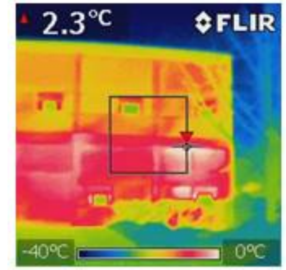
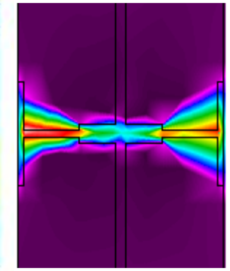
CAE 331/513
Building Science
Fall 2016





Week 1: August 25, 2016
Review of pre-requisites
Energy concepts and unit conversions

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Today's topics

- Review of fundamentals from prerequisite courses
  - Energy concepts and unit conversions

- Assign HW #1 (due Tuesday, August 30)

BRIEF REVIEW OF PREREQUISITES

Review of prerequisite topics

- CAE 208: Thermal-fluids engineering 1
  - Basic laws of thermodynamics
    1. Conservation of energy
    2. Entropy increases
       - Heat energy goes from hot to cold
       - Fluids go from high pressure to low pressure
  - Energy and mass flows and balances
  - Introduction to fluid mechanics

- CAE 209: Thermal-fluids engineering 2
  - Finish fluid mechanics
  - Heat and mass transfer
  - Energy and momentum equations
  - Convection, conduction, and radiation

Bernoulli's principle:

$$\frac{1}{2}\rho v^2 + \rho g z + p = \text{constant}$$

The sum of all forms of energy in a fluid along a streamline is the same at all points along the streamline (e.g., the sum of kinetic, potential and internal energy remains constant)

Some very important definitions: Energy

Energy

- Energy is the capacity of a system to do work
  - We use this term a lot
  - Primary units: Joules, kWh or BTU (or MMBTU = 10^6 BTU)
- Different forms of energy:
  - Thermal, radiative, solar, nuclear, geothermal, hydrocarbon
  - Energy efficiency
    - Energy that is utilized versus energy that is not utilized
  - Embodied or embedded energy
    - The energy required to extract resources, manufacture, and transport a product
- Energy use depends on the rate of energy use and the time/ duration of operation
  - Rate of energy use = Power

Some very important definitions: Power

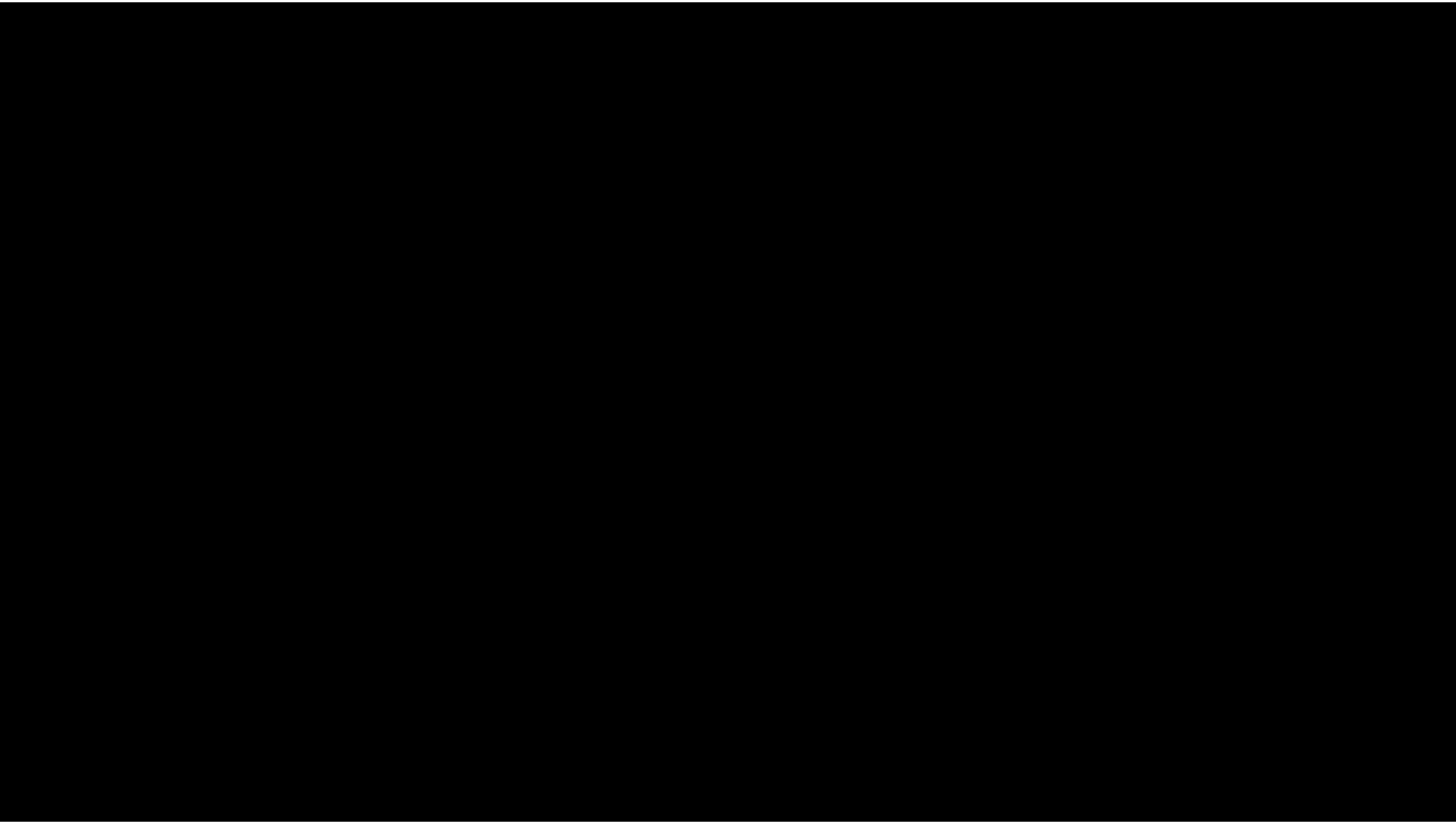
Power

- Power is the rate at which energy is produced or consumed
  - Units are energy per time
  - IP: BTU per hour (BTU/hr) or kBTU per hour (1000 BTU/hr)
  - SI: Watt (W = J/s) or kilowatt (kW = kJ/s) or megawatt (MW = MJ/s)

- Be careful when using units associated with energy and power
  - People often confuse these

- Example: Batteries don't store power; they store energy
  - They release that energy (Watt-hours) at a rate determined by the equipment's power draw (Watts, or amperage)

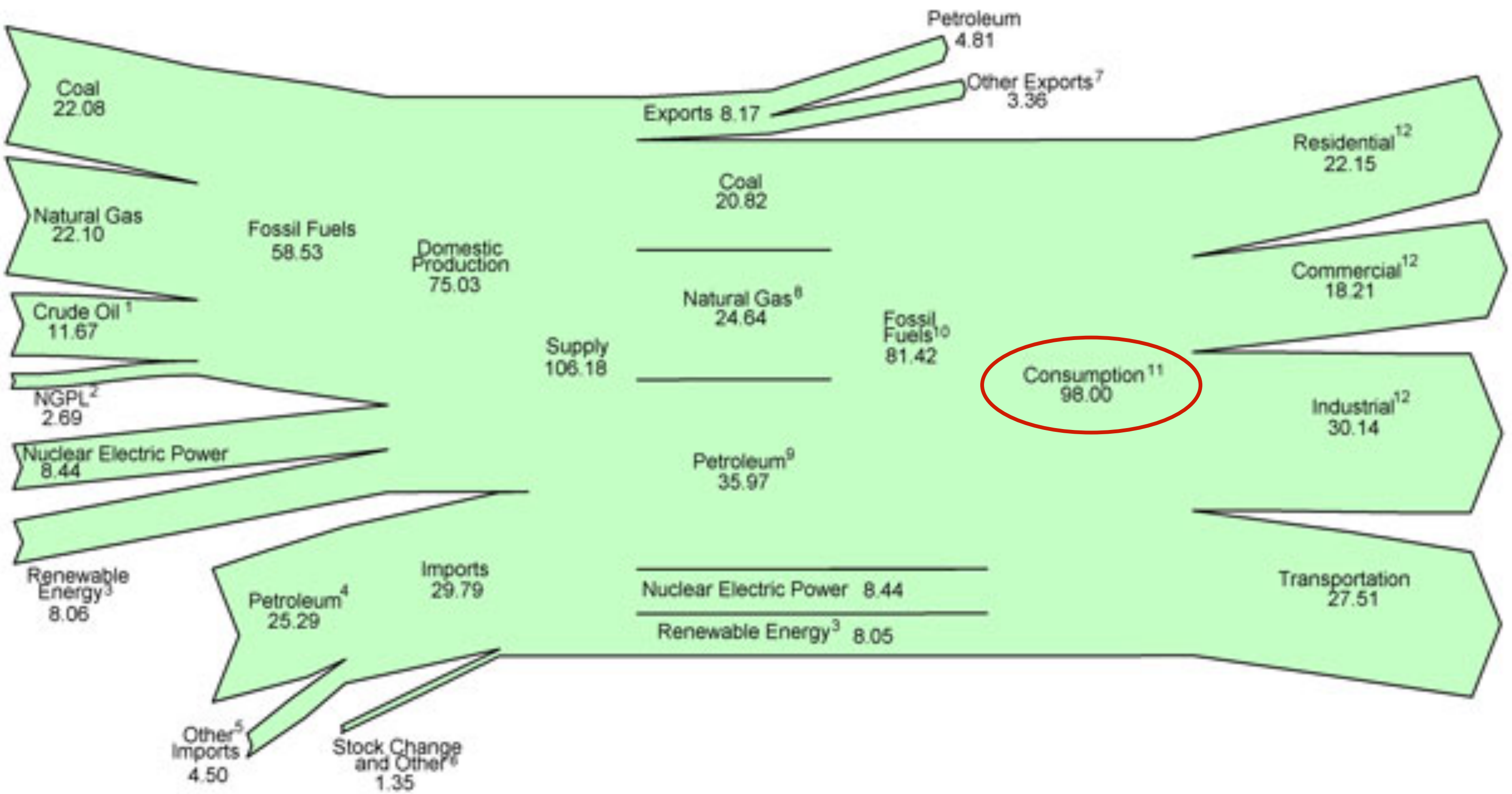
How much energy does the US use?



http://www.theatlantic.com/video/archive/2013/08/how-much-energy-does-the-us-use/278324/

Energy and units

As we just heard, the U.S. uses about **100 Quads** of energy per year

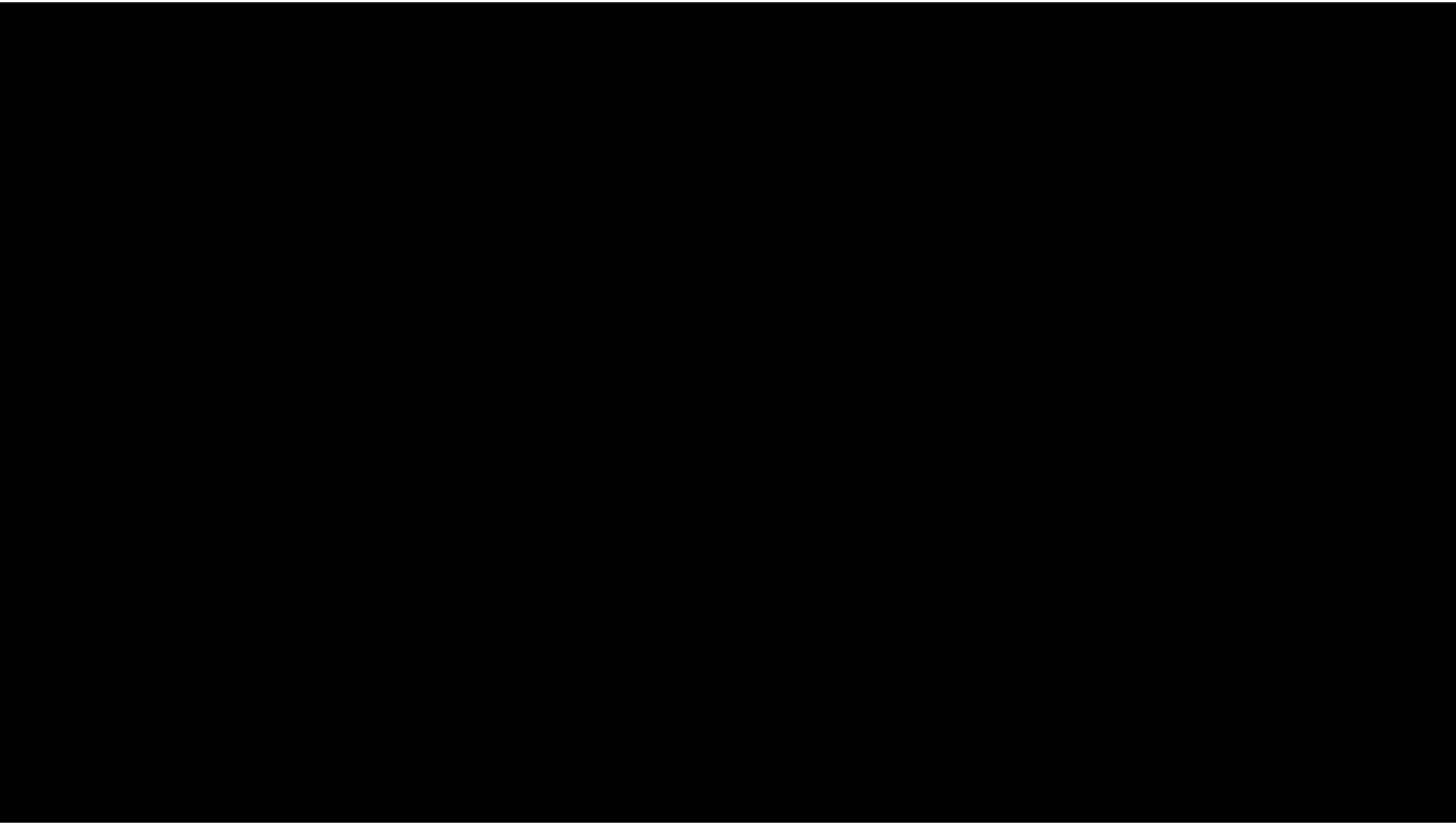


Q1: What is the US annual energy consumption in SI units? (J and kWh)
Q2: What is the average power draw per person in the US?

Building energy use

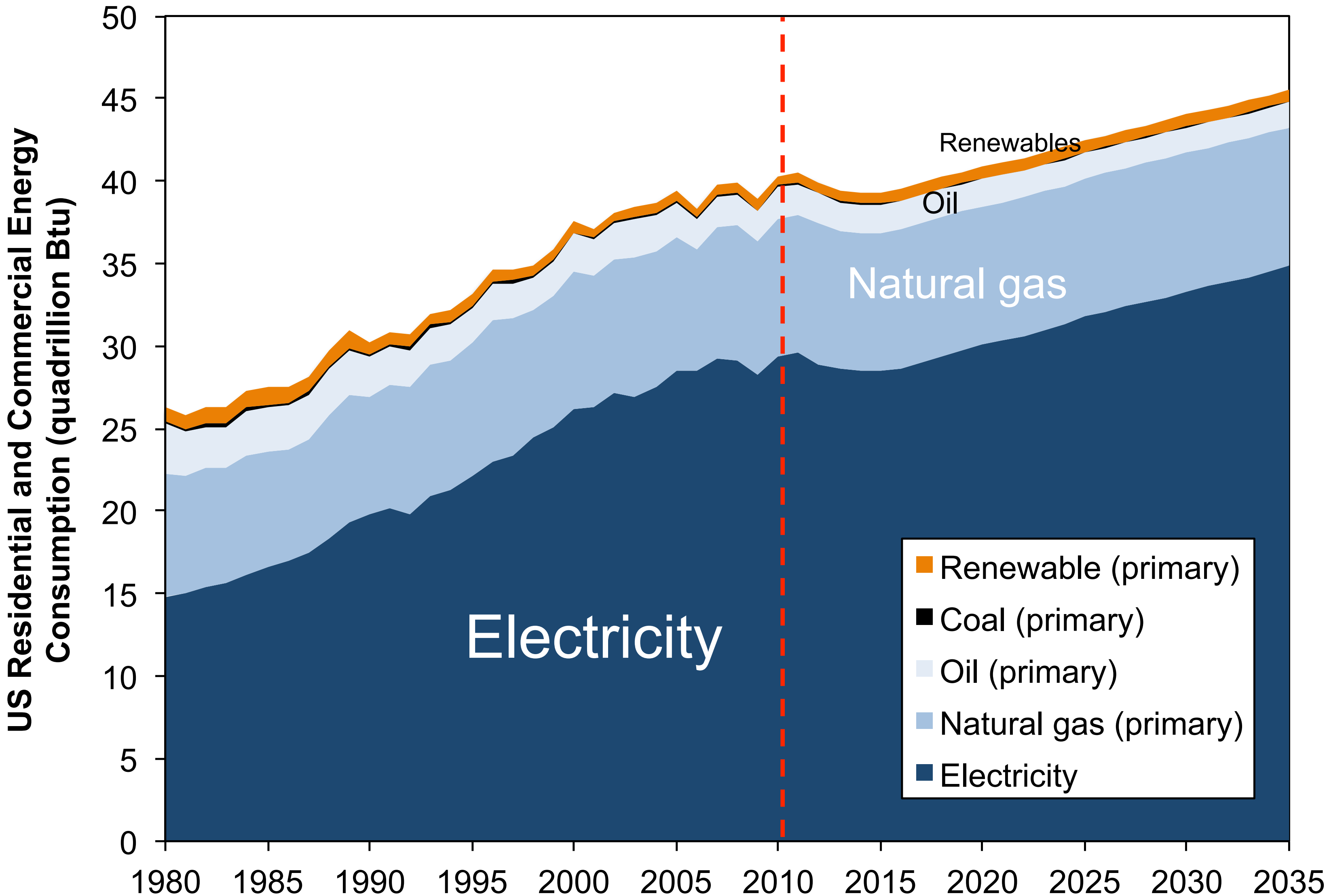
- How do we utilize energy in buildings?
- We burn some fuels directly
  - Natural gas (mostly), oil (much less)
- We burn other fuels to generate electricity
  - Natural gas, coal, nuclear
    - Electric conversion efficiency is not 100%
    - There are also distribution and transmission losses (a few %)
- Renewable sources directly generate electricity as well
- Great resource: The Building Energy Data Book
  - http://buildingsdatabook.eren.doe.gov/

How do we use energy at **home**?

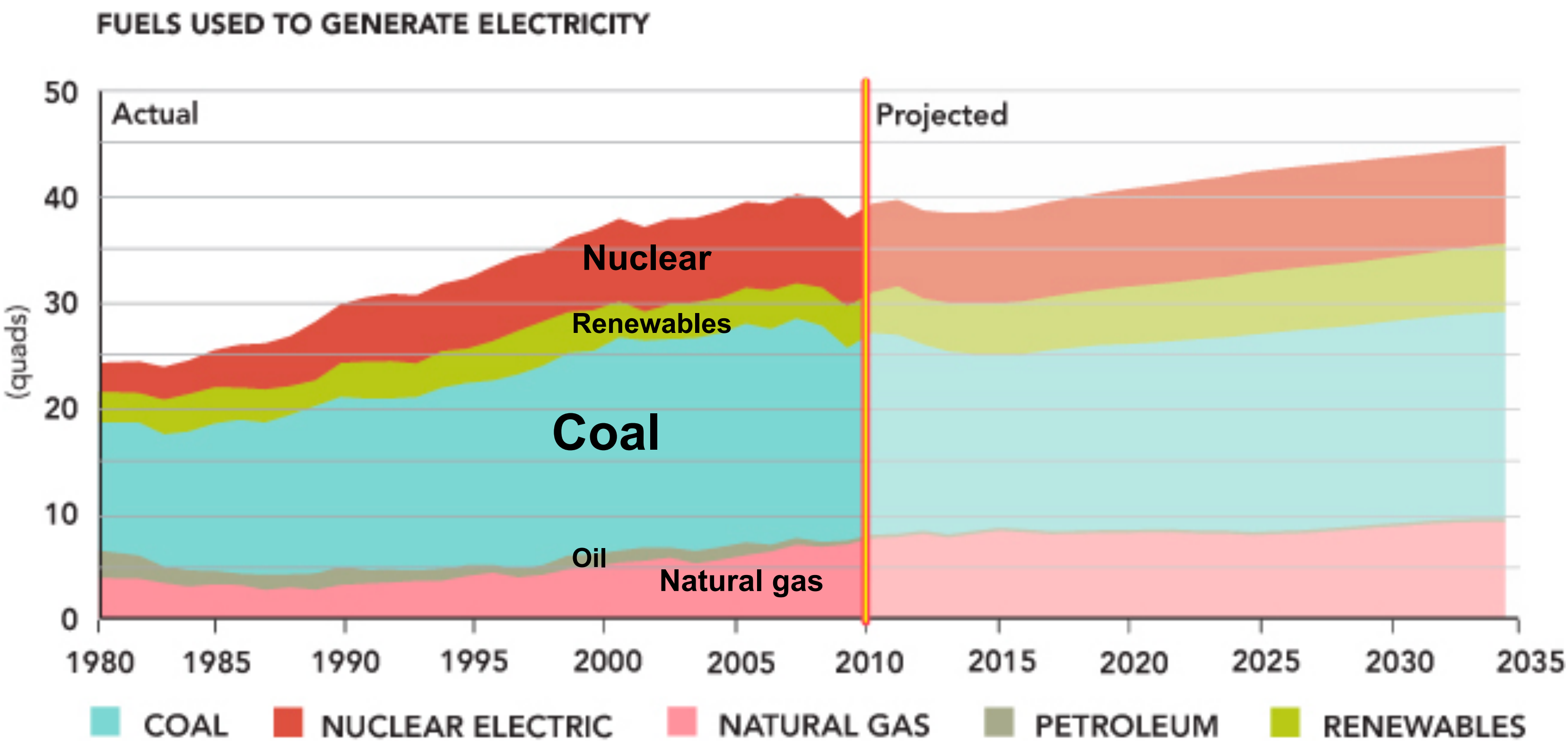


http://www.theatlantic.com/video/archive/2013/08/how-do-we-use-energy-at-home/278439/

US **building** energy consumption (*by fuel*)

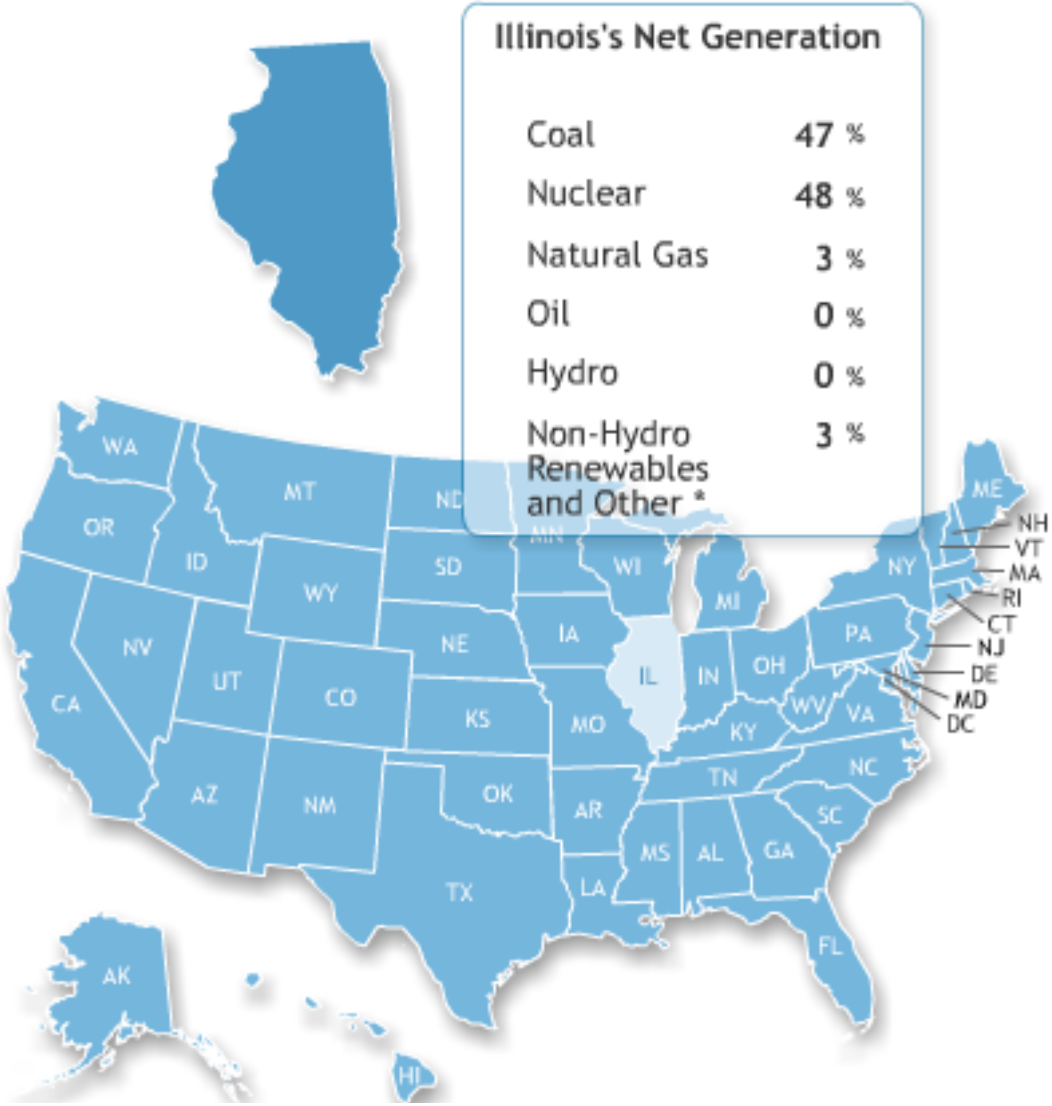


Where do we get our electricity in the U.S.?



http://buildingsdatabook.eren.doe.gov/ChapterIntro6.aspx?6

How does Illinois get its electricity?

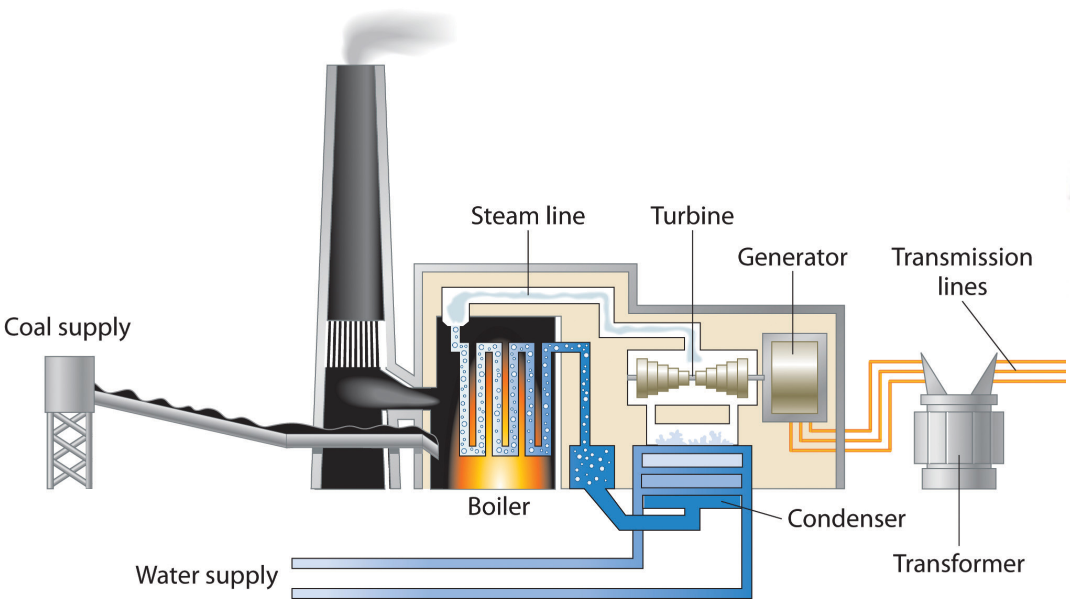


http://www.getenergyactive.org/fuel/state.htm

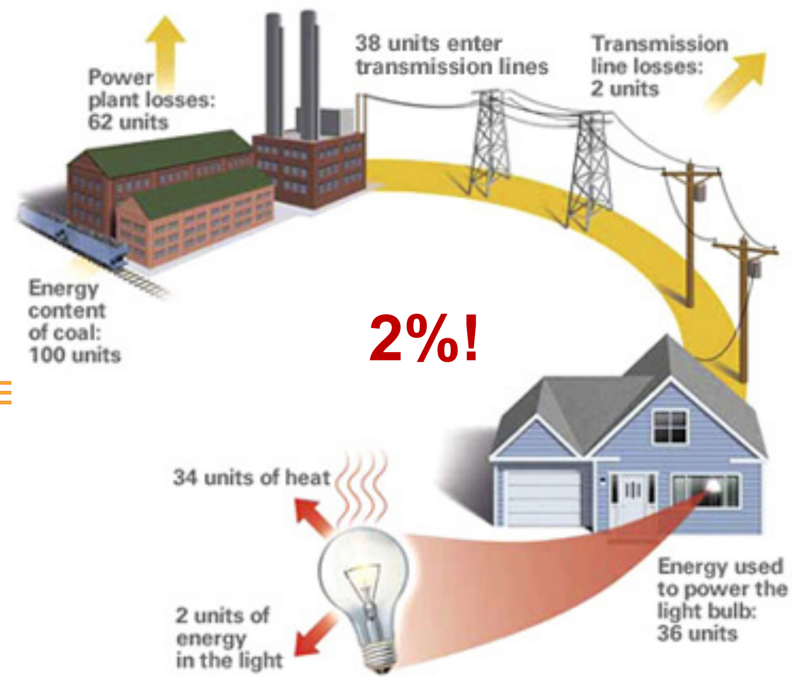
Conversion efficiency for electric generators

1st law of thermodynamics: Energy can be transformed from one form to another, but cannot be created or destroyed

- **Q:** What is a typical electric power plant efficiency? **30-45%**
- **Q:** What is the "round trip" efficiency for an incandescent light bulb?



Typical power plant schematic

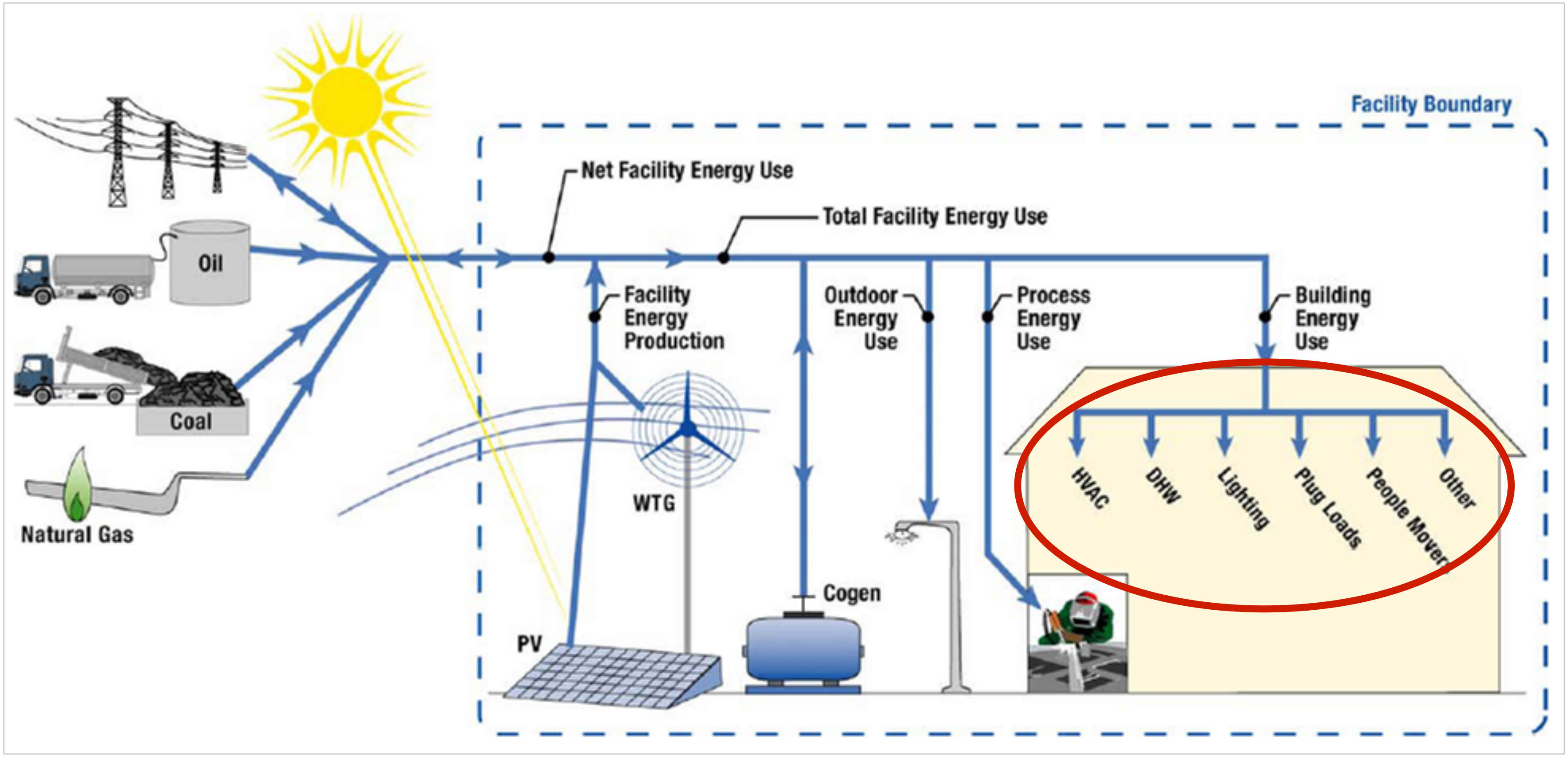


2%!

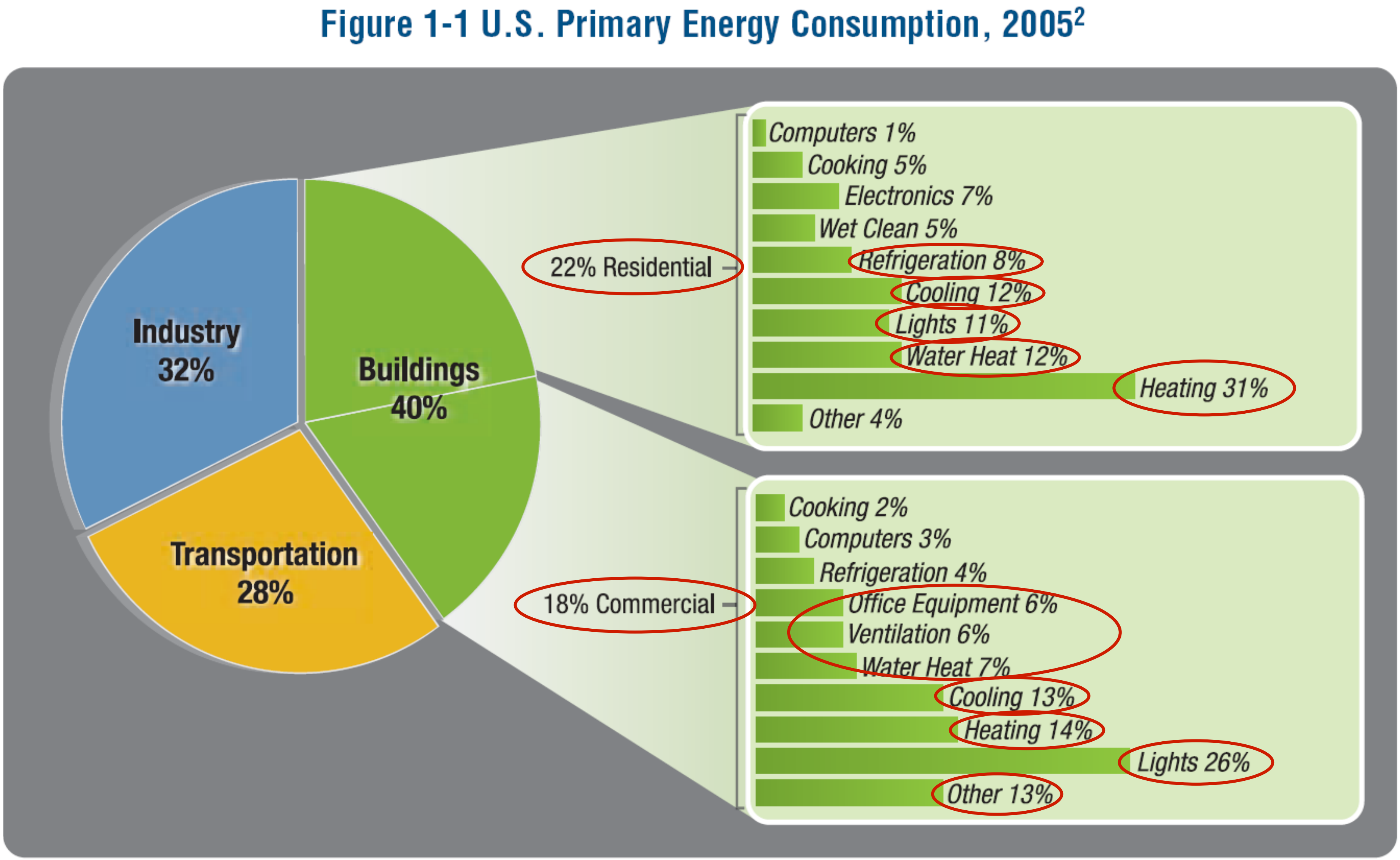
Natural gas used directly in buildings is typically **80-90%** efficient or more

http://www.eia.gov/tools/faqs/faq.cfm?id=107&t=3

Building boundaries and energy flows

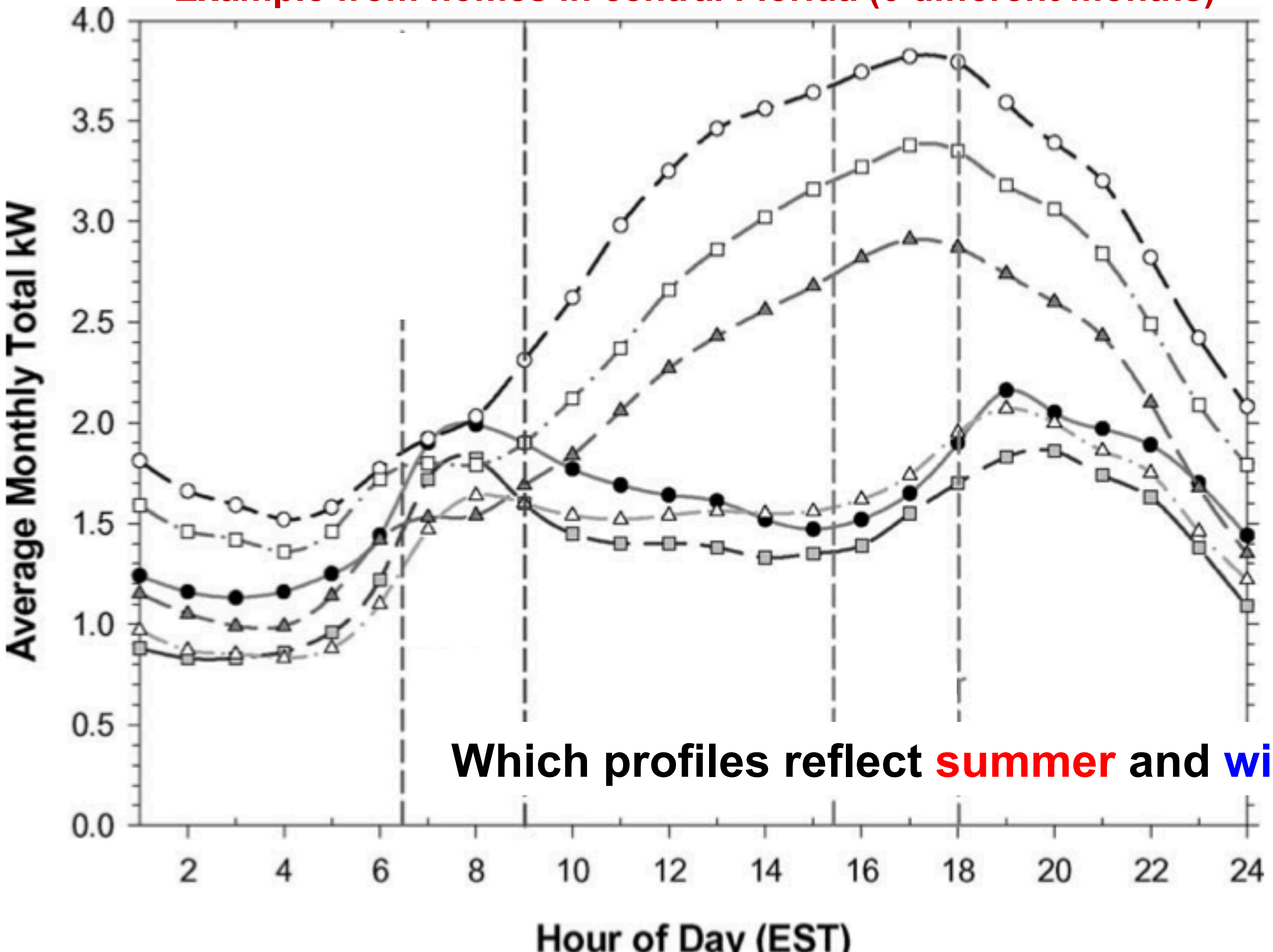


How do buildings use energy?



Understanding building energy use: Electricity profiles

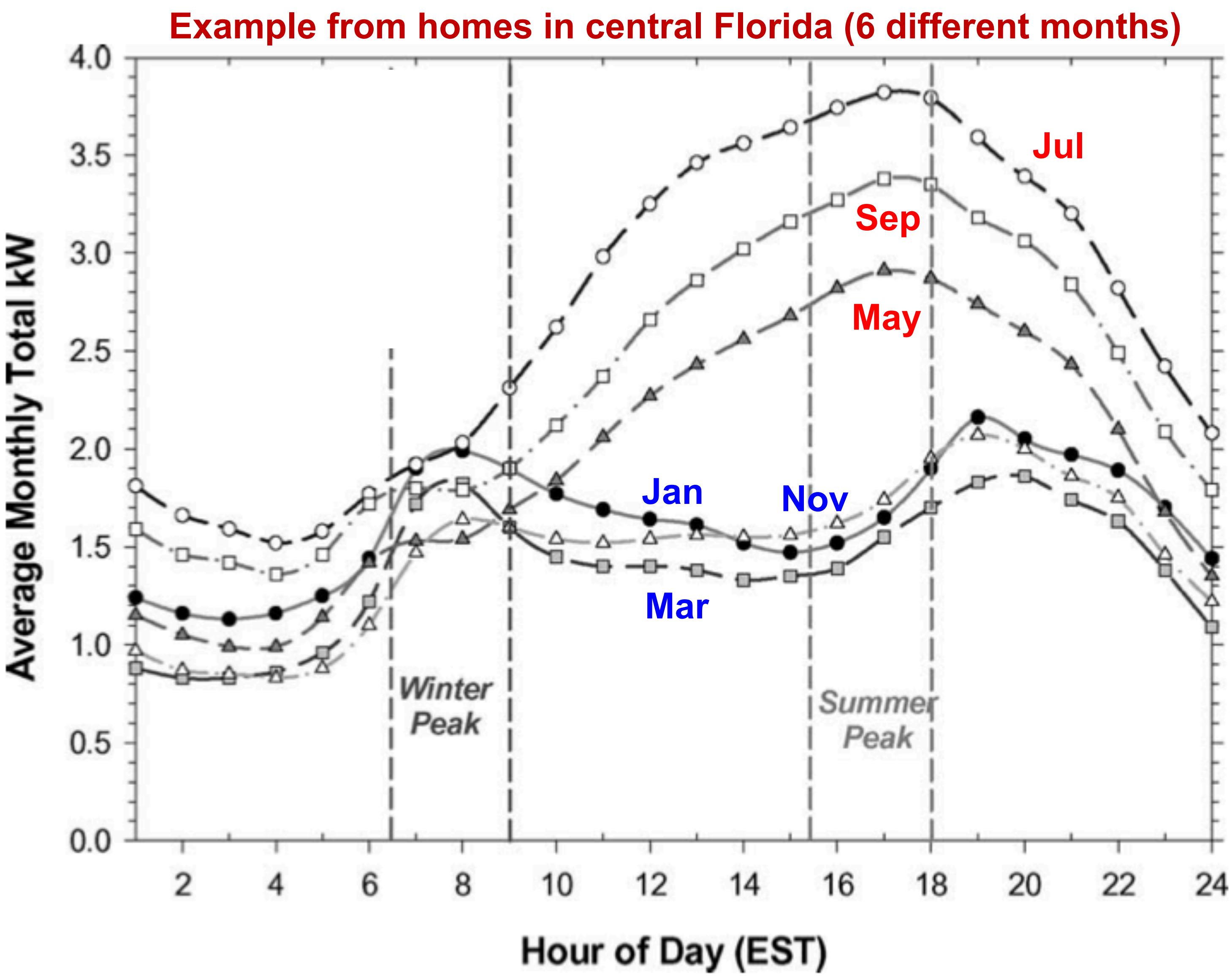
Example from homes in central Florida (6 different months)



Which profiles reflect summer and winter?

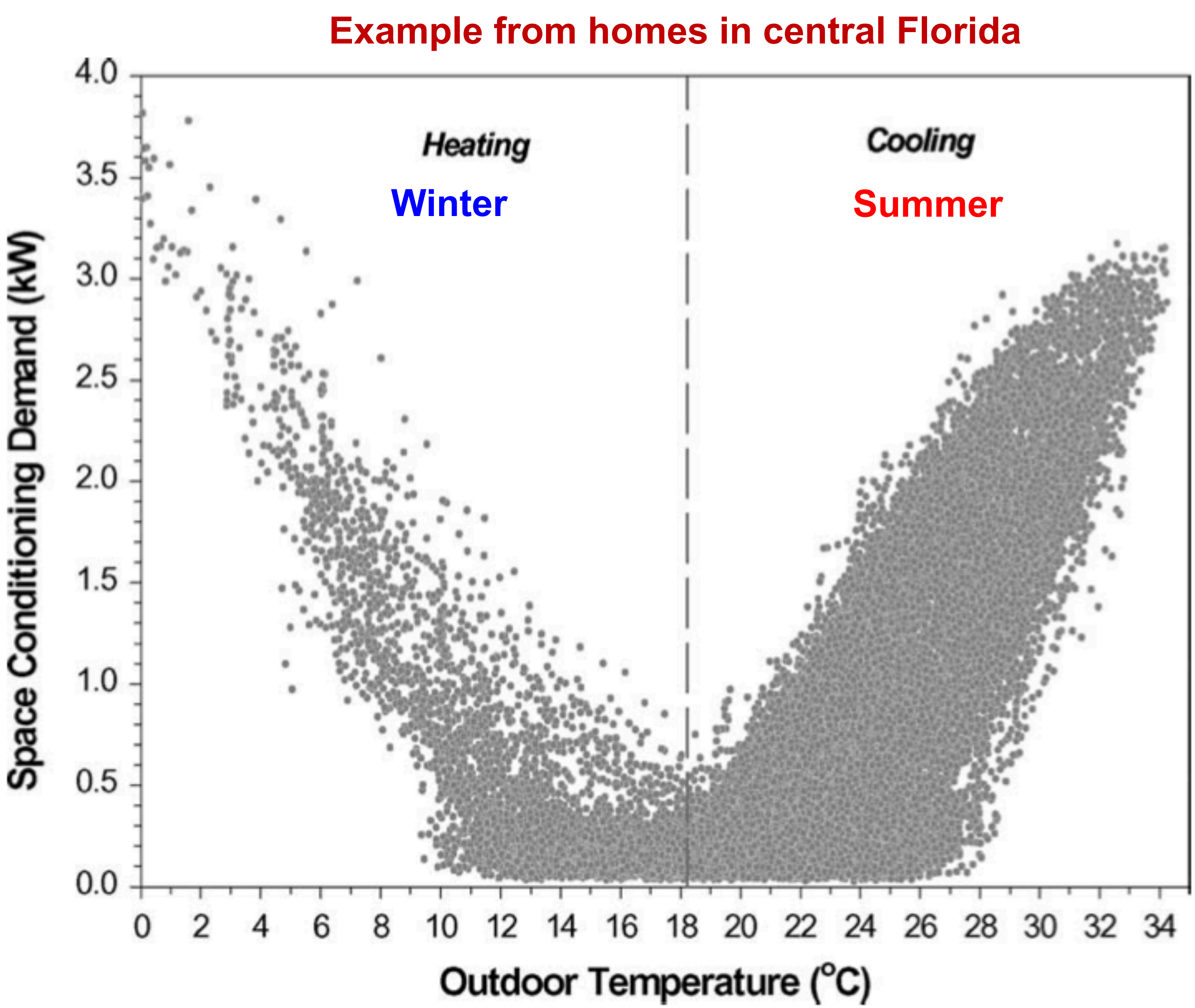
Parker 2003 *Energy and Buildings* 35:863-876

Understanding building energy use: Electricity profiles



Parker 2003 *Energy and Buildings* 35:863-876

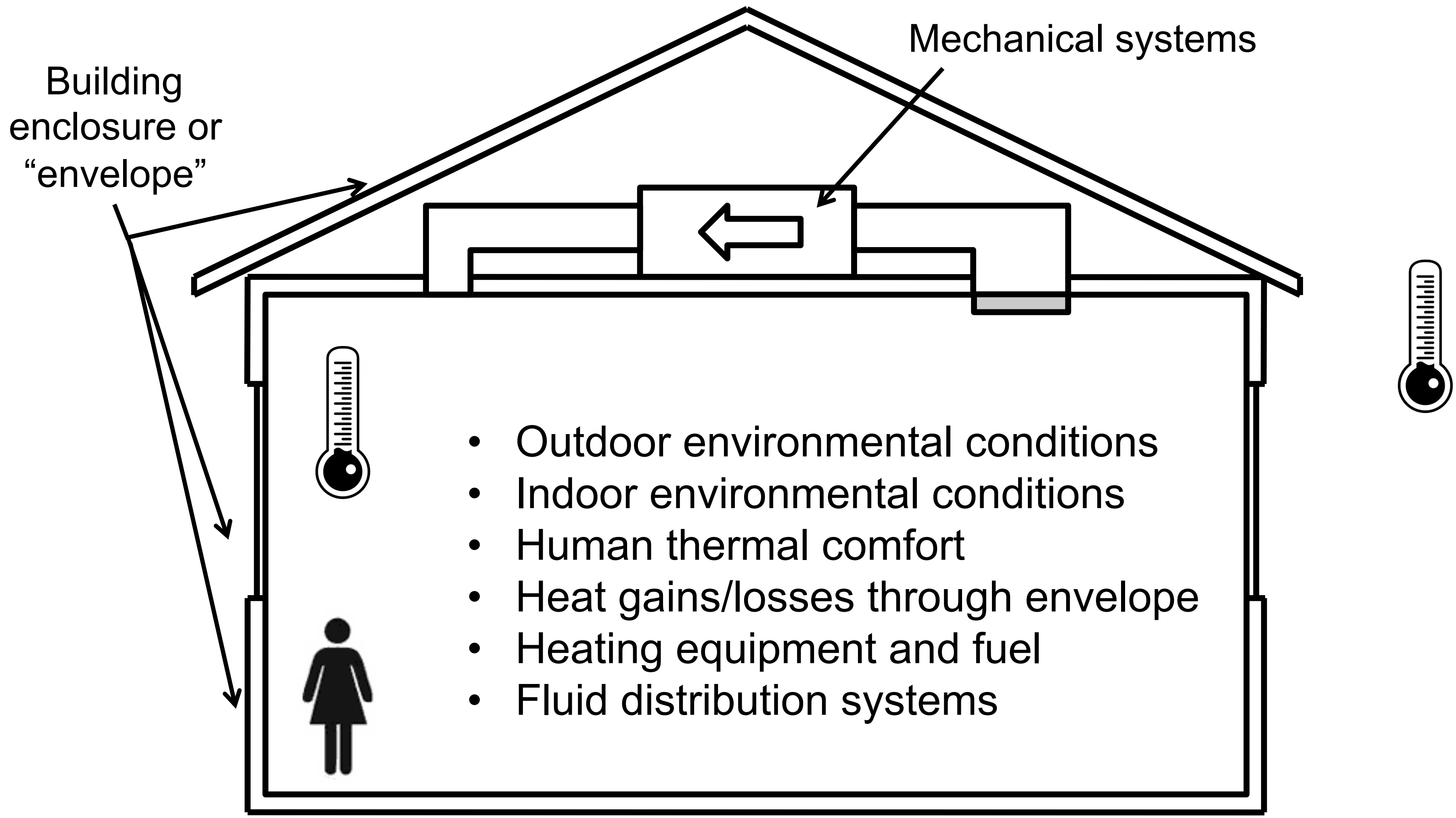
Understanding building energy use: Electricity profiles



Parker 2003 *Energy and Buildings* 35:863-876

Building energy use: Heating

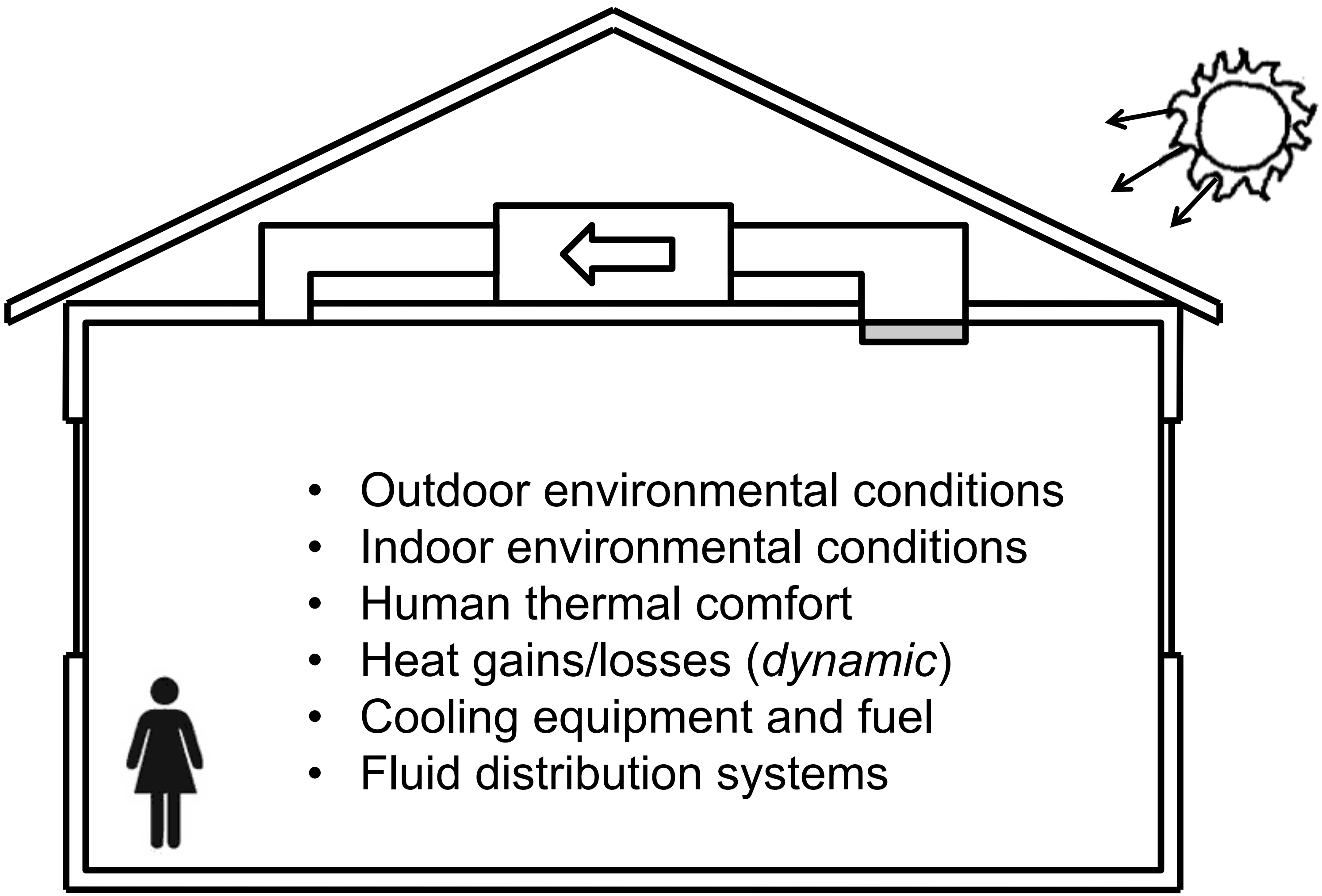
What do we need to know to understand how buildings **heat**?



- Outdoor environmental conditions
- Indoor environmental conditions
- Human thermal comfort
- Heat gains/losses through envelope
- Heating equipment and fuel
- Fluid distribution systems

Building energy use: Cooling

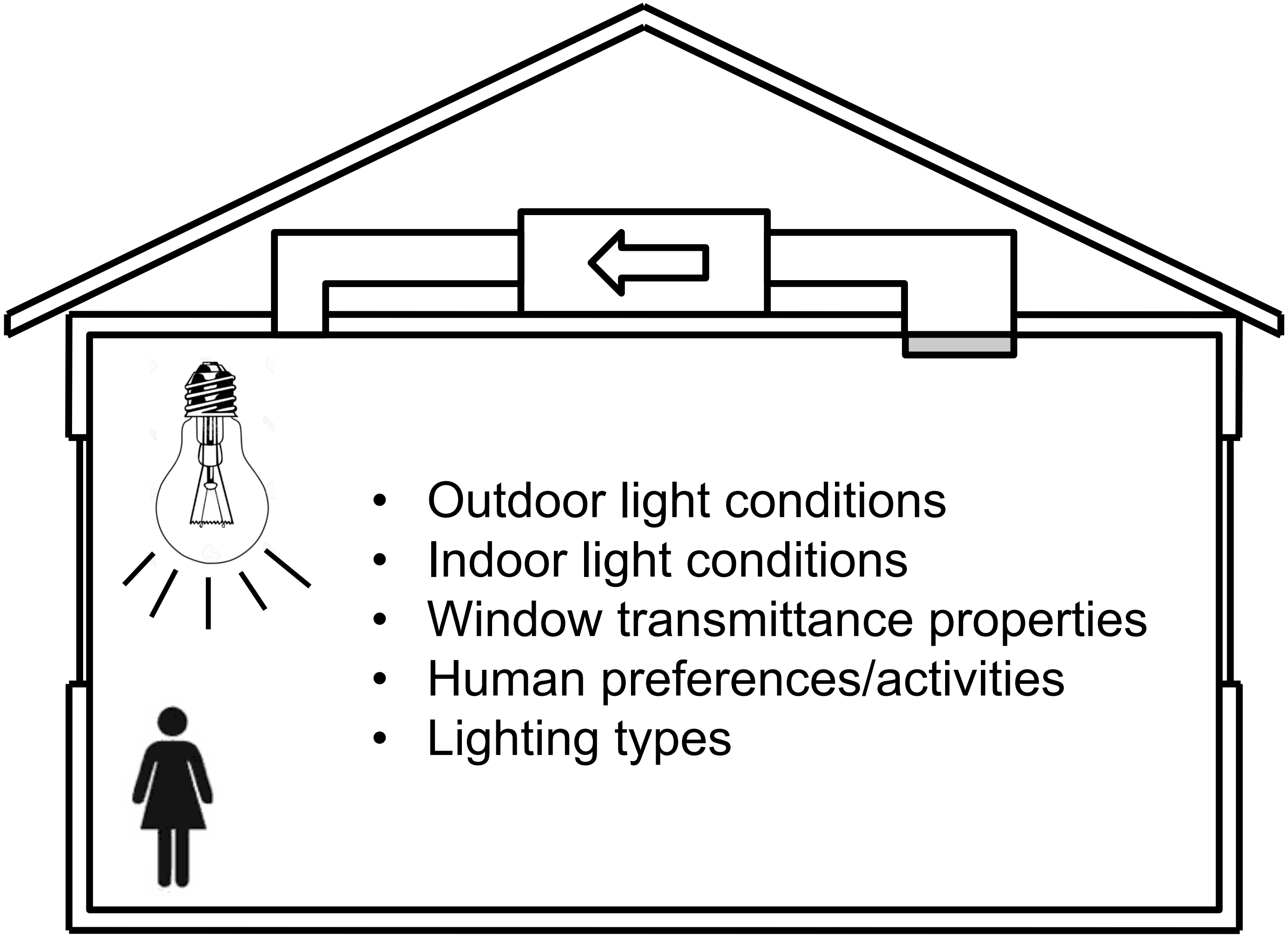
What do we need to know to understand how buildings **cool**?



- Outdoor environmental conditions
- Indoor environmental conditions
- Human thermal comfort
- Heat gains/losses (*dynamic*)
- Cooling equipment and fuel
- Fluid distribution systems

Building energy use: Lighting

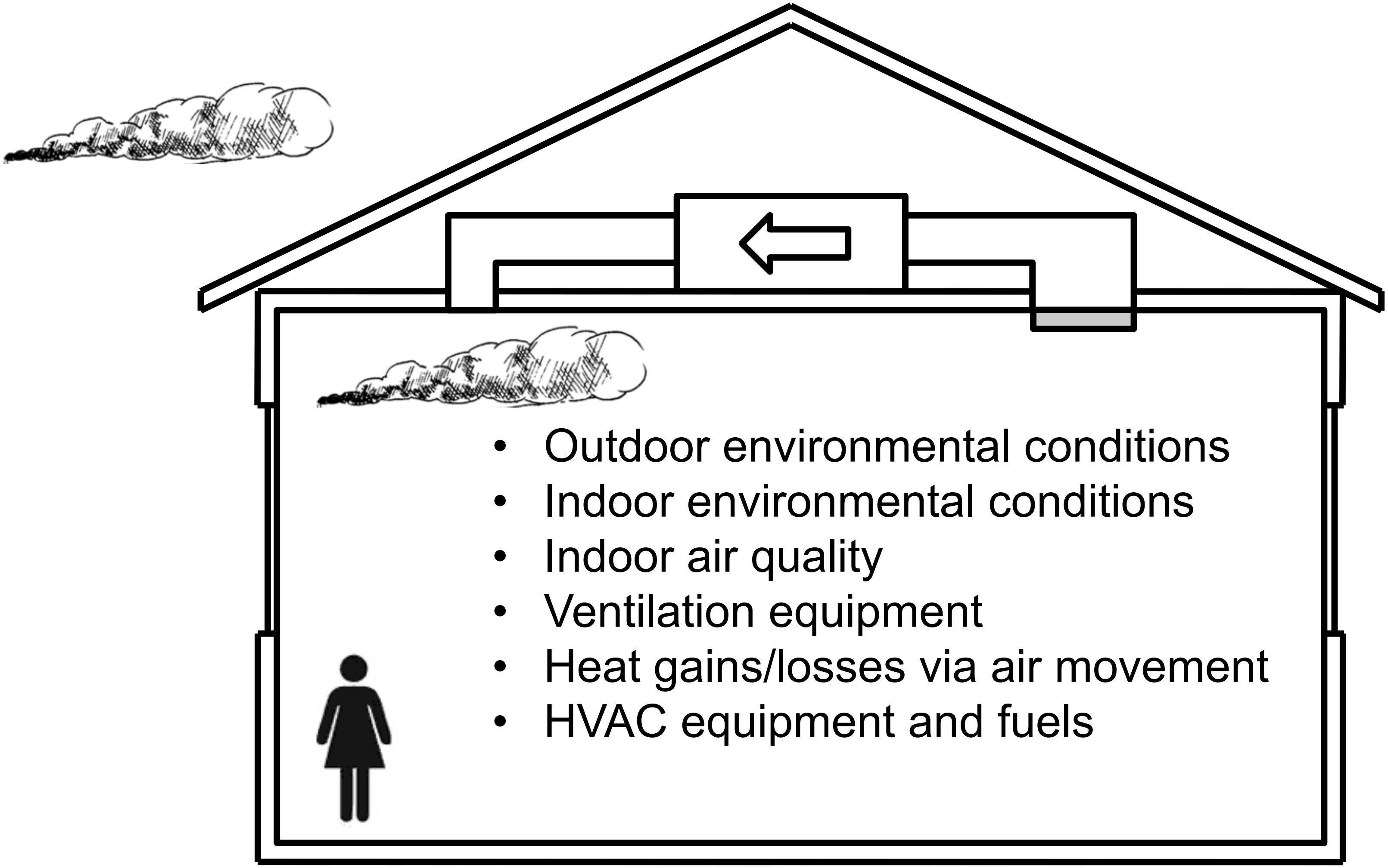
What do we need to know to understand **lighting**?



- Outdoor light conditions
- Indoor light conditions
- Window transmittance properties
- Human preferences/activities
- Lighting types

Building energy use: Ventilation

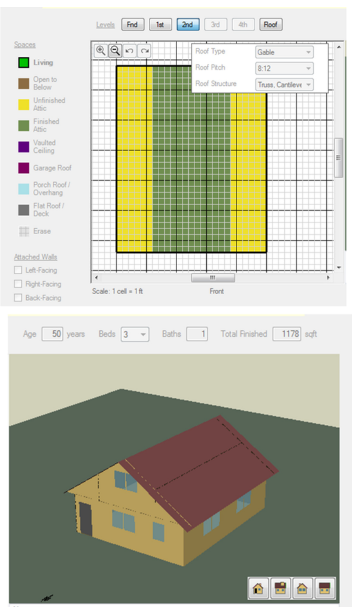
What do we need to know to understand **ventilation**?

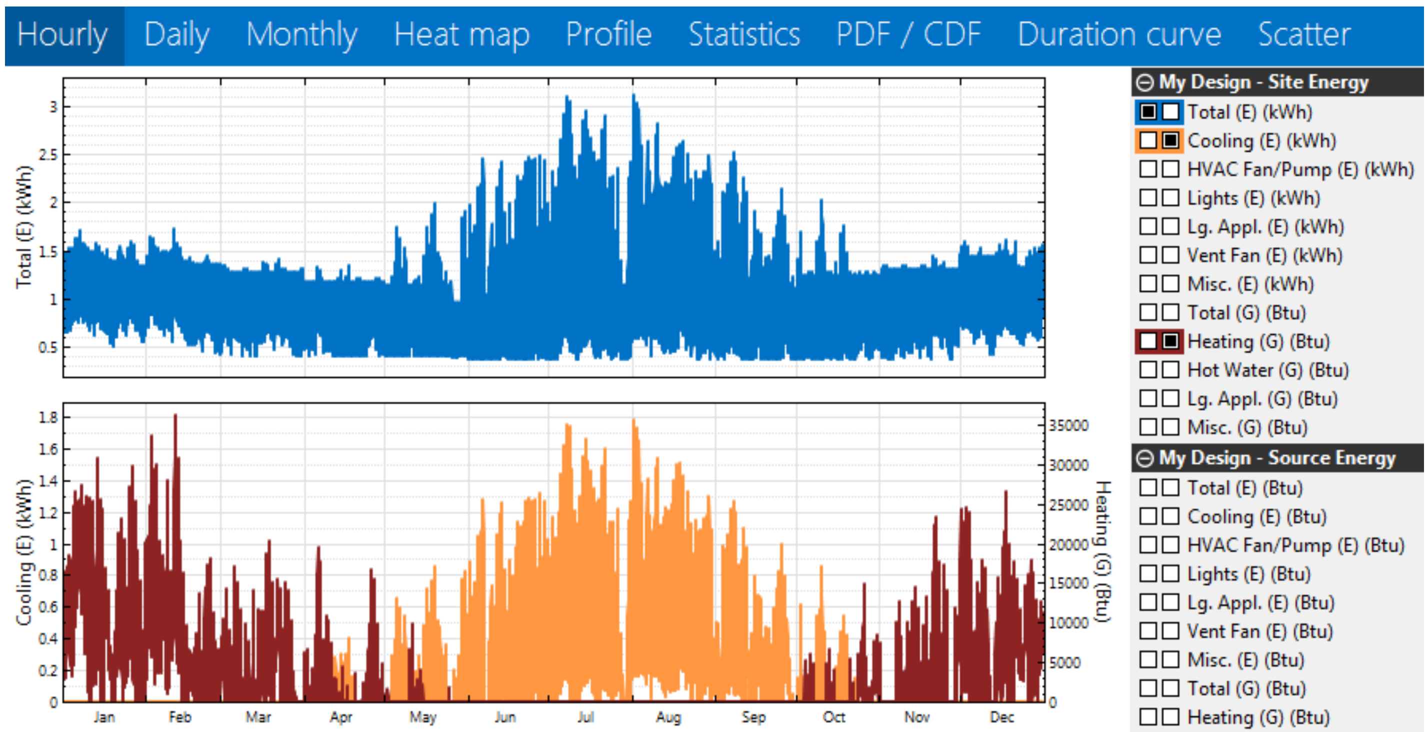


- Outdoor environmental conditions
- Indoor environmental conditions
- Indoor air quality
- Ventilation equipment
- Heat gains/losses via air movement
- HVAC equipment and fuels

Understanding building energy use

It all starts with understanding building and material properties and heat and mass transfer processes

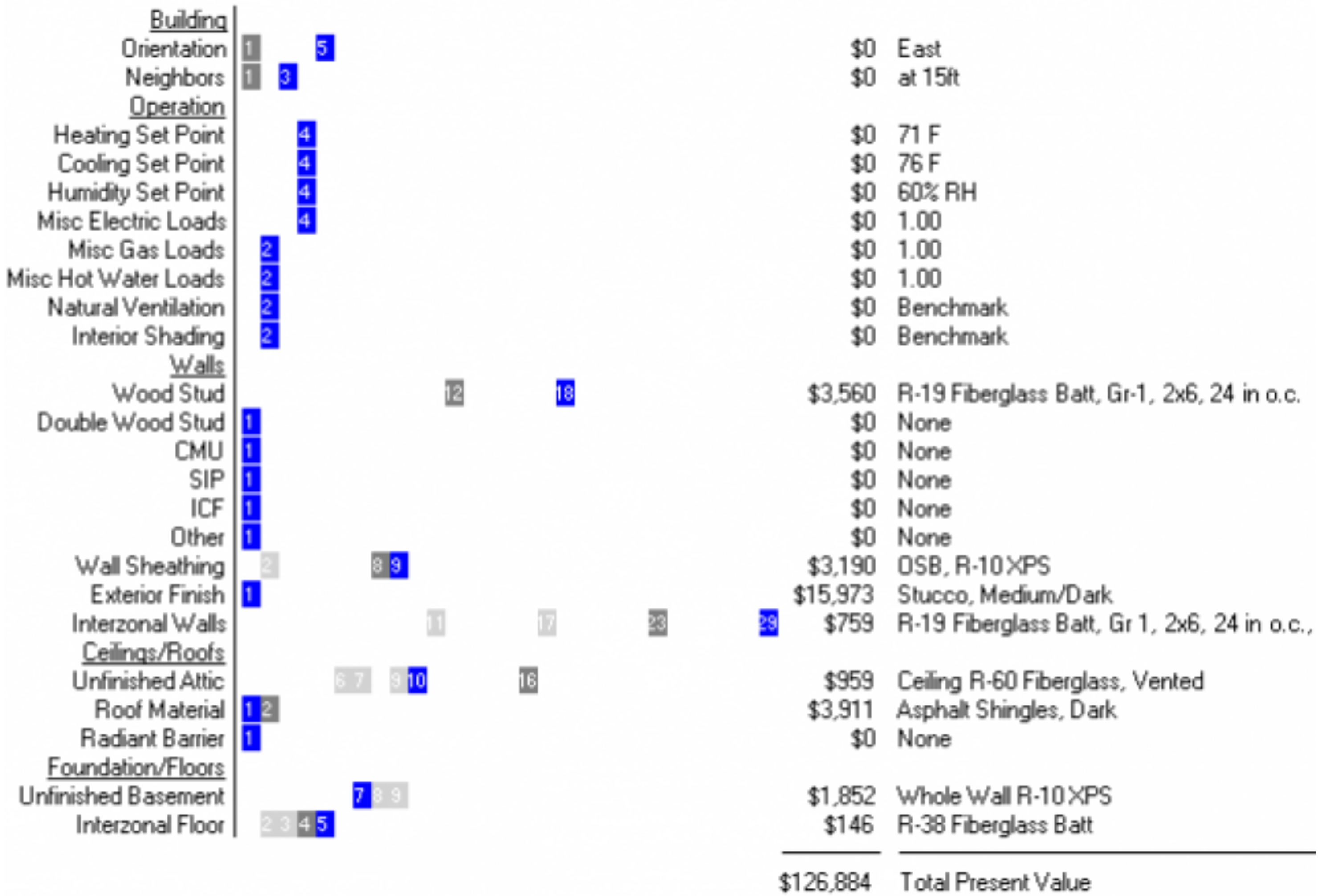




If we want to model this building….

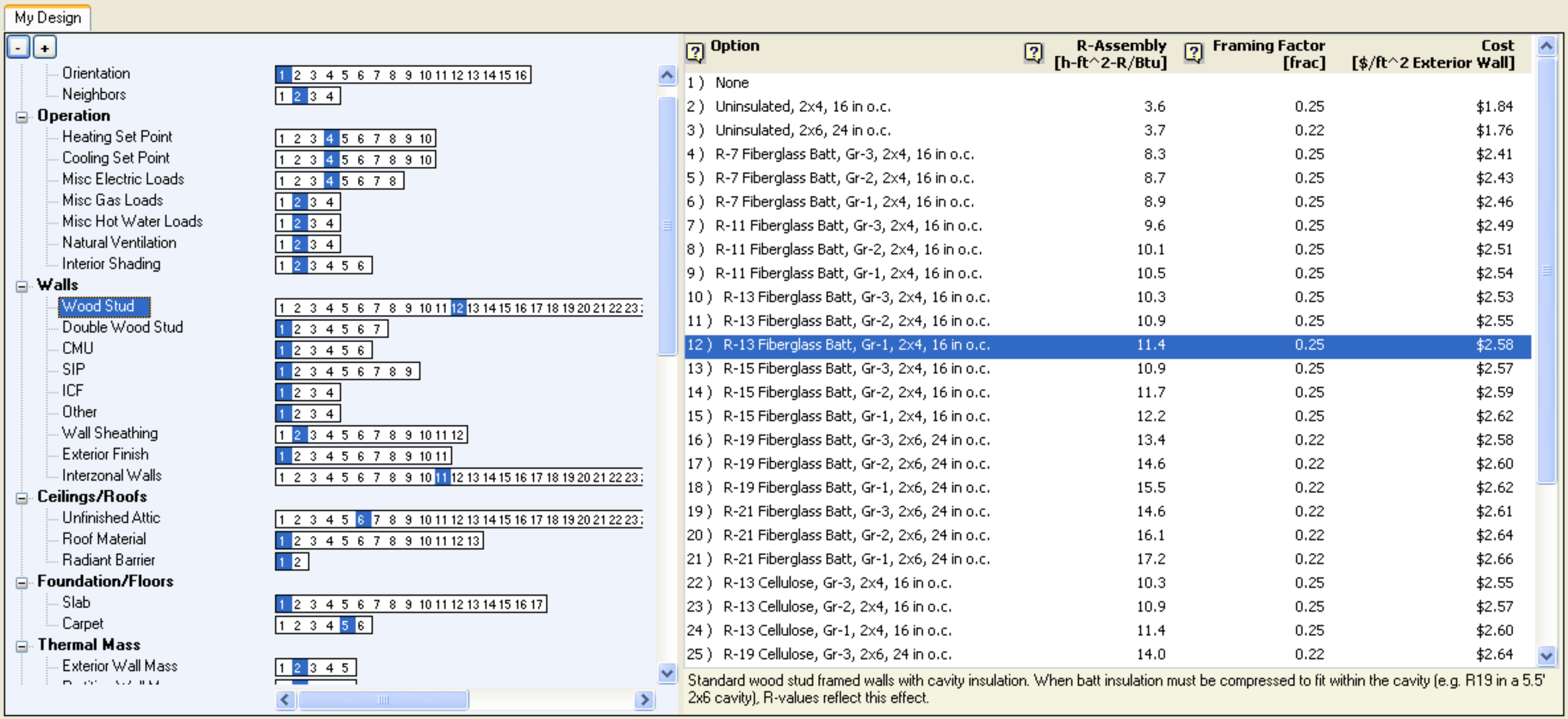
Understanding building energy use

It all starts with understanding building and material properties and heat and mass transfer processes



Understanding building energy-related properties

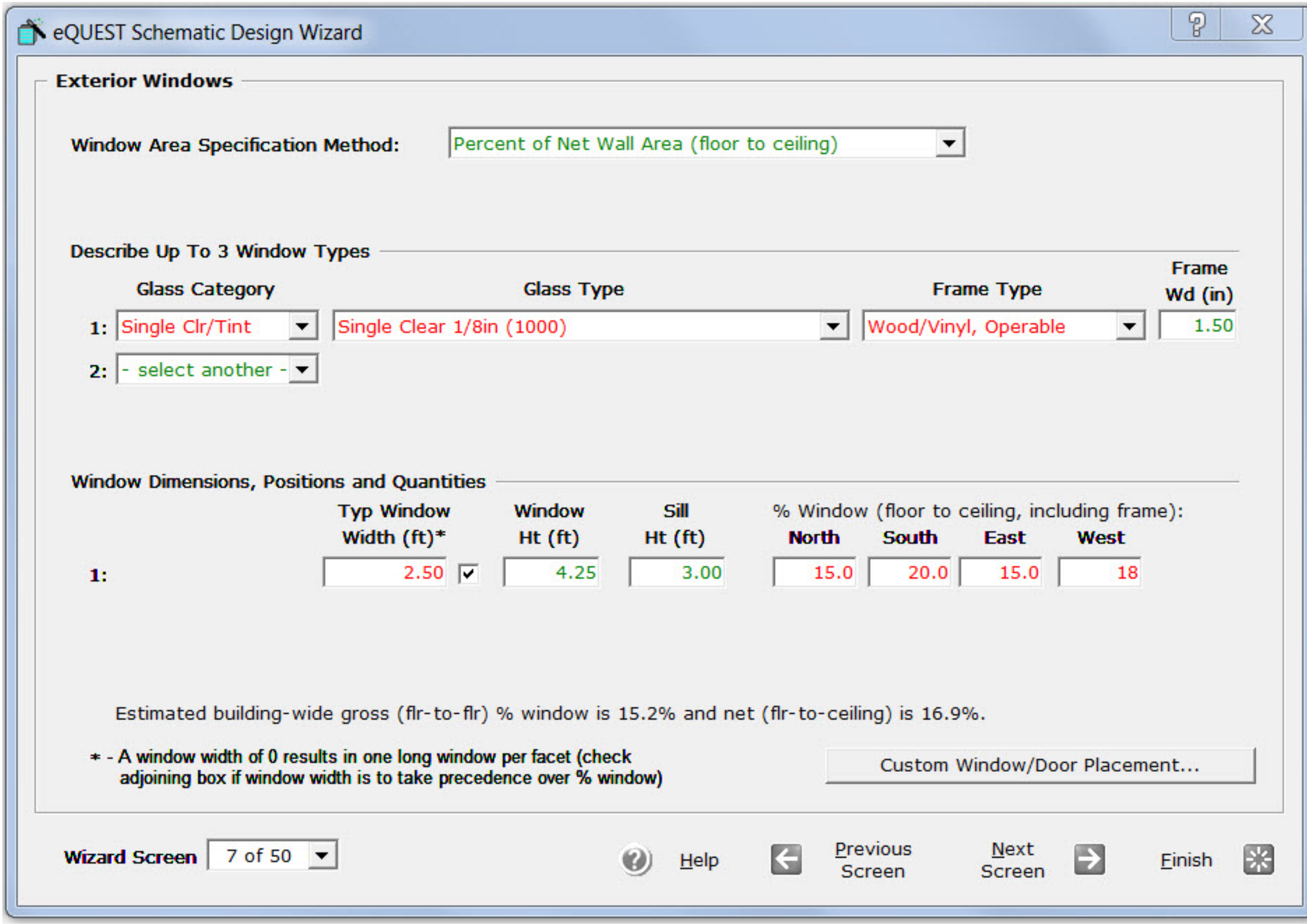
It all starts with understanding <u>building and material properties</u> and <u>heat and mass transfer processes</u>



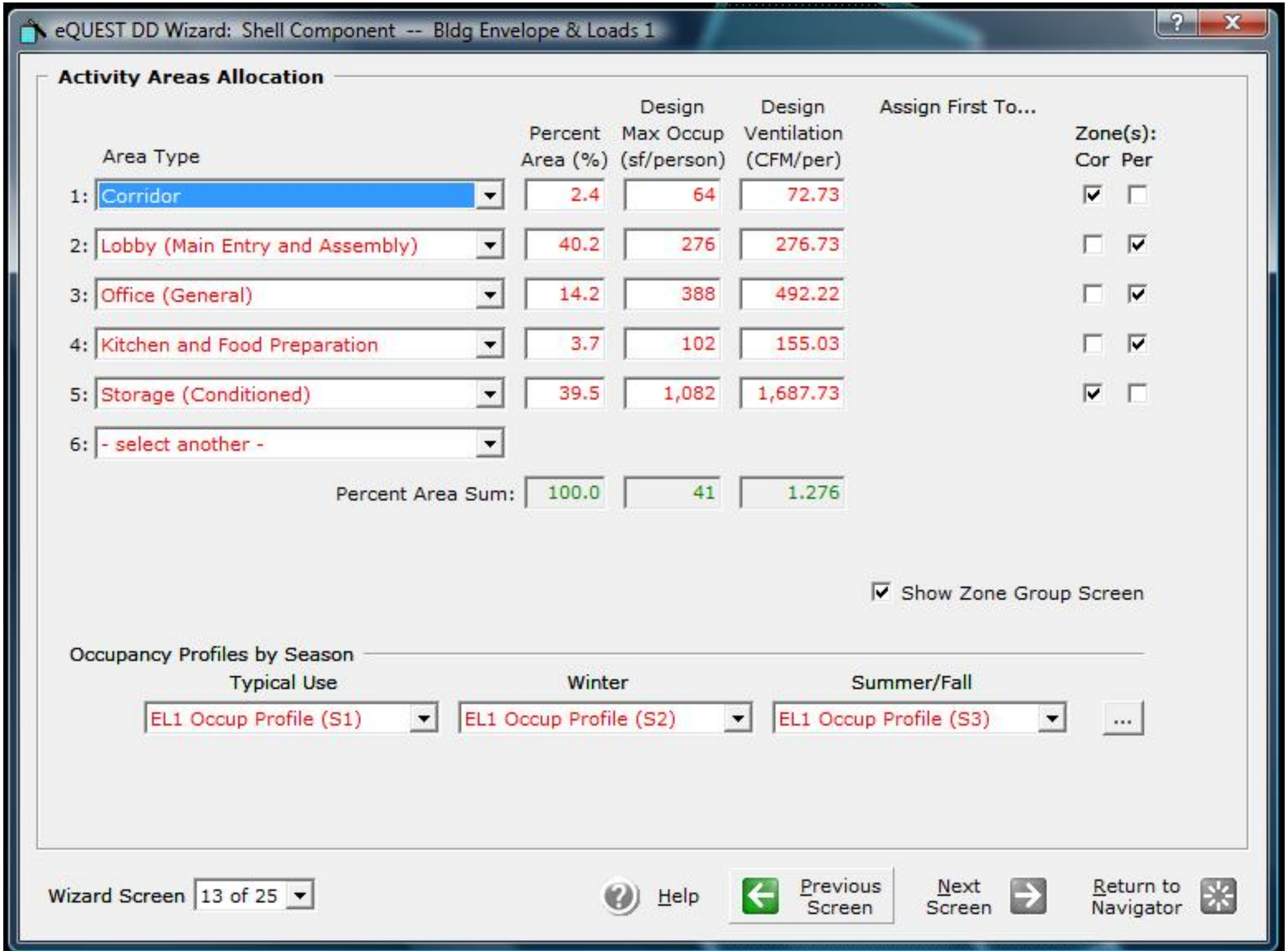
Option	R-Assembly [h-ft^2-R/Btu]	Framing Factor [frac]	Cost [$/ft^2 Exterior Wall]
1) None			
2) Uninsulated, 2x4, 16 in o.c.	3.6	0.25	$1.84
3) Uninsulated, 2x6, 24 in o.c.	3.7	0.22	$1.76
4) R-7 Fiberglass Batt, Gr-3, 2x4, 16 in o.c.	8.3	0.25	$2.41
5) R-7 Fiberglass Batt, Gr-2, 2x4, 16 in o.c.	8.7	0.25	$2.43
6) R-7 Fiberglass Batt, Gr-1, 2x4, 16 in o.c.	8.9	0.25	$2.46
7) R-11 Fiberglass Batt, Gr-3, 2x4, 16 in o.c.	9.6	0.25	$2.49
8) R-11 Fiberglass Batt, Gr-2, 2x4, 16 in o.c.	10.1	0.25	$2.51
9) R-11 Fiberglass Batt, Gr-1, 2x4, 16 in o.c.	10.5	0.25	$2.54
10) R-13 Fiberglass Batt, Gr-3, 2x4, 16 in o.c.	10.3	0.25	$2.53
11) R-13 Fiberglass Batt, Gr-2, 2x4, 16 in o.c.	10.9	0.25	$2.55
12) R-13 Fiberglass Batt, Gr-1, 2x4, 16 in o.c.	11.4	0.25	$2.58
13) R-15 Fiberglass Batt, Gr-3, 2x4, 16 in o.c.	10.9	0.25	$2.57
14) R-15 Fiberglass Batt, Gr-2, 2x4, 16 in o.c.	11.7	0.25	$2.59
15) R-15 Fiberglass Batt, Gr-1, 2x4, 16 in o.c.	12.2	0.25	$2.62
16) R-19 Fiberglass Batt, Gr-3, 2x6, 24 in o.c.	13.4	0.22	$2.58
17) R-19 Fiberglass Batt, Gr-2, 2x6, 24 in o.c.	14.6	0.22	$2.60
18) R-19 Fiberglass Batt, Gr-1, 2x6, 24 in o.c.	15.5	0.22	$2.62
19) R-21 Fiberglass Batt, Gr-3, 2x6, 24 in o.c.	14.6	0.22	$2.61
20) R-21 Fiberglass Batt, Gr-2, 2x6, 24 in o.c.	16.1	0.22	$2.64
21) R-21 Fiberglass Batt, Gr-1, 2x6, 24 in o.c.	17.2	0.22	$2.66
22) R-13 Cellulose, Gr-3, 2x4, 16 in o.c.	10.3	0.25	$2.55
23) R-13 Cellulose, Gr-2, 2x4, 16 in o.c.	10.9	0.25	$2.57
24) R-13 Cellulose, Gr-1, 2x4, 16 in o.c.	11.4	0.25	$2.60
25) R-19 Cellulose, Gr-3, 2x6, 24 in o.c.	14.0	0.22	$2.64

Standard wood stud framed walls with cavity insulation. When batt insulation must be compressed to fit within the cavity (e.g. R19 in a 5.5' 2x6 cavity), R-values reflect this effect.

Understanding building energy-related properties



Understanding building energy-related properties



UNITS IN BUILDING SCIENCE AND ARCHITECTURAL ENGINEERING

Importance of units

- Units are **EVERYTHING** in architectural engineering and building science

- Your first HW (assigned today) will cover unit conversions and energy concepts

- If you can understand and convert units, and if you can get a sense of scale and magnitude associated with units, you will be well on your way to becoming a building scientist

Building science units and dimensions

- Within architectural engineering, both SI and IP (inch-pound) units are used
  - I am **deeply sorry** for that
- IP is dominant in US engineering
  - (But changing slowly)
- We will use both in this class
  - So it will be useful to memorize the most commonly used constants and conversion factors between both units

Building science units and dimensions

- Lengths are usually in feet [ft] or meters [m]
- Volumes are usually in cubic feet [ft^3] or cubic meters [m^3]
- Volumetric flow rates are usually in [ft^3/min] (CFM)
  - Sometimes [m^3/hr], [m^3/s], [L/s]
  - Water flows are often [L/min] (lpm) or [gal/min] (gpm)
- Temperatures are either Fahrenheit [°F] or Celsius [°C]
  - Sometimes Kelvin [K], rarely Rankine [R]
- Velocities are either [ft/s], [m/s], or sometimes [cm/s]
- Concentrations are parts per million [ppm], parts per billion [ppb], or micrograms per cubic meter [$\mu g/m^3$]
- Mass is typically [lb_m] or [kg]

More building science units

- Energy is usually in [J] or [BTU]
  - Or [kWh] (for electric) or [therms] (for natural gas)
    - 1 kWh = 3412 BTU
    - 1 therm = 10^5 BTU
  - Or [MMBTU] = “million BTU” = 10^6 BTU

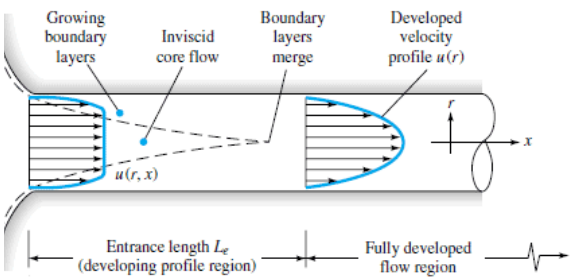
- Power is usually [W = J/s] or [BTU/hr]
  - Tons of refrigeration [1 ton = 12000 BTU/hr = 3412 W]

- Pressure is usually [Pa] or [in-wg or in w.c.] (inches of water)
  - Larger pressures are also [in-Hg] (inches of mercury)
    - Or [psi] (pounds per square inch) for very high pressures

Unit conversion examples

Unit conversion example problem:

- Water of density ρ = 62.44 lbm/ft^3 (1000 kg/m^3) flows at a rate of V = 10 gal/min (0.6308×10^{-3} m^3/s) through a pipe of interior diameter D = 1.0 inches (2.54 cm)



Velocity Profile of Fluid in a Pipe (laminar Flow)

- Find the velocity pressure, given by the formula:

$$P = \frac{\rho v^2}{2}$$

- Provide answer in units of [Pa] and [in-WG]

BB\Handouts\ASHRAE IP-SI Unit Conversions

	Enter I-P Number	I-P Unit	SI Conversion	SI Unit	Conversion Factor
2		acre (43,560 ft^2)	0	ha	0.4047
3		acre (43,560 ft^2)	0	m^2	4046.873
4		atmosphere (standard)	0	kPa	101.325
5		bar	0	kPa	100
6		barrel (42 U.S. gal, petroleum)	0	L	159
7		barrel (42 U.S. gal, petroleum)	0	m^3	0.1580987
8		Btu (International Table)	0	J	1055.056
9		Btu (thermochemical)	0	J	1054.35
10		Btu/ft^2 (International Table)	0	J/m^2	11,356.53
11		Btu/ft^3 (International Table)	0	J/m^3	37,258.95
12		Btu/gal	0	J/m^3	278,717.18
13		Btu·ft/h·ft^2·°F	0	W/(m·K)	1.730735
14		Btu·in/h·ft^2·°F (thermal conductivity k) .	0	W/(m·K)	0.1442279
15		Btu/h	0	W	0.2930711
16		Btu/h·ft^2	0	W/m^2	3.154591
17		Btu/h·ft^2·°F (overall heat transfer coefficient U)	0	W/(m^2·K)	5.678263
18		Btu/lb	0	kJ/kg	2.326
19		Btu/lb·°F (specific heat c_p)	0	kJ/(kg·K)	4.1868
20		bushel (dry, U.S.)	0	m^3	0.0352394
21		calorie (thermochemical)	0	J	4.184
22		centipoise (dynamic viscosity μ)	0	mPa·s	1
23		centistokes (kinematic viscosity ν)	0	mm^2/s	1
24		clo	0	(m^2·K)/W	0.155
25		dyne	0	N	1.00E-05
26		dyne/cm^2	0	Pa	0.1
27		EDR hot water (150 Btu/h)	0	W	43.9606
28		EDR steam (240 Btu/h)	0	W	70.33706
29		EER	0	COP	0.293
30		ft	0	m	0.3048
31		ft	0	mm	304.8
32		ft/min, fpm	0	m/s	0.00508
33		ft/s, fps	0	m/s	0.3048
34		ft of water	0	Pa	2989
35		ft of water per 100 ft pipe	0	Pa/m	98.1
36		ft^2	0	m^2	0.092903
37		ft^2·h·°F/Btu (thermal resistance R)	0	(m^2·K)/W	0.17611

Unit conversion and energy concepts

Order of magnitude example problem:

- How long would you have to operate a 60 W light bulb immersed in a bathtub to warm up the water by 1 degree C (1.8 degree F), assuming there are no losses?
  - Do not try this at home

Internal energy:

$$E = mC_pT$$

m = mass (kg)
E = internal energy (J)
C_p = heat capacity (J/kg/K)
T = temperature (K)

Unit conversion and energy concepts

Order of magnitude example problem:

- From what height would you have to jump into the same bathtub to warm up the water the same amount, assuming that all of the kinetic energy from the jump goes into heating the water (again, there are no losses)?

Work = change in energy

Work = force x distance

Change in energy = gravitational force x height

$$\Delta E = mgh$$

MOVING FORWARD

HW #1 due next week

- HW 1 is now available on blackboard
- Due Tuesday, August 30

Next time

- Beginning heat transfer in buildings