1 Gasoline Sun

(a) Electromagnetic radiation energy from the Sun arrives at the upper atmosphere of our planet at a rate of about 1350 $\mathrm{J/(s \cdot m^2)}$. Use this information, together with the average radius of the Earth's orbit, to show that the Sun radiates energy at a rate of about 4×10^{26} J/s.

(b) We know from radiometric dating of rocks on Earth (and the Moon and Mars) that our solar system is about 4 billion years old. Let's make a naïve hypothesis (like scientists did in the early 1900s) that the Sun is powered by burning hydrocarbons. What mass of gasoline would be needed to power the Sun at a rate of 4×10^{26} J/s for 4 billion years? Compare to the actual mass of the Sun.

Note: The energy density of hydrocarbon fuels, including gasoline, natural gas, dry logs of wood, chocolate, croissants, gummy bears, etc. etc. is ≈ 40 MJ/kg.

2 Hot showers and standard deviation

(a) Estimate the energy used during a typical 10-minute shower in the United States. The dominant variables in this problem are the temperature rise of the water and the flow rate of the showerhead. Develop a coarse-grained model that incorporates these two variables. For simplicity, you may assume: (i) The water heater is 100% efficient at converting electrical energy into heat, and (ii) the water heater is located close to the shower, so heat losses in the pipes can be neglected.

(b) Develop a reasonable estimate for the standard deviation of your answer to part a. That is, imagine measuring the energy used for a 10-minute shower in a thousand randomly selected U.S. households. How much would the energy use vary? To develop a reasonable estimate, spend a little time doing internet research (or in-person research) on the variability of shower flow rates, the variability of ground temperature, and the variability of shower water temperature (personal preference). Once you can justify reasonable numbers for the variability of these inputs, propogate the uncertainty through your coarse-grained model using the methods we discussed in class.

(c) **Sense making:** Compare the typical energy used for a 10-minute shower to the typical energy used to drive an elecric car at 70 mph for 10 minutes.

3 Heat loss from a single-family home in winter

Consider a family home that has a floor area of 50 feet × 50 feet, and a ceiling height of 10 feet. The house has typical the insulation for the Pacific Northwest: R-15 walls and an R-30 ceiling.

To help you with physics reasoning, I have converted the R-values into standard-international (SI) units for heat conductance per unit area:

$$\text{wall conductance per unit area} = 0.4\ \frac{\text{W}}{\text{K.m}^2} \tag{1}$$

$$\text{ceiling conductance per unit area} = 0.2\ \frac{\text{W}}{\text{K.m}^2} \tag{2}$$

Based on the units listed above, and the context (thermal insulation), you can visualize the meaning of these proportionality constants. For example, if there is a 1 kelvin temperature difference between inside/outside the house, every square meter of wall will leak energy at a rate of 0.4 J/s. Doubling the temperature difference, or doubling the wall area, will double the leak rate.

If the indoor temperature is 293 K (68°F), and the outdoor temperature is 273 K (32°F), how fast does heat energy leak out of the house (joules/second)? For this question, please assume the floor is perfectly insulated so that no heat leaks out of the floor.

Sense making 1: Three of the most significant categories of human energy use in the United States are (1) the embodied energy of the stuff we buy ≈ 170 MJ/day per person, (2) the energy used driving cars ≈ 140 MJ/day per person, (3) the energy used by jet flights ≈ 100 MJ/day per person (all these energy rates are averaged over the course of a year). How does the heat loss from a family home compare to the other categories on this list?

Sense making 2: How many small, portable heaters are needed to heat this house? (assume 1 kW heaters). Does this seem like a realistic number of heaters?

4 Tea kettle

Consider the electric kettle shown in the picture. There is 1 kg of water in the kettle (4 cups of water). This electric kettle transfers energy to the water by heating. The rate of energy transfer is 1000

J/s. The specific heat capacity of water is 4.2 J/(g.K). Calculate the rate that the water temperature rises. Give your answer in units of kelvin/s.

Note: This is an exercise in proportional reasoning. You should not need to look up any formulas.

Sense-making: Put it in context—At this rate, how long would it take to heat up a kettle for making tea? Does this seem like a realistic number?