CHAPTER 9

Housing and Households (MKH 6)

Households are sites of energy and material consumption. For example, Figure 4.5 shows that 11.9 quads of energy are consumed in U.S. residences[1], predominantly electricity, natural gas, and petroleum. This 11.9 quads represents 16% of final energy consumption. As Chapter 4 shows, energy consumption is the source of sustainability impacts (CO_2 emissions and resource depletion, for example) far beyond the site at which useable energy is converted to heat. In addition to energy, sustainability impacts arise from household decisions about food and material consumption, too. Thus, decisions made in households have sustainability implications far beyond the walls of each abode.

Often, people have little power to make decisions with sustainability implications at work, school, or church. Others (physical plant employees, custodial staff, or supervisors) control buildings and appliances that consume energy, material, and other resources. In contrast, households are the only place where some people have agency to make decisions that have sustainability implications.

> Households are a (the) site where sustainability meets everyday life.

Figure 9.1 shows how the average U.S. resident allocates their energy consumption, by showing the percentages of energy consumption for several end uses [32, Fig. 3]. The end use categories in Figure 9.1 illustrate how choices made in households intersect with sustainability topics covered in other chapters, including energy (Chapter 4), water (Chapter 5), and food (Chapter 7). Clearly, population (Chapter 2), the economy (Chapter 3), land use and urban planning (Chapter 10), government and regulations (Chapter 11), values (Chapter 13), and personal action (Chapter 14) also affect household sustainability.

The end uses in Figure 9.1 can be aggregated to form fewer major categories of residential energy consumption. Space heating and cooling comprise 36.6% of all energy household energy consumption (including furnace fans). Hygeine (including

[1] A quad is 1 short quadrillion BTUs, or 10^{15} BTU.

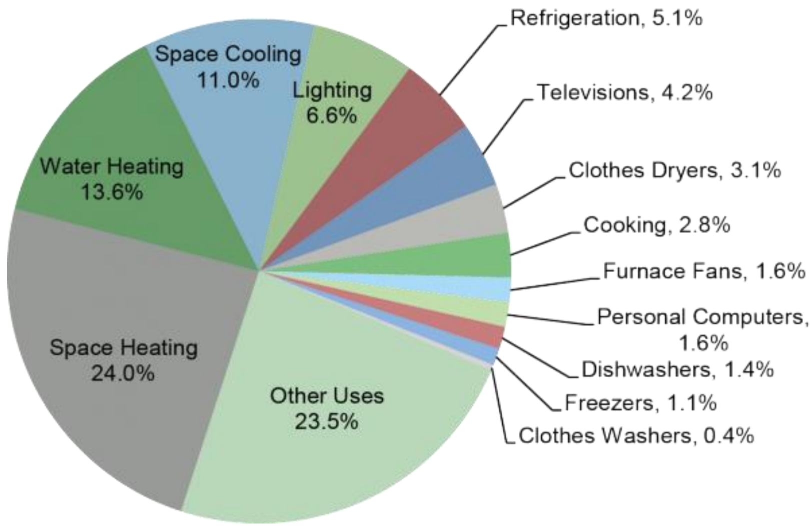

Figure 9.1: Average U.S. residential energy consumption by end use [32, Fig. 3].

water heaters, clothes dryers, dishwashers, and clothes washers) consumes 18.5% of household energy. Lighting consumes 6.6% of total household energy use.

Guided by the aggregation above, this chapter focuses attention on four important sustainability topics that intersect with household life, namely purchasing or renting a home or apartment, heating and cooling, hygeine, and lighting. This focus narrows the scope of this chapter and avoids repeating material from others.

9.1 PURCHASING AND RENTING

Many aspects of purchasing or renting a residence have sustainability implications, size and location chief among them.

9.1.1 SIZE

Figure 9.2 shows the trend of electricity consumption with respect to home size and confirms intuition that dwelling size is positively correlated with energy consumption. However, significant variation in annual electricity consumption is observed between the 20^{th} and 80^{th} percentiles at any home size. These variations indicate that decisions about *how* a dwelling is used are nearly important as the *size* of a dwelling for predicting residential electricity consumption.

**** Find data on natural gas consumption vs. size of home. 80–20 variations on that graph are likely due to climate and insulation differences. See the EIA's Residential Energy Consumption Survey (RECS), which may have the required information. May need to look at the "microdata" available from RECS. ****

Figure 9.3 shows the average floor space of new single family homes in the United States between 1970-2015 [33, Fig. 1]. Taken together, Figures 9.2 and 9.3 would suggest that residential energy consumption per dwellling is rising through time. However, per-dwelling energy consumption seems to be falling slowly in the U.S., with increased energy efficiency of appliances and building envelope improvements offsetting rising home sizes. However, total residential energy consumption is increasing, driven by increasing numbers of dwellings. Figures 9.4 and 9.5 show these trends.

One might think that increasing dwelling sizes are driven by more occupants per dwelling. However, Figure 9.6 shows that the percentage of single-person households is increasing through time [35, Fig. 2].

From a sustainability point of view, smaller, more-efficient homes with larger numbers of occupants are preferred. However, trends suggest that homes are becoming more efficient, but they are becoming larger and have fewer occupants through time.

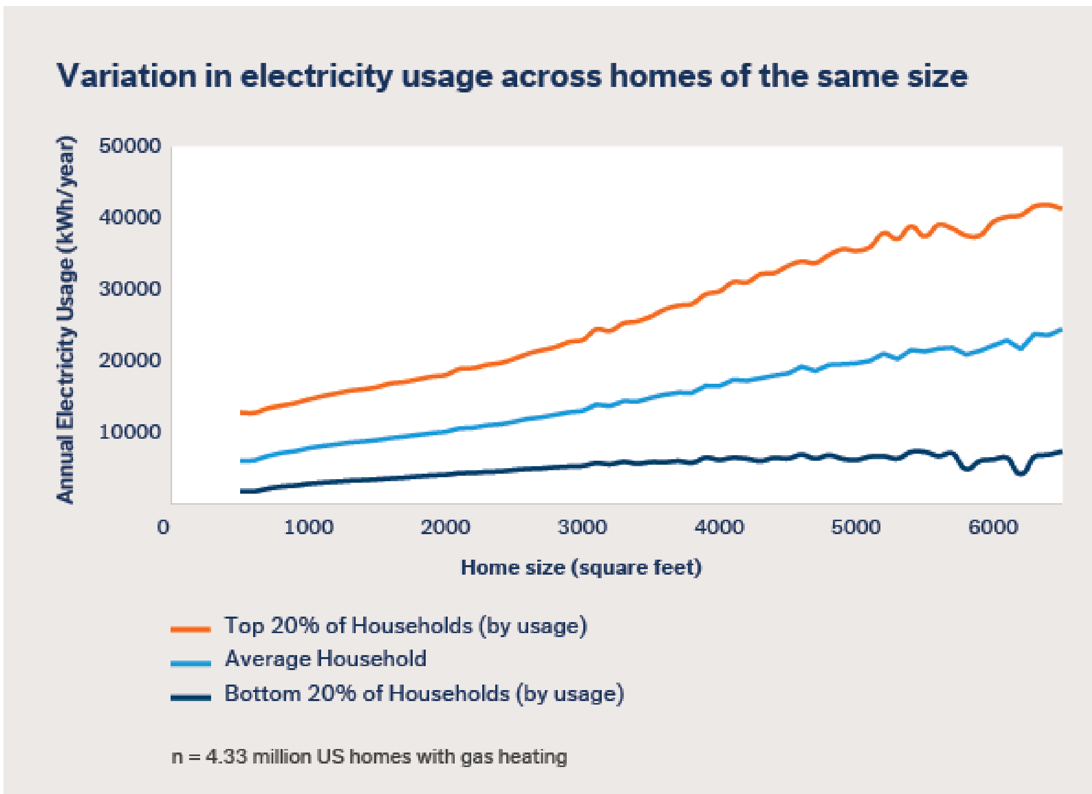

Figure 9.2: Annual electricity consumption vs. U.S. home size. **** Need to find reference. Found at `http://www.doomsteaddiner.net/forum/index.php?topic=9830.0`. ****

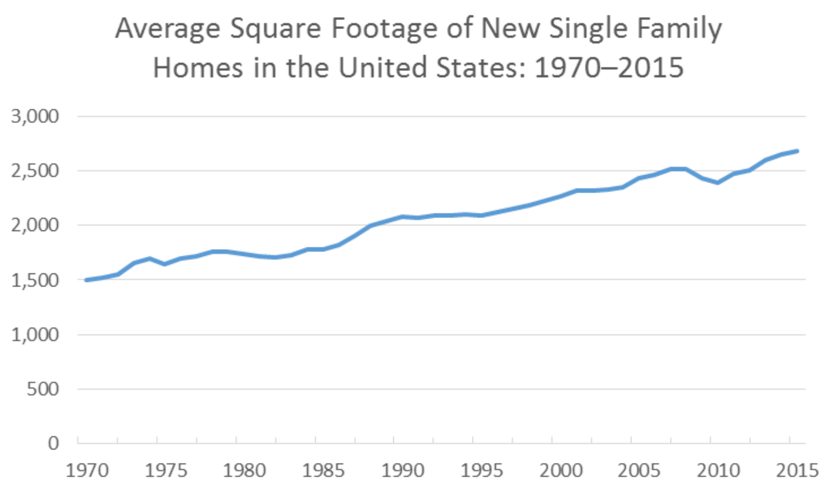

Figure 9.3: Average square footage of new single family homes [33, Fig. 1].

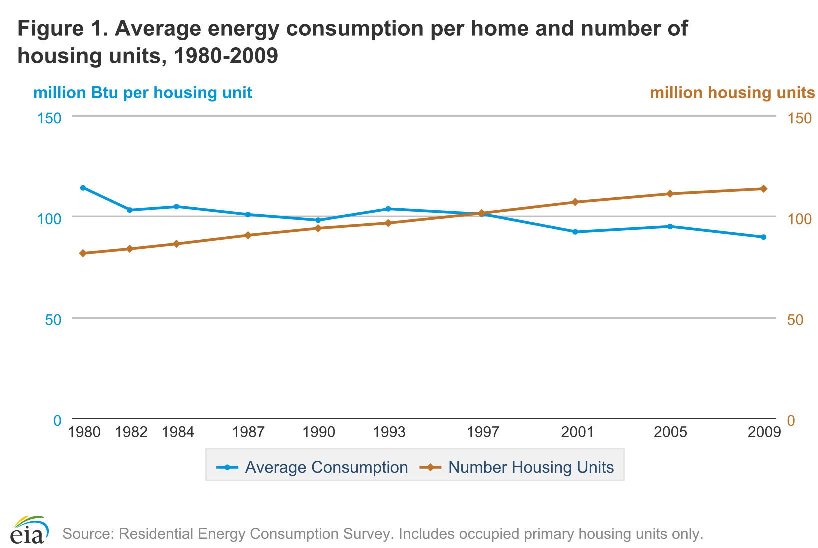

Figure 9.4: Average household energy consumption trend 1980–2009 [34, Fig. 1].

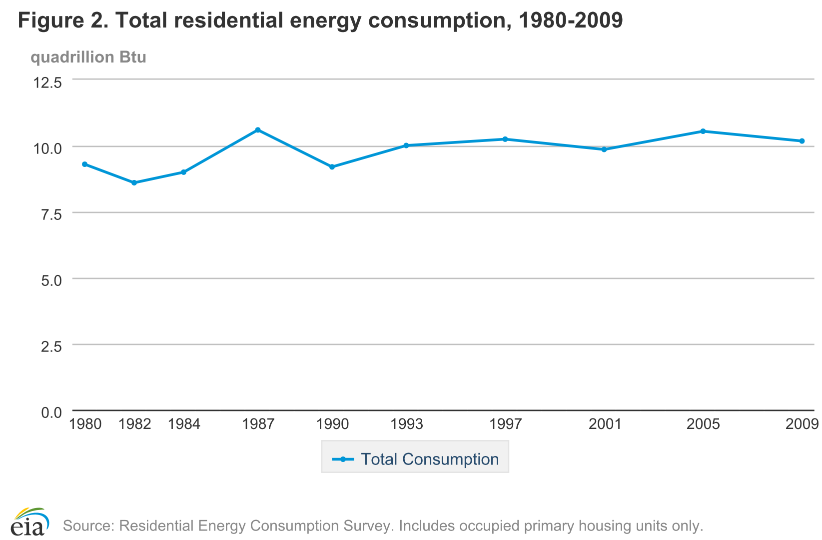

Figure 9.5: Total U.S. household energy consumption trend 1980–2009 [34, Fig. 2].

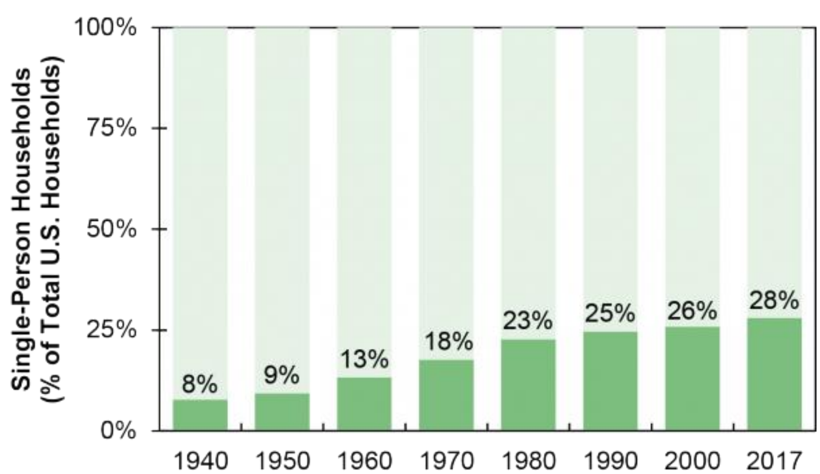

Figure 9.6: Percentage of single-person households 1940-2017 [35, Fig. 2].

9.1.2 LOCATION

Location of a dwelling is also an important determiner of energy consumption, not for the dwelling itself, but for energy consumed by the residents for transportation. Proximity to work, school, shops, church, and entertainment makes a significant difference to transportation energy demand. (See Chapter 8 for more information on sustainability issues related to transportation.)

9.2 HEATING AND COOLING

In most locations, daily and seasonal temperature variations are wide relative to the range of temperatures required for human comfort (approximately 20–23 °C, depending on humidity and clothing). Residential heating and cooling reduces the temperature variation inside the dwelling compared to the outside, providing thermal comfort to the occupants and enabling work, play, and entertainment. As shown in Figure 9.1, on average across the U.S., thermal comfort is provided by 36.6% of all residential energy consumption. Like all energy consumption, energy consumption for heating and cooling has sustainability implications. (See Chapter 4.) Greater efficiency can provide the same thermal comfort with less energy consumption. Increased residential heating and cooling efficiency can be obtained by improving the building envelope or by improving the efficiency of furnaces and air conditioners.

9.2.1 BUILDING ENVELOPE

The building envelope consists of the roof, walls, windows, and base of a dwelling. The purpose of the envelope is to shield occupants from outisde weather and to maintain dry and comfortable conditions inside the dwelling. The ideal building envelope would eliminate both heat loss in the winter and heat gain in the summer via perfect roof and wall insulation and windows that neither conduct heat nor allow radiation to pass through. But perfect insulation is not possible, and all windows conduct heat and are transparent to thermal radiation. So furnaces and air conditioners are used to replace the heat lost in winter and remove heat gained in the summer.

The effectiveness of roof and wall insulation is quantified by its R-value, a measure of the resistance to heat transfer through the insulation material, quantified by the R-value in units of hr-ft^2-°F/BTU. Higher R-values are better. Large R-values are achieved with thicker insulation constructed from low-thermal-condictivity materials. The Energy Star program recommends levels of roof, wall, and floor insulation at `https://www.energystar.gov/index.cfm?c=home_sealing.hm_improvement_insulation_table`. In Northern US climates, R-values of 49–60 hr-ft^2-°F/BTU are recommended.

Windows are an important part of any building's envelope. They provide natural illumination while shielding occupants from weather. Like walls and roofs, it is desireable that windows eliminate heat loss in the winter and heat gain the summer. However, windows are typically worse insulators than walls and roofs, owing to thin glazing.

The insulative properties of windows are quantified by the U-Factor. The U-Factor is the inverse of an R-value. Typical U-Factors for windows are 0.2–1.2 BTU/hr-ft^2-°F. (Corresponding window R-values are 5–0.83 hr-ft^2-°F/BTU.) Lower U values are more insulative. Heat gain from solar radiation is quantified by the solar heat gain coefficient (SHGC), the ratio of solar energy that enters the room to solar energy incident upon the window. SHGC values range from 0 to 1, and lower SHGC values indicate better insulative properties.

9.2.2 FURNACES

Furnaces provide space heating, often from an out-of-the-way location in the dwelling (e.g., basement). Furnaces convert a fuel (typically natural gas or heating oil) into heat by combustion. The heat is delivered to the dwelling via circulating water or air.

Furnace efficiency is quantified as Annual Fuel Utilization Efficiency (AFUE), the percentage of useful heat output to fuel energy input, accounting for transient effects during operation across the year. The maximum AFUE rating is 100%. Heat that leaves with the exhaust products serves to reduce AFUE. AFUE is different from and lower than steady-state thermal efficiency. The American Society for Heating, Refrigerating, and Air conditioning Engineers publishes Standard 103, which specifies how AFUE is to be measured.

All furnaces sold in the U.S. have an AFUE rating, and a minimum AFUE rating of 80% is required for gas-fired furnaces. (`https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/appendix-a.pdf`) High-efficiency furnaces recover heat from exhaust gases, and some reach AFUE values of 98% or higher. A tradeoff exists between efficiency and initial cost. Models with high AFUE are more expensive, initially, but save money on fuel costs over time.

9.2.3 AIR CONDITIONERS

Air conditioners cool and dehumidify indoor air to provide thermal comfort to building occupants. Air conditioners use electricity to achieve their objectives. The energy efficiency of air conditioners is quantified by the Seasonal Energy Efficiency Ratio (SEER), which is the ratio of cooling provided (in BTU) to electricity consumed (in W-hr) throughout the season. Larger SEER values indicate higher efficiency.

As of 2015, U.S. air conditioners must adhere to regionally dependent efficiency standards. In the southwest, a minimum SEER value of 14 BTU/W-hr is required. In other parts of the U.S., a minimum SEER value of 13 BTU/W-hr is mandated.

9.3 HYGIENE

Hygiene is a significant consumer of household energy and water for showers, dish washers, toilets, and clothes washers and dryers.

To minimize environmental impacts of showering and dish washing, low-flow showerheads can be installed. Low-flow showerheads provide the obvious cost benefit of reducing water bills. But if less water is consumed, low-flow showerheads also reduce energy consumption for water heating. Furthermore, sewerage costs are reduced, because low-flow showerheads decrease the amount of gray water released into the sewer system.

Saving water and energy in dish washing can be accomplished by purchasing an automatic dishwasher. At `https://www.energystar.gov/products/appliances/dishwashers`, the Energy Star program shows that automatic dishwashers save water and energy costs relative to hand washing dishes.

To save water consumed by toilets, displacement and dual-flush systems are recommended. A displacement system occupies volume in the tank, reducing the amount of water used for each flush. Dual-flush systems provide half- and full-flush for disposal of liquids and solids, respectively.

Clothes washers and dryers consume both water and energy. Purchasing washers and dryers with Energy Star ratings can reduce energy and water consumption by 25% and 33%, respectively (`https://www.energystar.gov/products/appliances/clothes_dryers`). The most energy can be saved by washing clothes less frequently, using a cold-water cycle, and line drying clothes.

9.4 LIGHTING

Indoor lighting provides illumination for rooms, typically by consuming electricity. Since Edison's invention of the electric light, filament-based incandescent lighting technology dominated household lighting. However, in recent years, Compact Fluorescent Lights (CFLs) and Light Emitting Diode (LED) lights have revolutioninzed the lighting industry and improved lighting efficiency significantly. LED bulbs are 6–10 times more efficient than incandescent lighting. In addition, LED bulbs promise much longer lifetimes, with more than 10 times longer service per bulb than incandescents. Both higher efficiency and longer life reduce total cost of ownership of LED bulbs compared to incandescent bulbs by nearly two orders of magnitude.

Of course, the least expensive light is the one you don't have to use at all. Building design techniques such as light harvesting utilize natural light to the greatest extent possible, eliminating the need to consume electricty for artificial indoor lighting.

QUESTIONS

9.1. This chapter covered four important aspects of household sustainability (purchasing, heating and cooling, hygeine, and lighting). What additional areas of household living are important from a sustinability point of view?

9.2. What tradeoffs do you observe in daily household living? That is, in what areas of household living does sustainability become worse as a result of improved sustainabiltiy elsewhere?

9.3. Locate the furnace in your dwelling, and find its AFUE rating. If you were to replace your existing furnace with a furnace with a 98% AFUE rating, how much energy would you save annually? What is the price of that saved energy? What is the annual cost savings from this energy efficiency intervention? Assuming that the 98% AFUE furnace lasts 20 years and that you want to break even financially, what is the maximum price you should pay for a 98% AFUE furnace?

9.4. Locate the air conditioner in you dwelling, and find its SEER. If you were to replace your existing air conditioner with an air conditioner with a SEER of 40 (near the maximum SEER rating as of this writing), how much energy would you save annually? What is the price of that saved energy? What is the annual cost savings from this energy efficiency intervention? Assuming that the 40 SEER air conditioner lasts 15 years and that you want to break even financially, what is the maximum price you should pay for a 40 SEER air conditioner?

9.5. Rank the U-Factor and solar heat gain coefficient (SHGC) for single-, double-, and triple-paned windows. Does the ranking make sense? Rank the costs of the windows.

9.6. If you are a college or university student, write a letter to yourself that describes the future household in which you want to live. What is the size of the dwelling? What are its sustainability features?