Future Energy: Opportunities and Challenges

Part III. Energy Demand

Chapter 15. Residential Energy Use

Future Energy:
Opportunities and Challenges

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15
Residential Energy Use

The Main Points

- **One-fifth of the energy produced in America is produced to serve residences.**

- **Over two-thirds of the energy produced to serve residences is used to generate and deliver electricity (includes losses in production and delivery).**

- **Delivered electricity and natural gas each supply slightly over 40 percent of residential energy.**

- **Technologies are available to reduce the energy needed in residences. These include:**

    - **More efficient appliances**
    - **More efficient lighting**
    - **Better insulation**
    - **More efficient glazing on doors and windows**
    - **Heat recovery from drain water**
    - **Geothermal (or ground effect) heat pumps (extract or deposit energy in subsurface regions)**
    - **Energy storage in thermal mass (heat or cool a mass of material and use to extract or deposit heat as needed)**
    - **Building designs that capture or exclude heat input as needed**

- **Technologies are available to replace purchased energy with energy produced on-site. These include:**

    - **Solar space heaters (possibly with energy storage for use when sunlight is unavailable)**

  - **Solar water heaters**
  - **Photovoltaic systems**
  - **Wind turbines for electrical or mechanical energy (mainly on farms)**

- **Residents can make lifestyle choices that minimize energy use**

15.1 Introduction

Citizens have direct control of the quantity of energy that they consume in their residences (along with their energy use for personal transportation). Additional indirect energy must be used to provide them with goods, services, and infrastructure. This chapter deals with direct energy consumption in residences.

Homeowners can take steps to reduce residential energy consumption without major impacts on comfort. Reducing energy consumption usually requires capital expenditure, but this is offset over time by reduced annual energy costs.

American residences consumed about 21 Quads, or 21 percent, of all energy produced in the country in 2009. This consumption, along with the commercial sector consumption of around 17 Quads, results in total consumption for buildings of around 38 Quads, which is the largest share of total U.S. energy consumption. Measures to reduce energy use in buildings are thus important and are increasingly receiving attention from the federal and state governments, from builders, from property owners, and from real estate investors.

15.2 Residential Energy Consumption

15.2.1 Total Consumption

Residential energy use has remained rather constant since 2000, with primary consumption ranging from 20 to 21 Quads per year. It is important to appreciate the difference between *delivered* energy consumption and the *primary* energy production required to provide that quantity of delivered energy. Delivered residential energy is the energy actually used in the residence, regardless of the amount of energy initially consumed to provide the delivered energy. Primary energy is the total energy needed to provide delivered energy. The difference between the two is due to energy losses between primary consumption and delivered consumption. Electrical energy production in thermal plants results in the unavoidable loss of about two-thirds of the energy released from the fuel to produce the electricity (see Section 2.6). Additional electrical losses occur during transmission.

Table 15-1 and Figure 15-1 show the uses of residential energy.

Table 15-1. 2006 Residential Energy Use[1]

Use	Delivered		Primary	
	Quads	Percent	Quads	Percent
Space Heating	4.78	44.3	5.51	26.4
Space Cooling	0.85	7.9	2.70	13.0
Water Heating	1.67	15.5	2.59	12.5
Lighting	0.76	7.0	2.41	11.6
Electronics	0.53	4.9	1.69	8.1
Refrigeration	0.47	4.4	1.50	7.2
Clothes washers, dryers, dishwashers	0.46	4.2	1.22	6.2
Cooking	0.48	4.4	0.98	4.7
Computer	0.07	0.6	0.21	1.0
Other	0.34	3.2	0.76	3.6
Adjustment	0.37	3.5	1.19	5.7
Total	**10.79**	**100**	**20.83**	**100**
Note: The adjustments are for discrepancies in the data sources.				

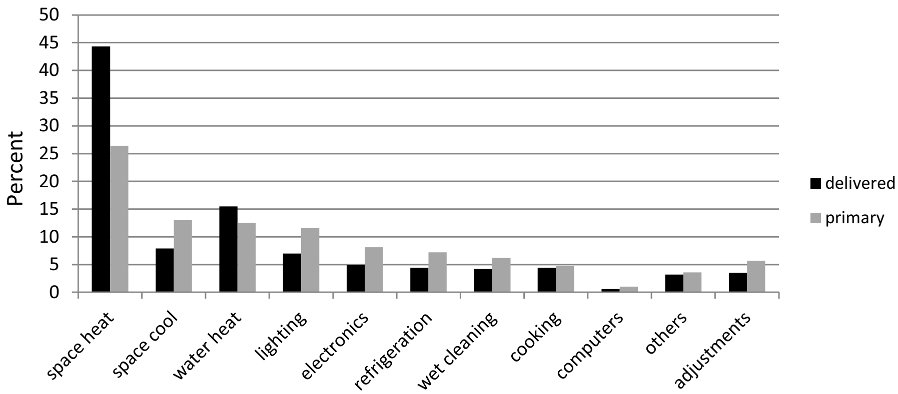

Figure 15-1. Residential Energy End Uses (2006)

It should be noted that other U.S. Department of Energy reports provide data on residential energy use, and the reports show slight differences in the data (for example, Reference 2). Since the data are presented here to provide a feel for energy use rather than for quantitative analysis, no attempt was made to judge or reconcile the sources.

The energy end use data show that space heating is the largest delivered energy user by a wide margin. Delivered energy for water heating is the second largest user of delivered energy (about one-third as great as space heating).

Delivered energy use is more important to residents who pay the bills for the energy they use. Primary energy use is more important when considering the nation's energy use and the consequences of producing that energy. In terms of primary energy end use, space heating is still dominant, but only around twice as great as three other applications: space cooling, water heating, and lighting.

Electrical energy consumption in residences deserves special attention. Around two-thirds (69 percent) of the primary energy production for residential use is for electricity. Energy losses in producing and delivering the electrical energy used in homes are about 10 Quads. In 2006, residential electricity consumption required 14.7 Quads of primary energy to produce 4.6 Quads of delivered electricity.

The distribution of electricity among the various residential end uses appears in Table 15-2.

Table 15-2. Residential Electricity Use (2006)[3]

End Use	Delivered Energy Quads	Primary Energy Quads
Space Heating	0.33	1.05
Space Cooling	0.85	2.70
Water Heating	0.42	1.34
Lighting	0.76	2.41
Electronics	0.53	1.69
Refrigeration	0.47	1.50
Clothes washers and dryers, dishwashers	0.38	1.22
Cooking	0.23	0.72
Computers	0.07	0.21
Others	0.19	0.61
Adjustments	0.37	1.19
Total	4.61	14.65
Note: The adjustments are for discrepancies in the data sources.		

These data provide a snapshot of residential electricity consumption and reveal applications where consumption reduction steps would have the largest benefit-to-cost ratio. For example, newer air conditioning systems can provide the same cooling as older units, but use as little as half as much energy. Refrigerators, lighting, and clothes dryers all use significant fractions of residential energy and newer, energy efficient systems are available for each of these applications. A 20 percent reduction in energy use in these three applications alone would save about 7 percent of the primary energy used to produce electricity for residential use.

As mentioned in Section 14.7, there are about 110 million U.S. households, and they use about 11 Quads of delivered energy per year (2008). The average delivered energy use per household is about 100 million BTU per year. To put this energy consumption into perspective, note that 100 million BTU could raise the temperature of 1 million pounds of water by 100°F.

15.2.2 Consumption by Energy Source

Electricity, natural gas, fuel oil/kerosene, propane, and renewables provide residential energy. In the early twenty-first century, the delivered residential energy consumption was around 11 Quads. The contribution of each source of delivered energy appears in Figure 15-2. Natural gas and electricity each provide a little over 40 percent of delivered residential energy. Fuel oil and liquefied petroleum gas (mainly propane) account for 10 percent, and renewables account for the balance of delivered residential energy.

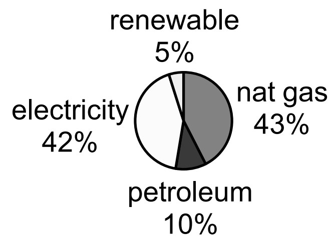

Figure 15-2. Residential Delivered Energy (2009)

Energy losses in producing and delivering the electrical energy used in homes were about 10 Quads.

Figure 15-3 shows the contributions of each primary energy source used to produce residential energy. Note that two thirds of the primary energy production for residential use is for electricity.

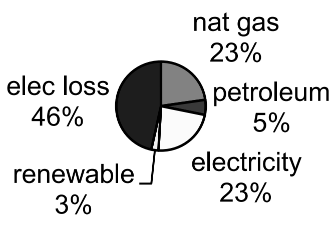

Figure 15-3. Residential Primary Energy (2009)

15.2.3 Heating and Cooling

American homes use over half of their delivered energy for space heating and cooling. Approximate assessments of heating and cooling energy needs are given by metrics called heating degree days and cooling degree days, defined as follows:

- Heating Degree Days (HDD) = sum of (days when the average temperature is below 65°F) × (65 minus the average temperature on that day)

- Cooling Degree Days (CDD) = sum of (days when the average temperature is above 65°F) × (Average temperature on that day minus 65)

For example, a day with an average temperature of 40°F contributes 25 Heating Degree Days to the annual total.

Yearly average HDD and CDD for several U.S. cities are shown in Table 15-3.

Table 15-3. Heating Degree Days and Cooling Degree Days[4]

City	Mean Temperature °F	HDD	CDD
Hartford, CT	50.2	6104	759
Laramie, WY	40.4	9038	71
Denver, CO	50.1	6128	696
Knoxville, TN	59.5	3531	1527
Atlanta, GA	62.1	2827	1810
Houston, TX	68.8	1525	2893
Miami, FL	76.7	149	4161

These data show the large variations in heating and cooling requirements across the U.S.

15.3 Space Heating and Cooling Systems

15.3.1 Space Heating Furnaces and Boilers

Home furnaces and boilers use natural gas, oil, or propane to heat air in the living space or to heat water that subsequently transfers heat to air in the living space. A metric called the "annual fuel utilization efficiency," or AFUE, defines their efficiency. The AFUE is the ratio of the output heat from a furnace or boiler compared to the total energy consumed by that furnace or boiler. Modern high-efficiency furnaces and boilers have an AFUE of over 90, up from around 60 a few decades ago[5].

15.3.2 Air Conditioners

Three types of cooling systems are used for home air conditioners: vapor compression systems, vapor absorption systems, and open-loop evaporative systems. The vapor compression type is the most common by a wide margin. All three systems remove heat from the surroundings by the evaporation of a fluid and are labeled phase-change systems. Appendix K addresses the principles of operation for all three types.

As discussed in Appendix K, a performance measure called the SEER (Seasonal Energy Efficiency Ratio) rating provides an indication of the energy efficiency of cooling with air conditioners and heat pumps. The SEER rating indicates the energy removed with the system (in BTUs) divided by the energy input to the system (in watt-hours) on a "typical" day. Manufacturers are required to meet minimum SEER requirements in their products. SEER ratings also provide consumers with a basis for comparing different products. Products that have SEER ratings at some level above the minimum requirement are designated "ENERGY STAR" systems and are so labeled.

Energy standards change over time, with higher efficiencies mandated as technology evolves and energy conservation concerns increase. In 2006, the minimum SEER requirement was 13, and the ENERGY STAR rating required a SEER of 14. Newer designs provide SEER ratings as high as the low twenties.

The efficiency of an air-source air conditioner or heat pump depends on the operating conditions (mainly ambient outdoor air temperature) as well as system design features. The efficiency at a specific operating condition is given by the Coefficient of Performance (COP), defined as the energy absorbed from the cooled space (for air conditioners) or energy delivered to the heated space (for heat pumps in the heating mode) divided by the energy delivered to the system. Both energies are in the same units, so COP is dimensionless. Typical COP values for current air-source air conditioners are 3 to 5, indicating that 3 to 5 units of heat are removed from the cooled space for every unit of energy supplied to the air conditioner.

The vapor compression and vapor absorption types are closed systems, in which all fluids are contained and circulated. The refrigerant in closed systems must be re-liquefied (condensed) after evaporation. The energy to drive the process is provided by electricity for the compressor in vapor compression systems and primarily by heating to separate the refrigerant from the solvent in vapor absorption systems.

In vapor compression systems, re-liquefaction is accomplished by compressing the refrigerant to re-liquefy it and then cooling the liquid refrigerant by heat transfer to the environment (see Figure 15-4). In vapor absorption systems, re-liquefaction is accomplished by dissolving the refrigerant in a solvent, heating the mixture to separate the refrigerant and the solvent, and then cooling the refrigerant by heat transfer to the environment.

There are two main variants of the vapor absorption process. One uses two components: a refrigerant and an absorber fluid. The other uses three components: a refrigerant, an absorber fluid, and an inert gas. The two-component version requires a pump that consumes a relatively small amount of energy in addition to the heat energy supplied. The three-component version does not require a pump. Using heat to power a refrigeration cycle is counter-intuitive, but it works at the expense of requiring a system with somewhat greater plumbing complexity than a vapor compression system. Vapor absorption systems can operate with any heat source, including solar energy (see Appendix K for details).

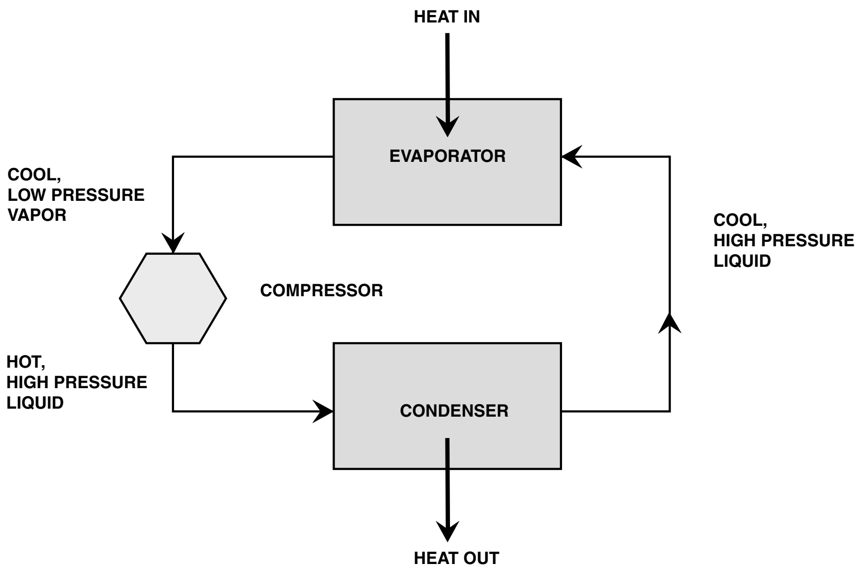

Figure 15-4. Vapor Compression Air Conditioner or Heat Pump

Open-loop evaporative coolers, often called "swamp coolers," are simple systems that use blowers to pass ambient air over a wick that is wetted with water (see Figure 15-5). Evaporation rates increase with increasing ambient air temperature and decreasing humidity. Consequently, these coolers are effective only in hot, dry climates such as occur in the U.S. Southwest.

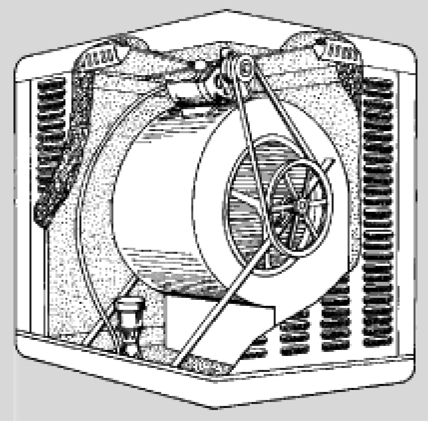

Figure 15-5. An Evaporative Cooler

A summary of the features of the three types of systems used for home air conditioning is given in Table 15-4.

Table 15-4. Features of Phase-Change Coolers

System Type	Open or Closed	Fluid	Energy Supply	Relative Complexity
Compression	C	single refrigerant	mechanical	intermediate
Absorption (two-component)	C	refrigerant, absorber	heat, low power pump	intermediate
Absorption (three-component)	C	refrigerant, absorber, inert gas	heat	high
Evaporative	O	water	low power fan	low

There is growing interest in the expanded use of vapor absorption systems. The attraction lies mainly in the ability of the system to use solar heating and thereby reduce or eliminate the need for grid electricity for air conditioning.

A novel cooling approach is nighttime production of ice to be used the following day for cooling[6]. This approach uses electricity when the grid demand is low and results in lower cost in regions where time-of-day pricing exists.

Subsurface regions with cool year-round temperatures may be used directly as heat sinks to cool air for living space. Tubes called earth cooling tubes carry air or a heat transfer fluid into sub-surface regions, where it is cooled before returning to the surface and used for cooling the living space.

15.3.3 Heat Pumps

Heat pumps can provide heating as well as cooling. In the cooling mode, heat is extracted from the living space by the evaporator. In the heating mode, heat is transferred to the living space by the condenser (see Figure 15-4).

Heating with heat pumps is much more efficient than resistive (Joule) heating. Since heat pumps use electrical energy to draw heat from a cooler environment, the total heat energy supplied includes energy from electricity, and the heat drawn from the environment. The heat provided by heat pump systems is several times the electrical energy used.

Currently, most heat pumps use ambient air to supply heat to the evaporator for operation as a heater. However, the ambient air is coolest in winter, thereby reducing the heat pump's ability to extract heat. For this reason, air-source heat pumps are not used in cold climates. An exception is dual-mode systems that include a heat pump and a gas furnace. In these systems, the heat pump provides heating until the air temperature drops too low for efficient operation. At that point, the operation switches to heating with the gas furnace.

Heat pumps can increase their heating capability by drawing energy from locations where the temperature is higher than the winter air temperature. So-called ground source heat pumps or geothermal heat pumps[7] use buried heat exchangers to draw heat energy from sub-surface regions, where temperatures are higher than ambient air temperature in winter. (For summer cooling, a ground-source heat pump dumps heat into sub-surface regions, where temperatures are lower than ambient air temperature.) Figure 15-6 illustrates the basic ground source heat pump.

Figure 15-7 shows the general features of seasonal soil temperature variations. Note that variations decrease with depth and they lag behind surface temperature variations. Typically, soil temperatures in the U.S. remain essentially constant year-round at depths of around 30 feet.

15.3.4 Solar Heating and Heat Dumping

Solar heating is very simple in principle. The first goal is to capture enough solar energy for immediate needs. The second goal is to capture and store

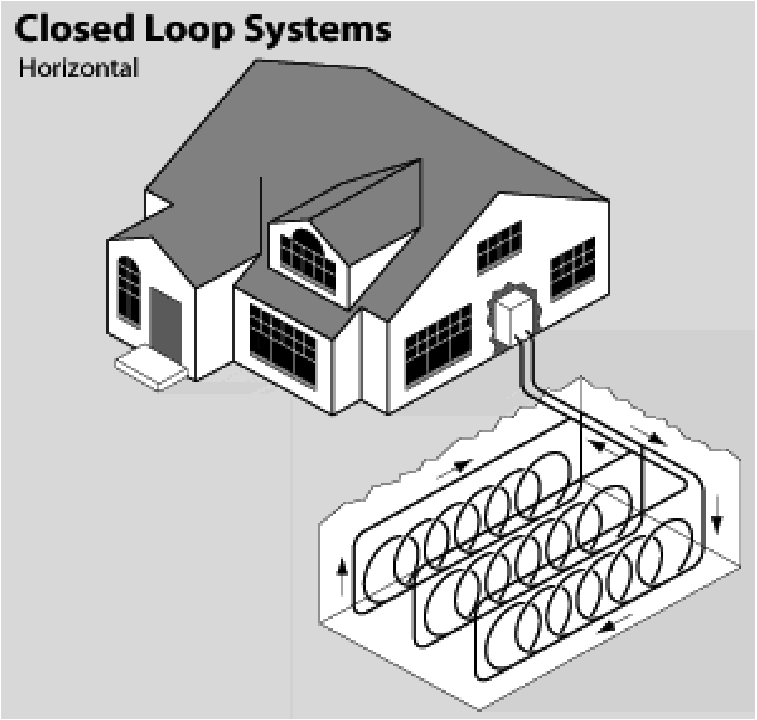

Figure 15-6. A Geothermal Heat Pump Layout (courtesy of U.S. Dept. of Energy)

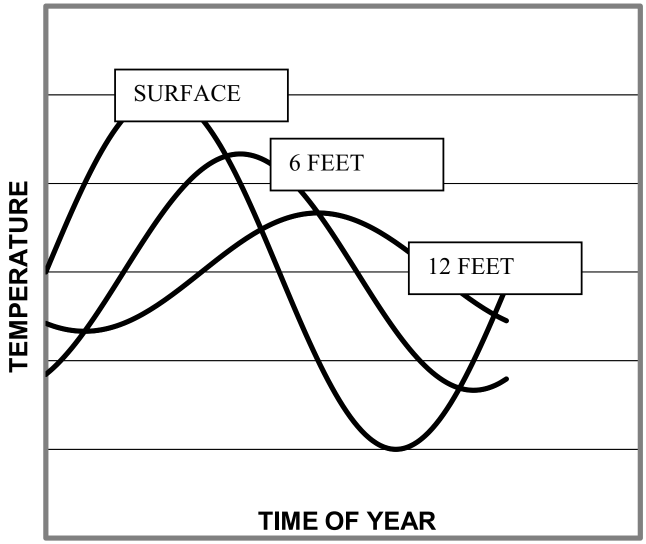

Figure 15-7. Annual Soil Temperature Variation at Various Depths

additional solar energy for future use when there is no incoming sunlight. The medium in which heat is stored is called a thermal mass. Heat dumping is the transfer of heat from a warmer thermal mass to cooler air or the transfer of heat from warmer air to a cooler thermal mass.

Daytime solar heating may be greater than is needed to warm a home adequately during the day. If this excess energy is stored during the day, it can be released at night when heat is needed. Energy storage involves heating material to a temperature above the desired temperature for the living space. At night, this heat is transferred to the air in the living space.

Similarly, nighttime air in summer is often cooler than the desired temperature for living spaces in summer. This cool air can be used to lower the temperature of a mass of material. During warm daytime hours, air in the living space is cooled by dumping heat to the cooled thermal mass.

Thermal mass is simply some material or structure that can store or deliver heat as needed. Walls, ceilings, floors, and furniture all contribute thermal mass, but the term is usually limited to separate systems designed for heat storage and for heat exchange with air from the living space. Thermal mass systems are most conveniently installed during initial construction, but retrofitting is also possible.

A thermal mass heating system that combines heat capture and storage and can be incorporated in new homes is the Trombe wall[8]. The Trombe wall is basically a south-facing wall located behind glass (see Figure 15-8.) The wall provides a thermal mass that can store heat. Materials used in Trombe walls include wood, stone, concrete, adobe, and water tanks. The energy capture is due to the greenhouse effect (see Chapter 19). That is, incoming radiation from the sun passes readily through glass, but the glass is less transparent to re-radiation from the wall. The wall–and the air in the space between the wall and the glass–are heated when the sun is shining. Trombe walls also have vents to the rest of the building at the top and bottom. Warm air rises and passes through the top vent and is replaced with cooler air entering through the bottom vent. Stored heat in the wall is available for transfer to the living space when the sun is not shining.

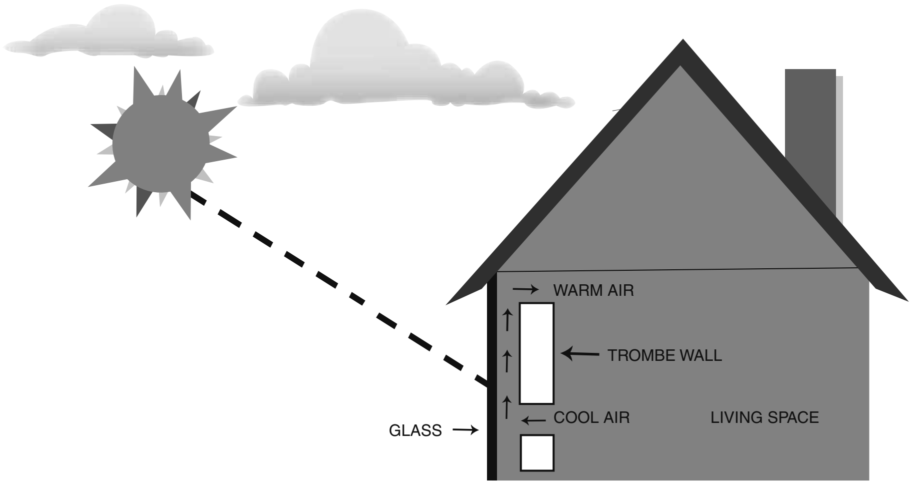

Figure 15-8. A Trombe Wall

Thermal mass systems may also be separate from building structures such as Trombe walls. These systems include an insulated container of some sort that holds thermal mass material, a means for transferring heat between the environment and the thermal mass, and a means for transferring heat between the thermal mass and the air in the living space. The container may be located in the building or sunk into the ground near the building. Thermal mass systems are heavy, so installations inside buildings are located at ground level.

Water and rocks are suitable thermal mass materials. Both are inexpensive and readily available. Because of water's large specific heat capacity and good heat transfer properties, water systems are smaller than rock systems of comparable capacity. Rock systems use blowers to pass air over the rocks during heating and cooling. The design and operation are simple, but use of uniform rock size so as to leave space for air flow is crucial. In water systems, it is necessary to transfer heat to or from air in the living space without causing excess humidity. Water-to-air heat exchangers can provide this capability. Water systems also must be protected from freezing, and they must be cleaned and treated to prevent algae buildup. Figures 15-9 and 15-10 show typical thermal mass systems.

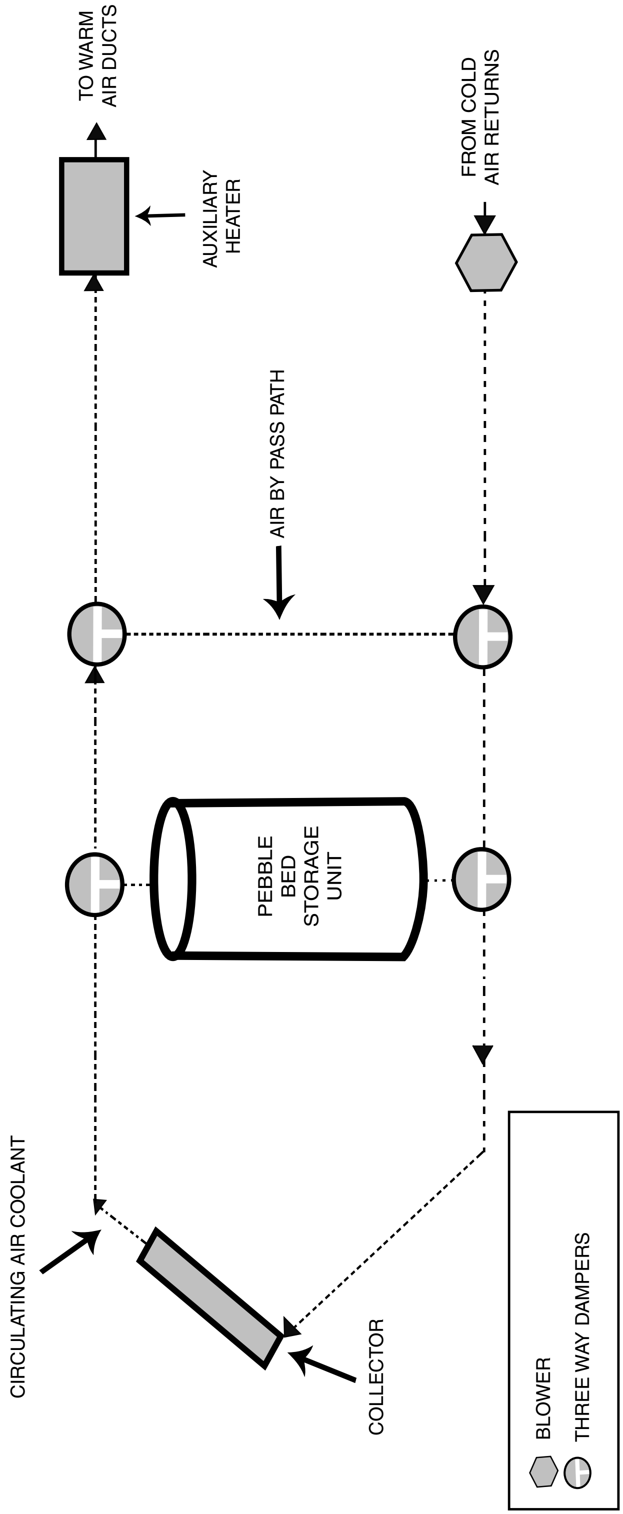
TO WARM
AIR DUCTS
AUXILIARY
HEATER
FROM COLD
AIR RETURNS
AIR BY PASS PATH
PEBBLE
BED
STORAGE
UNIT
CIRCULATING AIR COOLANT
COLLECTOR
BLOWER
THREE WAY DAMPERS

Figure 15-9.

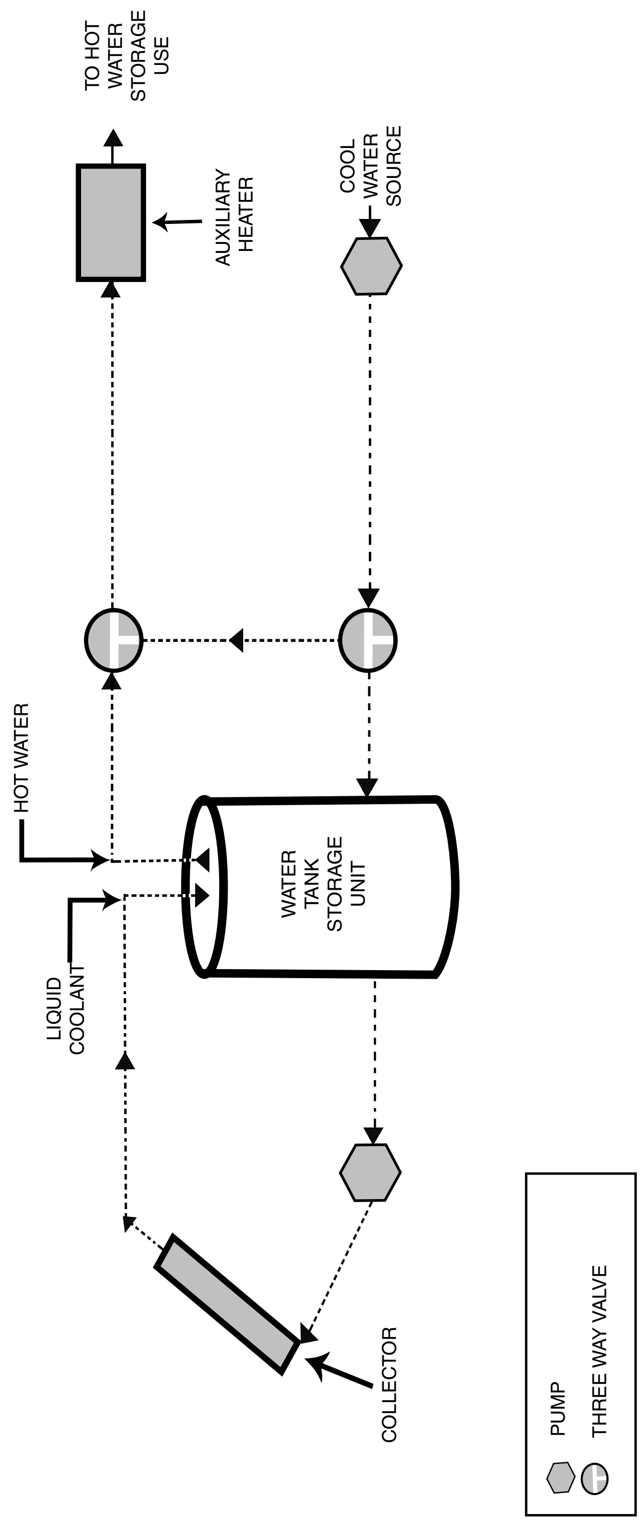
TO HOT WATER STORAGE USE
AUXILIARY HEATER
COOL WATER SOURCE
HOT WATER
LIQUID COOLANT
WATER TANK STORAGE UNIT
COLLECTOR
PUMP
THREE WAY VALVE

Figure 15-10.

A phase-change thermal mass system for heating is also possible. These systems require the use of a material that melts and freezes at a temperature slightly above the desired temperature for the living space. Glauber's salt (sodium sulfate decahydrate) melts and freezes at about 90°F and is potentially useful for energy storage. If solar heat can raise the salt to 90°F, then the salt will melt by absorbing heat at constant temperature. It can then release energy upon freezing due to heat transfer to air with a temperature below 90°F. The advantage of a phase-change thermal mass is the large amount of energy absorbed upon melting and released upon freezing, thereby minimizing the volume of thermal mass required.

We have seen the average delivered energy consumption in American residences is about 100 million BTU per year. About 60 million BTU per year provides space heating and water heating. We have also seen (Chapter 5) that the average solar insolation in the U.S. ranges from 1,100 to 1,800 BTU per day per square foot. However, solar insolation is lowest in winter, when heating is needed. Winter insolation in regions that need significant heating ranges from 25 to 40 percent of summer insolation (see Figure 15-11 for data for two selected cities, Atlanta and Hartford). Mid-winter insolation in the northern U.S. is only 400 to 600 BTU per day per square foot. The combination of a colder climate and lower insolation in the northern U.S. makes solar heating much less practical than in regions with a milder climate.

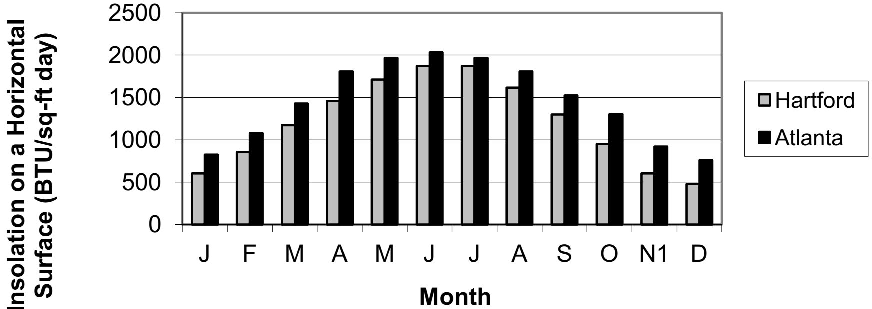

Figure 15-11. Insolation in Hartford and Atlanta

15.4 Water Heaters

Unlike space heating, water heating is needed year-round. According to the U.S. Department of Energy,[9] energy for water heating amounts to over 15 percent of residential energy consumption, and 80 to 90 percent of that energy leaves through the drains. This loss amounts to over 2 percent of total U.S. energy production.

Traditional water heaters in the U.S. are tanks with gas or electric heaters and a storage capacity of 40 to 80 gallons. These tanks are insulated, but there is unavoidable energy loss from the stored hot water.

Hot water must travel through pipes from the water heater to the point of use. When flow stops, trapped hot water in the pipes cools by heat transfer to the surroundings, thereby wasting the energy used initially to heat the water.

Various methods are capable of reducing energy losses in water heaters and delivery systems, but they require capital investment.

Heat recovery systems can be installed to reduce energy lost in drains.[9] For example, a heat exchanger can be used to transfer drain water heat to fresh water. Storing the heated fresh water in an insulated vessel and using it to feed the main water heater reduces the energy required in the water heater. See Figure 15-12.

Tankless, or on-demand, water heaters address the losses in storage. They use gas or electric heaters to raise the water temperature as it passes through the heater. These systems require high power capability in order to deliver the energy fast enough, but they eliminate hot water storage and the energy losses associated with storage.

Heat pump water heaters are available, and they provide efficiency advantages over direct heating. They use the same principle as heat pumps used to heat homes. Heat pump water heaters are usually located indoors (typically in a garage), but must be placed in locations with ample surrounding open

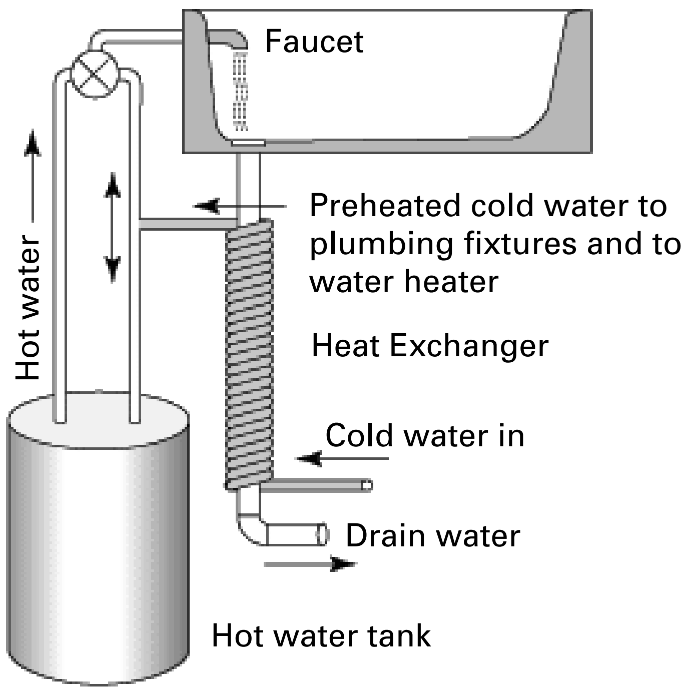

Figure 15-12. Drain Water Heat Recapture (courtesy of U.S. Dept. of Energy)

space so as to avoid excessive cooling of the air. Recall that heating with an air-source heat pump requires drawing energy from surrounding air and the efficiency of this process decreases as air temperature decreases.

Solar water heating is another option for homeowners, especially in summer when insolation is greatest. Delivered energy use for water heating in 2006 was about 1.67 Quads for around 110 million households, or an average of 15 million BTU per household per year. Since the need for hot water is fairly constant throughout the year, the average monthly and daily household uses are fairly constant with values of about 1.3 million BTU per month and 42,000 BTU per day. For example, in a location with an insolation of 1,000 BTU per square foot per day, a horizontal collector with 30 percent efficiency would need about 135 square feet of surface area to provide adequate energy. In northern regions, winter insolation is about half as great, causing the surface needed for water heating to double (see Section 6.2.2 for details).

15.5 Lighting and Appliances

15.5.1 Lighting

We have seen that lighting accounts for about 2.41 Quads of residential primary energy use. Traditionally, home lighting has meant incandescent lights. Improved lighting efficiency (more light per watt of electricity) is possible with fluorescent lights or light-emitting diodes (LEDs).

Fluorescent lights have been available for many years. Until recently, they were in the shape of long tubes. Aesthetic concerns largely limited the use of these lights to commercial and industrial buildings. Residential use of fluorescent lighting is currently increasing rapidly with the introduction of screw-in compact fluorescent lamps (CFLs).

The main attractions of fluorescent lighting are its efficiency and longevity advantages over incandescent lights. A fluorescent lamp can produce as much light as an incandescent lamp with only about one-fifth as much energy, while lasting up to 10 times as long.

A disadvantage of CFLs is the higher initial cost than incandescent lamps, but reduced energy use and longer life result in lower lifetime cost. There is also a need to deal with the small quantity of mercury that is incorporated in fluorescent lamps. There is concern about the release of toxic mercury in homes as a result of breakage and in landfills as a result of disposal.

Light emitting diode (LED) use is currently limited to special applications, where their high cost can be tolerated. However, LED costs are dropping, and their competitive position is improving.

The U.S. government mandated increased energy efficiency of light bulbs, essentially requiring the phasing out of incandescent bulbs in favor of CFLs or LEDs. This ruling proved to be controversial, as some objected on the basis of infringement on personal freedom.

15.5.2 Appliances

The energy efficiency of appliances has improved greatly in recent years, and further improvements are imminent. For example, in the first month of his presidency, President Barack Obama directed the Department of Energy to accelerate its work on appliance efficiency standards[10]. The government promotes energy efficiency in two ways: by requiring manufacturers to meet efficiency standards and by informing consumers about the efficiency and lifetime energy costs for appliances. Consumer information activities include required "ENERGY GUIDE" labels on appliances. The ENERGY GUIDE provides estimates of energy use and energy costs. Appliances that significantly exceed minimum requirements receive an "ENERGY STAR" designation and are so labeled.

Of course, consumers can reduce energy use by purchasing ENERGY STAR appliances. Additional energy-reducing steps include purchasing appliances that use gas rather than resistive (Joule) heating, avoiding unnecessary capacity and use, reducing unwanted energy losses or gains, and providing regular maintenance. Some specific energy-reducing options for home appliances are as follows[11]:

Refrigerators and Freezers

- Avoid purchasing units that are larger than needed
- Choose top-freezer refrigerators rather than side-by-side units
- Choose chest freezers rather than upright freezers
- Clean coils at least once per year
- Keep seals in good repair
- Locate refrigerators and freezers as far from heat sources (such as ovens) as possible

Ovens and Ranges

- Select gas rather than electric units (Gas heating is more efficient than resistance heating with electricity.)

- Select self-cleaning ovens because they have superior insulation, but use self-cleaning as infrequently as practical

Dishwashers

- Select models with booster heating to reduce the necessary water heater temperature settings

- Select models with multiple cycles for different size loads

- Select models with an air-dry feature

Clothes Washers

- Select front load washers, which use less water

- Use cool water when possible

Clothes Dryers

- Select gas rather than electric units

- Keep the filter clean

- Dry full loads

- Dry multiple loads consecutively

- Use air drying when possible

Appliance energy consumption also includes so-called phantom loads. A phantom load is energy consumption by an appliance when it is in a standby mode of operation. For example, appliances that respond to a remote control device must use energy continuously to be able to receive a signal to turn on. Residents can reduce phantom loads by unplugging appliances when they are to be idle for extended periods. The phantom load for individual appliances is typically small (a few watts), but residences usually have many such appliances, and the phantom loads continue around the clock. Estimates of residential phantom loads are as great as 10 percent of total residential electricity consumption.

15.6 Local Electrical Energy Production

Electricity can be produced locally for residences using photovoltaic (see Chapter 6 and Appendix I) or wind energy systems (see Chapter 8 and Appendix P). Photovoltaic panels, often mounted on rooftops, can produce significant quantities of electrical energy. The cost of these systems is still high, but costs are falling. Small wind turbines are also available for small-scale production of electricity, but their aesthetic impact often prohibits their use in urban or suburban areas. Wind turbines are potentially useful for farm applications, either to drive an electrical generator or as a source of mechanical energy to drive a pump for drawing well water for irrigation or other farm uses.

The electrical energy available from a photovoltaic system is equal to the product of the solar insolation, the solar-to-electrical conversion efficiency, and the surface area of the collector. For example, a collector with a horizontal surface area of 500 square feet and an efficiency of 30 percent will produce 150,000 BTU or 44 kw-hours of electricity per day in a location where the insolation is 1,000 BTU per day per square foot. At the current average cost of electricity, this production is worth about $4 per day (average electricity cost is about $.09 per kilowatt-hour).

Photovoltaic systems produce direct current (DC), but almost all residential applications require alternating current (AC). Conversion of DC to AC requires the use of a device called an inverter, an essential part of a photoelectric system.

The power produced by a photovoltaic system will rarely match electrical needs continuously in a residence. Electricity from the grid can supplement or replace locally-produced electricity when needed. Excess locally-produced electricity can be fed into the grid and sold to the utility during daytime. This works to the benefit of the consumer and the utility. Local photovoltaic electricity production operates during the day when grid requirements are greatest. Availability of photovoltaic electricity from consumers reduces the required generating capacity for the utility. The sale of electricity produced during the day to a utility helps the consumer by offsetting expenditures for the nighttime consumption of grid electricity.

15.7 Building Features and Lifestyles

Homeowners can reduce residential energy consumption by using efficient heating systems, cooling systems, lighting, and appliances as described above. They can also reduce energy consumption by adopting smart building features and lifestyle habits.

Buildings designed to maximize solar heating in winter can reduce winter energy consumption. Placing large windows in south-facing walls that are unshaded in winter admits solar energy into the residence. The trick is to shade these windows in summer when heat is unwanted.

Overhangs, awnings, and strategically placed deciduous trees reduce summer heating. The sun is high in the sky in summer and low in winter. Figure 15-13 illustrates the concept. Use of small windows on other walls reduces unwanted energy transfers.

Of course, it is helpful to avoid energy transfer to the outside in winter or from the outside in summer by using adequate insulation, by thoroughly sealing cracks and openings and by using energy efficient glazing in doors and windows.

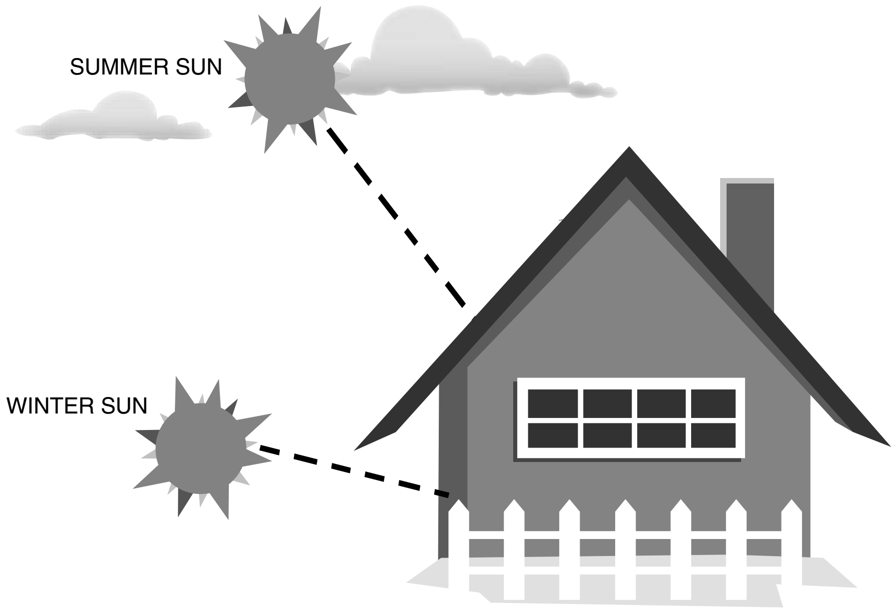

Figure 15-13.

Insulation's purpose is to reduce conduction heat transfer. Insulation is used in walls, attics, and beneath flooring to suppress heat transfer through these surfaces. The effectiveness of insulating material is specified by its "R value." The units for R values are ^{o}F/(BTU per hr per square foot) where ^{o}F is the temperature difference across the insulator. Larger R values indicate greater resistance to heat transfer. For example an insulator with an R value of 30 would transfer one BTU per hour for each square foot of surface when it experiences a temperature difference of $30^{o}F$. Common residential insulating materials are fiberglass, cellulose, and foam. Recommended R values range from 11 for walls and floors in mild climates to 49 in ceilings below ventilated attic spaces in cold climates.

Fans can be efficient aids to comfort in warm weather. Applications include convection cooling of residents by exposure to moving air, removal of hot air from attics and drawing cool night air into homes.

Residences must exchange indoor air with outdoor air to maintain adequate indoor air quality. However, air entering or leaving the residence adds or removes heat energy from the home and can cause departures from desired indoor air temperatures. Drafts around poorly sealed windows and doors are readily observable, but additional air leakage can occur through holes and cracks in the building structure and in any ductwork that carries heated or cooled air into the living space. Energy savings can be achieved with engineered air replacement systems that incorporate heat exchangers to transfer heat between exhaust air and incoming air.

Windows are essentially "holes" in the building envelope. The Department of Energy states that 10 to 25 percent of residential energy consumption is due to heat transfer through windows[12]. A number of design options are available for dealing with energy transfer through these "holes." The frames and the glazing affect energy transfer. A metric called the "U factor" is used to quantify the heat transfer through glazing or through complete framed window structures. The U factor has units of BTU/(hr square foot ^{o}F). It is essentially the reciprocal of the R value used for insulation. Lower U factors indicate a greater resistance to heat transfer. U factors range from 1 for single-pane glazing to about 0.3 with gas-filled multiple-pane glazing. Corresponding R values are 1 to 3, much lower than typical insulation R values, confirming that windows are truly responsible for major residential energy losses.

Energy flow through window frames is essentially all by conduction. Frame materials with low thermal conductivity transfer less energy than those with higher thermal conductivity. Therefore frames made of wood or plastic allow less energy flow than those made of aluminum.

The main design approach for reducing conduction through glazing is to use two or even three panes separated by thin layers of stagnant gas. The gas may be air, but greater resistance to heat flow may be achieved with low-conductivity gases such as argon or krypton.

Radiation heat transfer through glass can be affected by the use of coating materials[13]. Thin, transparent coatings of certain metal oxides reflect infrared radiation.

Lifestyle choices within residences can also influence energy consumption. We have all heard advice to keep our residences a few degrees cooler in winter and a few degrees warmer in summer and to accommodate these changes by dressing appropriately. Homeowners can also save energy by limiting heating and cooling to those parts of the residence that are in use. Closing doors and/or vents into rooms that are used infrequently can help. Some citizens choose to use supplementary heating of small areas only when they are occupied. Examples are electric bathroom heaters, small electric or kerosene heaters used for personal comfort and electric blankets. The low efficiency of these systems is offset somewhat by the limited space that they are called upon to serve.

15.8 Possibilities

Given the assortment of energy-reduction steps described above, one certainly must ask, “What is possible?” “What is affordable?” and “When can we expect to see significant reductions in residential energy use?” Some opinions appear below.

The useful life of most homes is many decades. Consequently, achieving improved energy efficiency exclusively in new homes will result in only slowly decreasing consumption. Efficiency upgrades in existing homes are needed along with improvements in new construction.

The U.S. Department of Energy has created a program called Building America[14] to help in improving energy efficiency in existing and new homes. Its goals include reduction of energy use in existing homes by 20 to 30 percent and in new homes by 30 to 90 percent.

These advances are part of an ongoing effort to develop "Zero Energy Homes." A zero energy home is one that has a net absence of energy inputs from external sources[15]. A zero energy home achieves this by:

- Minimizing energy losses through the design of the home (insulation, glazing, etc.)
- Minimizing energy need (efficient appliances, efficient lighting, etc.)
- Producing energy locally (solar heating, photoelectricity, etc.)

The idea is to reduce the energy needed by around 70 percent and to obtain the remaining 30 percent by local production. Since local electricity production will not match demand continuously, locally produced electricity that exceeds current demand will be fed into the grid. Conversely, energy will be extracted from the grid when demand exceeds the supply of locally produced electricity. The American Physical Society[16] estimates that new, cost-effective zero energy homes will be feasible by 2020.

A home that approaches, but does not reach, the zero energy level is called a near-zero or ultra-low energy home.

The cost-effectiveness of investing in an energy-efficient home depends on several factors, including:

- Interest rate for borrowed money
- Incremental cost of unconventional building features
- Cost of conventional energy supplies
- Financial incentives offered by state and federal governments (see Reference 17 for current incentives)
- The potential increase in resale value

The U.S. Green Building Council has developed a certification program called Leadership in Energy and Environmental Design (LEED)[18]. LEED certification is granted to buildings that meet design criteria that reduce energy use and environmental degradation. LEED certification is the basis for financial incentives offered by some city and state governments[19] .

Predicting the speed and scope of a transition to energy-efficient homes suffers from many uncertainties. Attitudes must change along with changing economic and technical conditions. However, as energy costs inevitably rise and building design and local energy production technologies improve, energy-efficient homes will become increasingly attractive investments.

15.9 Commentary

It is likely that Americans will have strong reasons to reduce residential energy consumption in the future. Citizens have some direct control over their residential energy consumption (along with energy consumed for personal transportation). Many energy-reducing steps require capital expenditure. Examples include switching to compact fluorescent lamps for lighting, installing ground-source heat pumps for heating and cooling and solar collectors for heating or local electricity production. The range of costs and associated benefits is enormous. Investments in energy efficiency will reduce resource depletion immediately and will reduce personal expenditures eventually. The rate of recapture of money spent initially will increase as energy costs inevitably rise in the future.

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