Buildings and Energy

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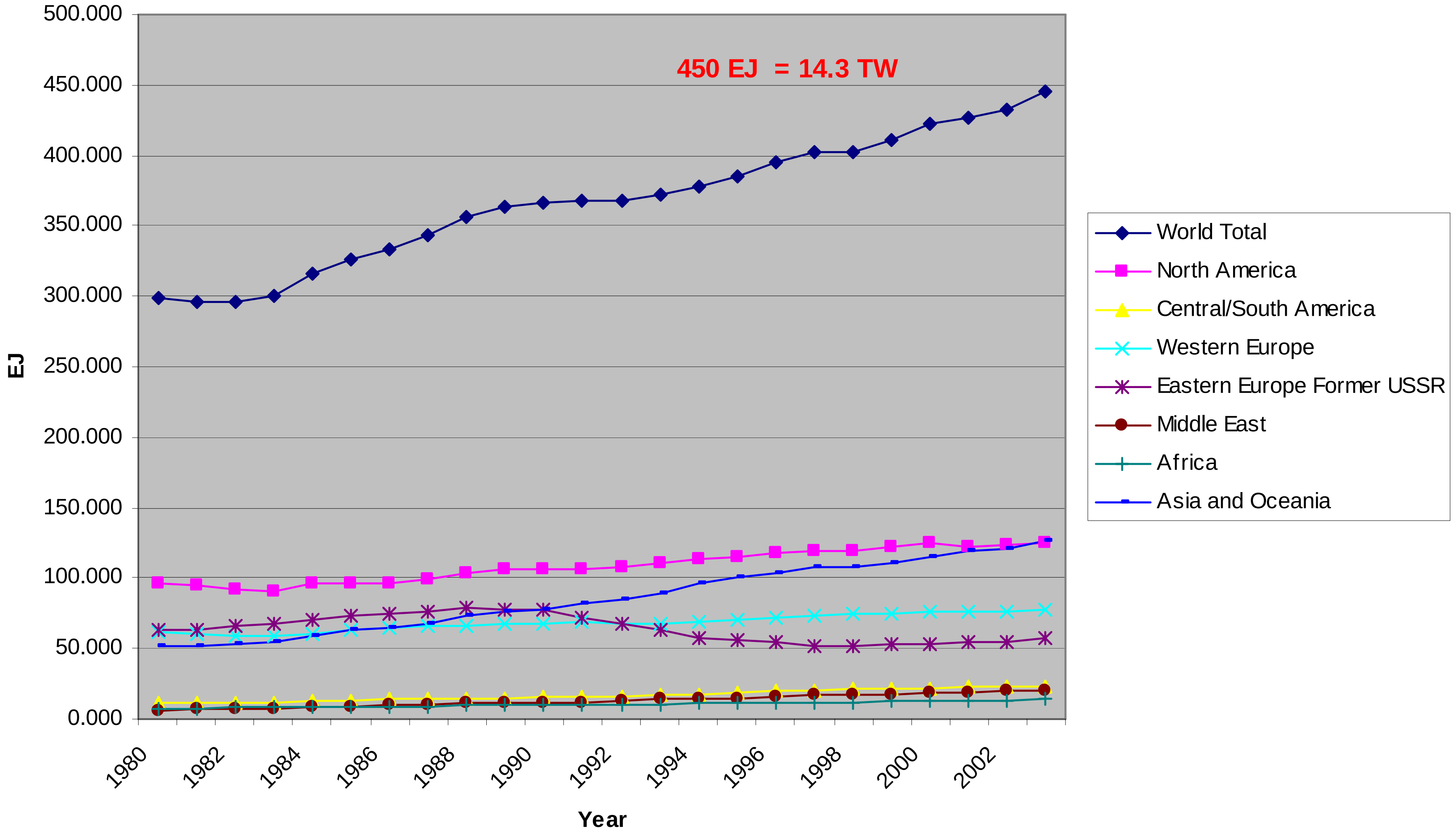
Outline

- 1. Buildings and energy – some data
- 2. Residential buildings
- 3. Commercial buildings
- 4. Buildings in other (mainly developing) countries
- 5. Is current progress good enough?

Global energy consumption



Does energy use correlate with quality of life?

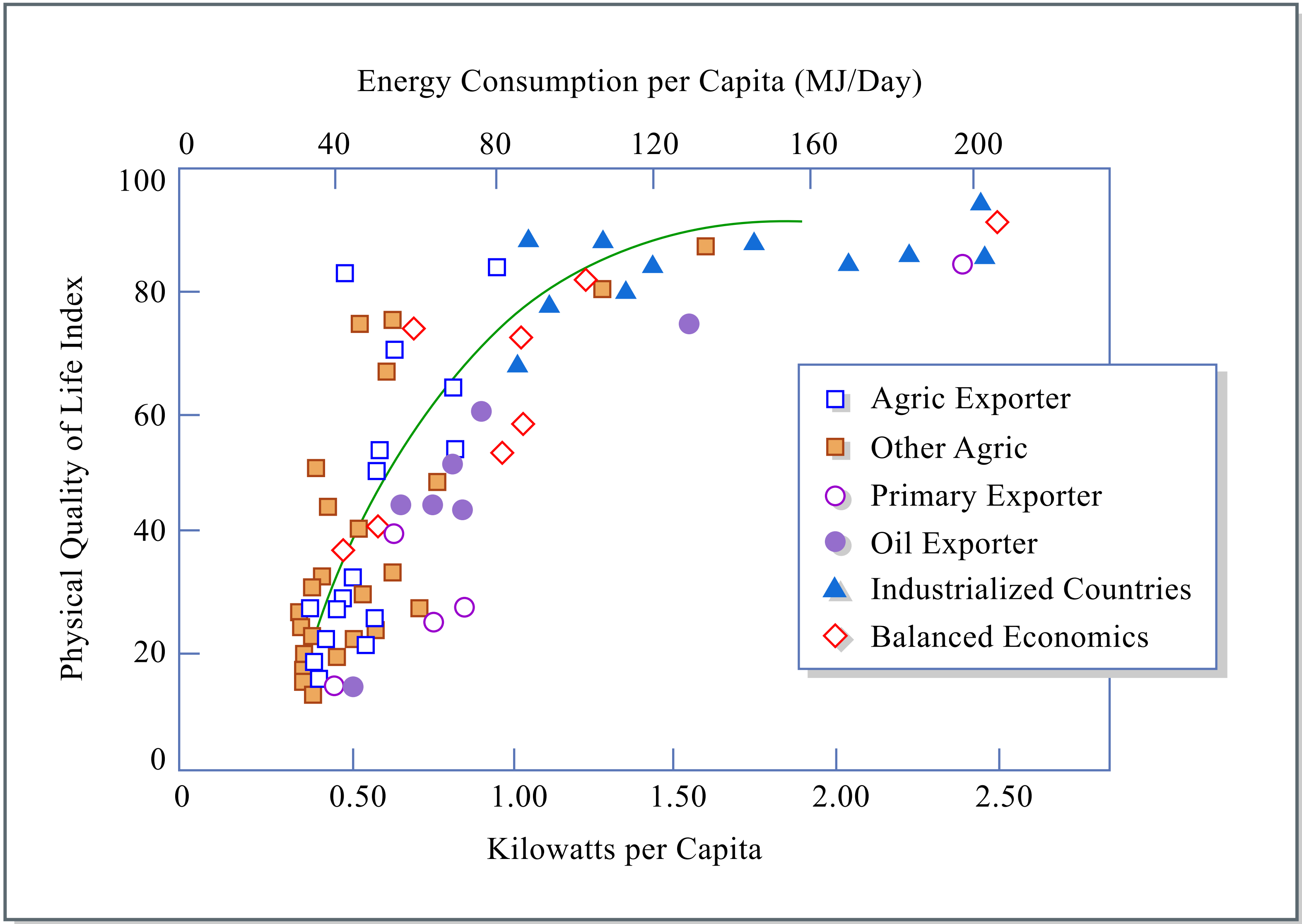


Figure by MIT OCW.

Source: Goldemberg et al.

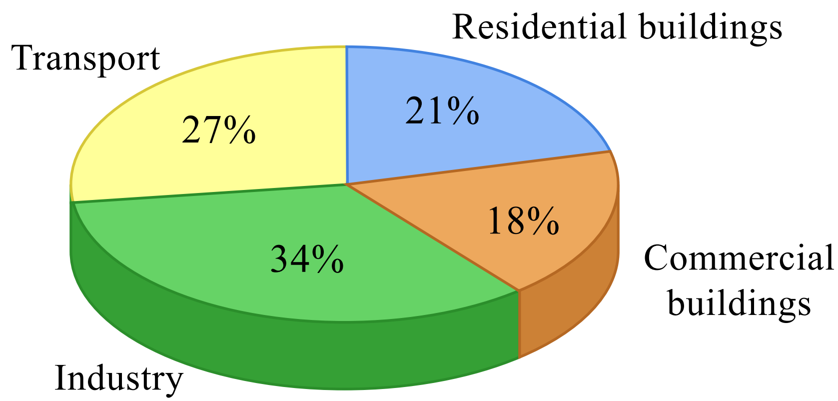
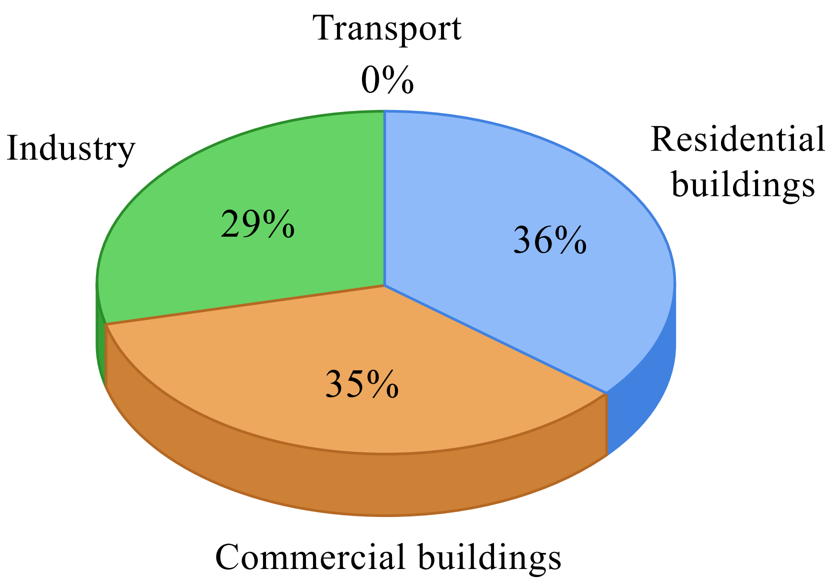


Figure by MIT OCW.

U.S. energy end-use

Total energy– buildings 39%

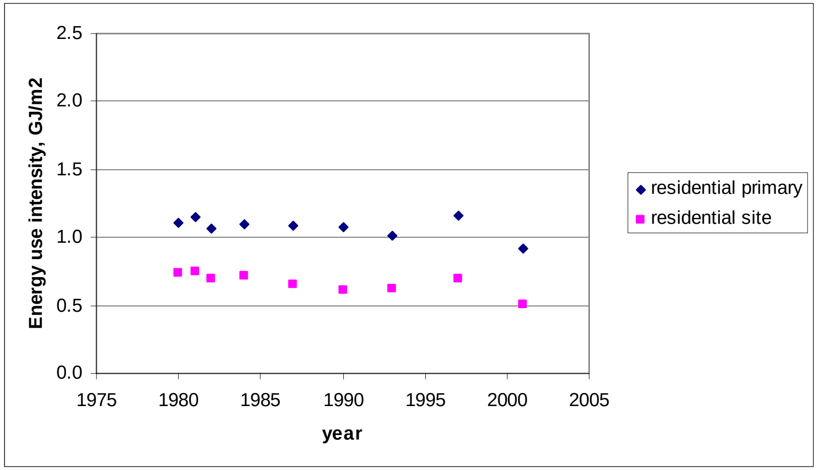


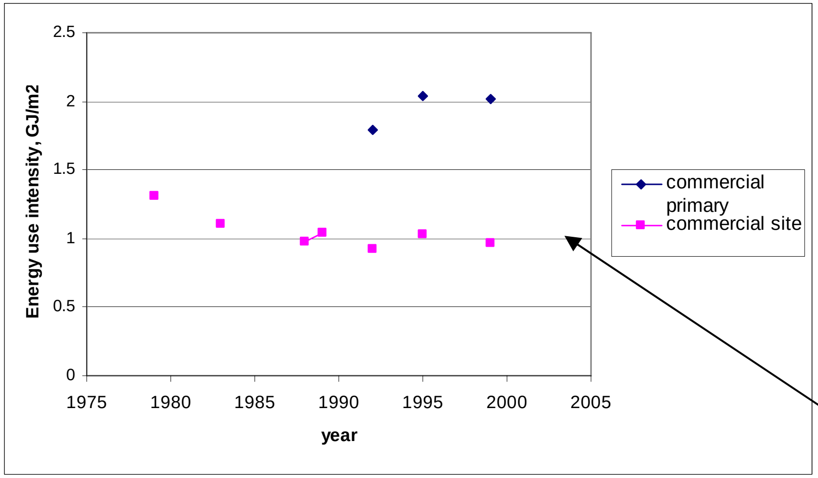
Electricity – buildings 71%

Source:EIA

Figure by MIT OCW.

U.S. residential and commercial building energy use intensities

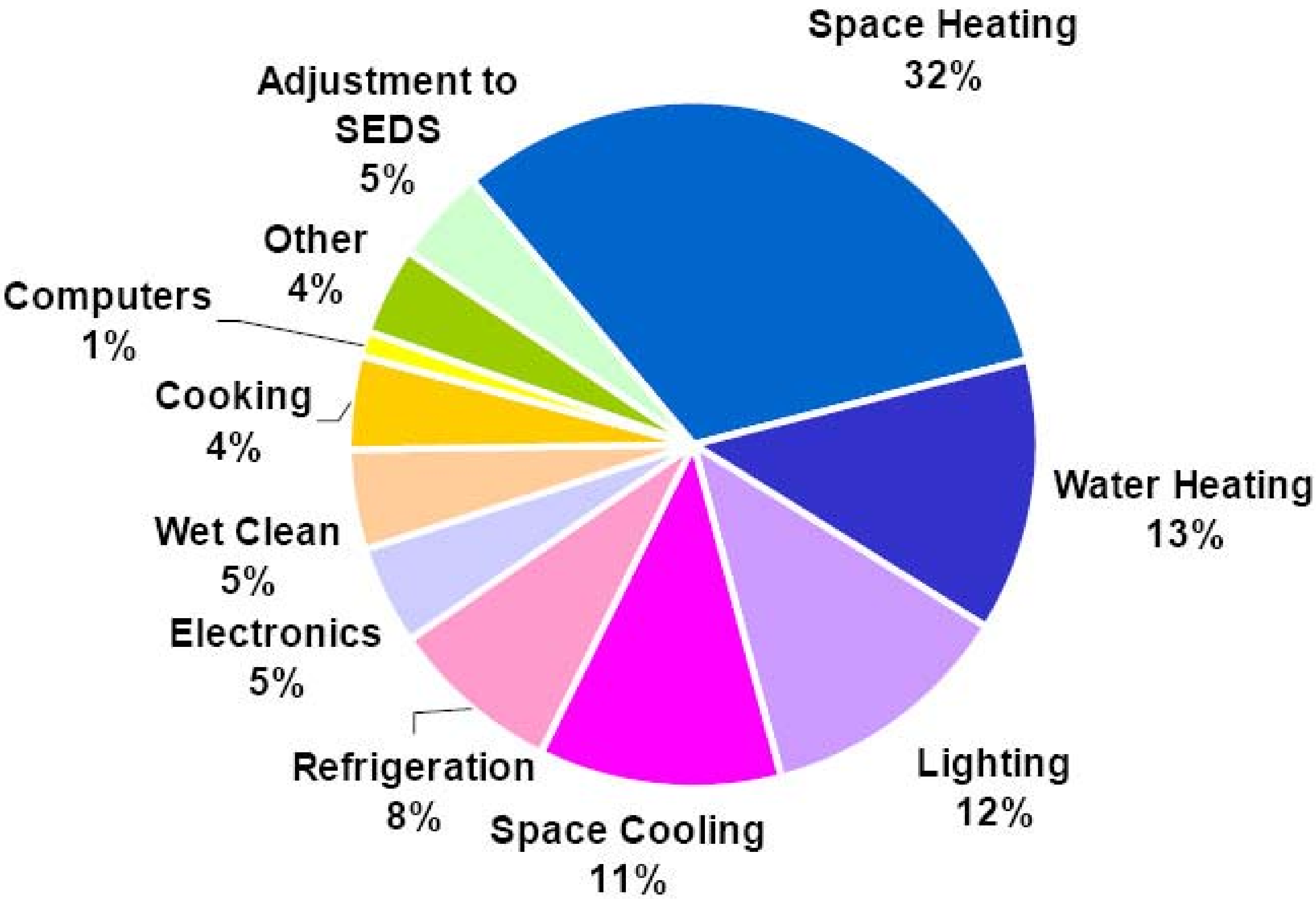




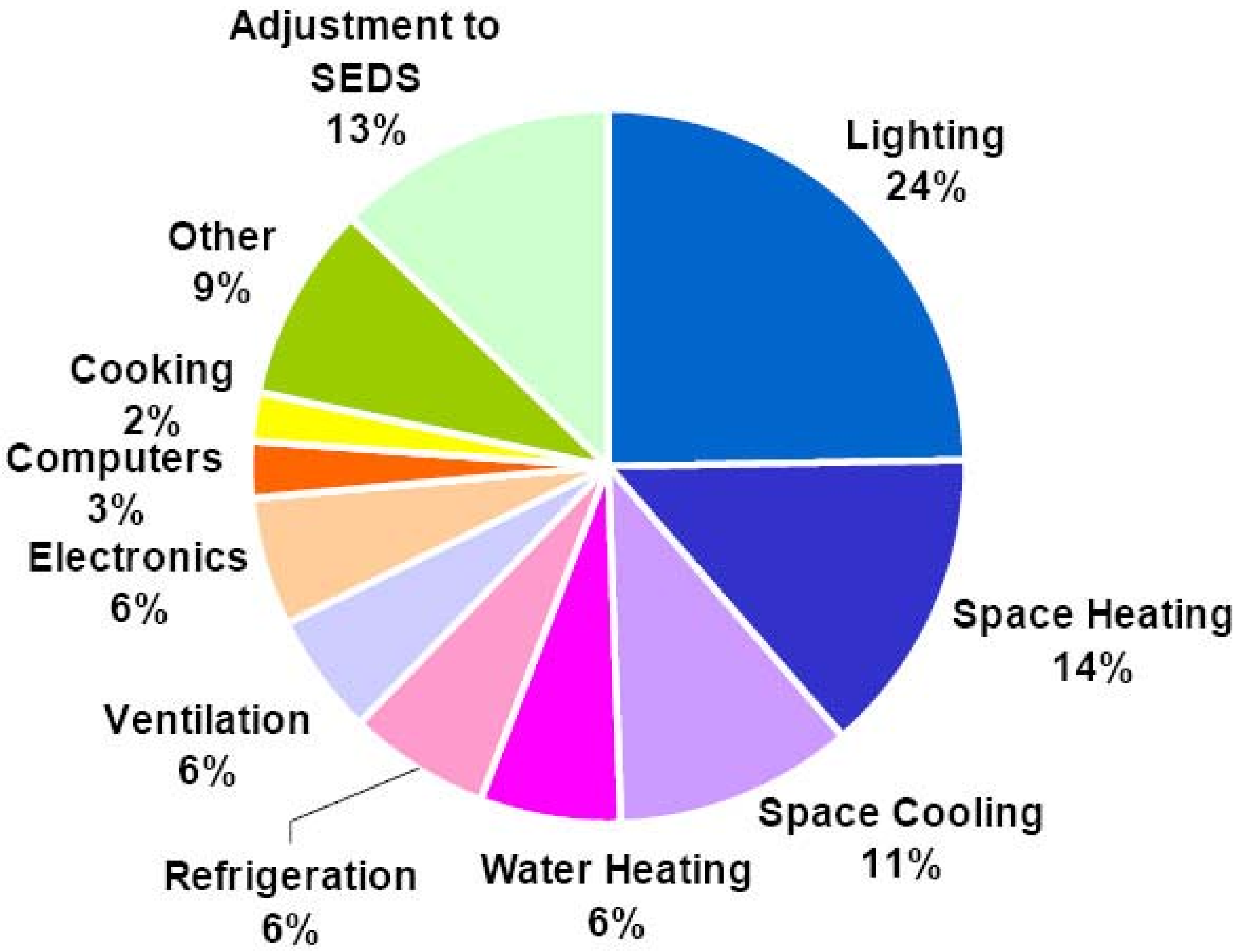
Apparently not a lot of progress in 25 years

$1\ \mathrm{GJ/m^2} = 277\ \mathrm{kWh/m^2}$

Residential buildings end-use energy 2003



Commercial buildings end-use energy 2003



2. Residential buildings: savings potential in new construction

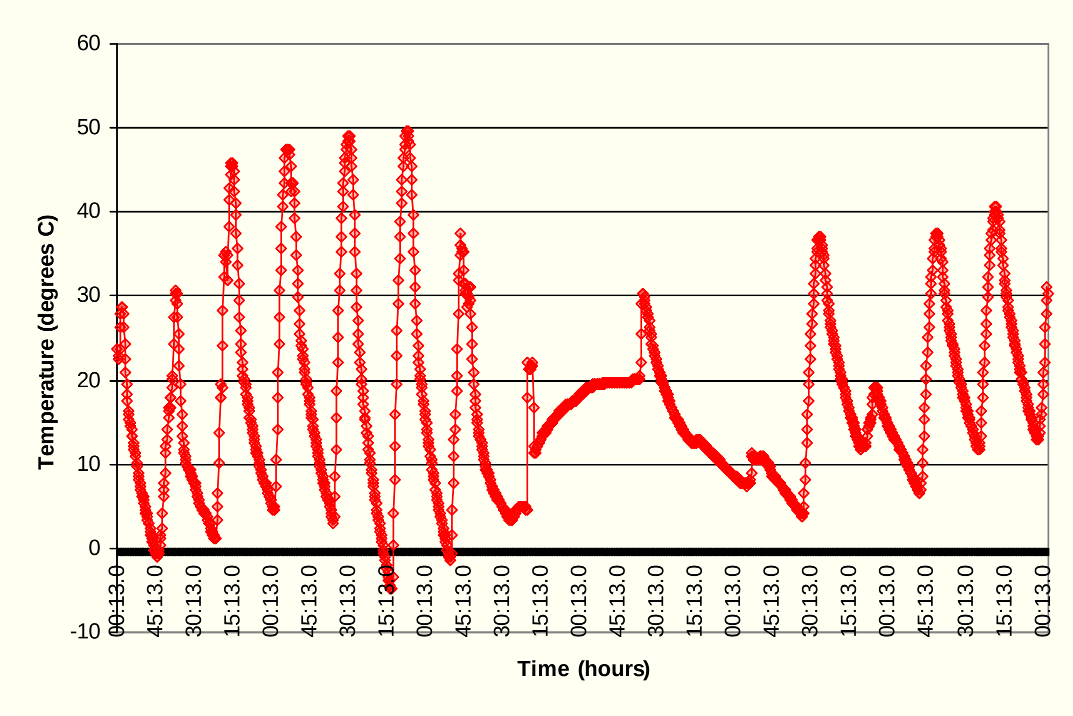
- 30%: little or no increase in first cost
- 50%: about the same life-cycle cost
- Net-zero energy or carbon neutral: much harder
- How? INTEGRATED, SYSTEMS DESIGN
  - Better walls
  - Better windows
  - Smaller HVAC equipment
  - Better appliances

Savings relative to early 1990s benchmark

Doing better with houses: lots of insulation!

Flickr photo courtesy of Smalloy.

Taking advantage of free heating for “elfhouse”



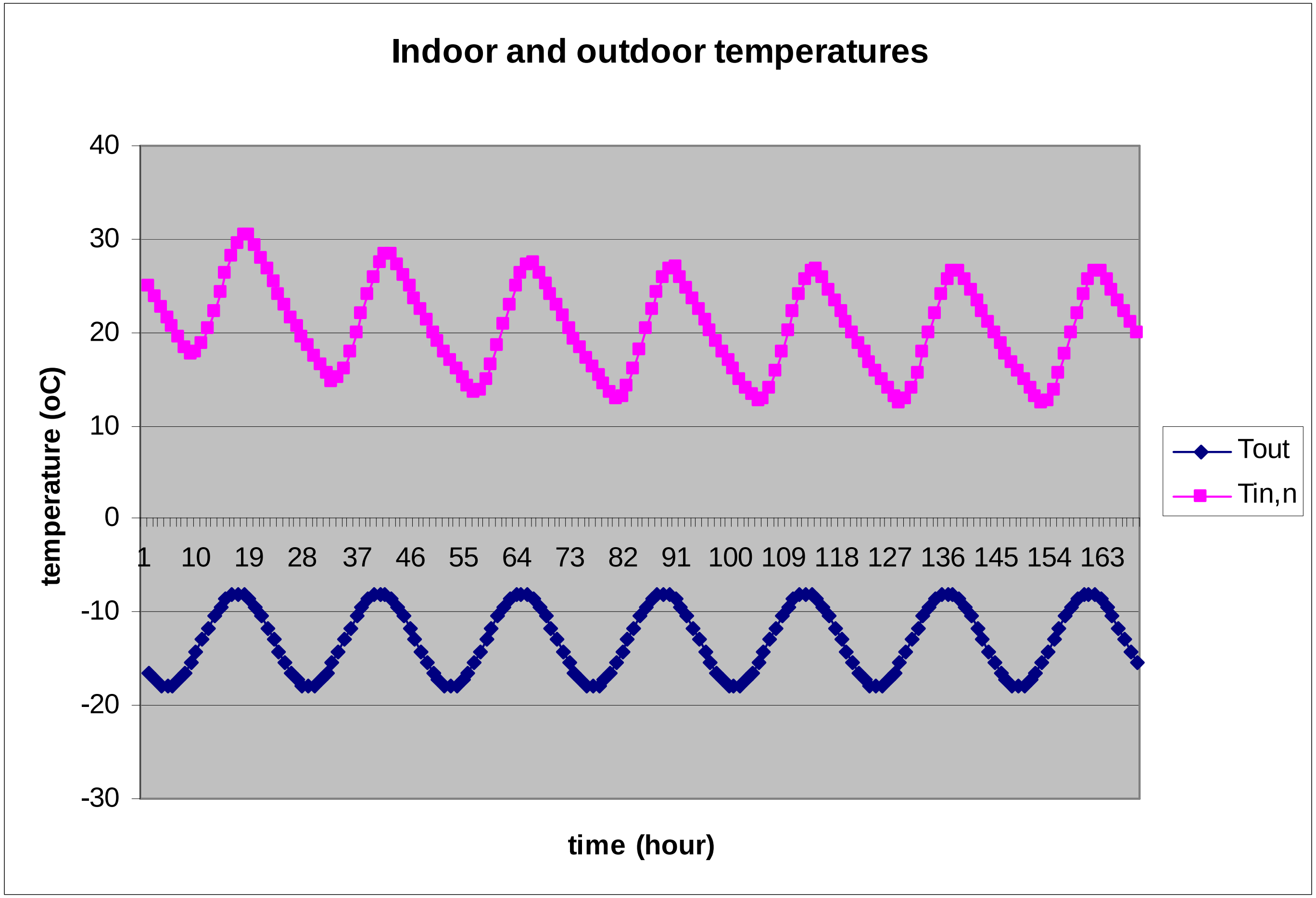
Average Temperature First Week = 16.9 deg C
Average Temperature Second Week = 17.3 deg C

Insulation, glass and mass for a full-size house

image: Montgomery Co. Public Schools, VA
www.mcps.org

- Walden made of 15 cm extruded polystyrene (no openings, no airflow): ~1,000 W of heat needed at 0 ^{o}F.
- Henry David needs fresh air, which requires another 500 W to heat.

Walden with south-facing, double-pane glazing and water for thermal storage

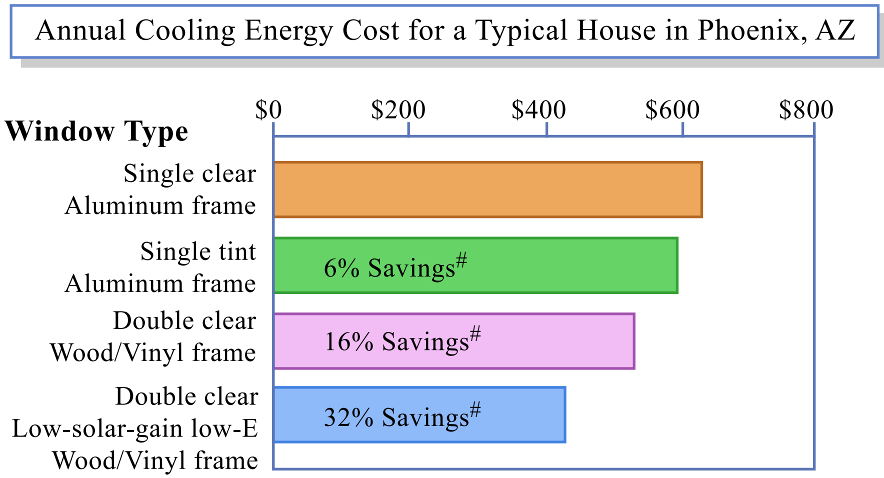


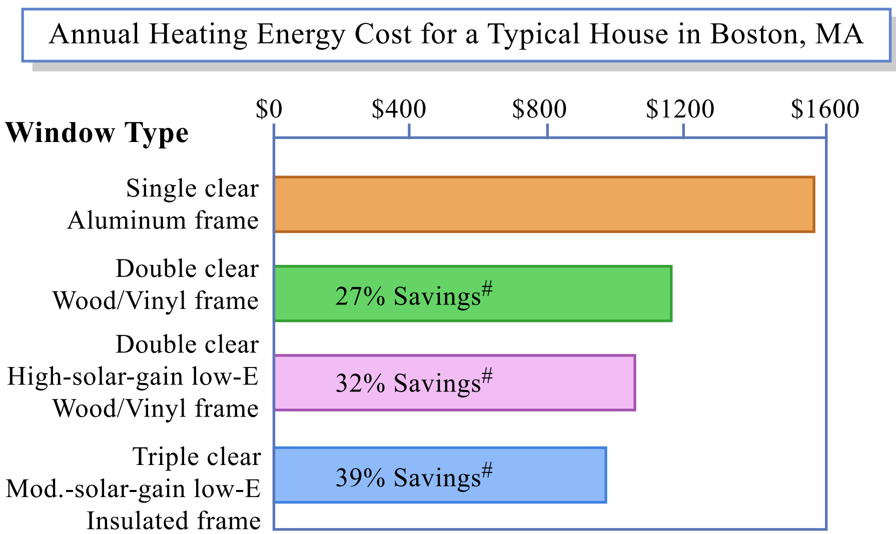
5 m^2 glazing, 1000 kg water

Building America

- USDOE-sponsored partnerships between consulting engineers and building industry, leading to prototypes and large-scale production
- ~33,000 houses constructed
- Goals
  - Design and construct more energy efficient homes
  - Reduce construction costs to provide more affordable housing
  - Improve comfort
  - Improve health and safety and indoor air quality
  - Increase resource use efficiency
  - Increase building durability
- Energy target: 35-45% reduction in heating, cooling and hot-water energy use

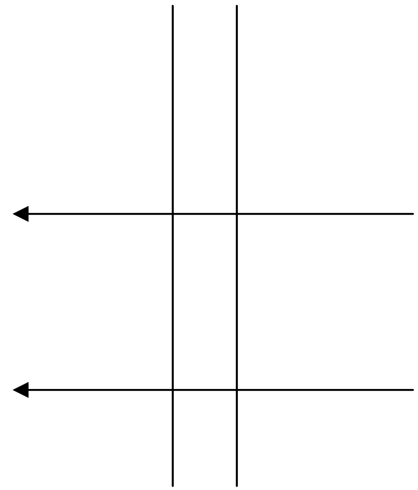
Glazing





#Compared to the same 2000 sf house with clear, single glazing in an aluminum frame.

Figure by MIT OCW.



visible

Full spectrum

~1/2 visible,
1/2 infrared

Window	**Visible transmittance**	**Solar heat gain coefficient**
Single clear	0.90	0.86
Double clear	0.81	0.76
Double low e	0.76	0.65
Double low e tint	0.45	0.35
Double low e, Ar fill, spectrally selective	0.72	0.40

http://www.efficientwindows.org/BuilderToolkit.pdf

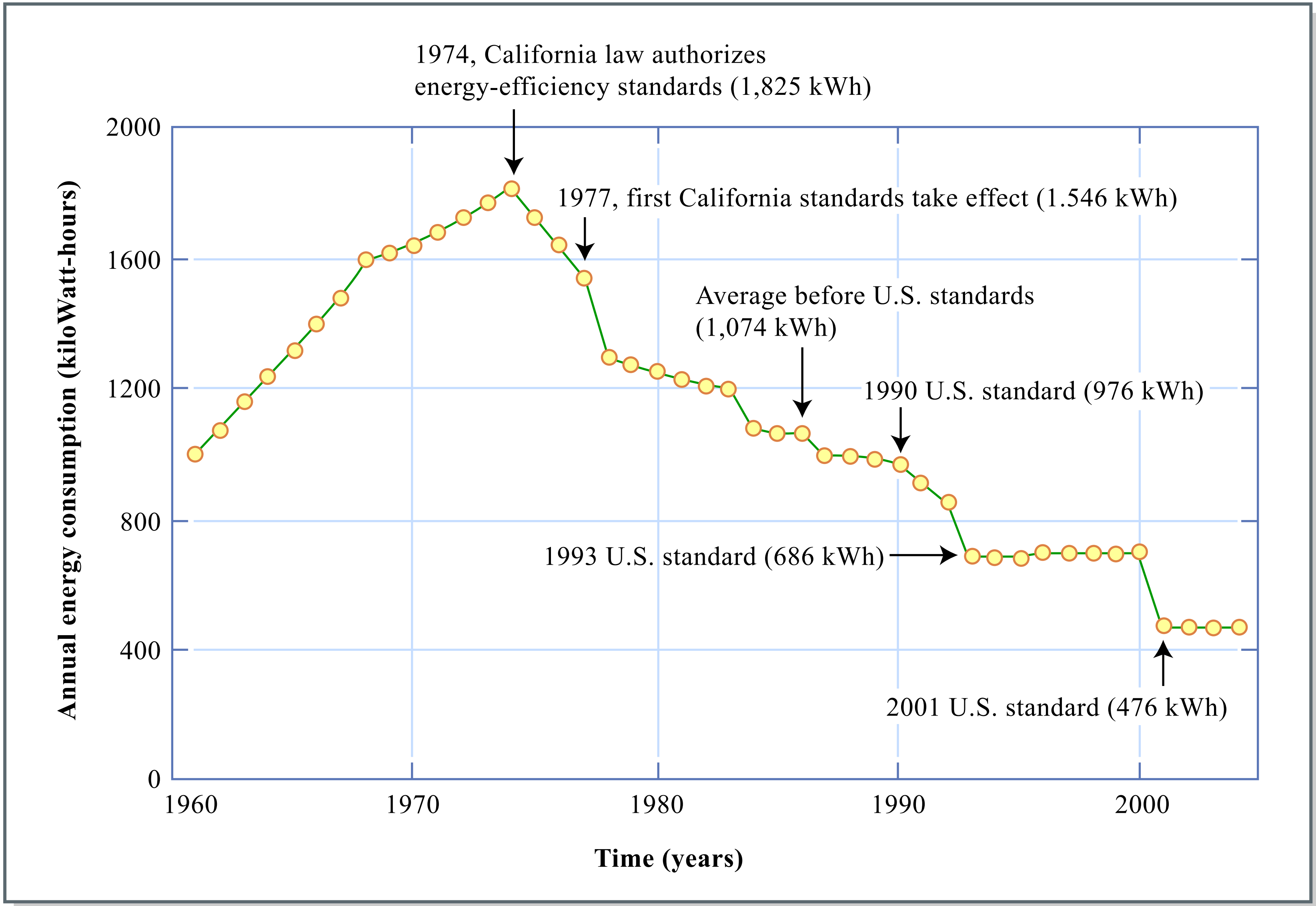
The builders' perspective: pros and cons

- Durability is key
  - Better moisture management
  - Fewer warranty problems
  - Happier customers and builders
  - More referrals, sales
- Less construction waste
  - Fewer dumpsters
  - Reduced tipping fees
- New construction system to learn
- New concepts may require changes to local building codes

The systems approach

Feature	Minneapolis	Grayslake, IL	Atlanta	Tucson	Banning, CA
Advanced framing	-250	-250	+250		
Insulating sheathing		0	+400		
Insulate basement		+600			
Slab-edge insulation			+200		
Unvented, conditioned attic				+750	+750
Eliminate roof vents				-500	
Eliminate housewrap			-400		
High-performance windows	+250	+1,000	+250	+300	+750
Reduce infiltration		+100			
Controlled ventilation system	+150	+125	+150	+150	+250
Locate ducts in conditioned space		0			
Simplify or downsize duct distribution	-250	-300			
Downsize air conditioner	-350	-750	-750	-1,000	
High-efficiency, direct-vent furnace		+750		+400	+400
Power-vented gas water heater	+300	+150			
Dehumidifier			+175		
Set-back thermostat		+100			
Total premium	**-150**	**+1,525**	**-25**	**+100**	**+2,150**
Annual homeowner savings	**225**	**480**	**400**	**390**	**370**

Refrigerators



Source: Collaborative Labeling and Appliance Standards Program

Figure by MIT OCW.

Lighting efficacies

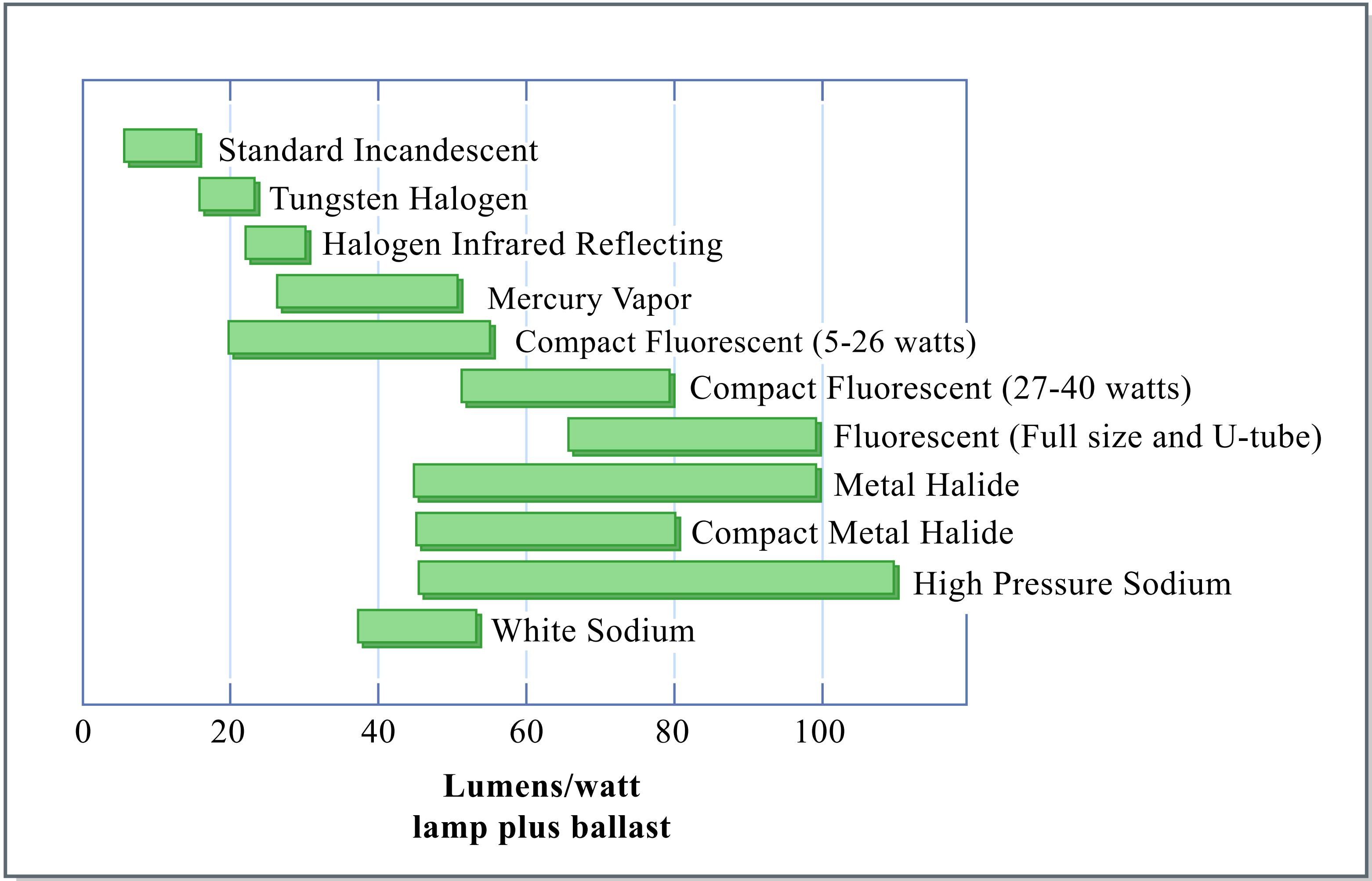


Figure by MIT OCW.

Source: IESNA

Potential gain from solid-state lighting

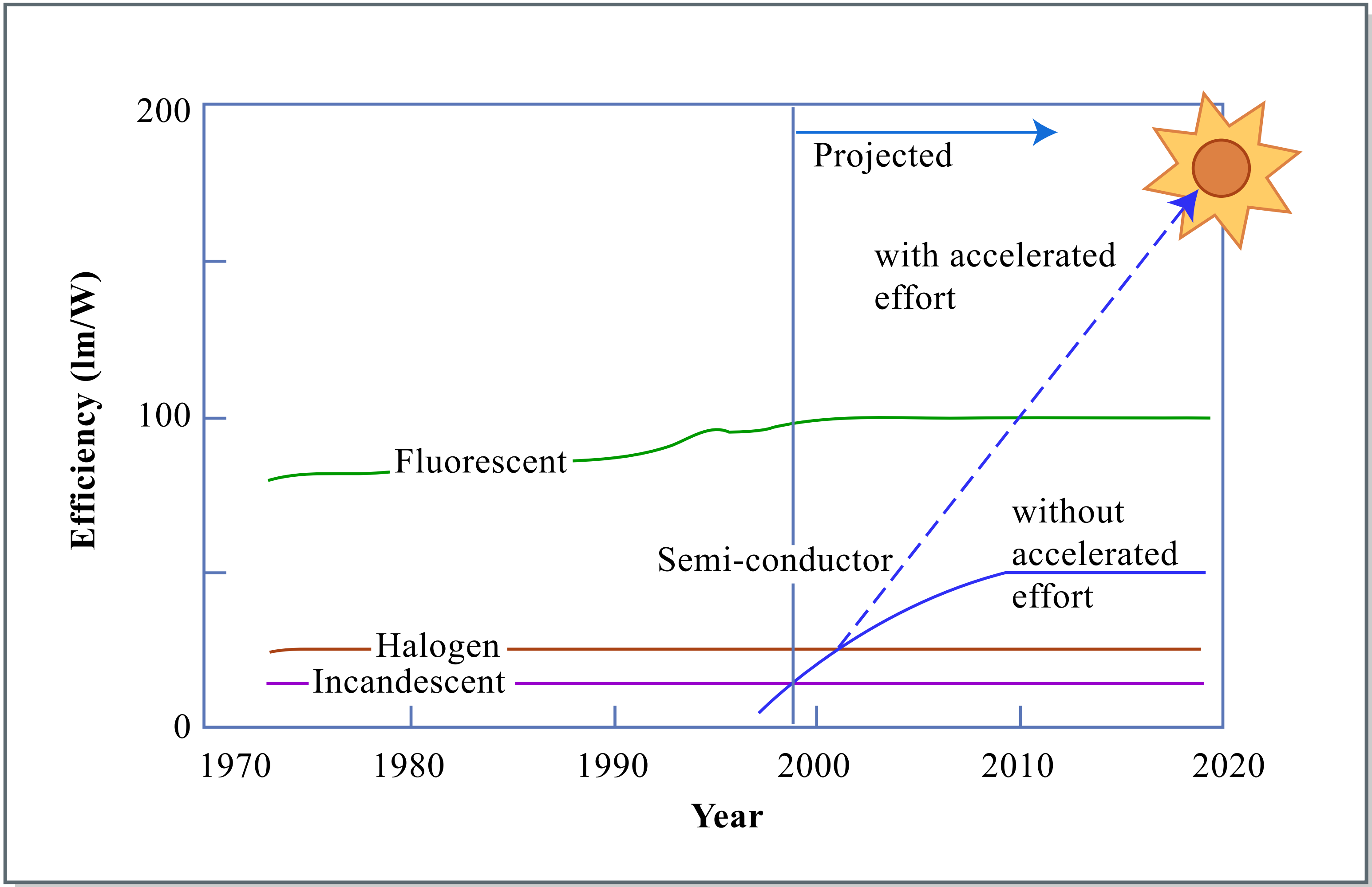
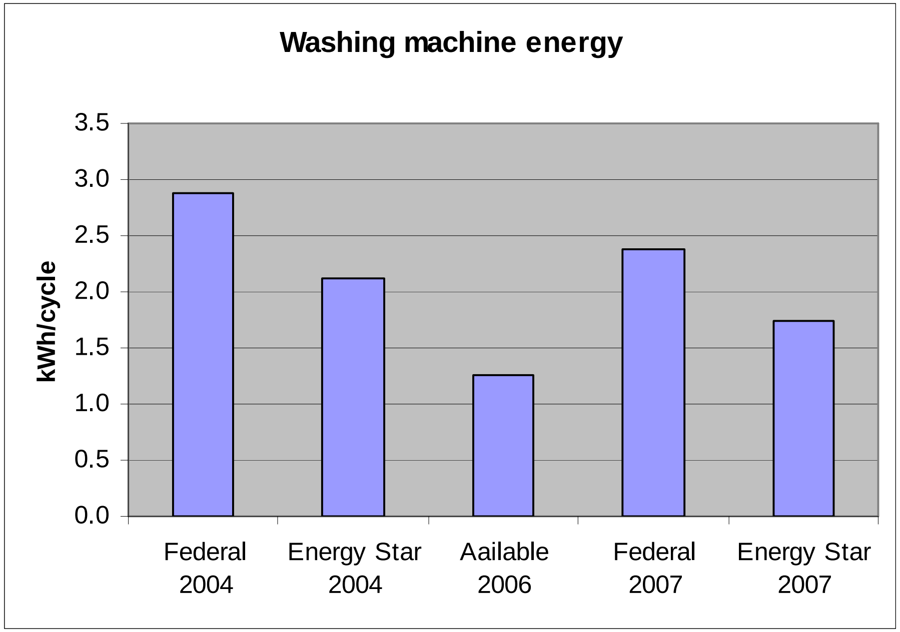
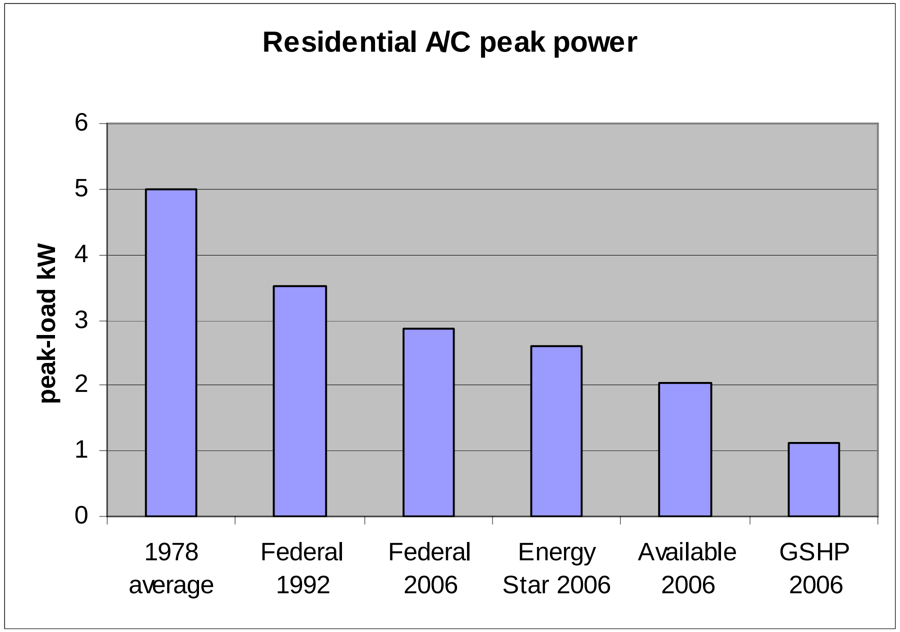


Figure by MIT OCW.

Source: Sandia National Lab

Residential clothes washers and central A/C



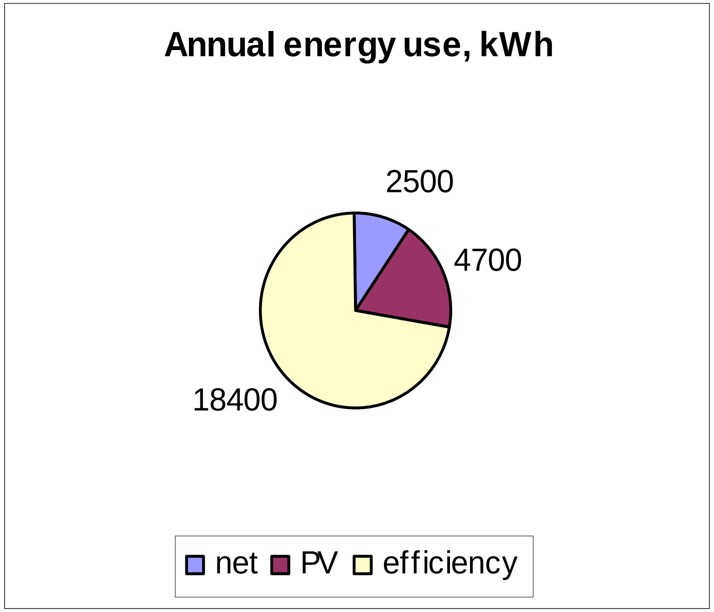


Manufacturers identify Energy Star products. A/C and furnace/boiler producers list efficiencies but clothes washer manufacturers do not tout energy consumption for their equipment, which only costs ~$20/year in electricity

Lakeland, Florida, PV house

Photograph of a photovoltaic house.

Image removed for copyright reasons.

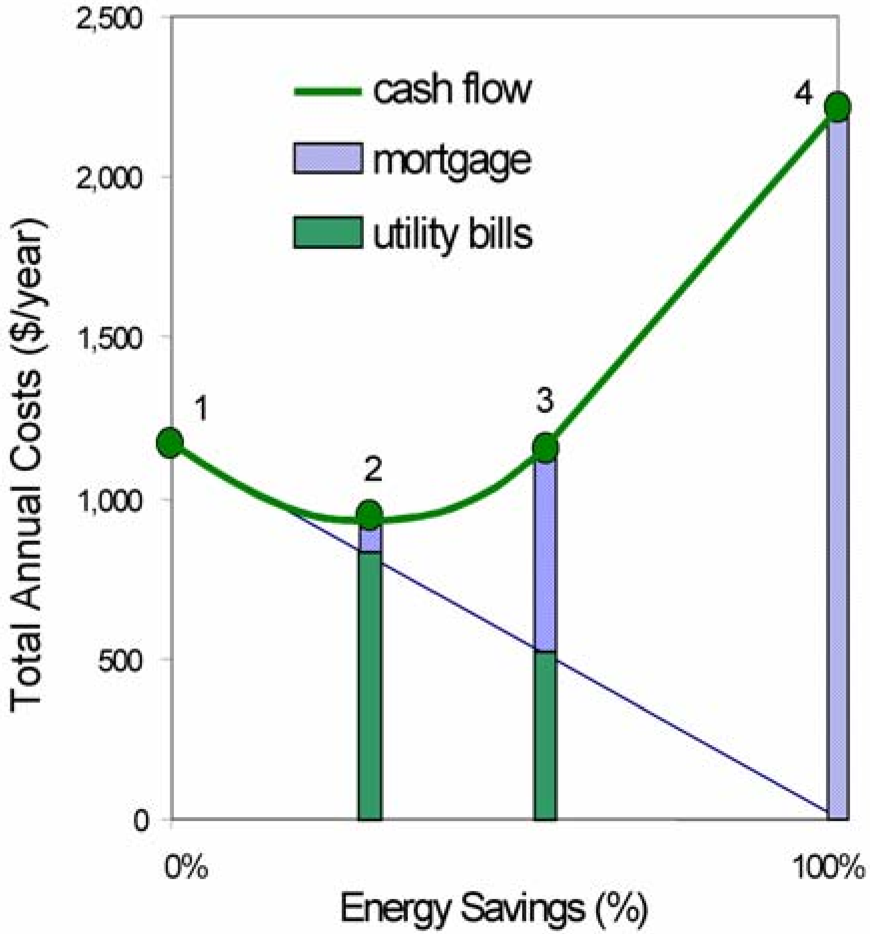


Better choice of envelope construction would drop payback period from 23 to 9 years without PV and 40 to 28 years with PV.

Habitat for Humanity houses, Tennessee – Oak Ridge National Lab

- Five low-energy houses with very advanced technologies: wall panels, mechanical ventilation, waste-heat scavenging for hot water, PV
- Heating, cooling and hot water costs about $0.70/ day (!!)
- "Other" costs $1.00-1.38/day – Christmas lights (!!)
- Research houses: not cost effective locally ($20K efficiency investment to save $400/year)

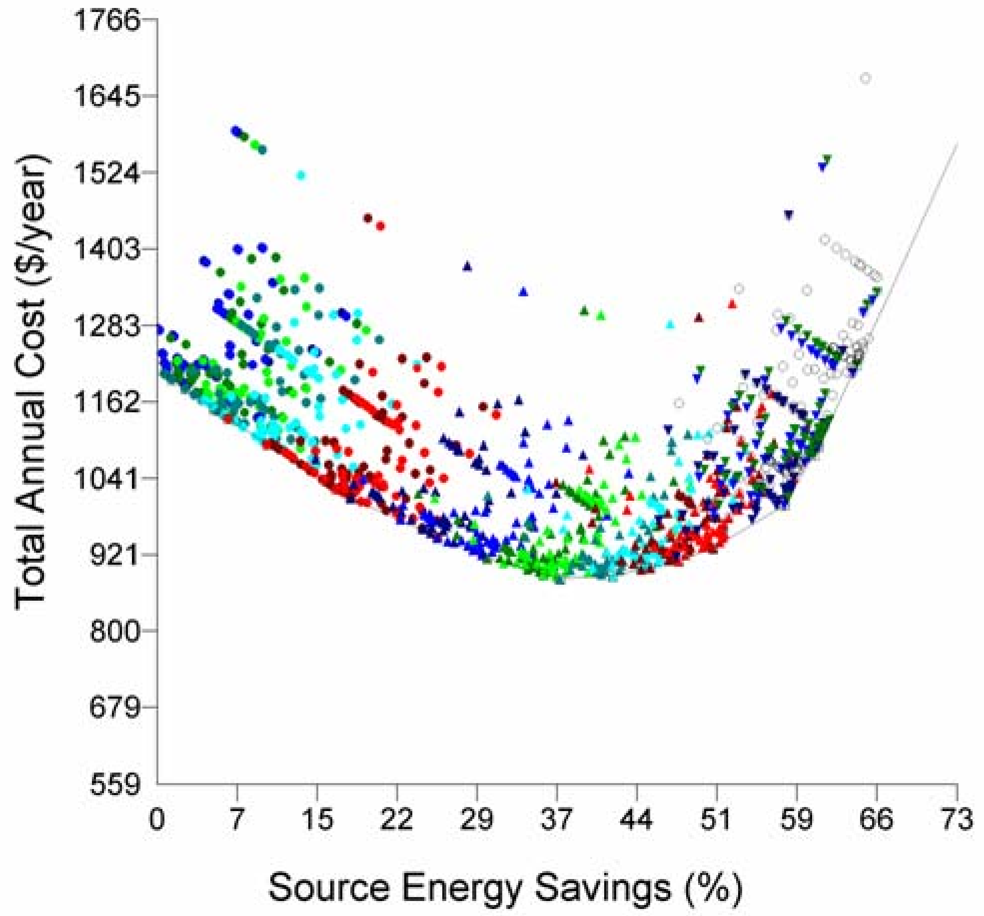
NREL's rational approach to efficiency and zero-net energy in houses



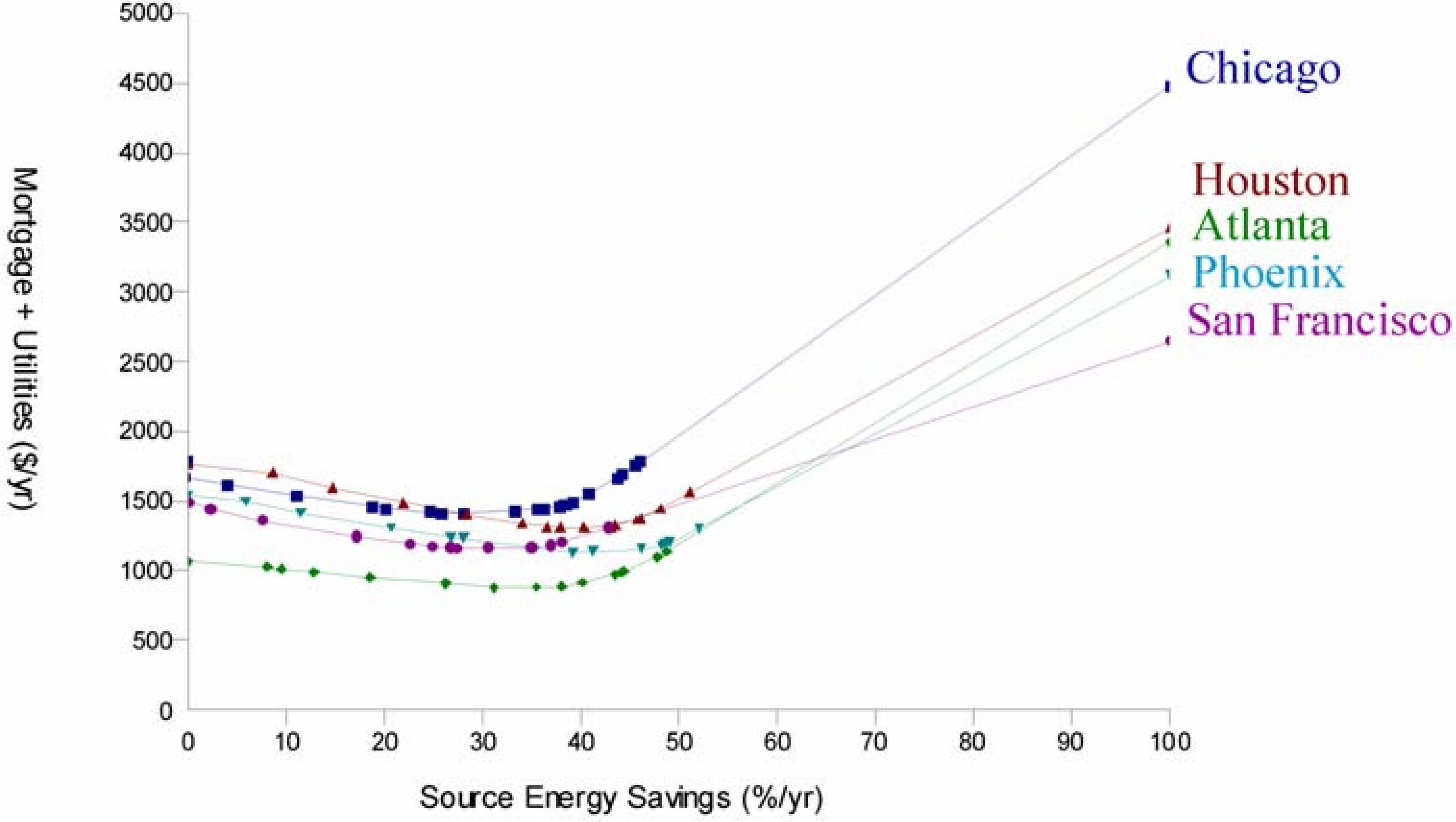
Source:

Ren Anderson, NREL

Automated search for best combination of improvements



Tuning efficiency investments for a given location



PV is expensive, at least for now

Location	Savings at minimum cost, %	Present value of efficiency investment, minimum cost, $	Savings at NZE, %	Present value of efficiency investment, NZE, $	PV cost
Atlanta	32	1,749	49	10,351	42,000
Chicago	28	3,899	46	15,168	57,000
Houston	38	2,585	51	8,762	46,500
Phoenix	39	2,585	52	9,553	40,500
San Francisco	27	1,337	43	8,432	36,000

Figure by MIT OCW.

Solar Decathlon National Mall 2005

Canadian Solar Decathlon House

Heat recovery from PV boosts efficiency from ~8% to ~35%

3. Commercial buildings

- Systems approach is lacking
  - No Building America equivalent
  - Optimization tools are not as well developed
  - Standards do not take systems approach
  - Few buildings go beyond basic code compliance
- Notable successes
  - Individual buildings, 1/3 -1/2 below average
  - Expanding data base of high-performance buildings
  - Private-sector labeling program (LEED) a help
  - Guideline for small commercial buildings

Massachusetts State Transportation Building, Boston: a 20-year oldie but goodie

Aerial photograph of the State Transportation Building.

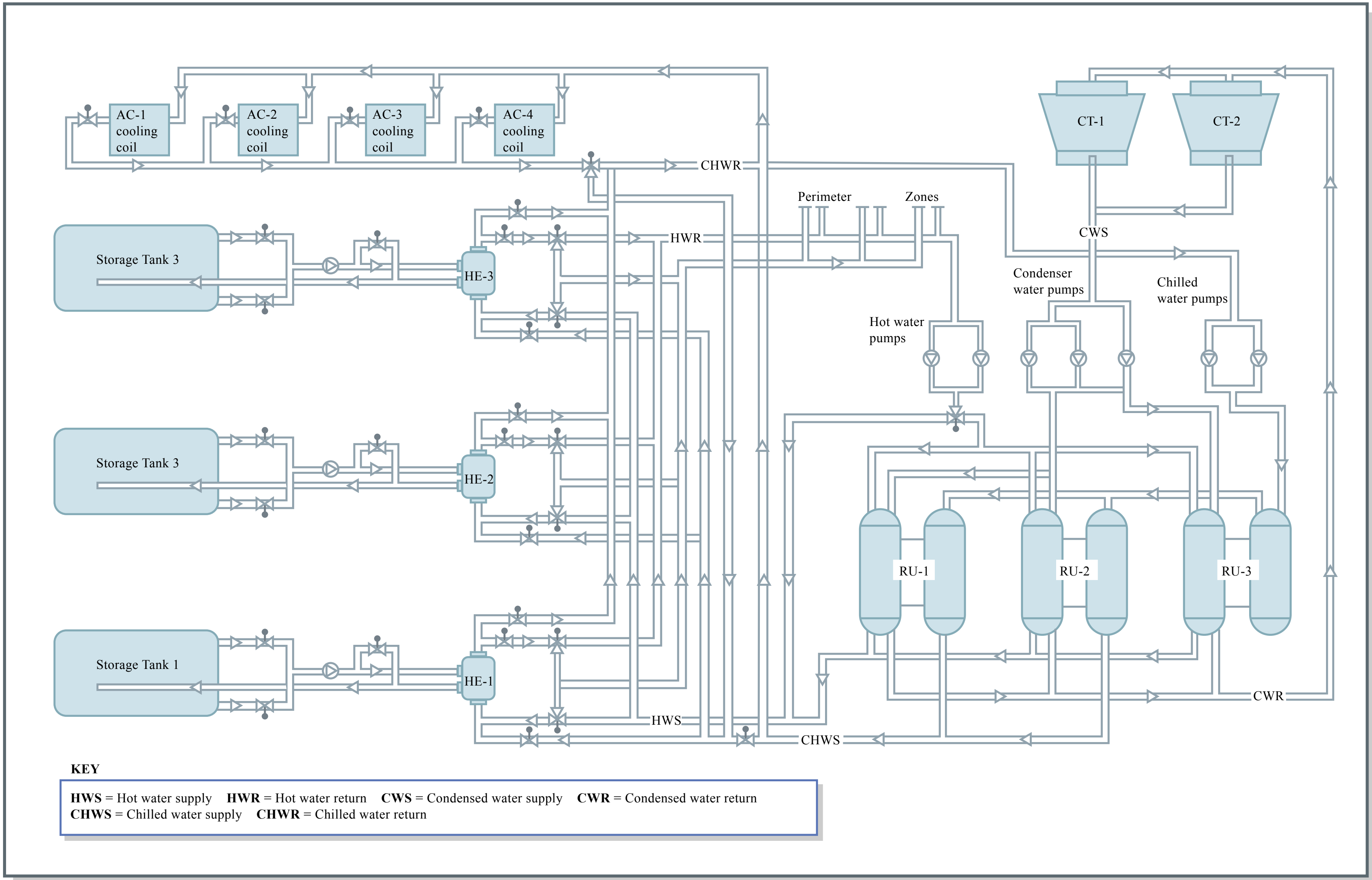
Image removed for copyright reasons.

Atrium as thermal buffer, source of daylight and central plaza

Photographs of atrium.

Images removed for copyright reasons.

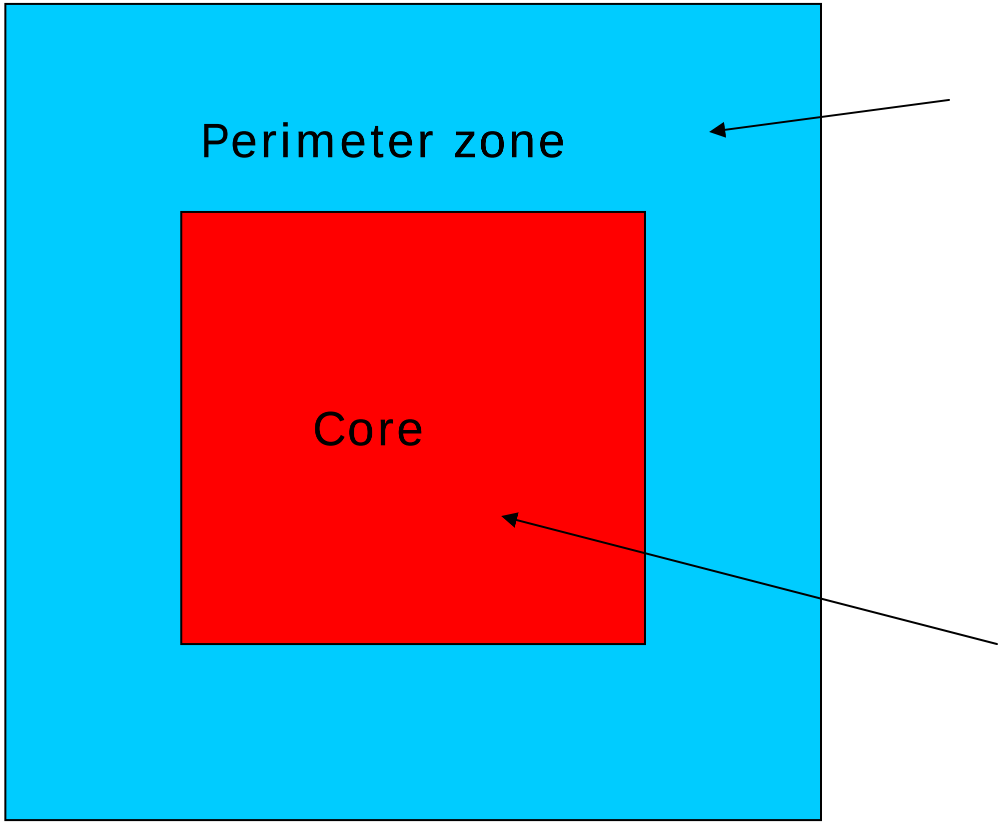
What's missing in this schematic?



Hint: not what you would expect in New England winters

Figure by MIT OCW.

Potential for wasted energy: simultaneous (same instant, same day) heating and cooling



Mild weather: perimeter may need heat in early morning, cooling in afternoon (like houses)

Year-round: core needs cooling constantly, even when perimeter must be heated

Energy consumption

- 173 kWh/m^2 year (277 – US average)
- End use energy:
  - Lights 41.6% (13.7 W/m^2 peak)
  - Variable mechanical 26.1%
  - Steam 11.2%
  - Appliances 5.4%
  - Elevators 6.2%
  - Computer rooms 5.4%
  - Base mechanical 4.0%

Is this a low-energy building?

- 173 kWh/m2 yr transp bldg
- 653 state office bldg
- 717 state office bldg
- 270 comm office bldg
- 196 comm office bldg
- 186 comm office bldg

The lower-energy buildings all recover heat from the building core

UK Office #1

- Three-story office building
- 5,100 m^2 (54,900 ft^2) net floor area
- Sealed windows
- 100% mechanical conditioning
- 1+ year of monitoring and modeling

Photograph of office building.

Image removed for copyright reasons.

Open atrium but closed conference rooms

Photographs of atrium.

Images removed for copyright reasons.

Airflow Measurements

Very important!! Air must be heated or cooled, seasonally

Photograph of people taking airflow measurements.

Image removed for copyright reasons.

40 L/s-person

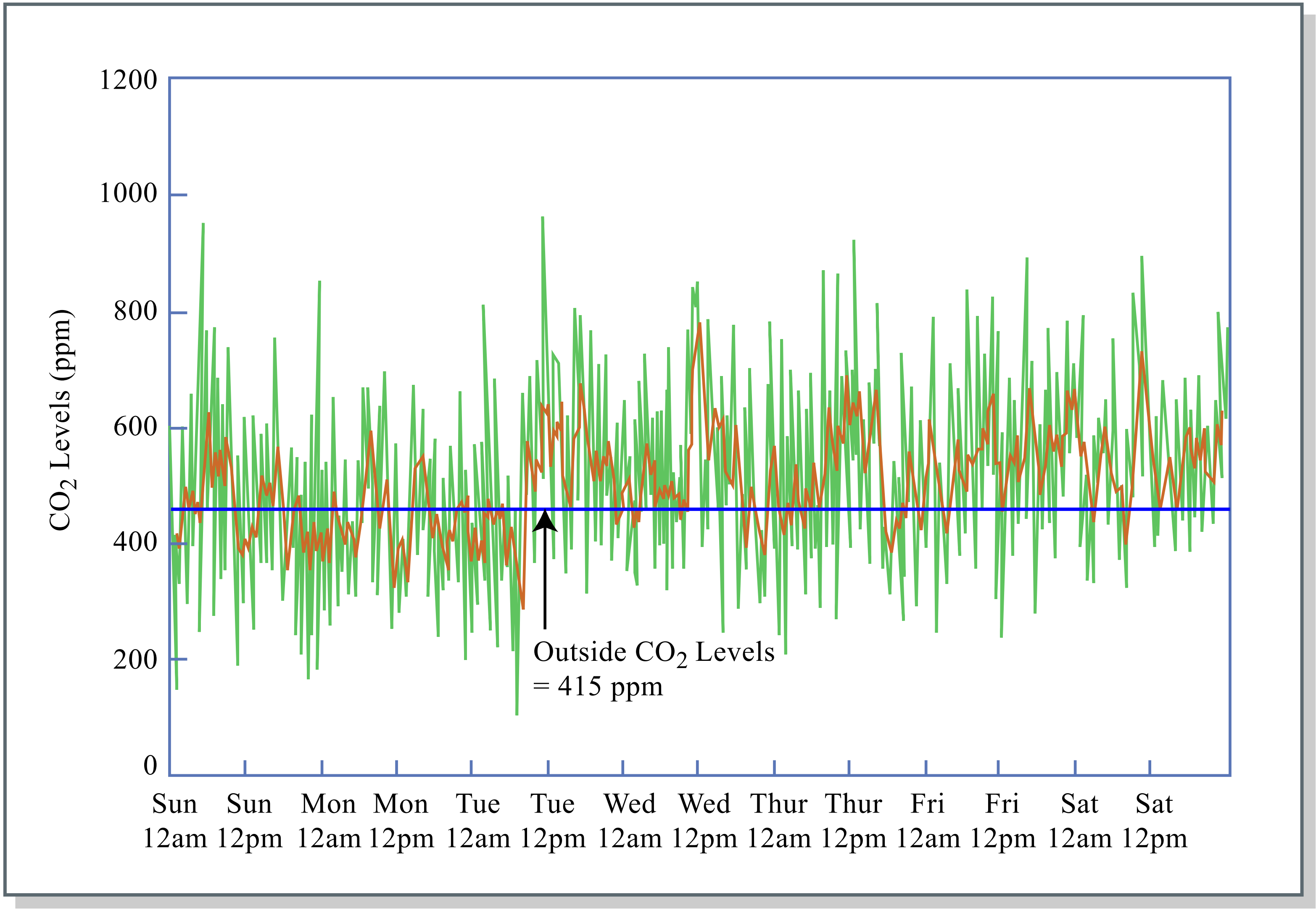
About four times code requirements

One-half expected occupancy

Conference rooms controlled design

Heat-recovery system broken

CO_2 in conference rooms



CO_2 levels were typically well below the 1000 ppm limit

Figure by MIT OCW.

Savings due to heat recovery and lower airflow

CO_2 emissions, kg/m^2

Energy consumption, kWh/m^2

	Natural gas	Electricity	Total
Current	30.8 162	71.7 156	102.5 318
Current airflow and heat recovery	19.8 104	71.7 156	91.5 260
Reduced airflow and heat recovery	24.7 130	45.0 98	69.7 228

Savings potential due to better operation of buildings

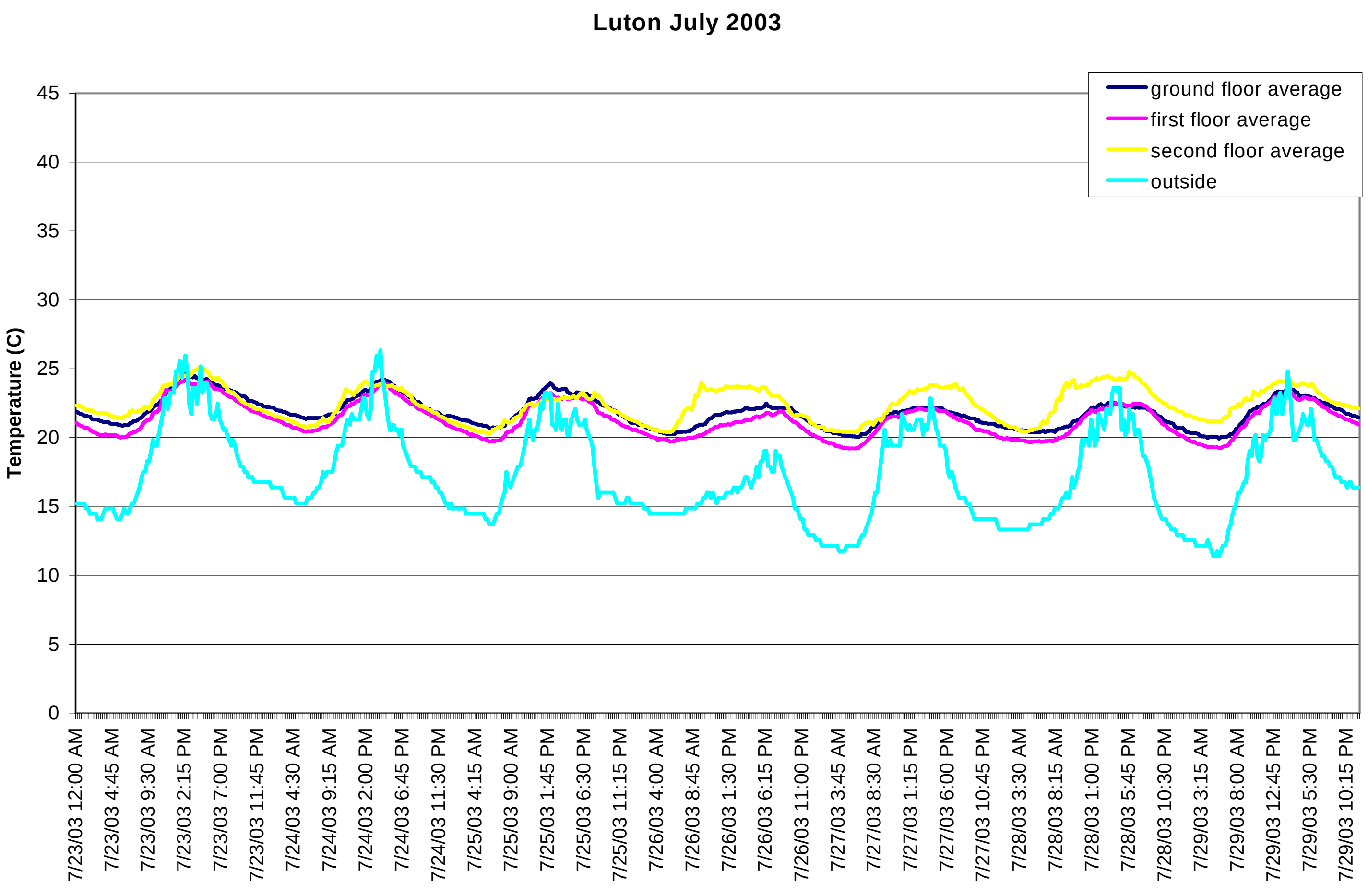
- California: energy crisis
  - 9% electrical demand reduction in 2001 relative to 2000, due to increased prices
- Texas: continuous commissioning
  - 20+% energy savings in 100+ large buildings, less than 3 year payback
  - For 20 buildings
    - 28% savings in chilled water
    - 54% savings in hot water
    - 2-20% savings in electricity (fans, pumps)

UK Office #2: nearby, naturally ventilated building

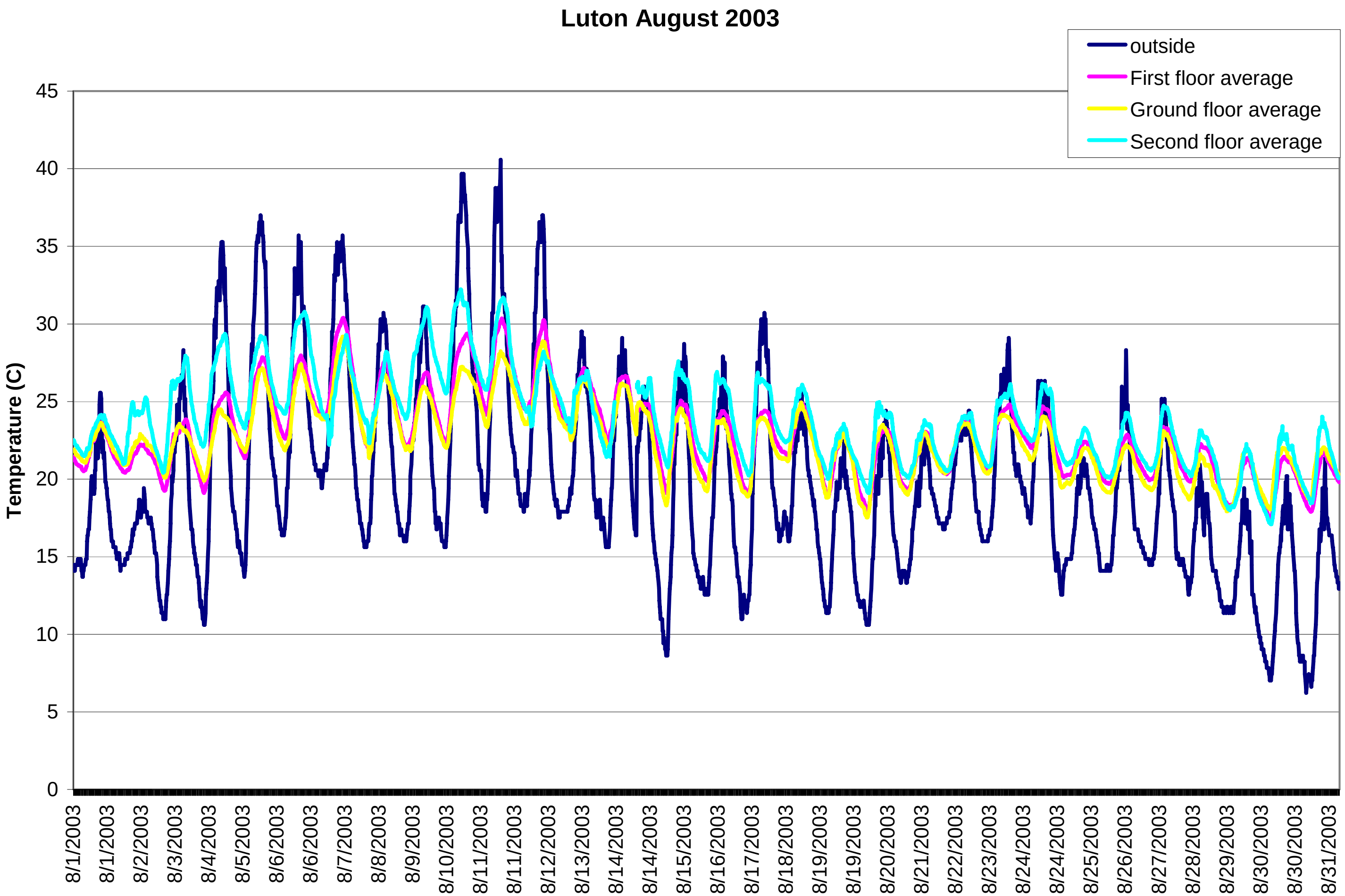
The following pages contained photographs of the office building, atrium views, interior views including windows and blinds, exposed structural mass, and open doors for airflow.

Images removed for copyright reasons.

Interior Temperatures: July 2003



Interior Temperatures: August 2003



Results from occupant survey – views on temperature

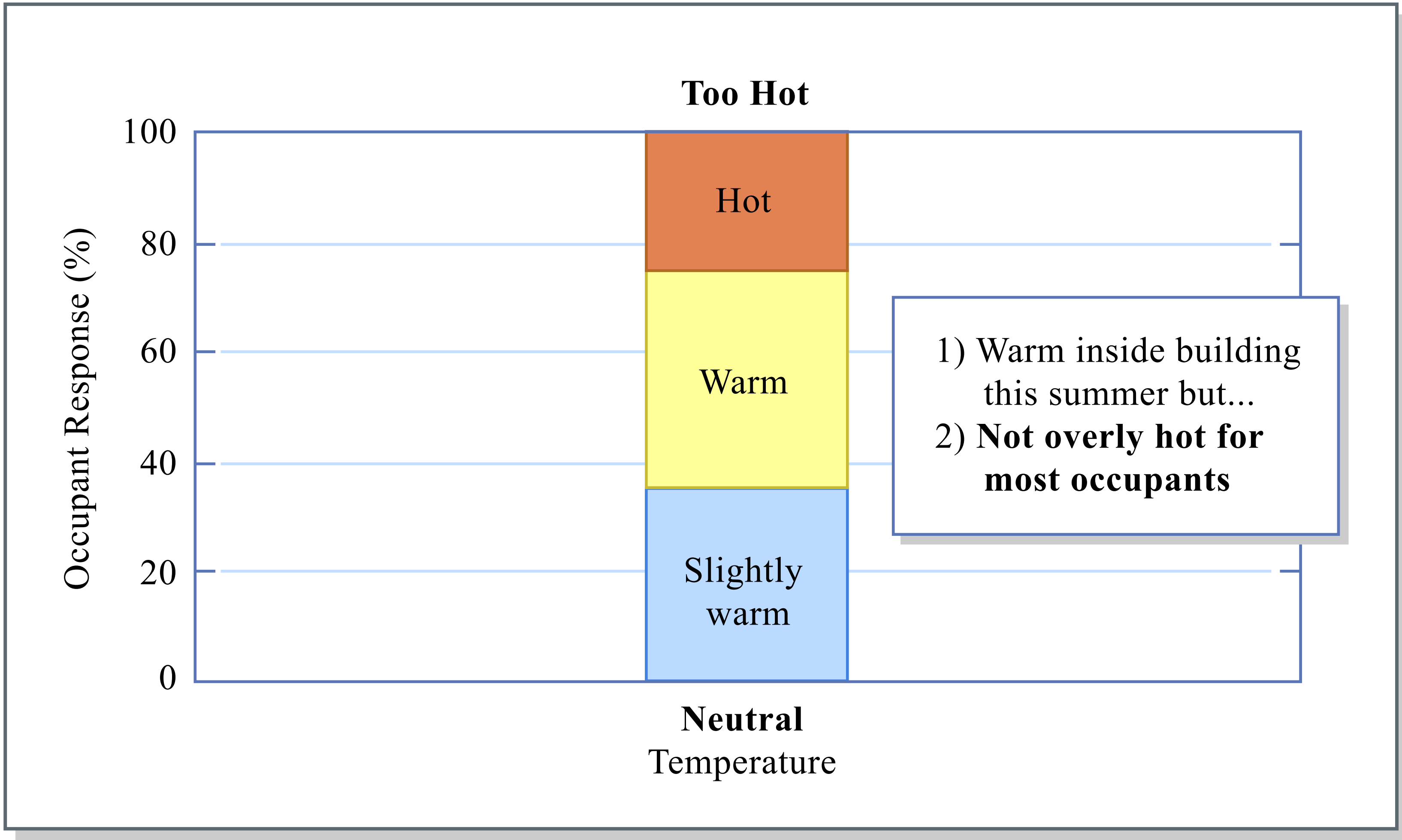


Figure by MIT OCW.

Comparison of UK #1 and UK #1, kWh/m2 year

	MV std	MV GP	NV std	NV GP	UK #1	UK #2
Total NG	178	97	151	79	162	140
Total elec	226	128	85	54	156	76
L +OE	85	50	65	42	55	51
Refrig	31	14	0	0	29	0
Fans + cntls	60	30	8	4	50	5

Dealing with conference rooms:
San Francisco Federal Building

Façade details coordinated

- Trickle vent and heater at floor
- Manual operable window at desk height
- Motorized window above

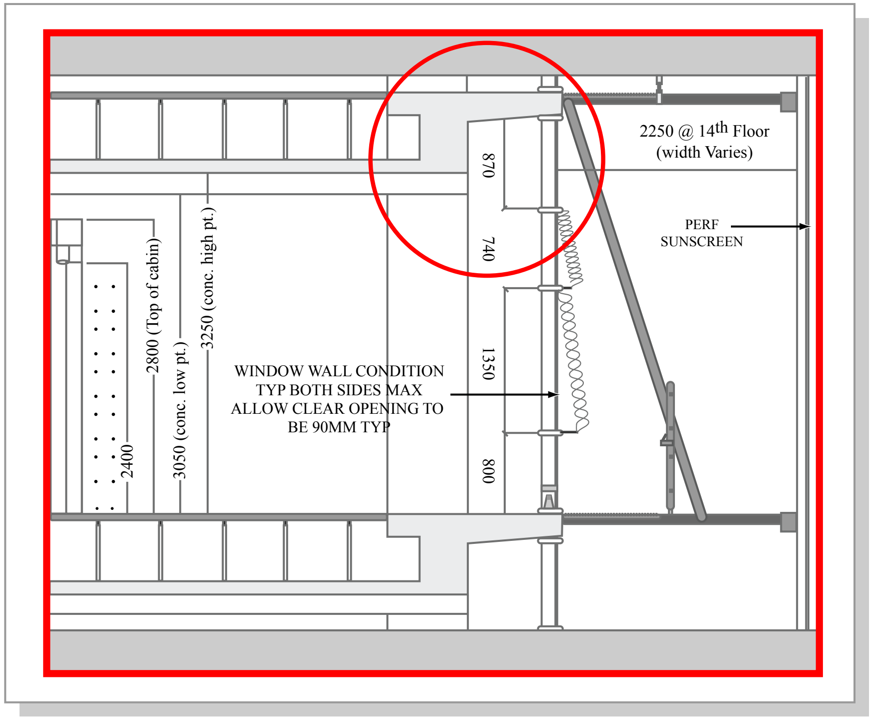
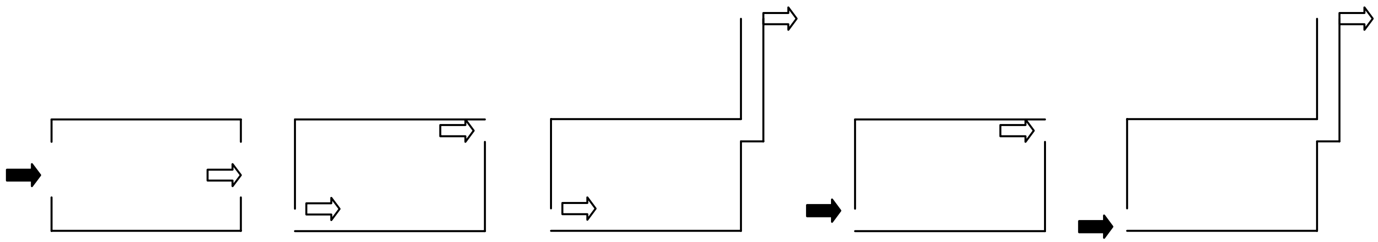


Figure by MIT OCW.

Testing the configuration: predicted degree-hours above base temperature



Base temperature (ºF)	Wind only	Internal stack	Int & ext stack	Int stack + wind	Int & ext stack + wind
72	288	507	432	279	285
75	80	118	103	76	76
78	13	25	19	11	12

DOE's high performance buildings data base

4 Times Square 201 kWh/m^2 simulated; daylight, fuel cells, a little PV

EPA office, NC, 89 kWh/m^2 simulated; shading, daylight, outside air when suitable

Chesapeake Bay Foundation

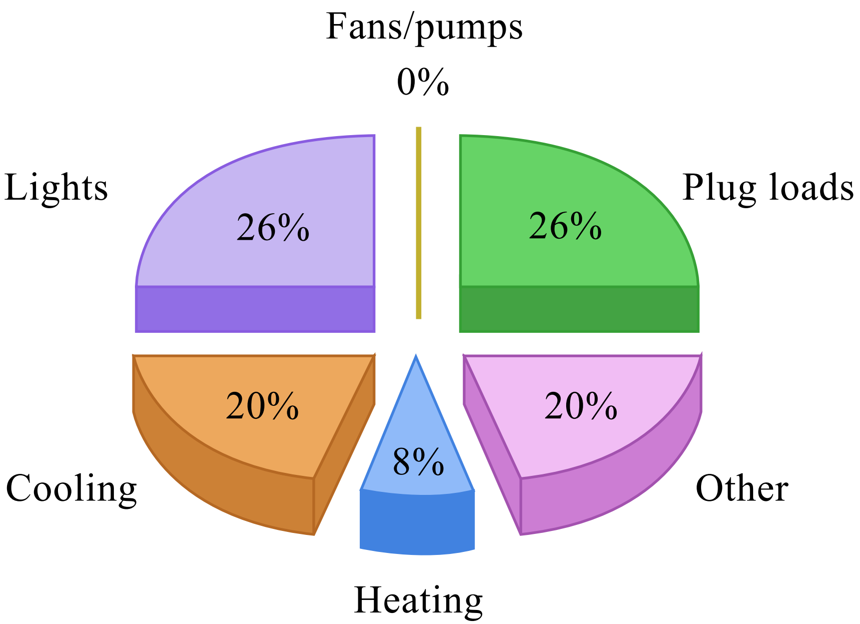
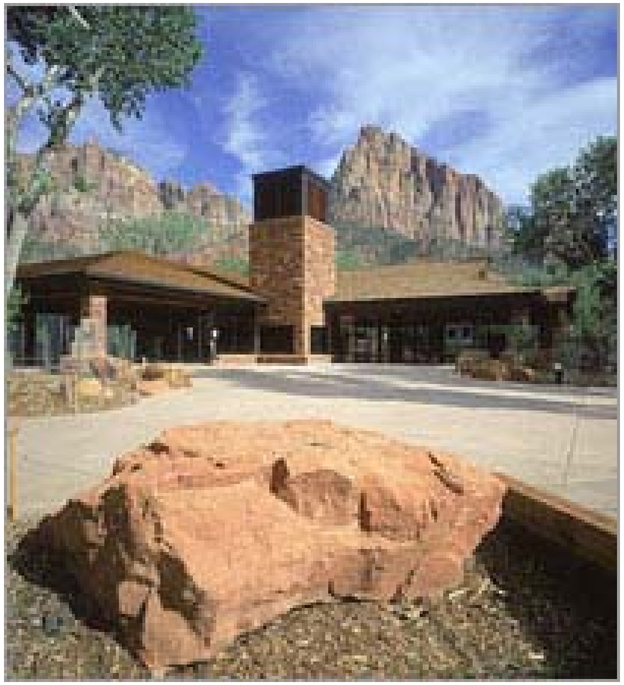


Figure by MIT OCW.

Chesapeake Bay Foundation, Annapolis 131 kWh/m^2 measured consumption, 117 kWh/m^2 purchased, 10% of consumed energy generated from solar thermal and PV on site; shading, daylight, natural ventilation, ground-source heat pumps

Zion National Park Visitor Center



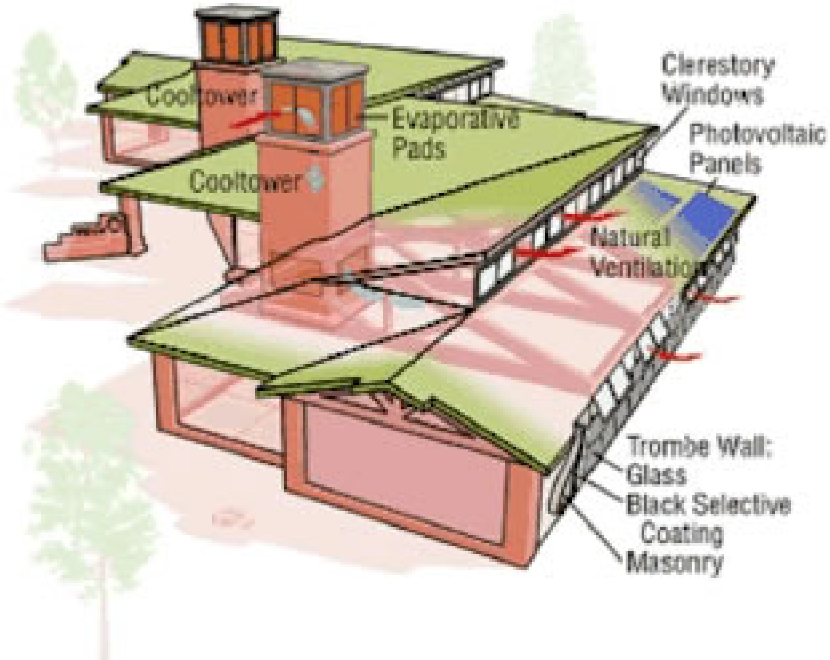


Image courtesy of the National Park Service.

California Courthouse candidate for night cooling

Photograph of courthouse windows.

Image removed for copyright reasons.

Annual Building-Total Electricity Costs

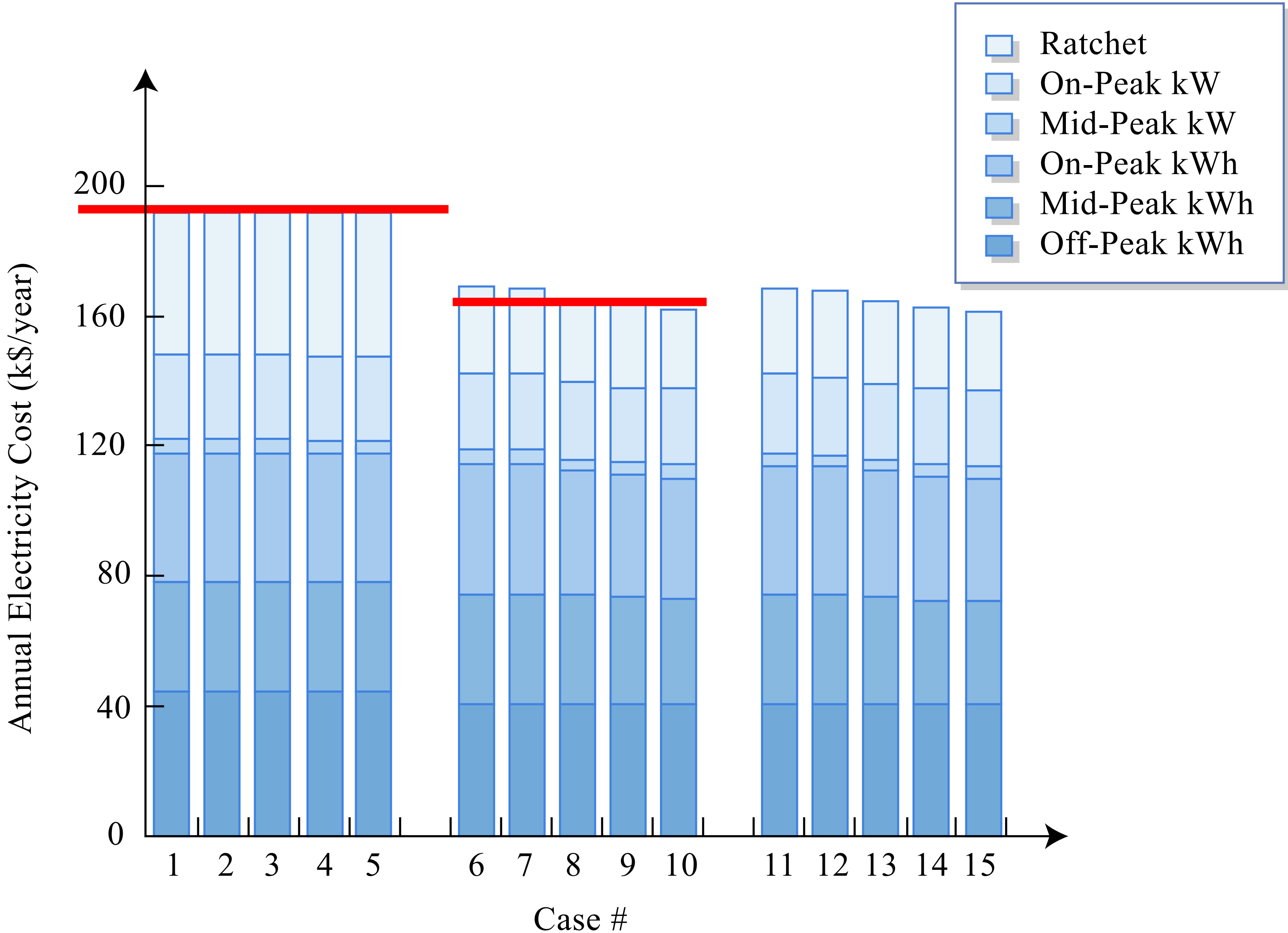


Figure by MIT OCW.

Energy Design Guide for Small ($< 20,000$ ft^2) Commercial Buildings

- 30% savings relative to 1999 standard
- Strategies
  - Reduce loads
  - Use properly sized, efficient equipment
  - Refine systems integration
- Climate-specific prescriptive recommendations:
  - roof, walls, floors, slabs, doors
  - windows, skylights, lighting
  - HVAC, ventilation, and hot water

4. Good enough?

- Lifestyle vs. efficiency
- Market acceptance and technology gains for lights, appliances and HVAC
- Growing but still modest evidence of cost-driven efficiency gains
- Opportunity to contribute to carbon stabilization
- Integrated design needs to be pushed

Floor area counters efficiency gains

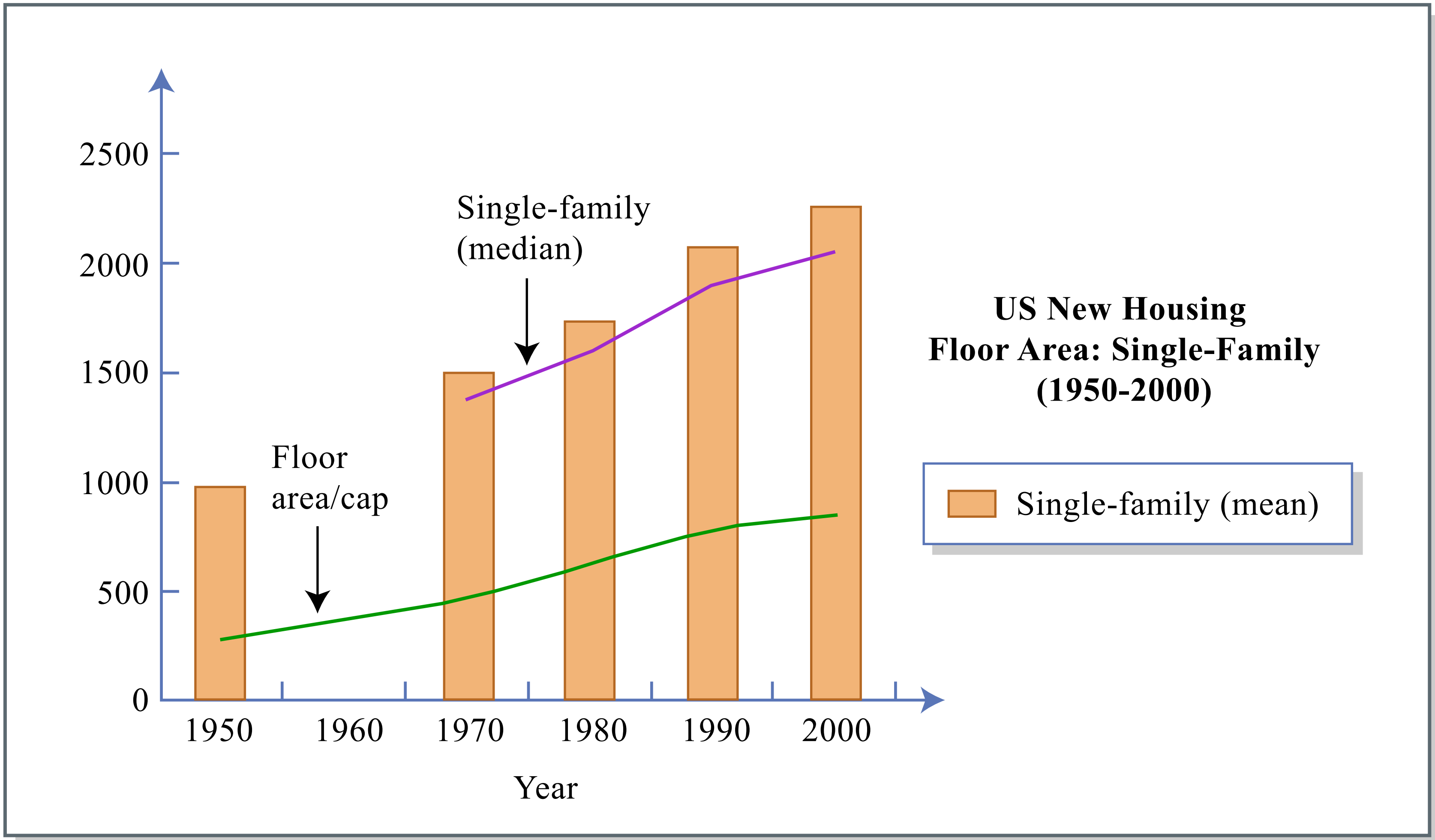


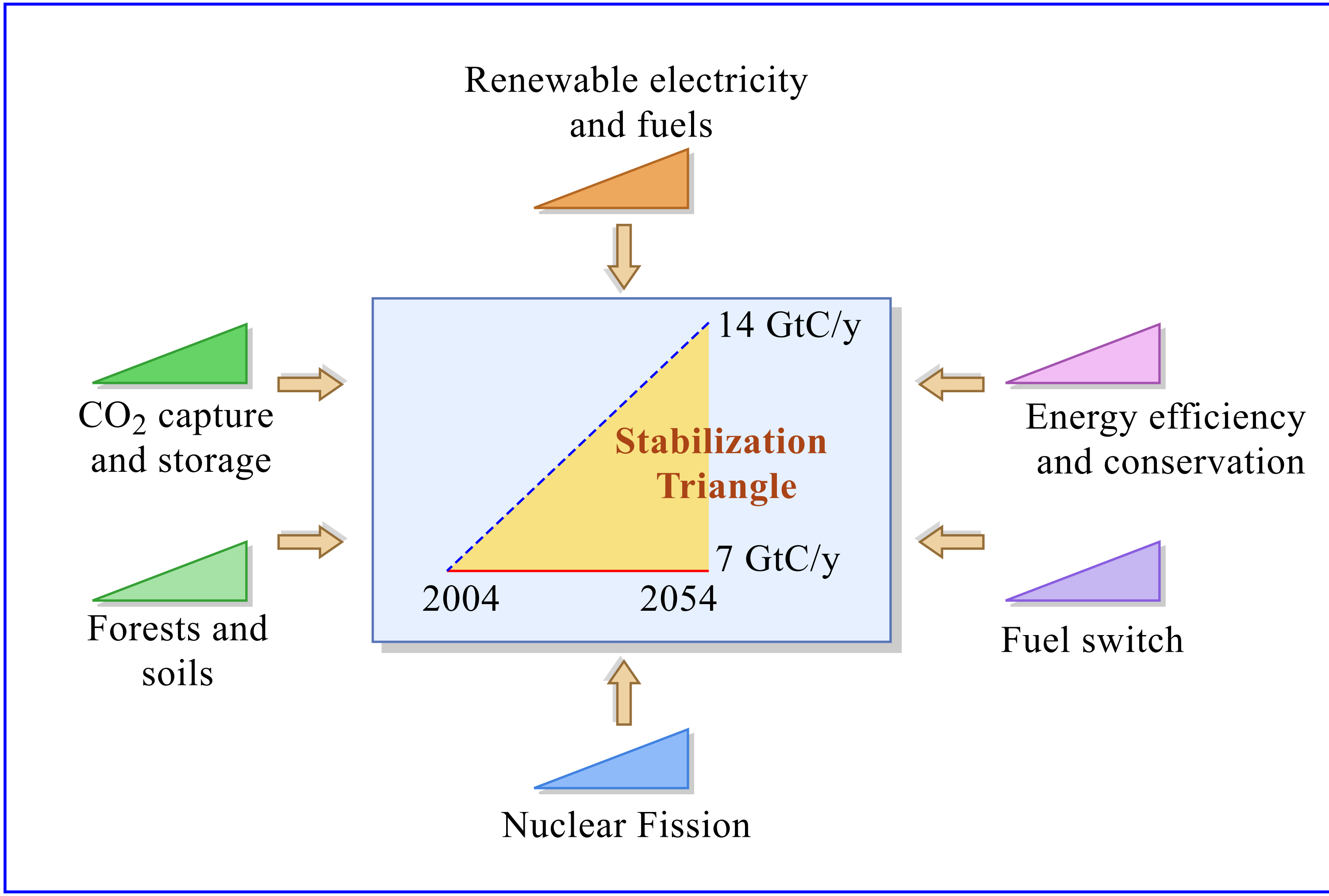
Figure by MIT OCW.

Source: LBNL report

Major potential gains from market acceptance

- CFL sales up 10x in Northwest, 2001 – 2004, but only 11% of market during energy crisis (source: J. DiPeso)
- High-efficiency appliances and HVAC are on the market now
  - Clothes washers 2x code efficiency
  - Residential A/C 1.5x code efficiency
- Near-maximum efficiency gains have been realized in some cases: fridges, furnaces

Atmospheric CO_2 stabilization wedges –Pacala and Socolow



Efficiency option: cut building and appliance emissions by 25% relative to business as usual

Figure by MIT OCW.

To-do list

- Promote market acceptance
  - Information
  - Carbon tax
  - Emissions trading at micro-level
- Work to do
  - Cheaper, more efficient technologies
    - Lights
    - PV, using waste heat
    - Ventilation: demand-controlled, heat recovery, night cooling
  - Ubiquitous integration tools for new construction and retrofits
    - Individual buildings
    - Communities (heat capture, local power generation)
    - Component-level optimization is NOT enough!! Think at systems level.