Chapter 19

RESIDENTIAL COMFORT

In residential and commercial buildings, the National Energy Strategy seeks to maintain or enhance comfort, indoor air quality, and affordability, while reducing energy use. The National Energy Strategy proposes the following actions:

• expand research and development;
• continue support of state and utility programs;
• expand use of mortgage financing incentives for residential energy efficiency;
• improve the efficiency of public housing;
• set cost-effective appliance and equipment standards and provide information to consumers through a labeling program;
• develop and encourage use of building efficiency standards;
• improve Federal energy efficiency.

(*National Energy Strategy, Executive Summary*, 1991/1992)

The Administration supports a strong, multifaceted effort to encourage cost-effective investments in energy efficiency and to speed the development and introduction of new, efficient technologies for buildings. [...] Although the Administration recognizes that policies that use market forces or market-based incentives are preferable in most circumstances, appropriate regulatory intervention can achieve efficiency gains that will benefit consumers, businesses, and the Nation.

(*Sustainable Energy Strategy*, 1995)

The central topic of this chapter is *energy conservation*. We see in Figure 19-1 that the residential and commercial sectors account for as much as one third of the overall energy demand in the United States. And given the fact that two thirds of the 100 million households are single-family homes, the impact on the national economy can be great.

In Chapters 6-17 we presented all the options that society has for satisfying its energy needs. In Chapters 2-5 we introduced all the science that is needed to evaluate these energy options, both technically and economically. So in this chapter we bring together this knowledge. The goal is to show that it is not necessary to take an engineering course to be able to make informed decisions on the energy options offered by the home builder or described by the real-estate agent.

The energy consumed for the sake of residential comfort (or for any other purpose) is the product of power and time. So there are two ways to conserve energy in our homes:
(a) decrease the power of the devices that we use, and/or
(b) cut on the amount of time that we use these devices.
How to achieve this is the question addressed in this chapter. Both the *National Energy Strategy* of the Bush Administration and the *Sustainable Energy Strategy* of the Clinton Administration are for increased energy efficiency in our homes. Let's see, in more concrete terms than available in those two documents, what the situation is and what can be done about it.

When we shop for a home, we are also making the single most important energy-related decision of our life. It stands to reason that we should make an informed decision. The impact on the family budget can be very significant. The key to option (a) is increased efficiency. Figure 19-2 illustrates this fact as it applies to a home, represented as an energy input/output system.

FIGURE 19-1. Energy consumption in the United States by economic sector.
[Source: Energy Information Administration.]

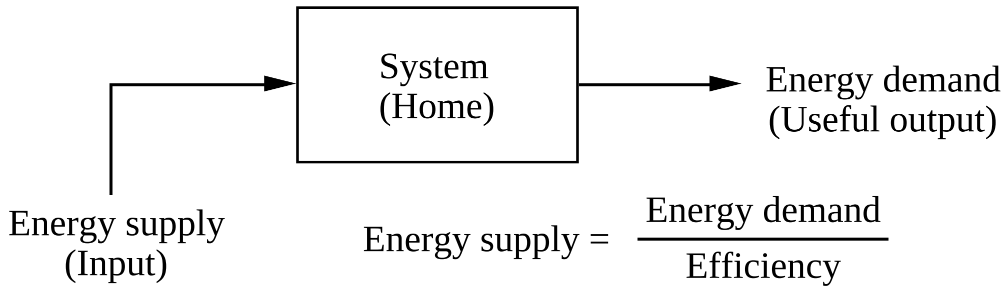


FIGURE 19-2. A home as an energy input/output system.

Saving energy means decreasing the energy input into a system, or decreasing energy supply. One way to achieve this is option (b) above: simply decrease the demand (that is, decrease the numerator in the expression shown in Figure 19-2). There is much room for improvement here (see Figure 5-7). The other way to reduce the energy input into our home is to increase the efficiency of energy use (that is, increase the denominator in the expression for efficiency shown in Figure 19-2).

Illustration 19-1. A home owner replaces an existing oil furnace, whose efficiency is 50%, with one that is more efficient (80%). If the energy demand is 1000 kilowatthours of heat per month, and if one kilowatthour of oil (chemical energy of fuel oil No. 2) costs three cents, how much fuel oil and how much money will he save?

Solution.
For the old furnace,

$$\text{Energy supply} = \frac{\text{Energy demand}}{\text{Efficiency}} = \frac{1000\ \frac{\text{kWh(th)}}{\text{month}}}{0.50\ \frac{\text{kWh(th)}}{\text{kWh(ch)}}} = 2000\ \frac{\text{kWh(ch)}}{\text{month}}$$

For the new furnace,

$$\text{Energy supply} = \frac{\text{Energy demand}}{\text{Efficiency}} = \frac{1000\ \frac{\text{kWh(th)}}{\text{month}}}{0.80\ \frac{\text{kWh(th)}}{\text{kWh(ch)}}} = 1250\ \frac{\text{kWh(ch)}}{\text{month}}$$

So, 750 kWh/month of fuel oil will be saved while providing the same heat output. This translates into monetary savings of

$$\$\ \text{savings} = \left(750\ \frac{\text{kWh}}{\text{month}}\right)\left(0.03\ \frac{\$}{\text{kWh}}\right) = \$22.50/\text{month}$$

In our homes energy is consumed in four ways: (1) for *space heating* in winter, or when the indoor temperature drops below 65 °F; (2) for operating the various *appliances*; (3) for *water heating;* and (4) for *air conditioning* in summer, or when the indoor temperature rises above 65 °F. A number of different energy sources can be used to satisfy these needs; the associated costs and environmental consequences vary widely as well. The consumption trends in the United States in the past few decades are summarized in Figure 19-3. We see that most of the residential energy is expended on space heating, and the least on air conditioning.

There are many ways to assess the technical potential and the economic incentives for energy conservation in our homes. One is to analyze an 'average' home and an 'average' household. That is what we shall do next. We shall then analyze the energy consumption situation in our own home and see if and how we can improve it.

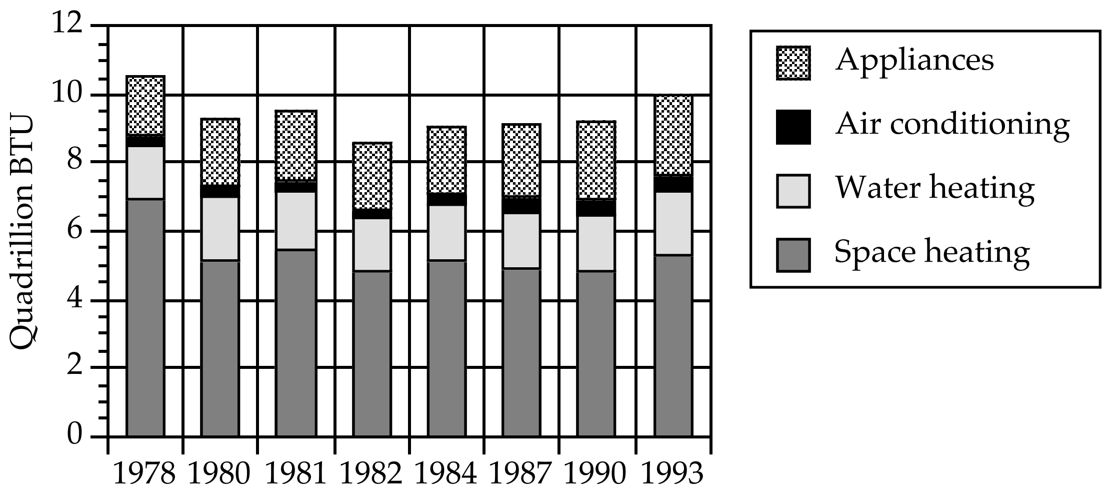


FIGURE 19-3. Residential energy consumption by application.
[Source: Energy Information Administration.]

A Typical Home: Energy Input and Output

Let us analyze a house as an energy input/output system, in a manner analogous to that used for our discussion of energy conversion devices throughout this book. Based on the statistical information summarized in Figure 19-4, we can construct the input/output diagram of a typical home. This is shown in Figure 19-5. We see that natural gas is the principal input into U.S. homes, accounting for about 50% of the total consumption. Oil use has been decreasing steadily in the period 1970-1983 and was replaced by electricity. Solar energy is included in Figure 19-5 because it does heat our homes to some extent, whether we like it or not, and because this can be used to our advantage (see Chapter 17).

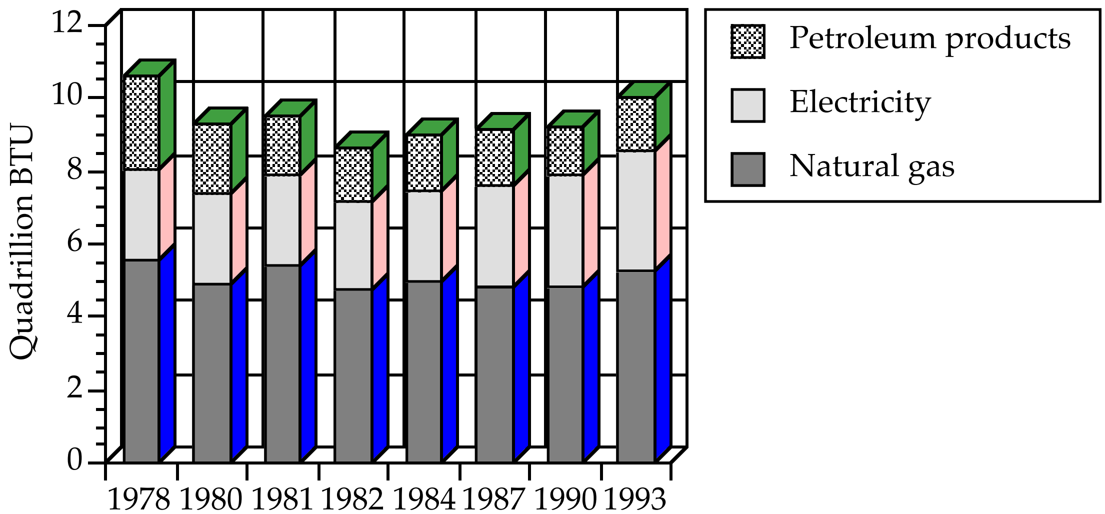


FIGURE 19-4. Residential energy consumption by source.
[Source: Energy Information Administration.]

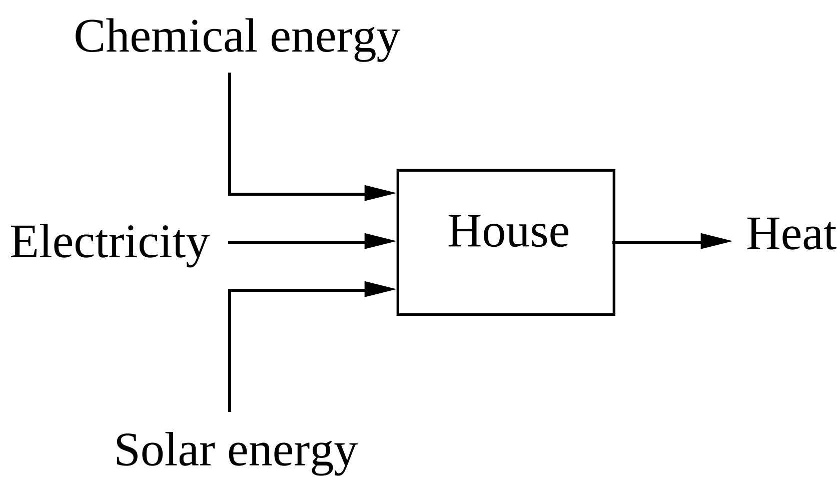


FIGURE 19-5
Energy input/output diagram of a house.

The only useful output in Figure 19-5 is heat. The principal inputs are in the form of chemical energy of natural gas and oil, electricity and solar energy. Let us analyze each one of them.

Solar Energy. Solar energy does not play a major role in providing energy for our homes. We typically have either too much of it, in summer, or too little, in winter. Its importance is great, however, for two reasons:
(1) Its influx determines how much space heating is required in our homes.
(2) In the coming decades, more of our energy needs will have to be satisfied using solar energy.

The first reason needs some elaboration. In Chapters 3 and 4 we saw that heat flows spontaneously from a high-temperature reservoir (T_H) to a low-temperature reservoir (T_L). In winter T_H is the interior of our house and T_L is outdoors. In summer the situation is reversed. What is of interest here now is the rate at which heat flows out of our home. The greater this heat loss is, the more energy we shall have to supply in order to maintain the indoor temperature at a comfortable level (60-70 °F).

Heat loss depends on three factors that we can easily understand from our daily experience. The first is the area through which heat flows; heat escapes more easily (or at a higher rate) through a large window than through a small window. The second factor is the temperature difference between the two reservoirs (ΔT): the greater this difference is, the more heat will escape. (This is why setting back thermostats is a good idea.) The third factor is the nature of the material through which heat flows; certain materials, called *insulators*, offer greater resistance to heat flow than others (called conductors). The greater this resistance is, the less heat will escape through them. The influence of all these factors is summarized in the following expression:

$$\text{Heat Loss} = \left(\frac{\text{Area}}{\text{Resistance}}\right)(\Delta T)$$

We can simplify this expression if we divide it through by the area. We thus obtain the following equation for the *heat loss per unit area* (say, per square foot):

$$\frac{\text{Heat Loss}}{\text{Area}} = \frac{\Delta T}{\text{Resistance}}$$

The resistance to heat flow is appropriately called the *R-value*. Table 19-1 shows the R-values of common insulating materials. Note that these values are given for a specified thickness of material. (In a more rigorous analysis, it can be shown that R-value is the ratio of the thickness of insulation and a fundamental property of all materials called thermal conductivity.) Therefore, the greater the thickness of the insulation, the greater the R-value and the smaller the heat loss. For example, one inch of fiberglass has an R-value of 3.5 (h °F ft^2/BTU). Six inches of fiberglass – corresponding to the depth of 2x6 studs which are commonly used in modern construction – would thus have an R-value of 21 (R-21).

Note in Table 19-1 that air and argon, when they are completely stagnant, have a very high R-value. Unfortunately, being gases, they are rarely stagnant. Double-pane and triple-pane windows are popular among energy conscious home owners and builders, but not because they have more layers of glass; in fact, Table 19-1 shows that glass is a poor insulator. They owe their greater insulating property to the fact that a gas enclosed between the panes becomes more stagnant.

The temperature difference is the driving force for heat loss. It depends on both the indoor and the outdoor temperature. The indoor temperature depends not only on the solar energy influx (see Table 17-1 and Figure 17-4) and on the design features of the house (see Chapter 17), but also on our lifestyle.

TABLE 19-1
Typical R-values of commonly used materials

Material	R-value, per inch (h °F ft^2/BTU)
Argon, completely stagnant	8.2
Polyurethane board	6.25
Air, completely stagnant	5.6
Fiberglass, batt	3.5
Wall board, insulating	2.98
Cardboard, corrugated	2.25
Rubber	0.83
Brick, masonry	0.22
Glass, window	0.18
Concrete, stone	0.15
Copper	0.00037

Illustration 19-2. Calculate the heat loss per unit area of glass window (1/8-inch thick) if the temperature difference across it is 30 °C.

Solution.
A 30 °C temperature difference corresponds to a 54-degree difference in Fahrenheit units. From Table 19-1, window glass has an R-value (per inch) of 0.18 (h °F ft^2/BTU). The smaller the thickness is, the lower the R-value will be; so our window glass has an R-value of 0.18/8 = 0.022 (h °F ft^2/BTU). Therefore,

$$\text{Heat loss (per unit area)} = \frac{\text{Temperature difference}}{\text{R-value}} = \frac{54\ °\text{F}}{0.022\ \dfrac{\text{h °F ft}^2}{\text{BTU}}} = 2455\ \frac{\text{BTU}}{\text{h ft}^2}$$

So, if the window is 1 ft long by 1 ft wide (that is, 1 ft^2), the heat loss will be 2455 BTU per hour. Obviously, if the window is larger, the heat loss will be greater.

For example, in winter we can wear sweaters and keep our house at 60 °F. If we are lightly dressed, it is more likely that we would keep the house at 75 °F.

The outdoor temperature depends on the climate. Obviously, our energy consumption also depends on where we live. This is illustrated in Figure 19-6.

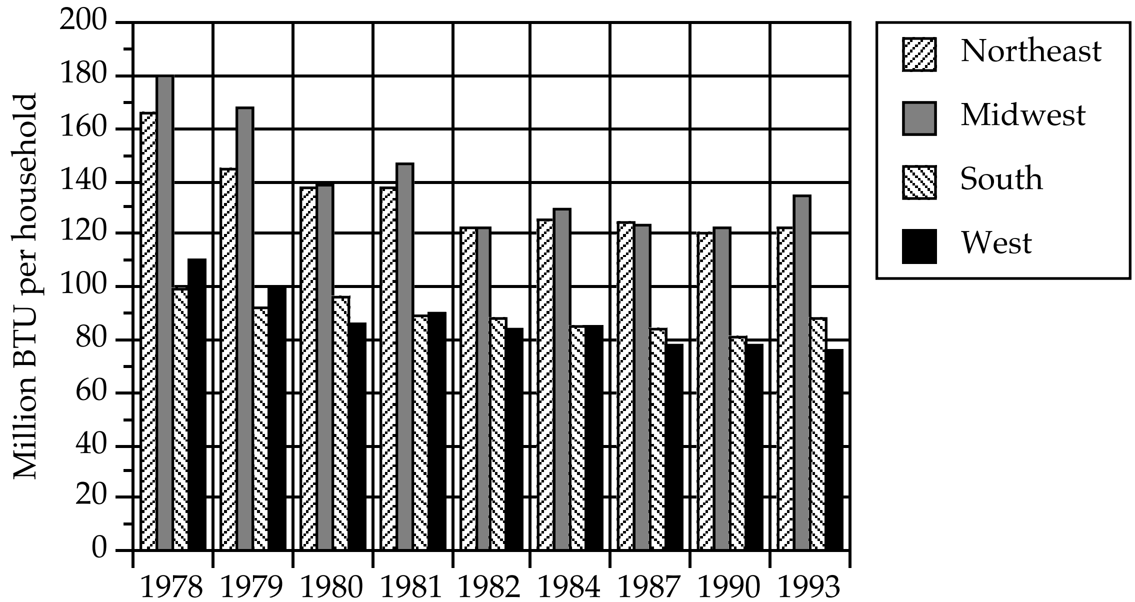


FIGURE 19-6. Household energy consumption by region.
[Source: Energy Information Administration.]

In Table 17-1 we showed how the average solar energy influx varies with geographical location. Knowing the climate of Phoenix, AZ and Buffalo, NY, it is not surprising that a house in Phoenix receives almost twice as much solar radiation as a house in Buffalo, 6 vs. 3.5 kilowatthours per square meter per day. To quantify these differences, the concept of a *heating degree-day* (HDD) has been introduced. It is obtained with the help of the meteorologists, as follows. First, we count the number of heating days; these are the days in a year during which the average outdoor temperature ($T_{avg,out}$) falls below 65 °F. Then we multiply this number by the temperature difference between 65 °F and the average outdoor temperature for these days. The term degree-day is seen to arise because the number of days is multiplied by the number of temperature degrees. Therefore,

$$\frac{\text{Number of heating degree-days}}{\text{Year}} = \left[\frac{\text{Number of heating days}}{\text{Year}}\right](65 - T_{avg,out})$$

Illustration 19-3. Calculate the number of degree-days in Buffalo and Phoenix, if they have 150 and 50 heating days in a year, respectively, and the average temperatures during this period are 17 and 35 °F.

Solution.

For Phoenix: $$\frac{HDD}{Year} = (50)\,(65\text{-}35) = 1500$$

For Buffalo: $$\frac{HDD}{Year} = (150)\,(65\text{-}17) = 7200$$

Using the statistical information as shown in Illustration 19-3, we can quantify the heating requirements based on different climatic conditions in different regions of the globe.

The number of *cooling degree-days* (CDD) is obtained in analogous fashion. Figure 19-7 illustrates the fact that the heating requirements are greatest in the Northeast and Midwest while they are smallest in the South. The variations within region are not large; for example, in PA, NY and NJ (Middle Atlantic region), the range was from a high 6200 heating degree-days in 1958 to a low 5000 in 1990. The opposite trend is seen for the cooling requirements, which have also been much more variable within a given region; for example, in the West South Central states (TX, OK, AR, LA) the range was from a high 2900 cooling degree-days in 1963 to a low 2000 in 1976.

The building codes for house insulation reflect these differences. For example, the recommended R-values for walls and floors vary from R-22 and R-25 in the northern states to R-12 and R-11 in the southern states.

Taking into account all these factors, the U.S. Department of Energy has come up with the following average annual heating and cooling requirements (in BTU) for a typical single-family home (1700 square feet):

Climate		Cooling	Heating
Cold	ME,VT,NH,NY,MI,WI,MN,ND,SD,WY,ID, AL	10,000,000	80,000,000
Moderate	MA,CT,RI,NJ,PA,OH,IN,IL,MO,IA,NE,WA, OR,CA(n),NV,UT,CO,KS,KY,WV,VA,MD,DE	20,000,000	50,000,000
Warm	CA(s),AZ,NM,TX,OK,AR,LA,MS,AL,TN, NC,SC,GA,FL,HW	50,000,000	20,000,000

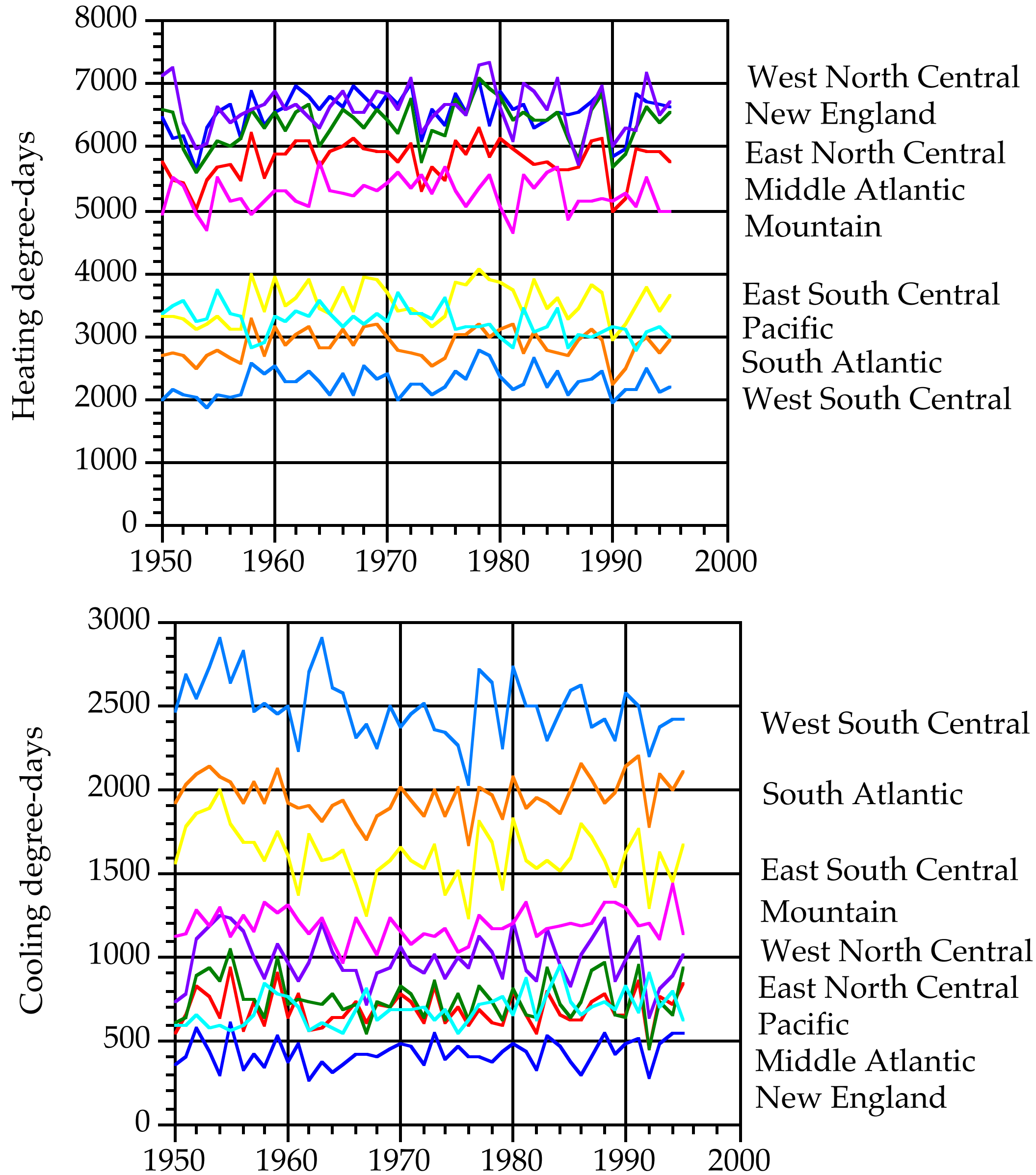


FIGURE 19-7
Weather variations in the continental United States, by census division, expressed in terms of heating and cooling degree-days. [Source: Energy Information Administration.]

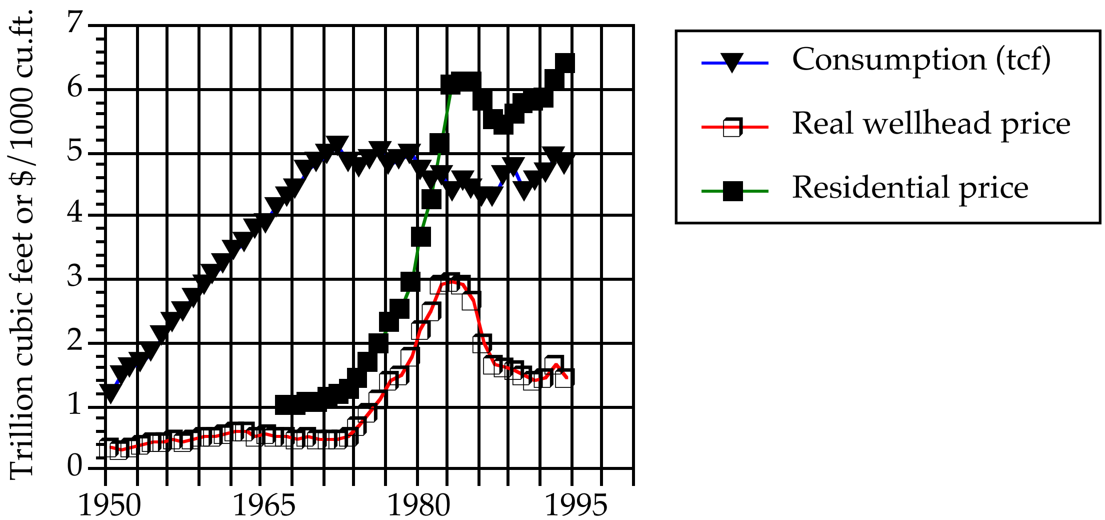


FIGURE 19-8. Trends in U.S. residential consumption and prices of natural gas. [Source: Energy Information Administration.]

Natural Gas. In Chapter 11 we concluded that natural gas is the ideal fossil fuel from an environmental standpoint. It is good news, therefore, that it is the principal fuel used in U.S. households, primarily for space heating. For example, in the Northeast almost 90% of the households with access to natural gas pipelines actually use natural gas.

The two main concerns are the price variability (see Figure 19-8) and CO poisoning (see *Newsweek* of 10/3/94, p. 60, for a recent highly publicized accident). As the prices are left without Government control, they may be susceptible to increases such as those that accompanied the sharp oil price rise in the 1970s. Carbon monoxide is a problem because it is deadly, odorless and invisible (see NYT of 9/22/94, "How to Keep a Warm House From Turning Dangerous"). In addition to annual furnace inspections, it is a good idea to have CO detectors installed in the house (see *Consumer Reports* of 11/96, p. 58).

Table 19-2 summarizes the ranges of typical natural gas heating bills, as estimated by the Department of Energy for the three climate zones mentioned previously; natural gas prices in the range $4-6 per 1000 cubic feet were assumed. Illustration 19-4 shows how these numbers were obtained. A homeowner in a moderate climate who replaces a 65% efficient furnace with a 95% efficient furnace can save about $150 per year. If the furnace costs $2800 and gas prices stay the same, the investment would be repaid in 19 years.

Fuel Oil. Figure 19-9 summarizes the information on the consumption and prices of petroleum products in the residential and commercial sectors. Demand grew as the prices stayed low until the early 1970s. When the prices increased in the period 1973-1982, the demand decreased accordingly and today it stands at around 2 quadrillion BTU per year.

Illustration 19-4. Show that the annual bill for a home in Pennsylvania that uses natural gas ($\$6/10^6$ BTU) to produce 50 million BTU of thermal energy is \$461 for a 65% efficient furnace and \$315 for a 95% efficient furnace.

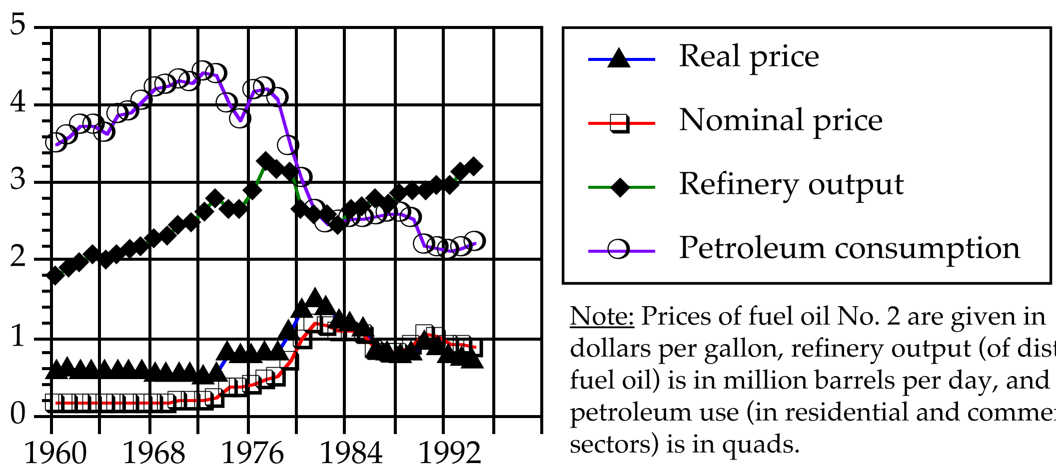
Solution.

$$\text{At 65\% efficiency: } \left\{\frac{\$6}{10^6\ \text{BTU(ch)}}\right\}\left\{\frac{1\ \text{BTU(ch)}}{0.65\ \text{BTU(th)}}\right\}\left\{\frac{50\text{x}10^6\ \text{BTU(th)}}{1\ \text{yr}}\right\} = \$461/\text{yr}$$

$$\text{At 95\% efficiency: } \left\{\frac{\$6}{10^6\ \text{BTU(ch)}}\right\}\left\{\frac{1\ \text{BTU(ch)}}{0.95\ \text{BTU(th)}}\right\}\left\{\frac{50\text{x}10^6\ \text{BTU(th)}}{1\ \text{yr}}\right\} = \$315/\text{yr}$$

Table 19-2
Ranges of annual gas heating bills by climate and furnace efficiency

Climate	Existing Furnace	New Standard Furnace	High-Efficiency Furnace
Cold	\$492-985	\$410-821	\$337-674
Moderate	\$308-615	\$256-513	\$211-421
Warm	\$123-246	\$103-205	\$84-168



Note: Prices of fuel oil No. 2 are given in dollars per gallon, refinery output (of distillate fuel oil) is in million barrels per day, and petroleum use (in residential and commercial sectors) is in quads.

FIGURE 19-9. Trends in consumption and prices of fuel oil by U.S. households. [Source: Energy Information Administration.]

The increase in refinery output in the 1980s and early 1990s may be due to increased use of this fuel (equivalent to diesel fuel) in the transportation sector (see Chapter 20). Table 19-3 summarizes the ranges of typical fuel oil heating bills, as estimated by DOE; the price range assumed was \$0.40-1.10 per gallon. Illustration 19-5 shows how these numbers were obtained. A homeowner living in a cold climate who replaces a 65% efficient furnace with an 85% efficient furnace can save about \$200 in annual fuel cost. If the furnace costs \$2500 and oil prices stay the same, this investment would be repaid in 12.5 years.

Illustration 19-5. Show that the annual bill for a home in Vermont that uses fuel oil (\$1/gallon; 1 gallon = 140,000 BTU) to produce 80 million BTU of thermal energy is \$879 for a 65% efficient furnace and \$672 for a 85% efficient furnace.

Solution.

At 65% efficiency: $\left\{\frac{\$1}{140000\ \text{BTU(ch)}}\right\}\left\{\frac{1\ \text{BTU(ch)}}{0.65\ \text{BTU(th)}}\right\}\left\{\frac{80\text{x}10^6\ \text{BTU(th)}}{1\ \text{yr}}\right\} = \$879/\text{yr}$

At 85% efficiency: $\left\{\frac{\$1}{140000\ \text{BTU(ch)}}\right\}\left\{\frac{1\ \text{BTU(ch)}}{0.85\ \text{BTU(th)}}\right\}\left\{\frac{80\text{x}10^6\ \text{BTU(th)}}{1\ \text{yr}}\right\} = \$672/\text{yr}$

Table 19-3
Ranges of annual fuel oil heating bills by climate and furnace efficiency

Climate	Existing Furnace	New Standard Furnace	High-Efficiency Furnace
Cold	\$621-976	\$518-813	\$475-746
Moderate	\$388-610	\$324-508	\$297-467
Warm	\$155-244	\$129-203	\$119-187

Electricity. This is the most convenient and at present the most expensive way to heat (and cool) our homes. The convenience is even greater when the cooling and heating tasks are combined in an electric heat pump. Figure 19-10 summarizes the information on the consumption and prices of electricity. Despite the continuous increase in residential consumption, the real residential price (adjusted for inflation) is as low today as it was before the "energy crises." Table 19-4 summarizes the DOE estimates of typical electric bills. Electricity prices ranging from 5 to 13 cents per kWh were assumed. To a much greater extent than was the case for natural gas and fuel oil, the climate zone is seen to have a profound effect on the economic justification of an electric heat pump. So, despite its popularity, an electric heat pump is not a good buy in cold climates. The reason for this was discussed in Chapter 4. When the temperature difference between the indoors and outdoors is large, or when we need the heat most, on a very cold winter day, the heat pump is least efficient. The relevant calculations, which compare heat pumps of different efficiency, are beyond the scope of our discussion.

Let's just conclude this section by calculating a typical electric heating bill. An 'average' house in a moderate climate requires 50 million BTU of thermal energy (see p. 363). If this is provided by an electric heater, at 100% efficiency and $0.10/kWh, the bill will be:

$$\left\{\frac{\$0.10}{1\ \text{kWh(e)}}\right\}\left\{\frac{1\ \text{kWh(e)}}{1\ \text{kWh(th)}}\right\}\left\{\frac{50\text{x}10^6\ \text{BTU(th)}}{1\ \text{yr}}\right\}\left\{\frac{1\ \text{kWh}}{3412\ \text{BTU}}\right\} = \$1465/\text{yr}$$

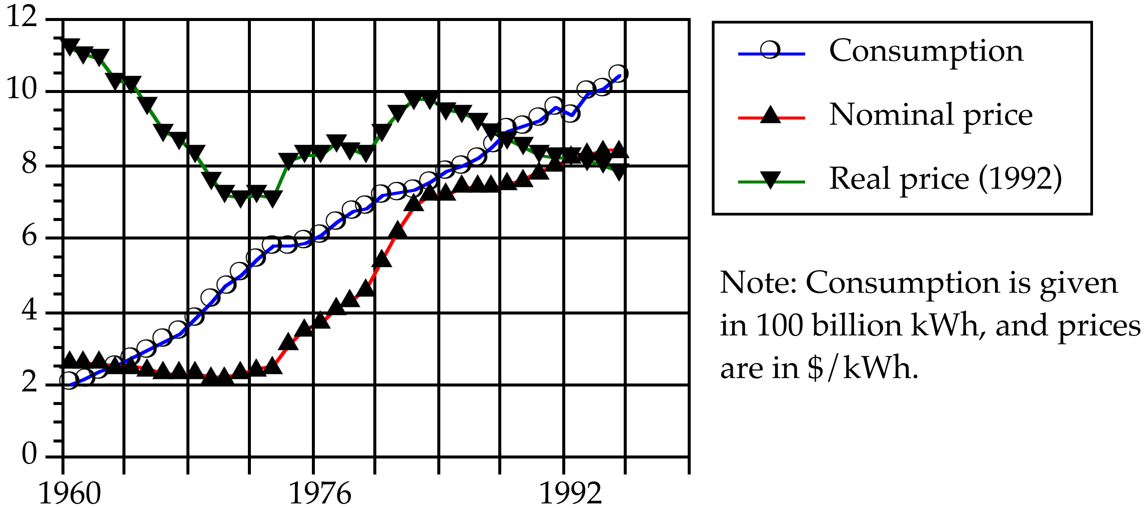


FIGURE 19-10. Trends in U.S. residential consumption and prices of electricity. [Source: Energy Information Administration.]

Table 19-4
Ranges of annual electric heat pump bills by climate and pump efficiency

Climate	Existing Unit	New Standard Unit	High-Efficiency Unit
Cold	$615-1600	$588-1529	$500-1300
Moderate	$385-1000	$368-956	$313-813
Warm	$154-400	$147-382	$125-325

Our Home: Analysis of Energy Input and Output

We have analyzed in the previous section how much energy, on average, is consumed in U.S. households. And, what is more important, we have shown the methodology to be used in such analysis. Now we can analyze our own energy situation. The first step in this process is to collect our energy bills.

Figure 19-11 reproduces a typical natural gas bill (from Peoples Gas, Pittsburgh, PA). Different gas utility companies provide different degrees of detail on the bill, but the basic information is the same. The quantity of gas used is given in one of the following units:

mcf = thousand cubic feet
ccf = hundred cubic feet
therm = 10^5 BTU

Because natural gas has a heating value close to 1000 BTU per cubic foot, one therm is essentially equivalent to one hundred cubic feet of gas.

In the example shown in Figure 19-11, over a period of one winter month, 23.7 mcf were consumed (identified as “gas usage charge”). The average consumption during this period was thus

$$\frac{23.7\text{x}10^3 \text{ cubic feet}}{30 \text{ days}} = 790 \frac{\text{ft}^3}{\text{day}} = \left(\frac{790 \text{ ft}^3}{\text{day}}\right)\left(\frac{1000 \text{ BTU}}{\text{ft}^3}\right) = 7.9 \text{ x } 10^5 \text{ BTU/day} .$$

FIGURE 19-11
Example of a residential natural gas bill (from Peoples Gas, a CNG company).

The gas usage charge shown is \$123.01. The unit cost of gas is

$$\frac{\$123.01}{23.7\text{x}10^3\ \text{ft}^3} = \frac{\$5.19}{1000\ \text{ft}^3}\ .$$

The cost of gas per day is

$$\left(\frac{790\ \text{ft}^3}{\text{day}}\right)\left(\frac{\$5.19}{1000\ \text{ft}^3}\right) = \$4.10/\text{day}.$$

If the fixed cost (of \$0.27/day) is included, the cost of gas is \$5.53 per thousand cubic feet or \$4.36 per day.

Figure 19-12 reproduces a typical electricity bill (from West Penn Power, PA). Again, the format of the bill varies from company to company, but the basic information provided is always the same.

FIGURE 19-12
Example of a residential electricity bill (from West Penn Power Company).

The highest item on the bill, and the only one that we can do something about, is the consumption during a specified time period. In Figure 19-12 it is identified as "Use: 5037 kWh at $0.06029 per kWh." The other important item of interest is the time interval over which the electric meter measurements were actually made (not estimated). In this case, it is 34 days. On December 19, the (estimated) meter reading was 61676 kWh and on January 22 it was 66713. The difference between these two numbers is multiplied by a constant (called the meter multiplier; in this case equal to one) and the total number of kWh consumed is thus obtained. The cost of one kWh of electricity, if not shown on the bill (as is sometimes the case) can of course be obtained when the total cost is divided by the number of kWh consumed, in this case $303.68/5037 kWh, or 6.0 cents per kWh.

The fixed costs of residential electricity utilization are reflected in the average cost per day, which as also sometimes given on the bill. This number is obtained when the total bill is divided by the number of days in the billing period. The unit cost of electricity including the fixed cost is thus

$$\frac{\$318.78}{5037\ \text{kWh}} = \frac{\$0.063}{\text{kWh}}$$

The bill shown in Figure 19-12 provides also some useful statistical information; this can help to understand the consumption patterns, as a first step toward any remedial action.

Figure 19-13 shows an electric meter and how to read it. The arrangement of the numbers on each one of the dials alternates between clockwise and counterclockwise for easier reading. The meters are (almost always) calibrated in kilowatthours. The correct reading of the meter shown is 15875 kWh. If we know the time interval over which such readings are taken, we can determine how much electricity has been consumed and how high our bill will be. This is, of course, how electric companies control our consumption, and how we can (and should) control it too.

Finally, the analysis of a typical heating oil bill is presented in Illustration 19-7.

Illustration 19-6. The following electric meter readings (in kWh) were recorded over a period of 30 days. Determine the total consumption and calculate the unit cost of electricity if the bill was $100 for this period.

Solution.

(June 1)

(June 30)

The total consumption is 836 kWh, and the cost of electricity is 12 cents per kWh.

FIGURE 19-13
Photograph of an electric meter and an example of its reading.

Illustration 19-7. The family of Pam Pezzola (MatSc 101 student, Fall 1990) has had the following fuel oil bills during two recent heating seasons:

1988/89:	$165.83	$264.40	$192.83	$193.84	$162.71
	November	December	January	March	July
$/gallon:	0.99	1.34	0.97	0.98	0.89
1989/90:	$169.27	$279.80	$228.93	$174.55	
	October	November	February	March	
$/gallon:	1.40	1.48	1.14	1.04	

Compare these consumption figures with the data shown in Table 19-3 and calculate the average monthly bills for the two seasons.

Solution.
The heating value of fuel oil is about $5.8x10^6$ BTU/bbl or $1.4x10^5$ BTU/gal. Therefore, the number of BTU consumed in Pam's household is obtained as follows:

$$1988/89\text{: Gallons consumed} = \left(\frac{\$165.83}{\$0.99/\text{gal}}\right) + 197.3 + 198.8 + 197.8 + 182.8 = 944$$

$$\text{BTU/household} = \left(944\ \frac{\text{gallons}}{\text{household}}\right)\left(\frac{1.4x10^5\ \text{BTU}}{\text{gallon}}\right) = 132x10^6$$

Both this number and the average monthly bill ($81.63) are significantly greater than the values given on p. 363, in Table 19-3 and in Illustration 19-5.

$$1989/90\text{: Gallons consumed} = \left(\frac{\$169.27}{\$1.40/\text{gal}}\right) + 189.0 + 200.81 + 167.84 = 678$$

$$\text{BTU/household} = \left(678\ \frac{\text{gal}}{\text{household}}\right)\left(\frac{1.4x10^5\ \text{BTU}}{\text{gal}}\right) = 95x10^6$$

The average monthly bill for this period was $71.05.

In what follows we analyze the energy consumption patterns in a number of households. These case studies are more illustrative than representative. The quantities consumed depend, of course, not only on climatic variations, as discussed above, but also on house type and size, as well as on the number and lifestyle of people living in it. Nevertheless, they do give the reader all the necessary ‘tools’ for his or her own residential energy analysis. Furthermore, some of their features are quite typical, as discussed below.

Case Study 1: An All-Electric Home

The home of Nathan Young (MatSc 101 student, Fall 1990) uses electricity, almost exclusively, for all energy needs (including space heating and air conditioning). It was built in 1978 and is well insulated. Its special features are high-performance windows (Andersen, with argon gas between glass panes instead of air), a passive solar room, and a solar water heater.

Figure 19-14 summarizes the energy consumption patterns over a period of ten years. Note the remarkable repeatability of the quantities consumed from year to year.

FIGURE 19-14. Energy (electricity) consumption in the home of Nathan Young (MatSc 101 student, Fall 1990).

Figure 19-15 summarizes the energy costs over the same period. The trends are the same, reflecting the fact that the cost of residential electricity has not changed dramatically in this ten-year period (see Figure 19-10). A comparison between the consumption of Nathan's home and the ‘average’ residential energy usage discussed in the previous section can now be made. On average, 20000 kWh of electricity are consumed every year, which is equivalent to 68 million BTU. This is comparable to the numbers shown on p. 363 and lower than those shown in Figure 19-6. Nathan's household is doing quite well!

An interesting analysis of the cost of electricity in the last two decades (in current or nominal dollars) was performed by Lori Brojack (MatSc 101 student, Fall 1990). Her house also uses electricity exclusively and the corresponding consumption is summarized in Figure 19-16. Even though the quantity of electricity consumed decreased by more than a factor of two during the decade following the first oil crisis, the cost of every BTU consumed has gone up dramatically (in Lori's area) over the twenty-year period. In 1971, the energy bill was $665 and in 1989 it was $1200. This is a solid basis for making informed decisions that could significantly affect Lori's family budget. She concludes her analysis in the following way: “Before I did this project, I was unaware of the amount of money spent for energy and fuels. I will be much more observant in the future!”

FIGURE 19-15. Summary of month-by-month electricity bills in the home of Nathan Young (MatSc 101 student, Fall 1990).

FIGURE 19-16. Analysis of electricity consumption and cost in the household of Lori Brojack (MatSc 101 student, Fall 1990).

Finally, a detailed analysis of my home, built in 1987, is summarized in Figure 19-17. We are a family of 2 adults and 2 children, with some 1800 square feet of living space before the 1994/95 heating season and additional 700 (finished basement) thereafter. In addition to baseboard heaters throughout the house, the big-ticket items are 4 room air conditioners which we use in June, July and August, because the summers in State College are hot and humid. The entire house is kept at 60-65 °F during the heating season. At night we turn the thermostats in the bedrooms to 55 °F.

Year in and year out, the trends are more or less the same, keeping in mind that the actual meter readings are made every two months. The high points in the winters of 1989/90 and 1995/96 have straightforward explanations. December 1989 was a very cold month (Figure 19-7); I also had the bad idea to paint the walls on both floors over the Christmas break last year, so we had to boost the thermostats to 75 °F for several days. I also understand the high consumption in July 1995: Figure 19-7 shows that it was an unusually hot month and we were not on vacation at the time. At roughly $0.06/kWh, our annual bills have been as low as $1000 and as high as $1400. I am certainly glad that we don't live close to a large metropolitan area, where residential electricity costs as much as 15 cents per kWh!

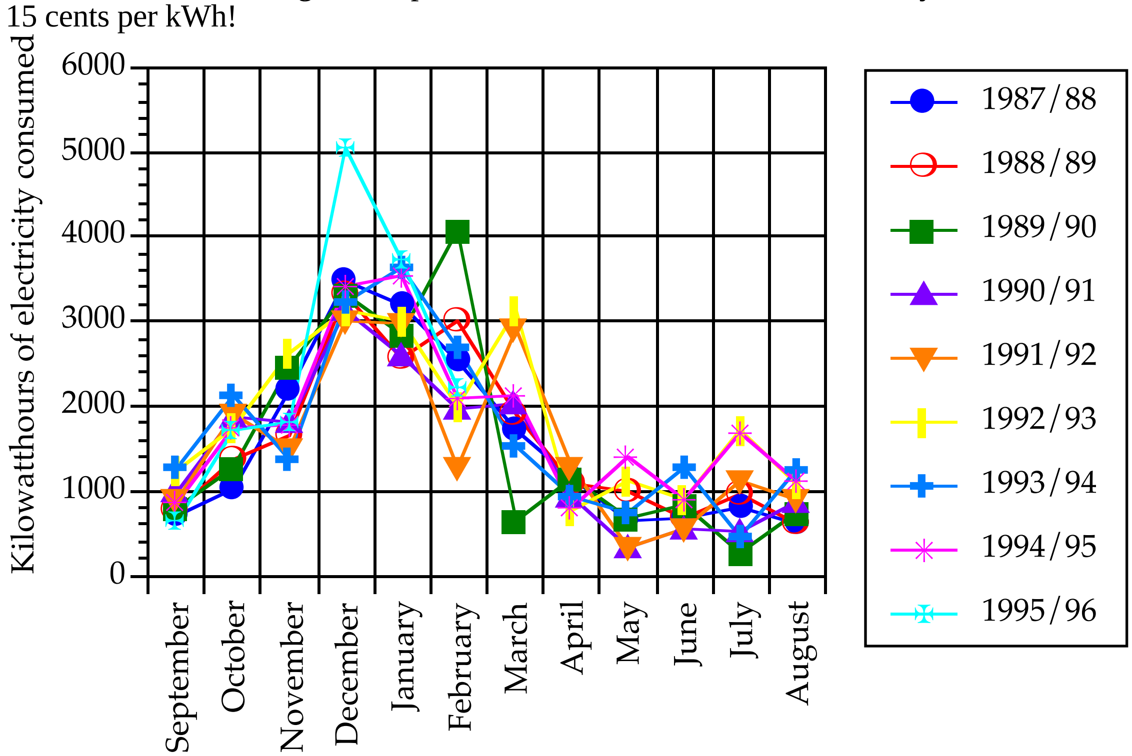


FIGURE 19-17a. Monthly consumption trends in the all-electric home of the author.

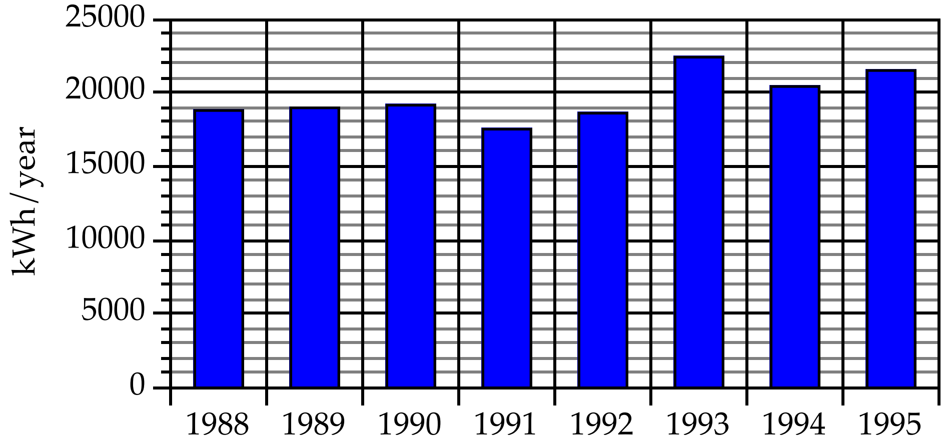


FIGURE 19-17b. Annual electricity consumption trends in the home of the author.

Case Study 2: Gas Heating and Electricity

This is one of the most common combinations. It is reflected in Figure 19-4 and my experience in the classroom confirms it.

Figures 19-18 and 19-19 summarize the energy consumption in the home of James Stewart (MatSc 101 student, Fall 1990). James lives near Greensburg, PA. Gas is used for both water and space heating. Its consumption follows the normal weather changes, being highest in the winter months. Electricity is used for the appliances (e.g., dishwasher, two refrigerators, two freezers, water pump, stove) as well as for the family farm. It is not surprising, therefore, that the fluctuations in the month-to-month consumption do not correspond to the normal weather changes (see below).

As emphasized throughout this book, a meaningful comparison of the various energy sources is made when the costs of a unit of energy of the same kind (e.g., one million BTU of thermal energy) are compared. In James's case, the consumption of electricity was 17,914 kWh in 1990, and that of natural gas was 250.3 mcf. The annual bills were $904.95 and $1382.11, respectively. Therefore,

$$\text{Cost of gas} = \left(\frac{\$1382.11}{250.3 \text{ x}10^3 \text{ cf}}\right)\left(\frac{1 \text{ cf}}{1000 \text{ BTU}}\right)\left(\frac{10^6 \text{ BTU}}{10^6 \text{ BTU}}\right) = \frac{\$5.52}{10^6 \text{ BTU}}$$

$$\text{Cost of electricity} = \left(\frac{\$904.95}{17914 \text{ kWh}}\right)\left(\frac{1 \text{ kWh}}{3412 \text{ BTU}}\right)\left(\frac{10^6 \text{ BTU}}{10^6 \text{ BTU}}\right) = \frac{\$14.81}{10^6 \text{ BTU}}$$

It should be realized that the numbers given above correspond to the cost of chemical energy for natural gas and of electric energy. If both are used for heating purposes, the efficiencies of the electric and gas heaters need to be considered, as follows:

$$\text{Cost of gas heating} = \left(\frac{\$5.52}{10^6 \text{ BTU(ch)}}\right)\left(\frac{1 \text{ BTU (ch)}}{0.8 \text{ BTU (th)}}\right) = \frac{\$6.90}{10^6 \text{ BTU}}$$

$$\text{Cost of electric heating} = \left(\frac{\$14.81}{10^6 \text{ BTU(e)}}\right)\left(\frac{1 \text{ BTU (e)}}{1 \text{ BTU (th)}}\right) = \frac{\$14.81}{10^6 \text{ BTU}}$$

Therefore, in James's home gas heating costs more than twice (~214%) less than electric heating.

Another common situation is the use of gas for heating and of electricity for air conditioning. This is illustrated for Diana Foxwell's home (MatSc 101 student, Fall 1990) in Table 19-5, and for Suzanne Wood's home (MatSc 101 student, Fall 1990) in Figure 19-19. For a comparison of these consumption patterns, see Illustration 19-8 and Review Question 19-15.

FIGURE 19-18a
Electricity consumption in the household of James Stewart (MatSc 101 student, Fall 1990).

FIGURE 19-18b. Natural gas consumption in the household of James Stewart (MatSc 101 student, Fall 1990).

TABLE 19-5
1989 energy consumption in a home in Philadelphia, PA
(Diana Foxwell, MatSc 101 student, Fall 1990)

Gas consumption (ccf/day)	Electric consumption (kWh/day)	Average outside temperature (°F)	Month
8.5	31	26	January
7.5	30	36	February
8.2	28	39	March
4.9	25	47	April
3.0	25.5	58	May
1.9	32	64	June
0.5	31.5	75	July
0.6	41	75	August
0.5	37.5	72	September
1.3	31	61	October
2.3	27	44	November
7.3	28	28	December

FIGURE 19-19
Energy consumption in the household of Suzanne Wood (MatSc 101 student, Fall 1990).

Table 19-5 illustrates quite well the usefulness of the concepts of heating degree-day (HDD) and cooling degree-day (CDD). Energy consumption for heating, in this case with gas, is inversely proportional to the outdoor temperature; energy consumption for cooling, using electricity, is directly proportional to the outdoor temperature.

Finally, a very recent example is that of the home of Alex Rhodes (MatSc 101 student, Fall 1996), who lives in a 25-year old 2200-ft^2 brick townhouse. His family uses natural gas for space and water heating. A central air conditioner is by far the most avid electricity consumer. Figure 19-20 is a summary of his report (see Review Question 19-16).

Illustration 19-8. Calculate the total energy consumption in D. Foxwell's home and compare it with the ‘averages’ shown in Figure 19-6 and on p. 363.

Solution.

$$\text{Gas consumption: } 140.9\ \frac{\text{mcf}}{\text{yr}}\left(\frac{10^6\ \text{BTU}}{1\ \text{mcf}}\right) = 140.9\text{x}10^6\ \text{BTU/yr}$$

$$\text{Electricity consumption} = 11{,}181\ \frac{\text{kWh}}{\text{yr}}\left(\frac{3142\ \text{BTU}}{1\ \text{kWh}}\right) = 38.1\text{x}10^6\ \text{BTU/yr}$$

So the total energy consumption is higher (by some 60 million BTU) than the Northeast/Midwest average. Gas consumption for heating is also higher than average.

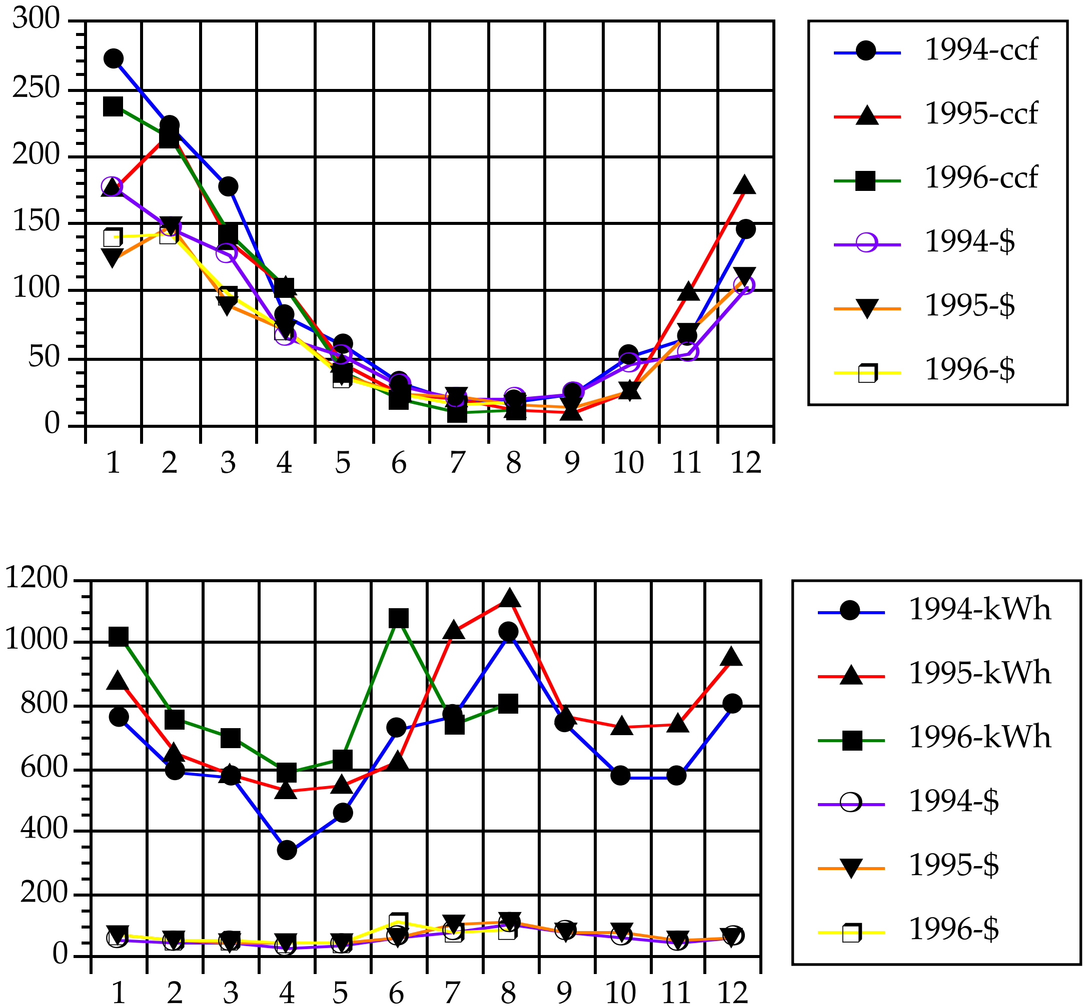


FIGURE 19-20. Month-to-month energy consumption trends in a Gaithersburg, MD townhouse (home of Alex Rhodes, MatSc 101 student, Fall 1996).

Case Study 3: Oil Heating and Electricity

The history of energy consumption in the home (2200 ft^2) of David Jenkins (MatSc 101 student, Fall 1990), in Reading, PA, is summarized in Tables 19-6 and 19-7.

TABLE 19-6
Analysis of consumption of fuel oil in the home of David Jenkins (Reading, PA)

Year	Oil consumed (gallons)	Oil cost ($)	Contract cost ($)	Total cost ($)	Total cost ($/$10^6$ BTU)
1986	493	484.30	74.50	558.80	8.22
1987	574	441.18	74.50	515.68	6.53
1988	762	602.07	89.50	687.57	6.55

TABLE 19-7
Analysis of consumption of electricity in the home of David Jenkins (Reading, PA)

Year	kWh consumed	Total cost ($)	Cost ($/kWh)
1986	10979	883.49	0.081
1987	11485	906.78	0.079
1988	11883	962.52	0.081

In addition to these sources of energy, this home uses a solar water heater. The quantity of energy consumed is very close to the ‘averages’ shown in Figure 19-6. For example, in 1987 the total consumption was approximately

$$(11485\ \text{kWh})\left(\frac{3412\ \text{BTU}}{1\ \text{kWh}}\right) + (574\ \text{gallons})\left(\frac{140000\ \text{BTU}}{1\ \text{gallon}}\right) = 120\text{x}10^6\ \text{BTU},$$

in excellent agreement with the average consumption in Middle Atlantic states for that year.

A more recent case study is summarized in Figure 19-21 for Eric Alexander's four-bedroom home on Martha's Vineyard island, MA. His large family (parents, four children and a dog) keeps the energy costs at reasonable levels, in spite of the electricity-devouring swimming pool, by wearing thick clothes in winter, burning about a cord of wood every year, and, yes (lucky them!), by spending much time outdoors. Between oil (950 gallons) and electricity (some 10000 kWh) they consumed about 160 million BTU of energy in the 1995/96 season. This is quite a bit above the ‘averages’ shown in Figure 19-6.

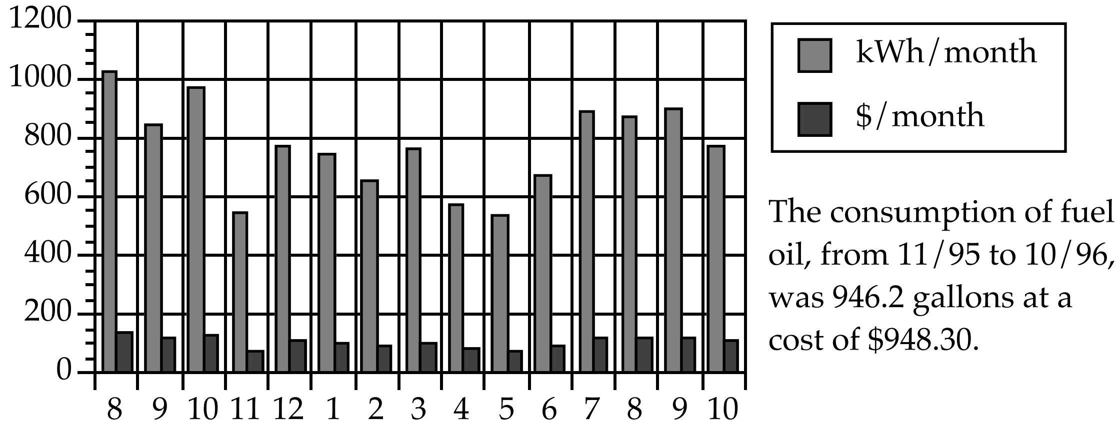


FIGURE 19-21. Summary of 1995-96 energy bills in the Martha's Vineyard home of Eric Alexander (MatSc 101 student, Fall 1996).

Case Study 4: A Complete Analysis by a New Energy Expert

On the following pages, we are reproducing the analysis of energy bills made by Robert Bigelow (MatSc 101 student, Fall 1990) in response to the following homework assignment:

Assignment. One of the principal objectives of our course is that you become your family's “resident expert” on energy issues. The first step in this direction is to understand and analyze your home energy bills.

You are asked to prepare a report on the energy consumption patterns of your household. For this purpose, you should collect your energy bills as far back in time as possible. All sources of heat should be considered (i.e., coal, wood, fuel oil, natural gas, electricity, etc.). You should note how much you are consuming in both quantity (i.e., tons, cords, gallons, cubic feet) and energy units, and how (and why) does your consumption vary over time (e.g., summer vs. winter months). You should also note how much you are paying for this energy. In particular, if you are using more than one source of energy, you should compare the economics of their use (in $/BTU thermal).

Solution (by Robert K. Bigelow).

House type:	*Geodesic dome, built in 1978*
Location:	*Perkiomenville, PA (near Philadelphia)*
Living space:	*1700 square feet*
Heat type:	*Strictly electric (Carrier heat pump, one unit)*
Air conditioning:	*Also from electric heat pump*

Heat distribution: *Central air (ducts and vents)*
Back-up heat: *Electric coil with blower*
R-value: *Walls and roof are the same, R-15*

Summary of last nine months of electric bills:

Period (days)	kWh used	kWh/day	Cost, $	Use
12/6-1/8 (33)	4645	141	338.85	heat/electric
1/8-2/6 (29)	2761	95	201.41	heat/electric
2/6-3/8 (30)	2751	92	200.66	heat/electric
3/8-4/6 (29)	1914	66	139.62	heat/electric
4/6-5/8 (32)	1400	44	102.13	electric
5/8-6/7 (30)	1196	40	87.24	electric
6/7-7/9 (32)	1390	43	101.40	electric
7/9-8/7 (29)	1383	48	100.88	air/electric
8/7-9/6 (30)	1352	45	98.62	air/electric

Note: Since both the electric usage and the electricity for heat are on the same bills, I had to do some math to determine what fraction of the bill was due to heat alone. In this case, I noticed that the bill leveled out in the period from 4/6/90 to 7/9/90 and this is the period when no heat and no air conditioning is used. I took the average kWh used for each of these months (44, 40 and 43, respectively), added them together (44+40+43=127) and averaged this (127/3=42.33). This is the average electricity usage per day not including any heat or air conditioning. Take this number and multiply by 30 (the average number of days in a month) and you have the kWh of electricity used per month without considering the heat or air conditioning; 42.33 x 30 = 1270. The adjusted figures for the kWh used per month for heating and air conditioning (cooling) are as follows:

Period (days)	kWh used	kWh/day	Cost, $	Use
12/6-1/8 (33)	3267	99	238.33	heat
1/8-2/6 (29)	1537	53	112.12	heat
2/6-3/8 (30)	1500	50	109.43	heat
3/8-4/6 (29)	696	24	50.77	heat
4/6-5/8 (32)	0	0	0	-
5/8-6/7 (30)	0	0	0	-
6/7-7/9 (32)	0	0	0	-
7/9-8/7 (29)	174	6	12.69	cool
8/7-9/6 (30)	90	3	6.57	cool

The total charge for heat during those four months was $510.65. If we take this number and divide it by four (the number of months), we come up with a figure of $127.66 per month. I can estimate that, on the average, heat is needed during six months in the year.

So, $127.66 x 6 = $765.98, were spent on heat each year. Even more interesting is to divide this dollar amount by $0.07295 (the cost per kWh), and you are left with the total amount of kWh consumed every winter for heat (10500 kWh). I can easily convert this to therms if I assume that each kWh yields approximately 3412 BTU. Therefore, my house uses roughly 36 million BTU per season. I will use this number in my next step, in comparing how much money we could save each year by using any of the other energy alternatives.

<u>Comparison of other heating types</u>

Electric heat (existing):

$$\left(\frac{\$0.07295}{kWh}\right)\left(\frac{1\ kWh}{3412\ BTU}\right)\left(\frac{10^6\ BTU}{10^6\ BTU}\right) = \frac{\$21.38}{10^6\ BTU} \qquad \text{(100\% efficient)}$$

Oil furnace (large capital):

$$\left(\frac{\$40}{barrel}\right)\left(\frac{1\ barrel}{5.8x10^6\ BTU}\right)\left(\frac{1}{0.65}\right) = \frac{\$10.61}{10^6\ BTU} \qquad \text{(65\% efficient)}$$

Gas furnace (not available):

$$\left(\frac{\$6.00}{10^3\ cf}\right)\left(\frac{1\ cf}{1000\ BTU}\right)\left(\frac{1}{0.85}\right) = \frac{\$7.05}{10^6\ BTU} \qquad \text{(85\% efficient)}$$

Coal stove (cost and inconvenience):

$$\left(\frac{\$75}{ton}\right)\left(\frac{1\ ton}{2000\ lb}\right)\left(\frac{1\ lb}{13000\ BTU}\right)\left(\frac{1}{0.50}\right) = \frac{\$5.77}{10^6\ BTU} \qquad \text{(50\% efficient)}$$

<u>Cost difference per million BTU</u>

oil:	*$21.38 - $10.61 =*	*$10.77*
gas:	*$21.38 - $7.05 =*	*$14.33*
coal:	*$21.38 - $5.77 =*	*$15.61*

<u>Potential cost savings per year (based on use of 36 million BTU)</u>

oil:	*$10.77 x 36 =*	*$387.72*
gas:	*$14.33 x 36=*	*$515.88*
coal:	*$15.61 x 36 =*	*$561.96*

<u>Overall analysis</u>

Heat losses will be difficult for us to curtail given the design of our house. The overall R-value is low, for walls and roof, considering the fact that our walls are the roof! Fiberglass insulation was never put in between the outside surface, -concrete, 2.5 inches thick - and the inside surface of drywall. There literally is no economical way of insulating now after the fact. In addition, we have four 8 ft x 7 ft sliding glass doors, which allow a great deal of heat to escape. Since the house was built, we did insulate the basement ceiling and we do cover the doors with a heavy cloth and reflective foil material every night during the winter. This has reduced our energy consumption by about 50%, compared with past years. Still, the bottom line is that we have electric heat, which is very inefficient, as we have discussed in class. Unfortunately, it is also very convenient and I doubt that my mother would agree to the costly initial investment, the construction, and the increased hassles in exchange for any long-term gains. The problem is that although we could save money, our system now is fairly economical and we do not use that much kWh anyway.

I know for a fact that the heat pump was not designed for our type of climate. The air conditioner part works fine, but the heat pump does not filter enough energy from the cold night air in December, January and February. In those months, the auxiliary heat kicks in, which uses (rather loses) a great deal of electricity. One alternative would be an oil furnace but the high initial investment, plus the increase in the cost of oil, would make this change uneconomical. Gas would be efficient, clean and convenient, only it is not available in my rural location. We live in the country and there are not enough houses on my street to allow the gas utilities economies of scale in running lines out. If more people move into the suburbs, then perhaps this could be an energy alternative in my home within the next ten years.

By far, the most sensible thing we could do would be to put a coal stove down in the basement and hook this up to our existing heating ducts. We considered this five years ago, but we were not in the mood to change the setup. First, we would have to purchase the coal stove and install this. Then, we would have to buy and place a coal hopper along our house under our 2000 square feet of deck. Chances are we would have to alter the deck and the setup might be unsightly. Also, we would have to deal with ordering coal 3 or 4 times each year. Last, we would have black soot and dust all over the house as we did when we used a small kerosene heater two years ago. And who wants to dispose of coal ash on the boundary of our yard in 20 degree weather? No, in spite of the $500, we could save every year with the use of a coal stove, it would probably take five years to pay for itself, and the inconvenience would decrease our already dwindling amount of leisure time. Perhaps a better alternative for us would be the invention of a more efficient heat pump.

The only comment that we can make on Robert's analysis, presented above, is that he has indeed become a real expert on residential energy issues! I hope that this example will stimulate the reader to do the same.

EnergyGuide Labels

Figure 19-4 shows that a large portion of the residential energy demand is satisfied with electricity. The previous section illustrated the fact that electricity use for heating purposes – in air conditioners, electric heaters, heat pumps, etc. – can be expensive. It makes sense, therefore, to pay close attention to the efficiency of these devices when we buy them. EnergyGuide labels, which are mandatory for all dishwashers, refrigerators, freezers, clothes washers, room air conditioners, water heaters and furnaces (produced after May 1990), are helpful in assisting us to do this. A typical label is reproduced in Figure 19-22.

FIGURE 19-22. EnergyGuide label for a 5000-BTU/hour room air conditioner.

Table 19-8 summarizes additional useful information about electricity consumption and cost for the most common household appliances. Illustration 19-9 and Investigation 19-9 show that the relevant calculations are relatively straightforward.

TABLE 19-8
Electricity consumption and cost for commonly used household appliances

Appliance	Typical OperatingCost	Average Use (kWh/month)
Air conditioner (8,000 BTU, EER=8)	5 cents per hour	207
Blanket, electric	7 cents per night	37
Clothes dryer	14 cents per load	83
Clothes washer	1 cent per load	10
Coffee maker	1 cent per brew	9
Dehumidifier	23 cents per day	126
Dishwasher	4 cents per load	32
Food freezer, frostless	35 cents per day	190
Microwave oven	0.5 cents per use	17
Range	18 cents per day	100
Refrigerator		
15 ft^3, frostless	30 cents per day	165
22 ft^3, frostless	39 cents per day	215
Water heater		
one adult	1 cent per gallon	150
additional person	1 cent per gallon	80

[Source: West Penn Power Company.]

Illustration 19-9. Using the information provided in Figure 19-22 and Table 19-8, verify whether the air conditioner cost of $62 per year, shown on the EnergyGuide label in Figure 19-22 agrees with the numbers given in Table 19-8.

Solution.
Using the information in Figure 19-22, the hourly cost of running the air conditioner is:

$$\left(\frac{\$62}{\text{year}}\right)\left(\frac{1\text{ year}}{1000\text{ hours}}\right) = \$0.062/\text{hour}$$

This is slightly more than the typical operating cost shown in Table 19-8. At 8 cents per kWh (for example, $50 for 1000 hours of use), the agreement is perfect. At 12 cents/kWh, the typical operating cost would be 7.5 cents per hour.

Reading the Press: Energy Conservation

The information provided in this chapter should be sufficient to allow the reader to become his or her family's "resident expert" on residential energy issues. It should also be helpful in providing an understanding, and indeed a basis for criticism, of the articles that frequently appear on these issues in the press. Especially in periods of high energy costs (as, for example, during the recent Persian Gulf war), energy is on the front pages and in the headlines. Conservation tips for home owners abound. Energy-related advertisements are also more frequent. The case of Mobil Corporation, and Texaco to some extent, has been illustrated throughout the book. The Investigations at the end of this chapter contain other representative examples.

Consider the following advertisement (*The New York Times*, 9/14/90, p. D18), entitled *"IF YOU THINK GAS HEAT WILL SAVE YOU MONEY, HERE'S A LITTLE HISTORY LESSON."* The fine print reads as follows: "Before you give much thought to switching to gas heat, here's some information that will prove you've been smart to stay with oil all along... The most recent report conducted by the Department of Energy concludes that heating with oil is 16% more efficient than heating with gas... And if the situation in the Mideast has you concerned about the supply of heating oil, you can relax. America has more than an ample supply on hand to get us through the winter and beyond." One should be at least skeptical about statements such as these. The arguments for this skepticism have been presented in Chapters 4, 5, 8 and 9. (See also Investigation 19-5.)

An example of an informative and – it is hoped – completely understandable article is reproduced (in part) below.

INSULATING HOUSES FROM OIL CRISES
(by Nancy Miller, *USA Today*, 9/17/90, p. 3B)
Copyright 1990, *USA Today*. Reprinted with permission.

Houses built today don't look very different from houses built 20 years ago. But they are. And you can thank OPEC for the quiet revolution in home construction that has transformed the old, drafty homestead into an airtight, energy-efficient one.

"Homes today are about 50% more efficient than they were in the early '70s, before the (1973) oil embargo," says Tom Farkas, energy program manager at the National Association of Home Builders.

The 1973 oil shortage spawned massive efforts by home builders, appliance makers and construction suppliers to improve energy use in the typical new house... Total annual residential energy use was 2.5% lower in 1987 (the latest year available) than in 1978. During that period, the number of households rose 17.8%. Further, the average home built since 1972 is 30% bigger, at 2,035 square feet.

There have been other benefits for home dwellers in every state. For example, [...] a 1500-square-foot house built on 1970 standards in Omaha, Nebraska, would have run up $527 in utility bills that year for heating and cooling costs. The same-size Omaha home, *built in 1990, would be billed at about $615. That's even though the region's utility rates more than tripled in those 20 years. Today it would cost $2,633 to heat and cool the 1970s home in Omaha.*

Where energy efficiency has changed
Walls – Insulation: 1970, none; 1990, R-13
Windows – Panes of Glass: 1970, single; 1990, double
Ceiling – Insulation: 1970, minimal; 1990, R-30
Furnace – Efficiency rating: 1970, 0.60; 1990, 0.72
Gas bill (heating) – Annual cost ('90 rate): 1970, $1,918; 1990, $527
Electric bill (cooling) – Annual cost ('90 rate): 1970, $715; 1990, $88
Electricity – Cost per kilowatt-hour: 1970, 2 cents; 1990, 6 cents

Improvements in energy efficiency
Refrigerator (kWh/year): 1972, 1,726; 1988, 964
Room air conditioner (kWh/year): 1972, 1,282; 1988, 900
Clothes washer (kWh/year): 1972, 3.8; 1989, 2.7

The big changes:
•***More insulation** – about three to four times as much... Before the 1973 oil crunch, insulation was about 3 inches thick. Today it's as thick as 12 inches.*
•***More efficient appliances**. The Association of Home Appliance Manufacturers reports that since 1972, refrigerators with automatic-defrost top freezers use 51.7% less electricity, clothes washers 29.7% less, dishwashers 35% less and room air conditioners 29.8% less. Appliances will become even more efficient in the next few years as tougher legislation is phased in.*
•***Thicker windows.** Double- and triple-paned windows have become the norm... And no one uses steel window frames, which conducted cold air in during winter and let in hot summer air [...].*
•***More efficient equipment.** Furnaces are twice as efficient. Previously, [...] only 40% of furnace fuel burned actually made it into the house. The rest was lost up the chimney. Today, 88% of the fuel burned is likely to be used in the house and in some cases as much as 95%.*
[...]
Builders today struggle between giving clients greater energy efficiency or greater luxury. Either feature can make the house more expensive. The question is what customers will buy. And luxury seemed to have been gaining the upper hand before the Iraqi invasion of Kuwait... As a result, annual per capita energy consumption edged higher between 1983 and 1989, to 246 million BTU (British Thermal Units) from 226 million. But that's still well below the 1973 peak of 285 million BTU...

The reader will understand all the details in this article. Furthermore, many of the important numbers used can be verified for their agreement (or lack thereof) with the information presented in this book.

INTERNET INFO	Useful information on residential energy issues, including conservation tips, can be found at the following Web sites: Rocky Mountain Institute, www.rmi.org; Southern California Edison, www.edisonx.com; and Pacific Gas and Electric Company, www.pge.com.

REVIEW QUESTIONS

19-1. The NYT of 7/19/93 (p. B1) reports the 1992 average residential household consumption of electricity in Connecticut, New Jersey and New York to be about 8000, 7000 and 5000 kilowatthours. On a summer day in Long Island between 4 and 5 P.M., as much as 41 percent of the consumption by Lilco customers goes to air conditioning. Compare these data with your electricity consumption.

19-2. The NYT of 11/22/93 (p. B1) provides information on average prices for home heating oil and residential natural gas in the period 1984-1993. Statistics of use of residential fuels for Connecticut, New Jersey and New York (for 1990) are also given. It is interesting that heating oil is used in a much greater percentage of homes in Connecticut than in the other two states. Compare these data with your home heating consumption.

19-3. Texaco, “the star of the American road,” has been selling petroleum products for the last 100 years (see D. Yergin's “The Prize,” Further Reading, p. 459). It has been sponsoring the Metropolitan Opera radio and TV broadcasts for the last 50 years (see www.texaco.com). More recently it is advocating energy conservation, of all things! Under the title “Let's Put Our Energy Into Saving It,” it has taken out a whole-page advertisement/quiz, with the following multiple-choice, energy-saving tips for our homes:
(1) How much can you reduce your annual energy bill by lowering your thermostat from 72 ° to 68 °? (a) less than $25.00; (b) around $50.00; (c) up to $82.00.
(2) Proper insulation of your attic floor can reduce annual energy costs by (a) up to $342.00; (b) less than $34.20; (c) $3.42.
(3) Having an annual heating system “tune-up” can reduce your annual energy costs by (a) as much as $17.00; (b) as much as $34.00; (c) as much as $68.00.
Check Texaco's math and check out Texaco's solutions in *Time* magazine of 11/26/90.

19-4. It is quite likely that you have received (and probably thrown away without reading) an advertisement from your local electric utility such as this one:

"How do you know which is the best heating system for your home? Take a look at the chart. It lets you see at a glance why the high-efficiency electric heat pump is your best value in a heating system."
The fine print says that the following assumptions have been used: (a) electricity costs 6 cents per kWh and the heat pump has a COP of 7.5; (b) the gas furnace is 70% efficient and gas costs $6.50/1000 cubic feet; (c) the oil furnace is 60% efficient and heating oil costs $1.00/gallon. Check these comparisons and comment on the validity of the conclusion.

19-5. The Oil Heat Association of Centre and Clearfield Counties had the following advertisement in the Centre Daily Times (PA) of 9/20/96: "Oil Heat... It's Just Better... Still the Smartest Way to Heat a Home." To support this claim they give the following prices ($/million BTU): heating oil, 8.62; natural gas, 9.70; electricity, 24.32. Are these comparisons reasonable? (Hint: Estimate the assumed furnace efficiencies and prices per gallon, mcf and kWh.)

19-6. The 2750 sq.ft. home of Marc Jones (MatSc 101 student, Fall 1992) in Yardley, PA uses oil for space and water heating. The 1992 energy consumption was 969 gallons, at $0.91/gallon, plus 8012 kWh of electricity, at $0.15/kWh. (a) Compare the costs of electricity and oil in $/$10^6$ BTU. (b) Compare this consumption with the information provided in Figure 19-6.

19-7. The 1991 energy consumption in the Lansdale, PA home of Jen Frankel (MatSc 101 student, Fall 1993) is summarized in the following table:

Month	kWh	Cost of electricity, $	ccf	Cost of gas $	Average T (°F)
January	787	110.22	250	168.22	39
February	686	96.72	239	161.15	37
March	515	73.86	204	138.65	41
April	483	69.58	139	96.86	49
May	472	68.87	73	54.43	56
June	758	111.72	24	22.93	73
July	896	137.11	24	22.93	76
August	631	95.84	16	16.79	79
September	782	119.10	22	21.64	76
October	558	84.20	24	22.93	69
November	505	75.25	75	55.72	57
December	615	90.53	164	111.82	48

(a) Compare the costs of electricity and gas in $/$10^6$ BTU. (b) Compare this consumption with the information provided in Figure 19-6.

19-8. The home of Rebecca Hughes (MatSc 101 student, Fall 1992) is all-electric and is being charged for on-peak ($0.10/kWh) and off-peak ($0.04/kWh) consumption as follows:

Month	Peak kWh	Off-peak kWh	Total Bill, $
August 1992	211	727	64.04
July 1992	235	1013	78.83
June 1992	432	1188	108.07
May 1992	532	1351	126.03
April 1992	1230	2765	268.26
March 1992	1506	3507	335.53
February 1992	1762	3797	377.36
January 1992	1722	3681	368.35
December 1991	1446	2436	281.45
November 1991	958	2262	218.47
October 1991	453	1177	113.30
September 1991	212	652	62.42

Where do you think Rebecca lives (see Figure 19-6)? Make as many comments as you can on the energy consumption trends in her home.

19-9. The 1600-sq.ft. two-story home of Julie Boyce (MatSc 101 student, Fall 1993) in Cecil, PA (built in 1978) is also all-electric. Make as many comments as you can about its energy consumption on the basis of the following information (for 1992):

Period (days)	kWh used	Cost, $
12/8-1/20 (33)	4472	244.05
1/20-2/19 (30)	3061	168.66
2/19-3/19 (29)	2637	146.00
3/19-4/20 (32)	2313	128.33
4/20-5/19 (29)	1486	83.77
5/19-6/18 (30)	2250	124.24
6/18-7/20 (32)	1145	65.70
7/20-8/18 (29)	2190	116.76
8/18-9/18 (31)	1837	102.35
9/18-10/16 (28)	1520	85.57
10/16-11/17 (32)	2191	121.11
11/17-12/17 (30)	3035	165.81

19-10. In the 11/9/92 issue of the NYT ("Staying Warm May Take Extra Fuel This Winter"), Matthew Wald quotes Department of Energy data on the impact of one heating degree-day on the daily quantity and cost of fuel used in the U.S.:

Heating Oil	28,000 barrels	$1.2 million
Propane	33,000 barrels	1.5 million
Electricity	29 million kilowatts	2.4 million
Natural Gas	729 million cubic feet	4.4 million

How do you think these numbers were obtained? Compare them with those shown in Figure 19-4. Is the number for electricity correct?

19-11. The *USA Today* of 10/30/90 ("The high cost of heat") reported the following breakdown of fuel use for heating U.S. households: Natural gas, 56.5%; electricity, 19.5%, heating oil, 11%, wood, 5.6%; liquefied petroleum gas, 4.6%; kerosene, 1.5%; other, 1.3%. Do these numbers agree with the information provided in Figure 19-4?

19-12. General Electric advertises its Energy Choice™ light bulbs by saying that their use (at 67 watts instead of conventional 75-watt soft white bulbs) reduces fossil fuel consumption and carbon dioxide emissions. The numbers given are the following:

Reduce:	Coal	Oil	Natural gas
Fossil fuel consumption	23 pounds	1.7 gallons	250 cubic feet
Carbon dioxide emissions	52 pounds	43 pounds	28 pounds

The advertised monetary savings are $1.90, based on 8 cents/kWh and 750-hour lifetime. Show how some of these numbers were obtained.

19-13. A 6000 BTU/h room air conditioner bought at Sears has an energy efficiency rating (equivalent to COP, see Chapter 4) of 9.0. The EnergyGuide label shows that if it used for 1000 hours per year, the annual expense will be $67 (at $0.10/kWh). Show how this estimate was made.

19-14. You are embarking on a conservation project and doing the following two things:
(a) *Replacing single-pane windows with double-pane windows.* Using Table 19-1 and Illustration 19-2, show that by switching from 1/8" single pane to double pane, a typical heat loss reduction is from 2500 to 100 BTU per hour per square foot. If your house (30 ft wide, 30 ft deep and 20 ft high) has 20% windows and 80% walls (R-value of walls is 22.4 h °F ft^2/BTU), show that the new annual energy consumption will be some 120 million BTU for a temperature difference of 54 °F.
(b) *Replacing 60%-efficient oil furnace with 90%-efficient gas furnace.* Assume that the costs of fuel oil and gas are $1/gallon and $6/mcf.
Estimate the annual savings in fuel expenses resulting from these two conservation measures. Compare them with the numbers cited in Investigation 19-8.

19-15. Calculate the total energy consumption in S. Wood's home and compare it with the 'averages' shown in Figure 19-6 and on p. 363.

19-16. (a) Calculate the total energy consumption in A. Rhodes' home and compare it with the 'averages' shown in Figure 19-6 and on p. 363. (b) Compare the 1996 costs of gas and electricity in $\$/10^6$ BTU.

19-17. Emily Kaltreider (MatSc 101 student, Fall 1996) lives in an old remodeled farmhouse in central Pennsylvania. In the early 1980s her family used some six tons of coal per year (at $60/ton) to heat their home. In mid-1980s, they switched to all-electric heat. Here are some of their data:

Year	Annual kWh consumed	Cost ($/kWh)
1988	24,177	0.0550
1992	28,531	0.0550
1993	27,199	0.0630
1994	34,091	0.0602
1995	38,080	0.0602

Do you think that the house is well insulated? (Compare these data with Figure 19-6.) How much more are Emily's parents paying now in comparison with the coal days? Comments?

INVESTIGATIONS

19-1. In the Economic Scene column of the NYT, 7/27/95 ("Energy standards aren't as oppressive as they may seem"), Peter Passell asks whether it makes sense to set and enforce energy efficiency standards for household appliances, buildings, etc. Summarize the arguments in favor of and against such measures.

19-2. Southern California Edison, the nation's second largest electric utility, has an interactive Internet site that allows utility customers to see their energy savings when they create energy-efficient 'virtual' homes. Visit this site at http://www.edisonx.com. Investigate some of these room-by-room savings when you use high-efficiency appliances. See also www.sce.com/homelink.

19-3. Find out more about 'smart' energy-efficient refrigerators and EPA's Super Efficient Refrigerator Program. See "Putting More Brains Into the Refrigerator," NYT of 7/31/95; "Public Housing Efficiency Plan, Step 1: Get New Refrigerators," NYT of 6/20/95; "The $30 Million Refrigerator: How Whirlpool designed America's most energy-efficient icebox," *Popular Science* of 1/94. See also "A $30 million Carrot: Whirlpool and Frigidaire in Refrigerator Contest," NYT of 12/8/92; "The Refrigerator of the Future, for Better and Worse," NYT of 8/30/92.

19-4. In a NYT article entitled "It Costs More to Save Energy" (11/20/94), H. Inhaber and H. Saunders argue that energy conservation is "much less useful than the conventional wisdom has it." Summarize the arguments that support this unconventional wisdom. In particular, investigate whether demand-side management (see Chapter 18) is working.

19-5. Find out about the different thermostats that are available on the market today. In addition to talking to a salesman at your local houseware store, read the following articles: "Modern thermostat is easy to install-and worth it," PI of 11/17/91; "Energy-saving thermostats," *Consumer Reports* of 10/93.

19-6. Find out more about compact fluorescent lamps. See *Consumer Reports* of October 1992. Also stop by your local hardware store and compare the current prices to those cited in this article. See also Investigation 19-11.

19-7. In the New York City region, petroleum-based products (fuel oil and kerosene) and natural gas appear to be neck and neck in their share of the residential market. In the article "Try Gas. (No, Keep Oil.) It's Better. (No, It's Not.)," the NYT of 2/14/93 summarizes the pros and cons of these two heating options. Comment on the validity of the arguments used and take a stand that will simplify the article's headline.

19-8. The NYT of 3/20/93 gives a detailed account of one household's energy conservation project: "Cutting Energy Costs: A Fondness for Heat-Loss Calculation Helps." Over 90% of the investment went into a new furnace and replacement windows. The heating requirements were reduced by 40% ($360/year). Consult this article for inspiration to do something similar. In particular, compare the effects of windows and furnace replacements with the results of Review Question 19-14.

19-9. Table 19-8 shows a column of 'average' use of different household appliances. To understand these numbers, verify how they were obtained for the case of an electric range. Check the power rating of your range. Estimate the amount of time you use the range every day. Multiply the power rating by this time interval and then by the cost of electricity. Is the number thus obtained close to 18 cents per day? Then obtain your electricity consumption in kWh/month. Is your value close to the 'average'?

19-10. Even more sophisticated windows than argon-filled double-pane or triple-pane ones may be available on the market. Find out about these 'smart' windows in NYT of 9/29/92 ("Researchers Develop 'Smart' Window to Cut Energy Consumption"). Summarize the most important facts mentioned in this article.

19-11. The Department of Energy has a "Back To School" program whose goal is to increase awareness of the benefits of compact fluorescent lights over incandescent light bulbs. The centerpiece of the program is a 'do-it-yourself' home and business energy analysis using a newly created computer software. The software is available at Home Depot stores and on the Internet. Check it out, at www.eren.doe.gov/femp or www.gsusa.org or www.crest.org. Provide an example of energy savings achieved by switching to CF lights.