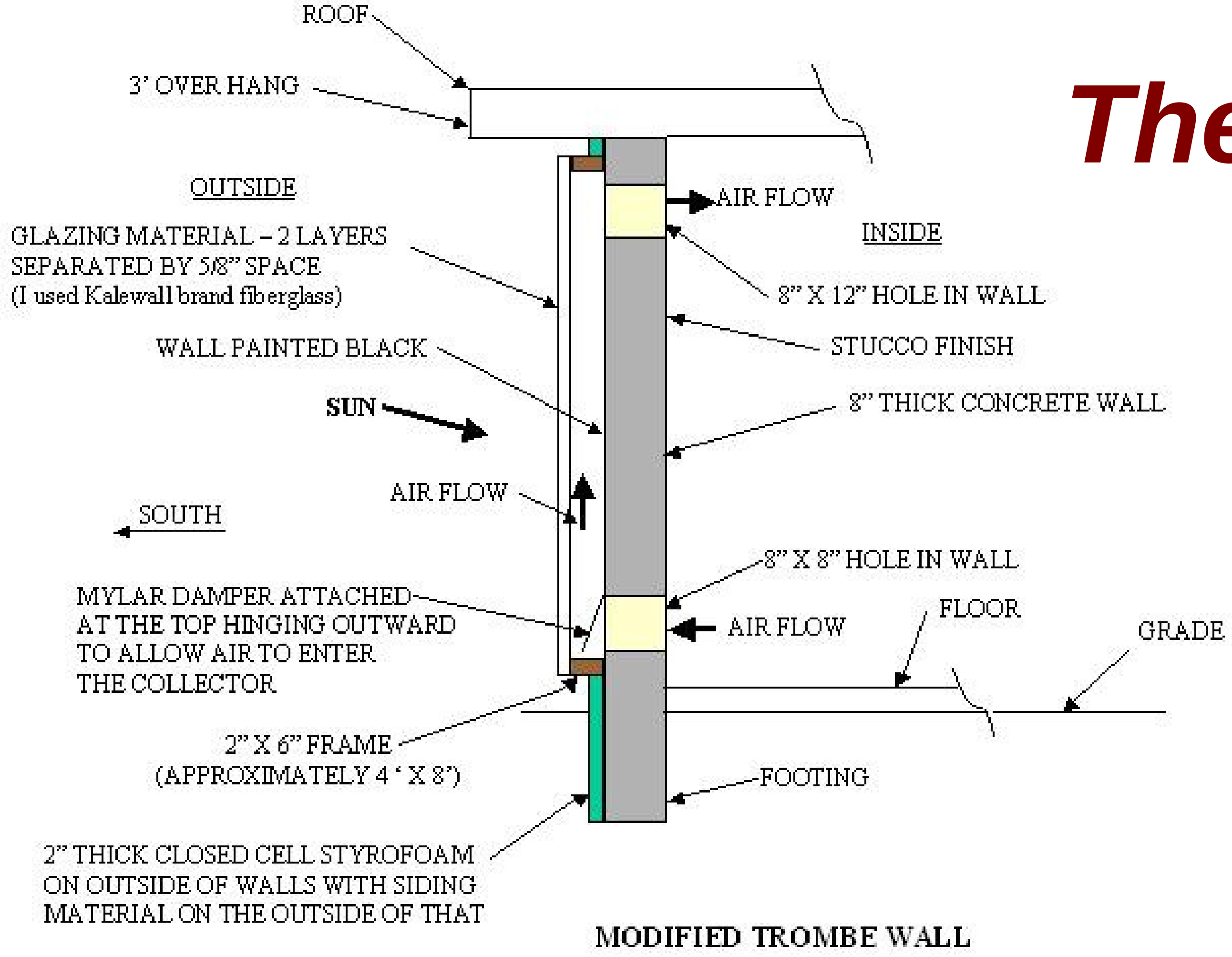


- Slow the escape of heat and cold
- Materials with air pockets, commonly fiberglass, cellulose (straw, blankets), foam
- R-value: temperature difference per unit heat flux ($m^2 \cdot K/W$ or $ft^2 \cdot °F \cdot h/Btu$)

Ventilation

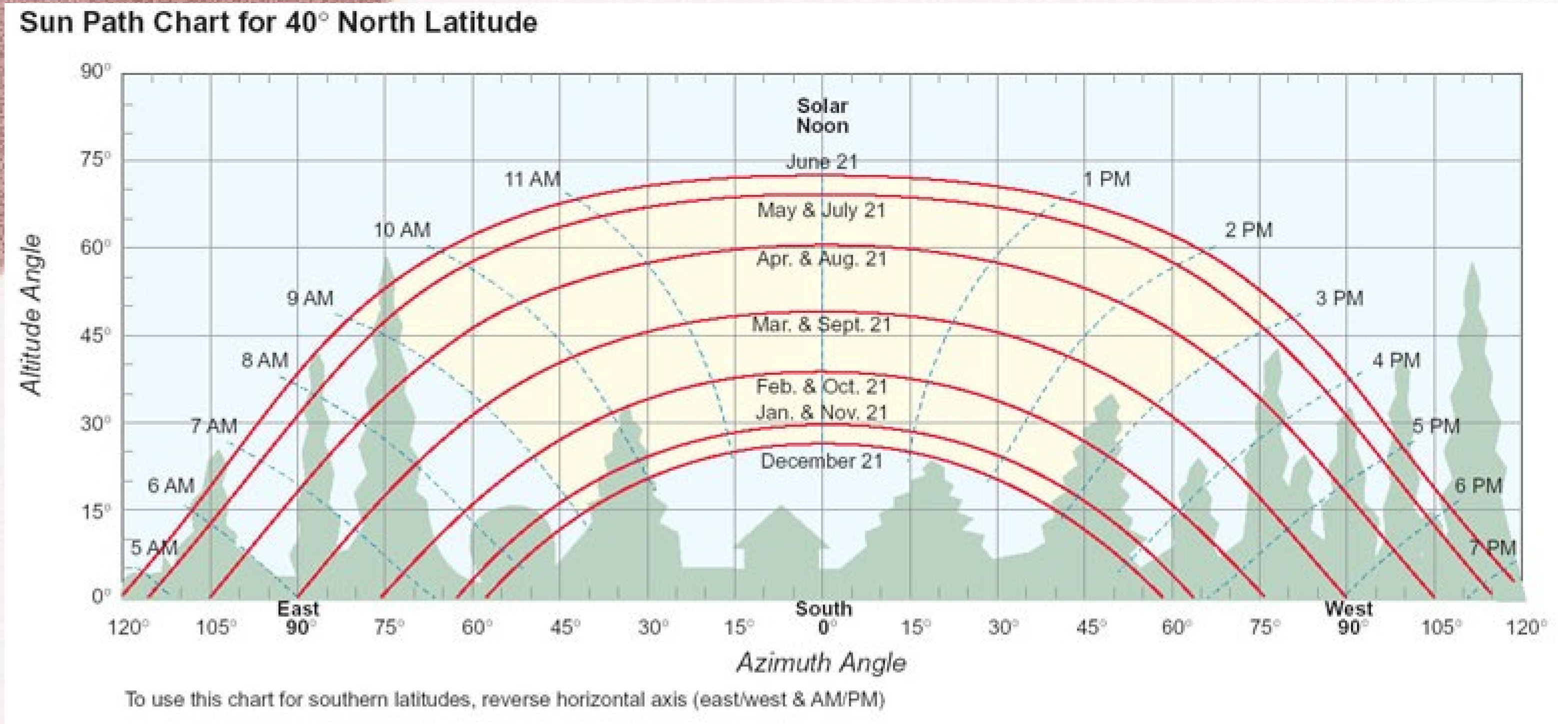
- Exhalations make unventilated rooms feel stuffy; emissions from plastic and mold can cause outright indoor air pollution
- Minimum ventilation rates typically required by building codes
- Important for summer thermal comfort – exploit prevailing wind, thermal gradients, fans
- Too much, uncontrolled ventilation (leaky building) means that more energy is required to heat/cool the incoming air

Thermal mass



- Store heat from sun (or coolness from night) over daily or longer periods, maintaining a more constant temperature
- Concrete, brick, stone, straw, water, etc.

Solar building orientation



- Put windows (greenhouse, solarium, dark walls, etc.) in S (NH) to intercept heat and light from winter sun; avoid windows in N
- Arrange windows for cross-ventilation in summer, consider windbreaks to intercept winter wind

Solar heating

- Southern exposure to heat with winter sun
- May need covers and insulation to reduce night heat loss
- Combined with insulation and thermal mass to maintain stable temperatures across nights and cloudy days

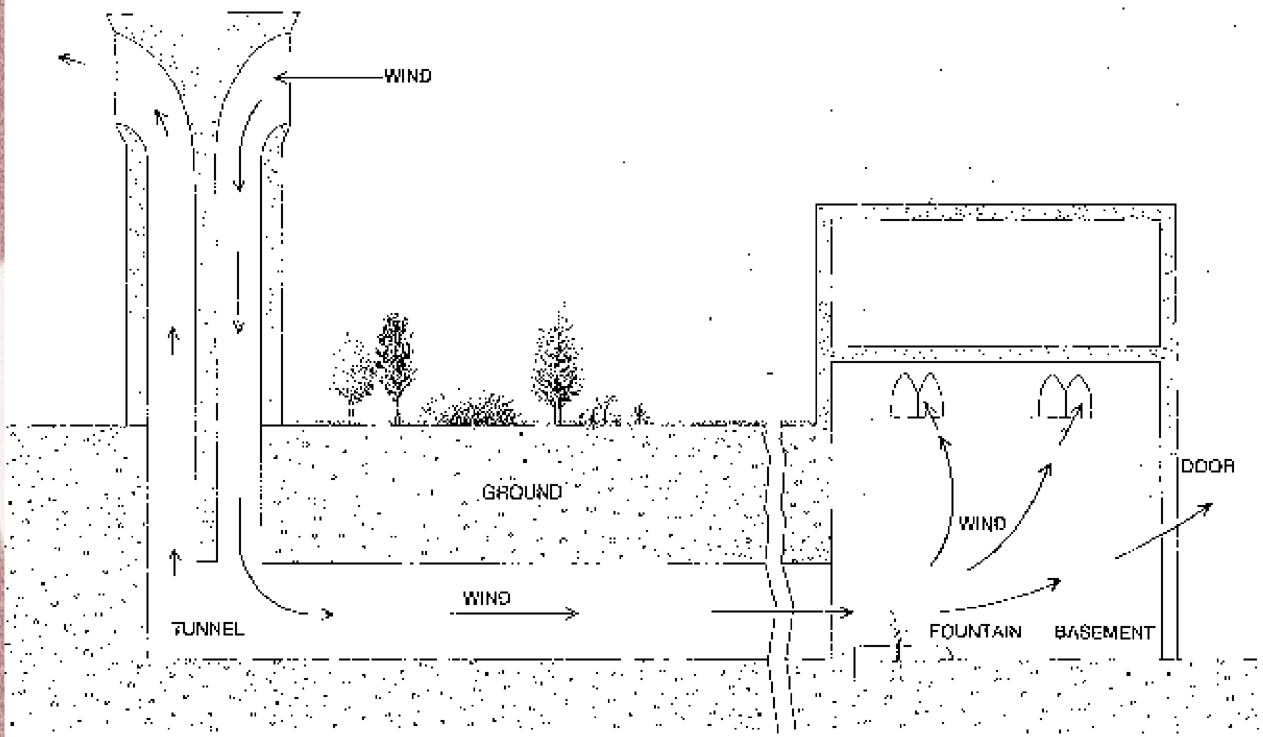
Wood heating

- Less environmentally friendly than reputation – can pollute indoor and regional air, lead to deforestation where population densities are high
- Use efficient fireplace designs only when necessary

Solar cooling

- Advantage over heating is that there’s normally plenty of sunlight to work with!
- But heat generated by people and appliances works against you – just bringing the inside temperature down to the outside temperature can be hard

Wind tunnels and chimneys



TWO KINDS OF COOLING operate in the passive system shown in this section. In sensible cooling heat loss from the air results in a decreased air temperature but no change in the water-vapor content of the air. Air in the upper part of a wind tower is sensibly cooled. When water is introduced into a system, evaporative cooling occurs. Such cooling involves a change in both the water-vapor content and the temperature of the air. When unsaturated air comes in contact with water, some of the water is evaporated. This process is driven by heat from the air, so that the temperature of the air is decreased as its water-vapor content is increased. A wind-tower system that cools air evaporatively as well as sensibly is particularly effective. In most wind towers water in the ground seeps through to the inside of the basement wall of the tower, so that air passing over the wall is evaporatively cooled. Evaporative cooling plays an even larger part in the system shown here. The wind tower is placed some 50 meters from the building and is connected to it by a tunnel. When the trees, shrubs and grass in the ground over the tunnel are watered, water seeps through the soil and keeps the inside surfaces of the tunnel walls damp. Thus air from the tower is evaporatively cooled as it passes through the tunnel. Pool and fountain in the basement of the building further cool the air.

- Send cool, moist air from underground into house
- Driven by convection (hot air exhausts from roof), perhaps assisted by fan

Mehdi N Bahadori, Passive cooling systems in Iranian architecture, *Scientific American* (1978)

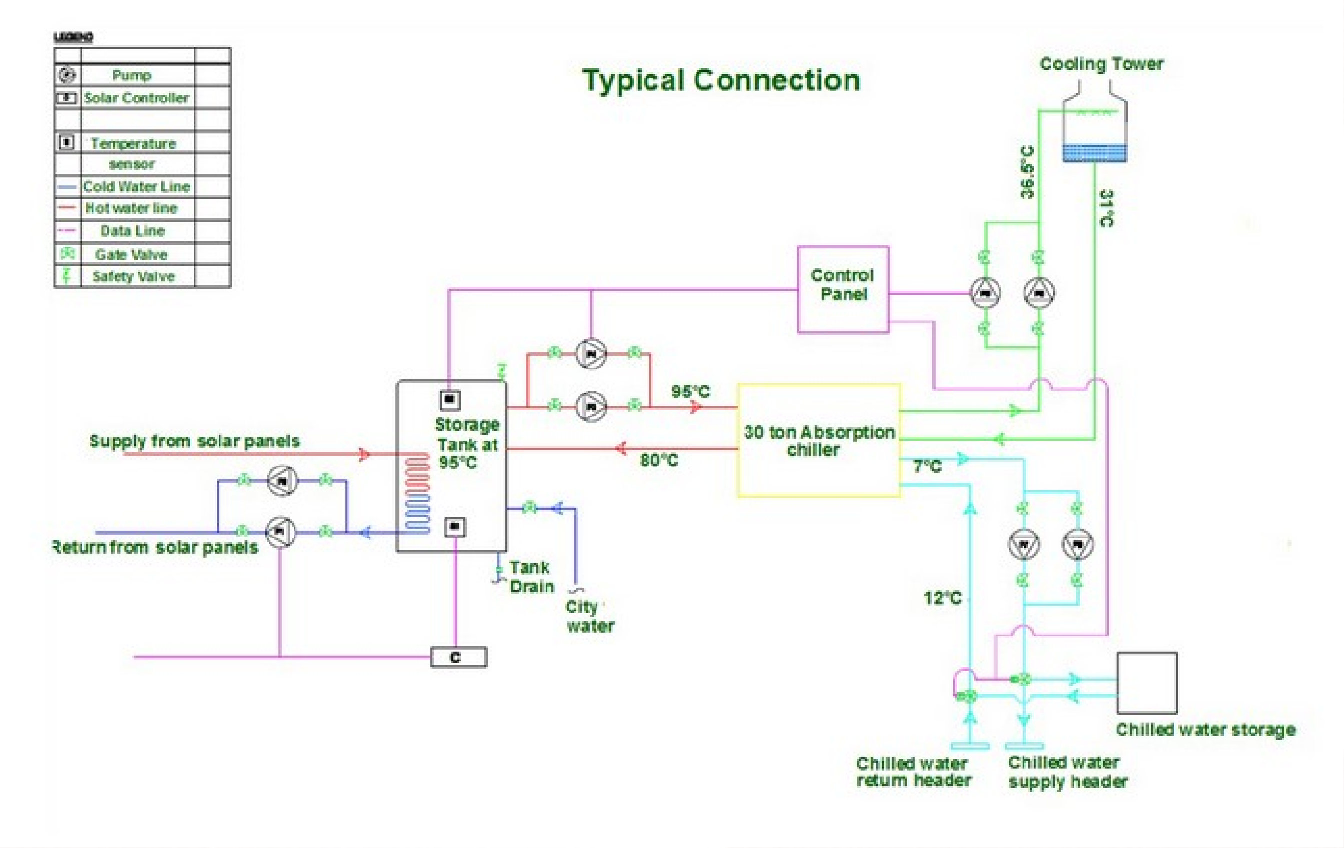
Evaporation

- The high latent heat of water makes evaporation effective for cooling, particularly during arid summers – green or pond or tree/vine shaded roofs
- For humid conditions, can indirectly cool ambient air via heat exchanger instead of direct spray cooling to avoid adding more humidity

Shading

- Deciduous trees shade buildings during warm season, let sun in during cold season
- Window awnings and adjustable covers or louvers (preferably placed outside)

Active solar chilling



- Heat from solar collectors evaporates a refrigerant and drives a cooling cycle; this can even make ice for refrigeration and for later cooling

Putting the parts together

- Need experience and/or computer simulation (e.g. EnergyPlus) to optimize design for all year round
- Cold climates: maximize solar gain (S exposure), super-insulation
- Desert climates: limit solar gain, high thermal mass, evaporative and convective cooling, take advantage of night cooling
- Tropical climates: either high insulation with air conditioning, or light construction for constant ventilation with shade and moisture

Lighting

- Daylighting thru windows, skylights, light tubes can reduce light requirements by ~50%, make occupants happier
- Exergy efficiency of artificial light (compared to ideal of ~300 lumens white light per W):
  - Candles 0.05%
  - Incandescents: 4%
  - Fluorescents: 20%
  - LEDs: 25% (current), 75% (ideal) – good for low-wattage applications

Considerations for high rises

- Less need for heating, more need for cooling (esp. for office buildings) because of internal heat generation
- Can take advantage of faster wind at height and convective circulation for ventilation (operable windows are good)

Multi-tenant buildings

- Tenants may not pay for some utilities and so have no incentive to conserve; where tenants do pay, they may not be able to make changes in building layout
- ‘Green leases’ where landlords are responsible for utility bills but require tenants to follow operating procedures can help (esp. for commercial buildings)
- Stringent building standards are also needed

Retrofits

- Less effective than integrated new building, but also much less expensive – insulation, new HVAC controls, ...
- Creates jobs quickly – local incentives like rebates common
- Likely to grow as energy costs increase

NYC policies

- LL 84 (2009): requires large buildings to report exergy and water use annually; LL 33 (2018): energy efficiency score must be displayed
- LL 97 (2019): limit the exergy consumption and GHG emissions of large buildings starting 2024 requires annual reports
- LL 92 + 94 (2019): all new buildings must have green or solar roofs
- LL 154 (2021): phase out fossil fuel combustion in new buildings

Current building standards

- Code requirements are all woefully short of the technically feasible, though some are better than others
- CalGreen: reduces water consumption by 20%, reduce building energy consumption by 15% (compared with current CA code), requires recycling of 50% of construction waste
  - Allows either a perscriptive or a performance approach for energy efficiency
  - Some provisions adopted by International Code Council (International Energy Conservation Code)
  - Most states lag years behind
- Nationally: DOE model code, mortgage incentives

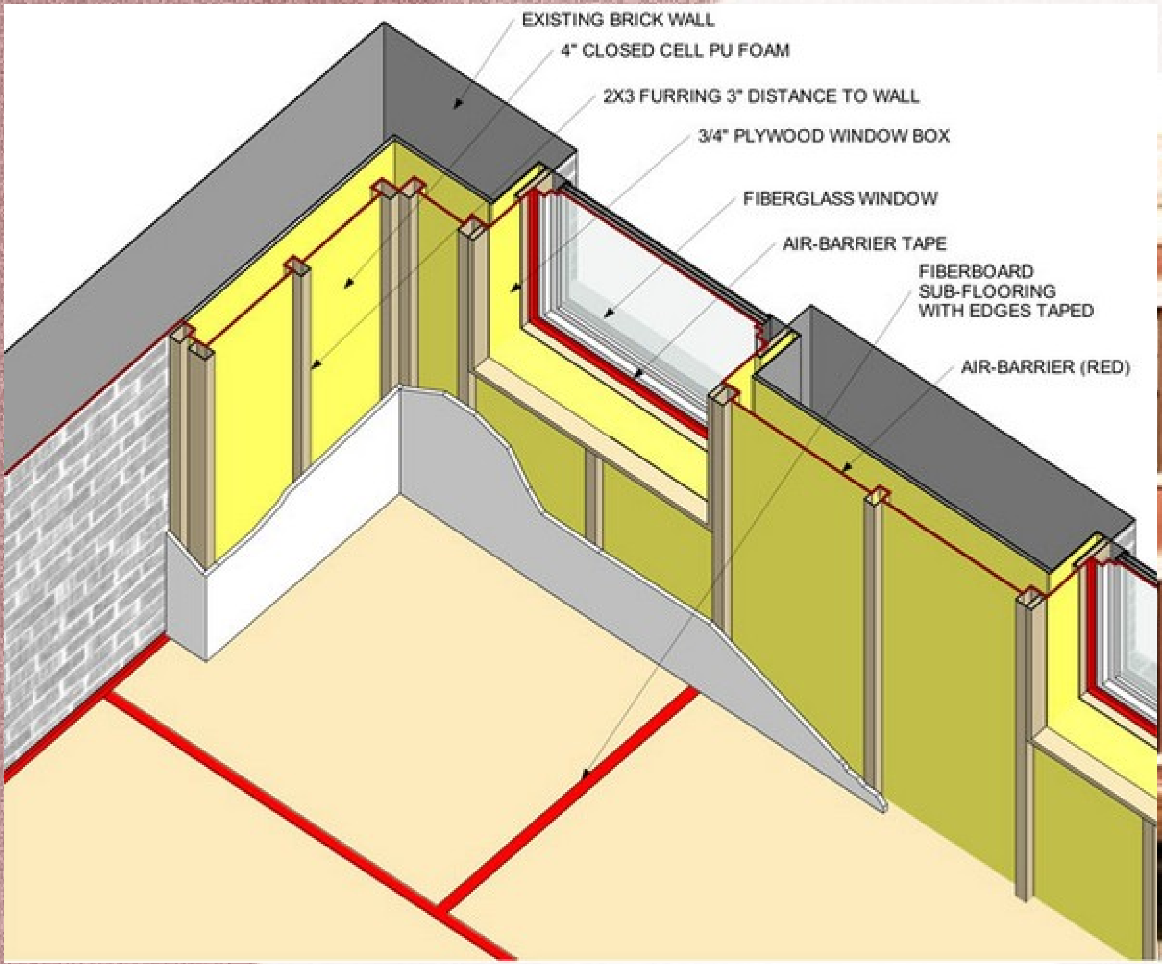
Green building and LEED

- US Green Building Council scoring system, popular and adapted internationally
- Allows broad choice from a menu of "environmentally friendly" procedures to earn points, beyond a low minimum standard
- Possible to get high LEED rating without being very energy-efficient – there's an incentive to do so if other options are cheaper
- Rating is based on specifications, without monitoring actual performance (viewed as not the contractor's problem)
- Specific energy efficiency indices like HERS are more reliable

The Passivhaus standard

- Developed in 1990s Germany, 10s of thousands of buildings in Europe, reached US
- Careful construction to prevent pathways for air leakage or heat transfer in the envelope (which could also cause condensation and mold); mechanical ventilation needed since building is airtight
- A performance-based standard. Requires 85% less energy for heating than buildings meeting current US codes, ~60% less for HVAC+hot water (per unit area); intended to support goal of “2-kW society”
  - Cf. zero-heating buildings, using quadruple-pane windows
- Remaining energy requirement can be met with small PV, ground-source heat pump, etc., with no conventional heater

A passivhaus grows in Brooklyn



“the interior of the building has been demolished to have access to the brick walls in order to enable installation of passive house insulation and an air barrier. Right now we are searching for the right windows, which turns out to be quite difficult as the PH movement is still young in the US”

The Living Building standard

living-future.org

- Requires buildings to use only on-site solar energy and ambient water flows, determined by post-construction monitoring
- Also includes requirements related to health, equity, and community
- “It challenges us to ask the question: What if every single act of design and construction made the world a better place?”