Energy Footprint

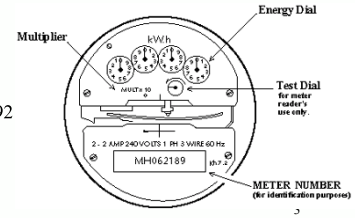
A Case Study

Electricity meter

- Electricity meters read in kWh (kilowatt-hour)
  - this is a unit of energy: power times time
  - 1 kWh is 1,000 W over 1 hr = 3,600 seconds
    - or 1 W over 1000 hours, or 100 W over 10 hours
  - thus 1 kWh = 3,600,000 J (= 860 kcal)
- My electricity bill indicates a cost of $0.13 per kWh
  - try getting 860 kcal of food for $0.13
  - lesson: eat your electricity—it's cheap!
  - tastes bad, though: burnt tongue smell/taste

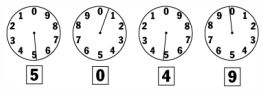
Measuring your electricity consumption

- All houses/apartments have energy meters to monitor electricity usage
  - this is what the bill is based on
- Dials accumulate KWh of usage
- Disk turns at rate proportional to power consumption
  - Kh value is the number of Watt-hours per turn (1 Wh = 3600 J)
- Example: one turn in 10 sec
  (7.2 Wh)×(3600 J/Wh)/(10 sec) = 2592 J/s ≈ 2.6 kW
- Takes 138.9 turns for 1 kWh



Reading those tricky dials

- Let's say you want to read a utility electricity meter…
- Be careful to note the direction of the numbers (usually flips back and forth)
- Round *down* is the safe bet
- Note the third dial below looks like 5, but it's really 4.9 (next digit is a nine)
  - so looking at next dial helps you figure out rounding
  - note second dial halfway between 0 and 1: next digit ~5
- This meter reads 5049.9
  - the 9.9 reads between the lines in the last dial



Clicker question

- What does this meter read?
  - A. 11198.8
  - B. 11088.8
  - C. 11199
  - D. 11188.8
  - E. 22199

Measuring the wheel rate

- Recall that the Kh constant is Watt-hours per turn of the disk
  - so power is Kh×3600×disk rate
  - units are: (Watt-hour)×(sec/hour)×(turns/sec)
- On top of the rotating disk are tick marks with labels every 10 units.
  - 100 units around disk
- If disk is moving slowly, can measure half a rotation*
  - example: from 30 to 80 or 70 to 20
- If disk is moving fast, can measure time for 5 or 10 rotations
- The the turns/sec could be, for example:
  - 0.5 turns / 132.0 sec → 98 W for Kh = 7.2
  - 10 turns / 44.0 sec → 5890 W for Kh = 7.2
  - 0.2 turns / 35.0 sec → 148 W for Kh = 7.2

 * careful here: disk rate can be highly non-uniform; best to measure full rotation

Digital Meters

- Digital meters more pervasive lately
- Cycles through several displays
  - one is "odometer" reading in kWh
  - no tricky dials
- "Disk" is simulated by blocks that appear/disappear
  - each change constitutes 1.0 Wh for my meter
  - my meter has six "disk" states
  - so full cycle is 6 Wh

"disk" blocks

Example day electricity profile

- Run microwave (1000 W) for 12 minutes total (0.2 hr)
  - 0.2 kWh
- Clothes washer (300 W) for 1 hour
  - 0.3 kWh
- Clothes dryer (5000 W) for 1 hour
  - 5 kWh
- Movie on TV/DVD (200 W) for 2 hours
  - 0.4 kWh
- Desktop computer (100 W) on all day
  - 2.4 kWh
- Refrigerator (average 75 W) on all day
  - 1.8 kWh
- Lights (total 400 W) for 5 hours
  - 2 kWh
- Total comes to 12.1 kWh: not *too* different from average usage
  - costs about $1.50 at $0.13 per kWh

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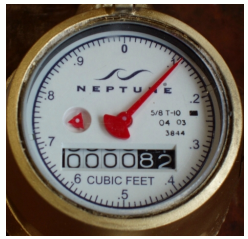
Natural Gas Meter

- Dials work just like electricity meter
  - same round-down method
- Lowest dial usually indicates 1000 cf per full revolution
  - cf means cubic foot, or ft^3
- Thus each tick is one hundred cf (hcf)
  - therefore numerical reading in hcf
- 100 ft^3 delivers 1.02 Therms of energy
  - 1 Therm is 100,000 Btu = 105,500,000 J = 29.3 kWh
  - my gas bill indicates about $1 per Therm
  - equivalent to $0.034 per kWh: cheaper than electricity
- My meter also has a 0.5 cf dial and a 2 cf dial
  - which I have used to monitor slow usage

Water meter

- Though not a measure of energy, this can be important because one thing we do with water is *heat it*
- Meters typically measure in cubic feet
  - 1 ft^3 = 7.48 gallons
  - 1 gallon is 8.33 lb, so 1 ft^3 = 62.3 lb
  - recall that heating 1 lb H_2O 1°F takes 1 Btu = 1055 J
- The meter at right reads 82.114 ft^3
  - the ones digit usually snaps into place quickly so it's not halfway between numbers for very long
  - the little triangle spins if water is flowing



And finally, gasoline

- Gasoline energy content is:
  - 34.8 MJ/liter
  - 47 MJ/kg
  - 125,000 Btu/gallon = 132 MJ/gallon = 36.6 kWh/gallon
- At $4.00 per gallon, this is $0.11 per kWh
  - slightly cheaper than electricity, more expensive than natural gas

Energy Profile

- Looking at my bills April 2006–March 2007, I saw that my household (2 people) used:
  - 3730 kWh of electricity in a year → 10.3 kWh/day
  - 330 Therms of natural gas in a year → 0.9 Therms/day = 26 kWh/day
  - 10 gallons of gasoline every 2 weeks → 26 kWh/day
- Total is 62 kWh/day = 2580 W
  - or 1300 W per person
  - 13% of 10,000 W American average
  - says most activity in commercial sector, not at home

Something doesn't add up…

- Something wasn't making sense
- 0.5 Therms/day = 50,000 Btu/day during summer months when the only natural gas we used was for hot water
- A typical 10-minute shower at 2 gallons per minute means 20 gallons or 166 lbs of water
- To heat 166 lbs water from 60 °F to 120 °F (60 °F change) requires 166×60 = 10,000 Btu
- Averaging 1 shower/day, we should be using 5 times less natural gas, or about 0.1 Therms/day
- Where is the 0.5 Therms coming from?!

Watching the dials

- I started watching the 2 cf/turn dial on my gas meter
  - no gas was being used (no furnace, no hot water)
  - it was making about 0.72 turns per hour, so 1.44 cf/hr
  - steady rate, hour after hour
  - that's 34.6 cf/day, or 0.346 hcf/day = 0.35 Therms/day
  - this is close to the missing amount!
- Where was that gas going?

The Fix

- Shutting off gas to the furnace resulted in a much slower dial progression
  - rate was about 0.11 Therms/day
  - this part must be the water heater pilot
  - the rest (0.24 Therms/day) was the furnace pilot
    - this means the (useless) furnace pilot matched the (useful) hot water heater gas consumption!
    - also, half the hot water heater gas (0.11 Therms/day) is the pilot
- The resultant cost for both pilots was
  - (0.35 Therms/day)×(30.6 days/month)×($1.30/Therm)
  - $14 per month
  - save almost $10/month by turning off furnace pilot

But I'm not done measuring yet!

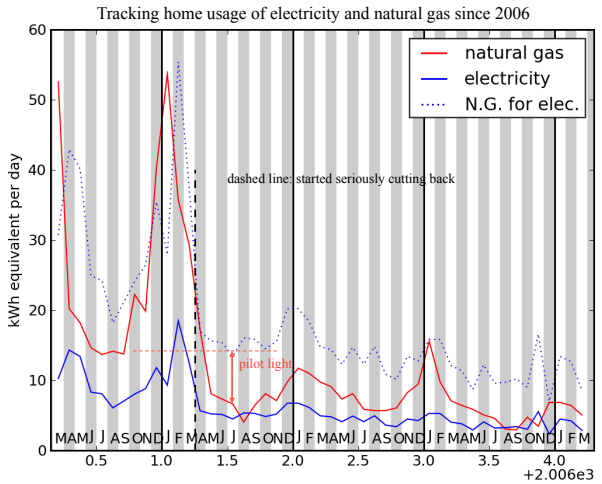
- How much does a shower take?
  - 10 minute shower: measured 2.75 ft^3 = 20.57 gallons via meter
  - gas kicked on and used 15.3 ft^3 = 0.156 Therms before it stopped
    - at rate of 0.5 cf/minute
    - 0.005 Therms/minute = 500 Btu/minute = 30,000 Btu/hr = 8800 W
    - water heater says 34,000 BTUH on side
  - Used 15,600 Btu for shower
    - 20.57 gallons = 171 lbs
    - heating by 60 °F requires 10,280 Btu at 100% efficiency
    - so must be about 10280/15600 = 65% efficient
    - actually less since shower used 20.57 gallons, but not *all* hot

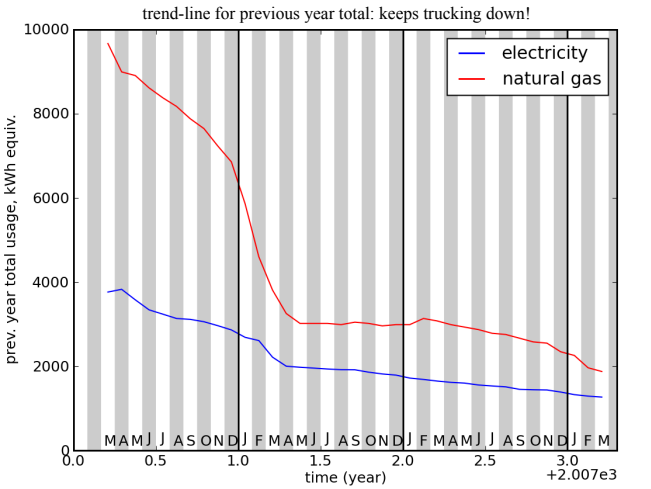
Average Americans

- 830 kWh electricity per month per household
  - about 300 kWh per person per month (10 kWh/day)
- 6×10^{12} ft^3 of natural gas use in residences per day
  - 480 kWh gas equivalent per month per person (16 kWh/day)
- 0.5 gallons gasoline per day per person
  - 560 kWh per month equivalent (18 kWh/day)
- Total power is 1340 kWh/month (44 kWh/day) = 1820 W
  - this is 18% of the average American's total of 10,000 W
  - so again, most is outside the home (out of sight, out of mind)

How much better can we do?

- Starting in 2007, my wife and I challenged ourselves to reduce our energy footprint
  - never turned furnace/pilot back on
    - low power electric blanket helps!
  - shorter showers, with cutoff for soaping up
  - line-dry clothes
  - all bulbs compact fluorescent, some LED
  - diligent about turning off unused lights
  - bike/walk around neighborhood (and bus to work)
  - install experimental (small) solar photovoltaic system (off-grid; battery-based) to run TV & living room
    - since expanded to 1kW peak system; fridge, TV, modem/wireless





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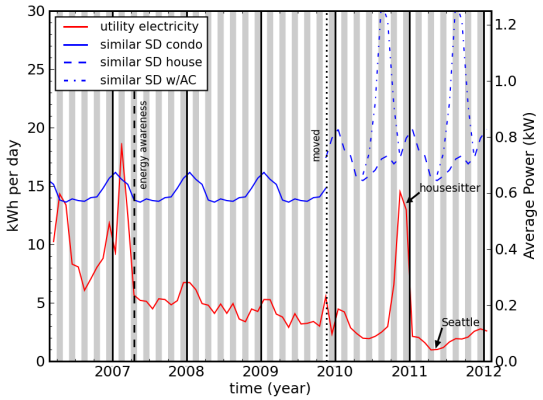
Update: Livin' the Low Life in S.D.



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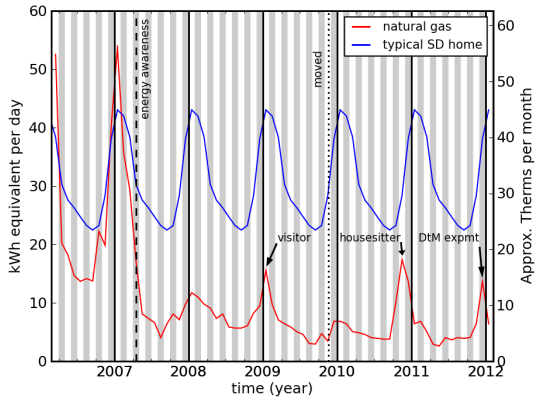
Update: Gas Use History



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Big Reductions

- Most substantial savings was gas (no furnace)
  - Immediately went from 0.84 Therms/day to 0.28 Therms/day
    - equivalent to 25 kWh/day, now down to 8 kWh/day
    - now at ~5 kWh/day
    - now using a fifth of what we used to!
- Line-drying clothes had largest electricity impact
  - some space-heater activity to compensate for no heat
  - Immediately went from 10.5 kWh/day to 5.5 kWh/day
    - now at <3 kWh/day
    - now using a fourth of what we used to
    - but this requires about three times the energy in natural gas due to the inefficiency of generation, plus some transmission loss, so the real post-reduction usage is more than twice that of natural gas

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Carbon Footprints

- Each gallon of gasoline contributes 20 lb CO_2
- Each kWh of electricity from natural gas plant (at 33% net efficiency) contributes 1.2 lbs CO_2
- Each Therm of natural gas contributes 11.7 lbs CO_2
- So my annual household CO_2 footprint (2 people):
  - 4600 lbs + 3600 lbs from elec. plus N.G. before April 2007
  - 2400 lbs + 1200 lbs from elec. plus N.G. just after April 2007
  - 7130 lbs per year from gasoline (@ 10,000 miles per year)
  - 15,000 lbs from air travel (at 0.48 lbs/passenger-mile)
- See: http://www.earthlab.com/carbon-calculator.html
  - also Google: carbon footprint calculator

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Lessons

- It is illuminating to assess your energy footprint
  - how much do you get from which sources?
  - how much would you have to replace without fossil fuels?
  - how can you cut down your own usage?
- Again we see that the bulk of energy expenditures are not at home or in our cars
  - but in the industry, agriculture, transportation, commercial sectors.

Announcements and Assignments

- Lots of Do the Math posts on this topic
  - see Guide to Posts from menu bar; list at bottom of page
    - 38. Pilot Lights are Evil
    - 39. Home Heating for the Hardy
    - 41. The Phantoms I've Killed
    - 46. My Neighbors Use Too Much Energy
    - 53. TED-Stravaganza
- Read Chapter 4 for next lecture
- HW #4 due Friday 5/03
  - HW drop box outside my office (SERF 336) for early turn-in
- Quiz 3 due by midnight tonight