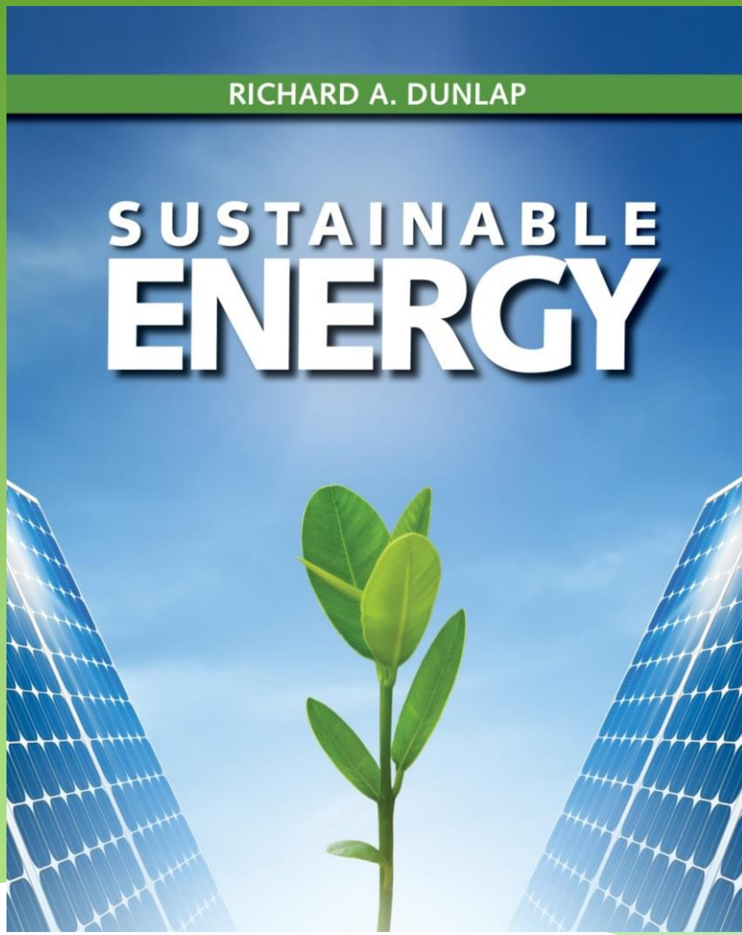
Sustainable Energy



Chapter 17

- Energy Conservation

©2015 Cengage Learning Engineering. All Right Reserved.

CENGAGE Learning

Learning Objectives

- How government energy policies deal with conservation matters.
- How combined electricity and heat production can make the best use of resources.
- Approaches to electricity distribution and how the smart grid can be used to integrate different energy sources and regulate the use of electricity.
- Energy conservation in the community through the use of LED streetlights.
- The efficient operation of residential HVAC systems.
- The application of heat pumps to space heating needs.
- Reducing heat transfer in and out of buildings.
- High-efficiency lighting technologies.
- Vehicle fuel efficiency and government standards.
- The viability of hybrid vehicles as a means of fossil fuel conservation.

©2015 Cengage Learning Engineering. All Right Reserved.

Energy conservation

Energy conservation can be practiced at various levels (for example)

- individual
- industry
- community
- state/provincial
- national

©2015 Cengage Learning Engineering. All Right Reserved.

Important aspects of energy conservation

Some important aspects of energy conservation that are considered in this chapter are

- National energy policies
- Utilizing waste heat through cogeneration
- Implementation of smart grid technologies
- Municipal energy conservation using LED streetlights
- Efficient residential heating and cooling
- Minimizing residential heat loss
- Efficient residential lighting
- Improving vehicle fuel economy
- Hybrid vehicles

©2015 Cengage Learning Engineering. All Right Reserved.

National energy policies

Energy policies may include a consideration of such factors as

- The assessment of energy needs.
- The availability of energy resources.
- The possibility of energy self-sufficiency.
- The environmental consequences of energy use.
- The promotion of energy-efficient products.
- The promotion of energy conservation measures.
- Interaction with energy-related activities at state/provincial and/or municipal levels.
- The development of mechanisms to implement energy policy, including incentives, subsidies, and the like.

©2015 Cengage Learning Engineering. All Right Reserved.

Cogeneration

Cogeneration is the use of more than one type of energy from a single method of energy production.

This generally refers to the use of excess heat produced by a heat engine during the production of electricity in a thermal generating station.

Since the Carnot efficiency of a thermal generating station is about 40%, then 60% of the energy content of the fuel is normally wasted.

©2015 Cengage Learning Engineering. All Right Reserved.

Applications of cogeneration

Cogeneration is commonly used by industries, universities, hospitals etc. where a small electric generating station provides electricity for a single customer and heat can be utilized and distributed to the local community.

©2015 Cengage Learning Engineering. All Right Reserved.

Cogeneration at Cornell University

Central facility provides most of the heat and electricity used on campus

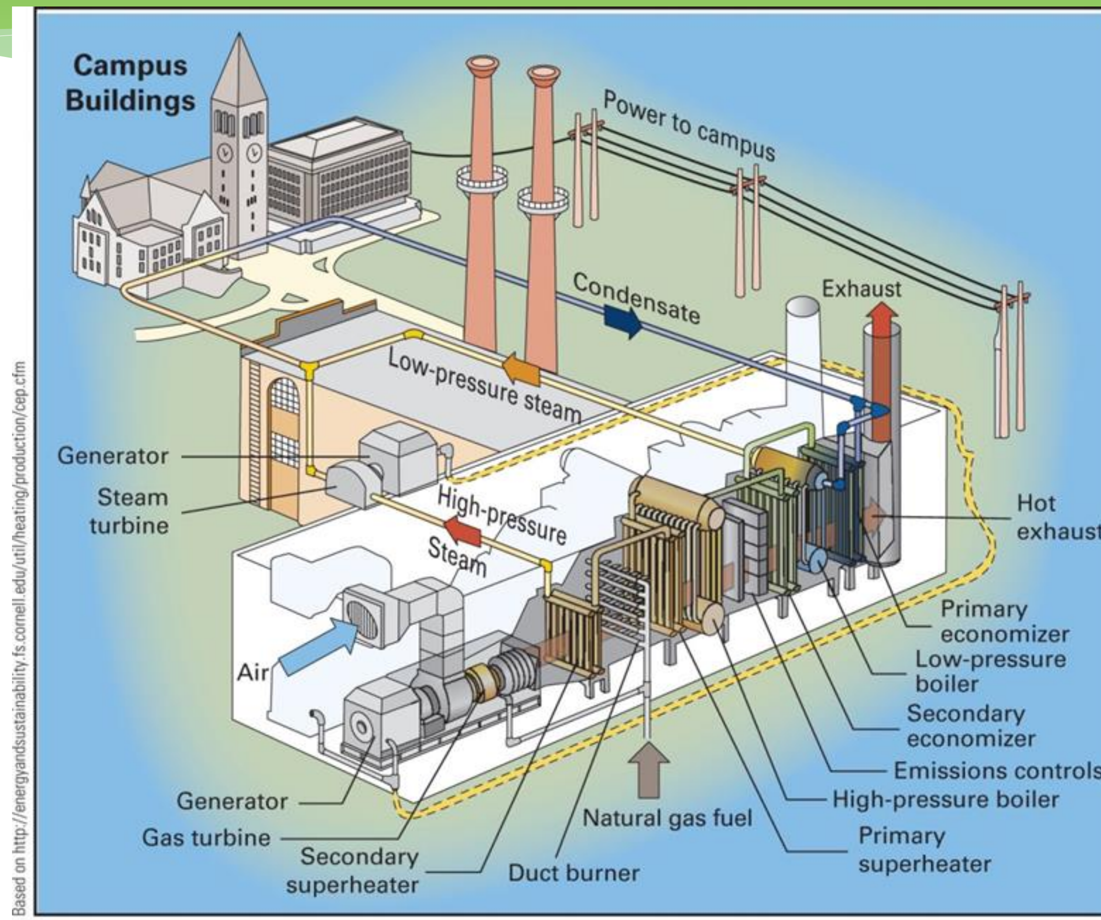


Figure 17.2: Schematic diagram of Cornell University cogeneration plant.

©2015 Cengage Learning Engineering. All Right Reserved.

Smart grid

Smart grid technology can optimize the efficiency of power generation and use.

This can include

- The effective integration of base power generation with alternative energy technologies and energy storage
- Real time monitoring and control of electricity use to optimally match generating capabilities with demand

Several power utilities in Europe, the United States and Canada have begun smart grid implementation.

©2015 Cengage Learning Engineering. All Right Reserved.

LEDs

The basic physics of the LED (light emitting diode) is the same as that of a photodiode except in reverse.

A voltage is applied to a semiconducting diode and light (photons) is produced.

This is a much more efficient way of producing light from electricity than incandescent bulbs.

©2015 Cengage Learning Engineering. All Right Reserved.

White LEDs

Generally, for most applications, a white light source is desirable.

LEDs produce light over a limited range of wavelengths.

Three LEDs of different colors can be combined to produce the appearance of white light.

This is analogous to a triple junction photodiode.

©2015 Cengage Learning Engineering. All Right Reserved.

Three color LED spectrum

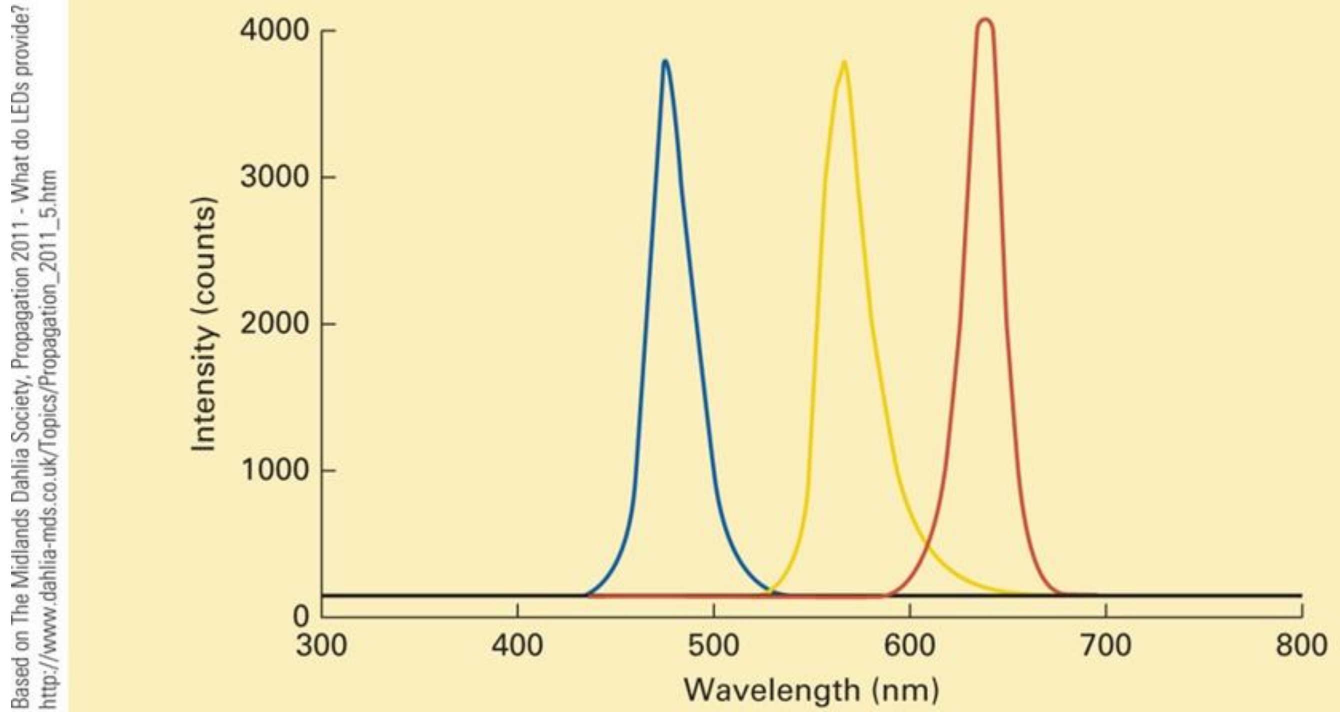


Figure 17.3: Spectrum of a three-color LED producing white light.

©2015 Cengage Learning Engineering. All Right Reserved.

Phosphor coatings in LEDs

An alternative (and more economical) method of producing white light uses light from a blue LED which is incident on a phosphor coating and this re-emits light over a wide range of wavelengths.

©2015 Cengage Learning Engineering. All Right Reserved.

Spectrum of LED with phosphor coating

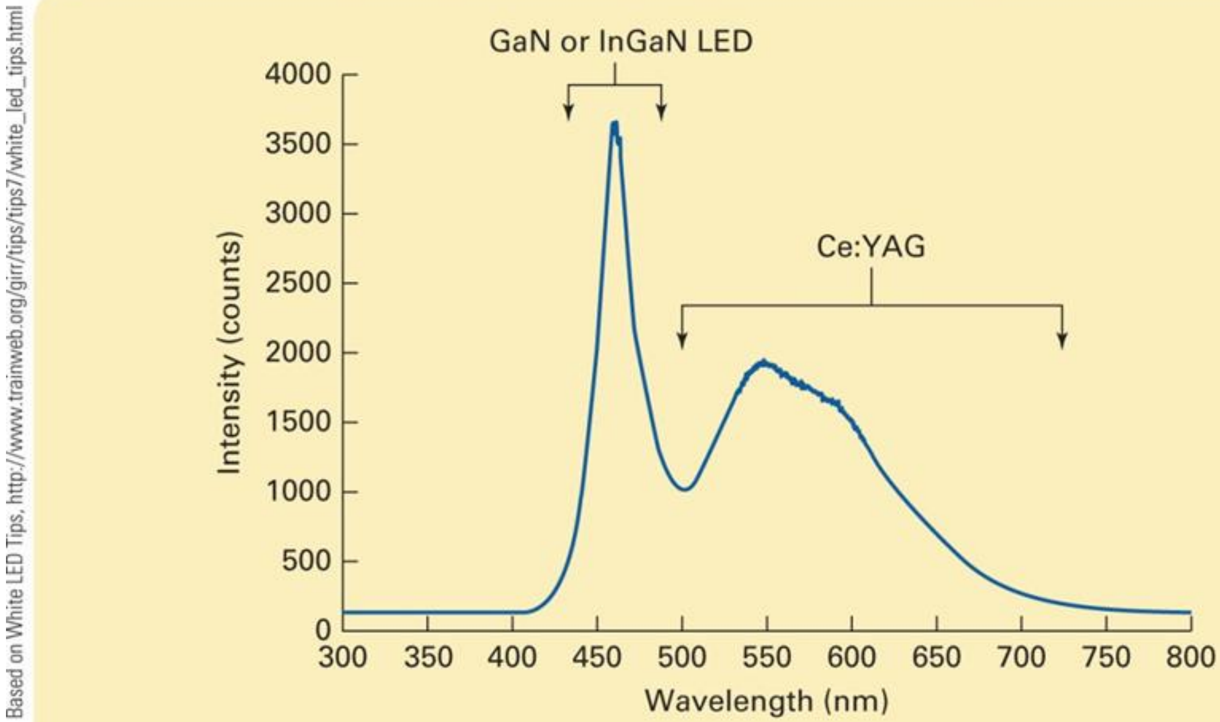


Figure 17.4: Spectrum of a blue GaN or InGaN LED with a cerium-doped yttrium aluminum garnet (YAG) phosphor coating.

©2015 Cengage Learning Engineering. All Right Reserved.

LED streetlights

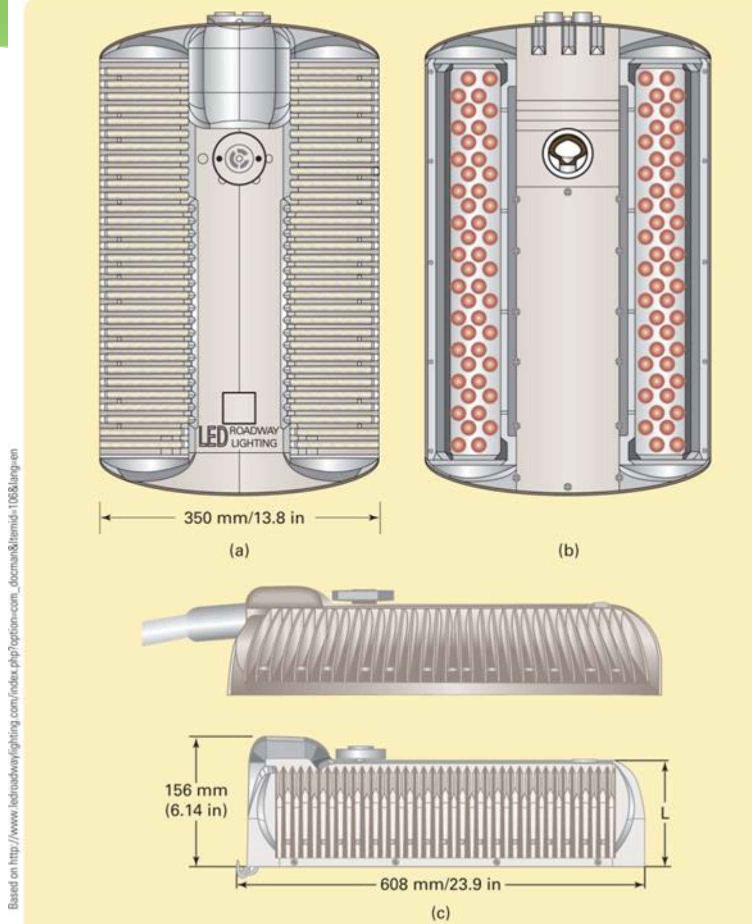


Figure 17.5: Top (a), bottom (b), and side (c) views of an 86-W LED streetlight containing 96 LEDs manufactured by LED Roadway Lighting.

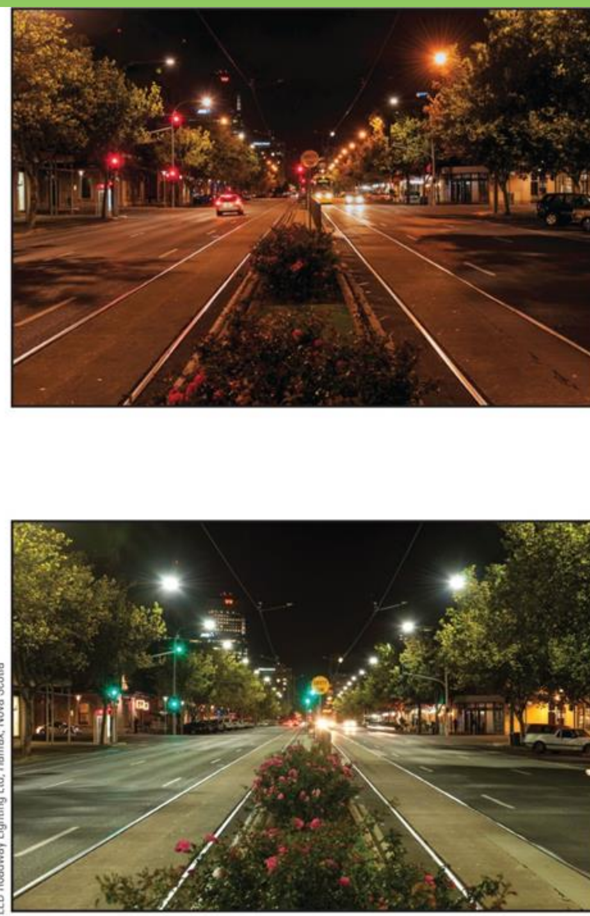
©2015 Cengage Learning Engineering. All Right Reserved.

Advantages of LED streetlights (compared with traditional sodium vapor lamps)

- reduced energy consumption for equivalent (or greater) light output
- long lamp life expectancy
- can be dimmed when full illumination is not required
- light more effectively directed to road surface
- more accurate color rendering
- elimination of toxic materials

©2015 Cengage Learning Engineering. All Right Reserved.

Applications of LED streetlights



LED Roadway Lighting Ltd, Halifax, Nova Scotia

Figure 17.6: Conversion of streetlights on King William Street, Adelaide, Australia from (top) high-pressure sodium fixtures to (bottom) LED streetlights.

©2015 Cengage Learning Engineering. All Right Reserved.

Home heating and cooling

HVAC = heating, ventilation and air conditioning

HVAC systems may be single family or district system

The design of HVAC systems depends on climate conditions

©2015 Cengage Learning Engineering. All Right Reserved.

Furnace efficiency

A furnace produces heat through the combustion of a fuel

The fuel may be oil, coal, natural gas, propane or wood pellets

Efficiency depends on

- efficiency of combustion of the chemical fuel
- efficiency of heat distribution systems

©2015 Cengage Learning Engineering. All Right Reserved.

Typical furnace design

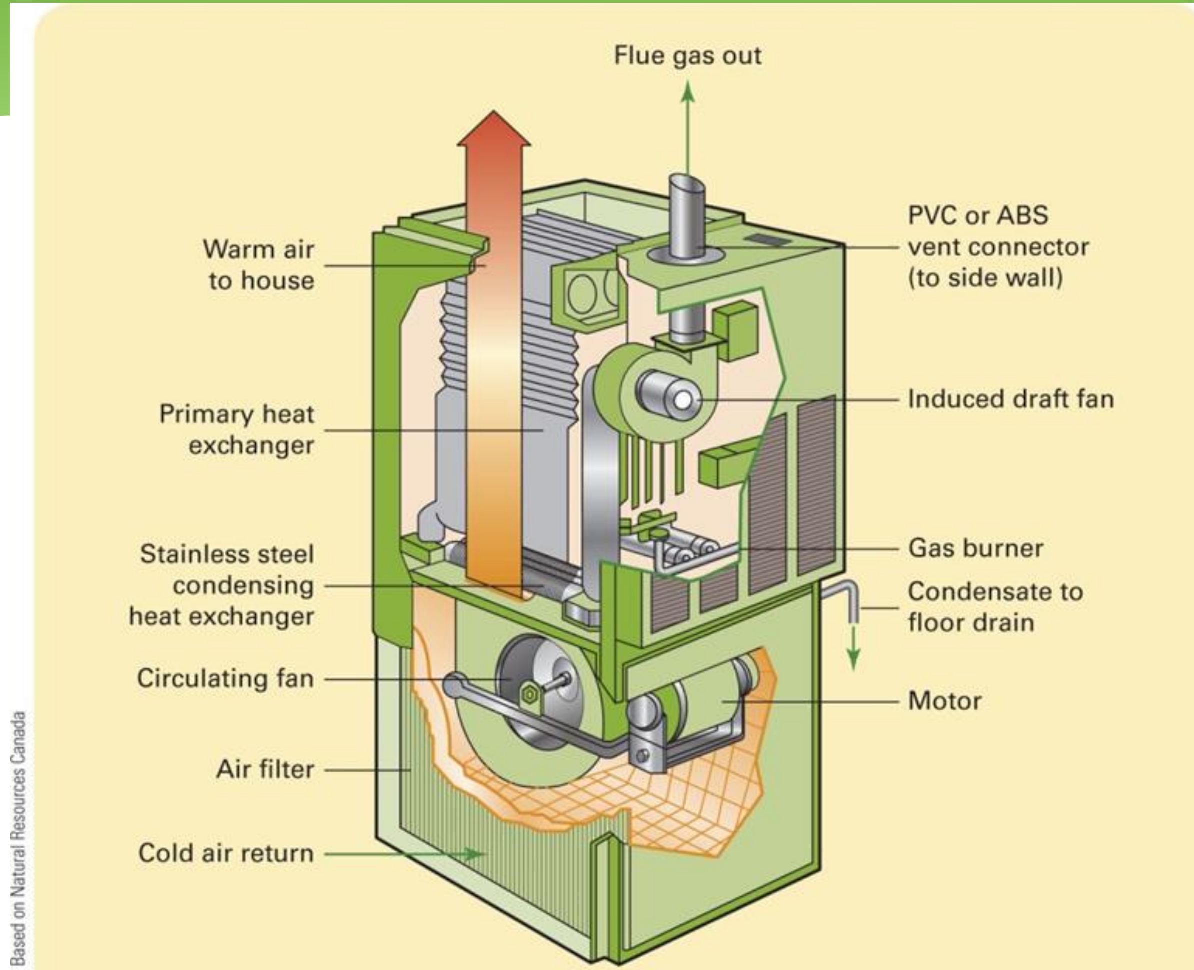


Figure 17.7: Design of a condensing gas furnace.

©2015 Cengage Learning Engineering. All Right Reserved.

Heat pumps

Heat pumps use mechanical energy (typically provided by an electric motor) to transport heat from a cold reservoir to a warm reservoir.

Heat transferred depends on the Coefficient of Performance

$$Q_h = COP \cdot W \qquad (17.2)$$

where the COP is determined from Carnot's principle;

$$COP = \frac{1}{1 - \frac{T_c}{T_h}} \qquad (17.3)$$

©2015 Cengage Learning Engineering. All Right Reserved.

Hot and cold reservoirs

The hot reservoir is the interior of the building that needs to be heated.

The cold reservoir can be

- the outside air
- the ground
- outside body of water

©2015 Cengage Learning Engineering. All Right Reserved.

Air source heat pump system

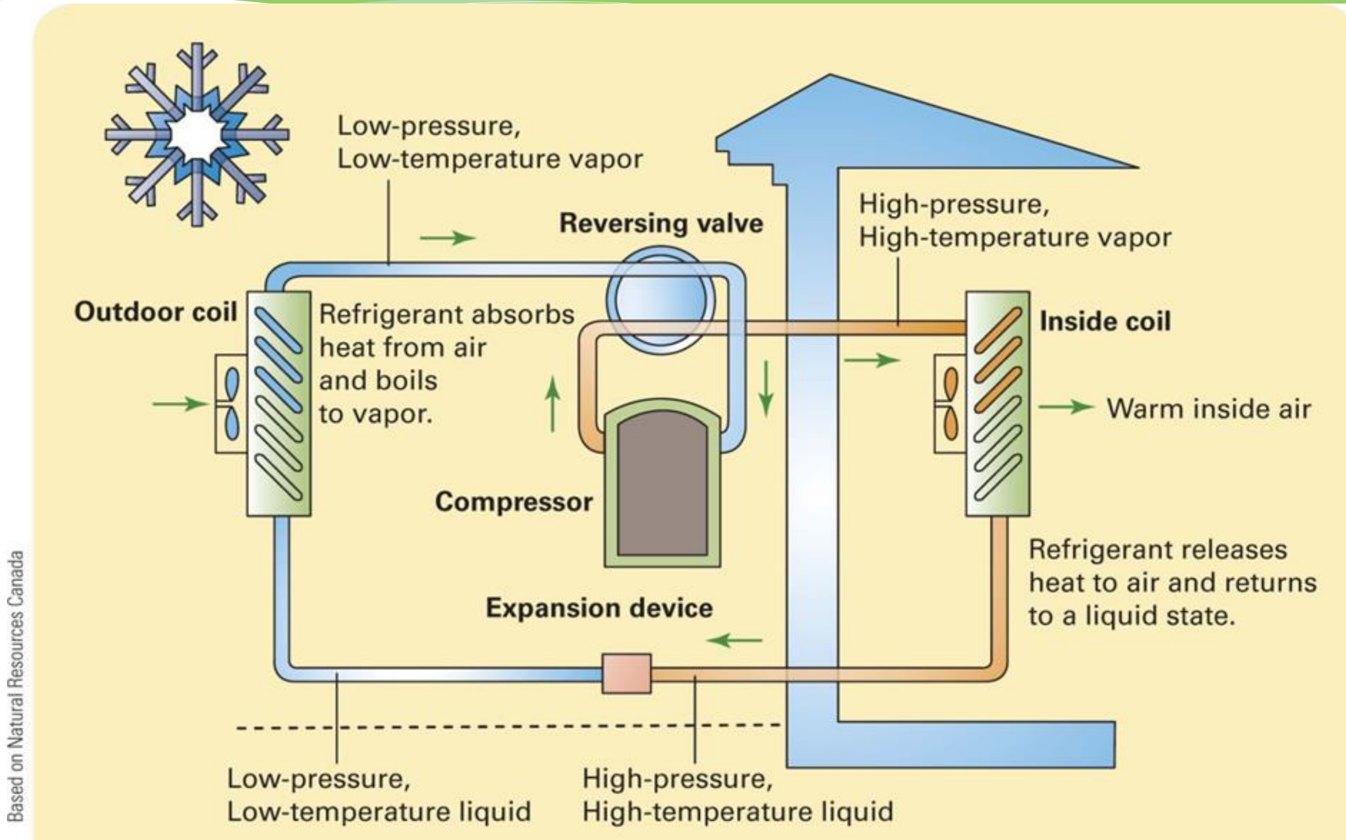


Figure 17.8: Schematic illustrating the operation of an air source heat pump.

©2015 Cengage Learning Engineering. All Right Reserved.

Ground source heat pump system

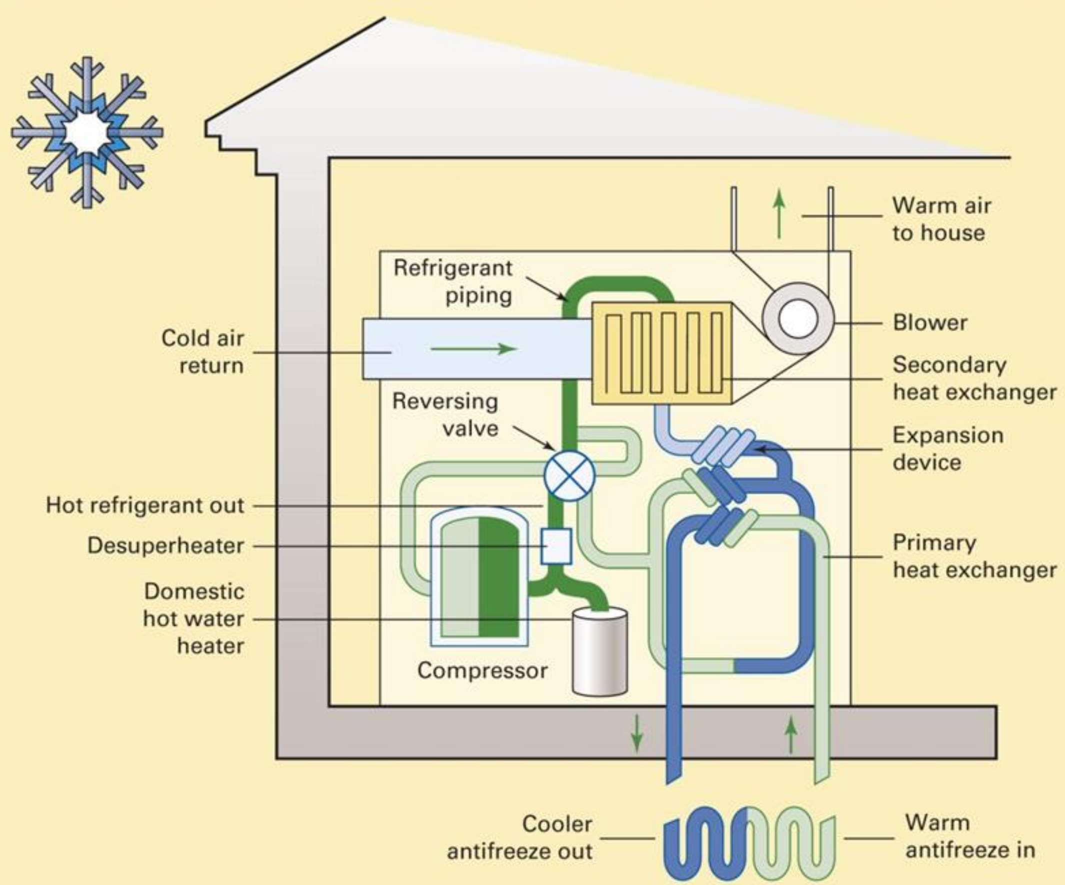


Figure 17.10: Diagram of a ground source heat pump.

Based on Heating and Cooling with a Heat Pump, Office of Energy Efficiency, Natural Resources Canada (Cat. No. M144-51/2004E)

©2015 Cengage Learning Engineering. All Right Reserved.

Heat pump balance point

The heat transferred per unit time (power) is given by the Carnot COP

$$P = \frac{P_{\text{in}}}{1 - \frac{T_c}{T_h}} \qquad (17.4)$$

The heat loss from the building is given by

$$P = \frac{A(T_h - T_c)}{R} \qquad (17.5)$$

The balance point occurs when these two powers are equal.

©2015 Cengage Learning Engineering. All Right Reserved.

Temperature range for heat pump operation

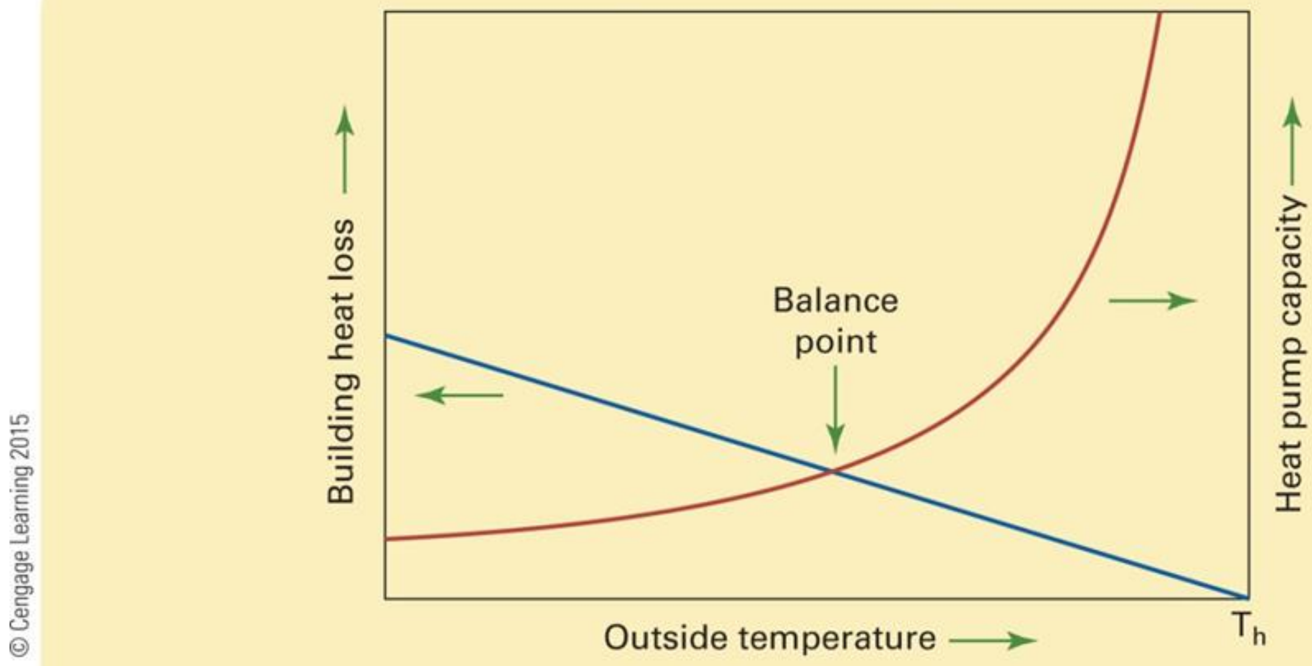


Figure 17.11: Balance point for a heat pump.

©2015 Cengage Learning Engineering. All Right Reserved.

Air conditioning

An air conditioner is a heat pump where

- The cold reservoir is the interior of the building to be cooled
- The hot reservoir is the warm outside air

An air conditioner uses mechanical energy to pump heat from the inside of the building to the outside.

©2015 Cengage Learning Engineering. All Right Reserved.

Integrated HVAC systems

Heat pumps and air conditioners can be integrated with conventional furnaces to provide HVAC.

©2015 Cengage Learning Engineering. All Right Reserved.

Integrated air conditioning and furnace

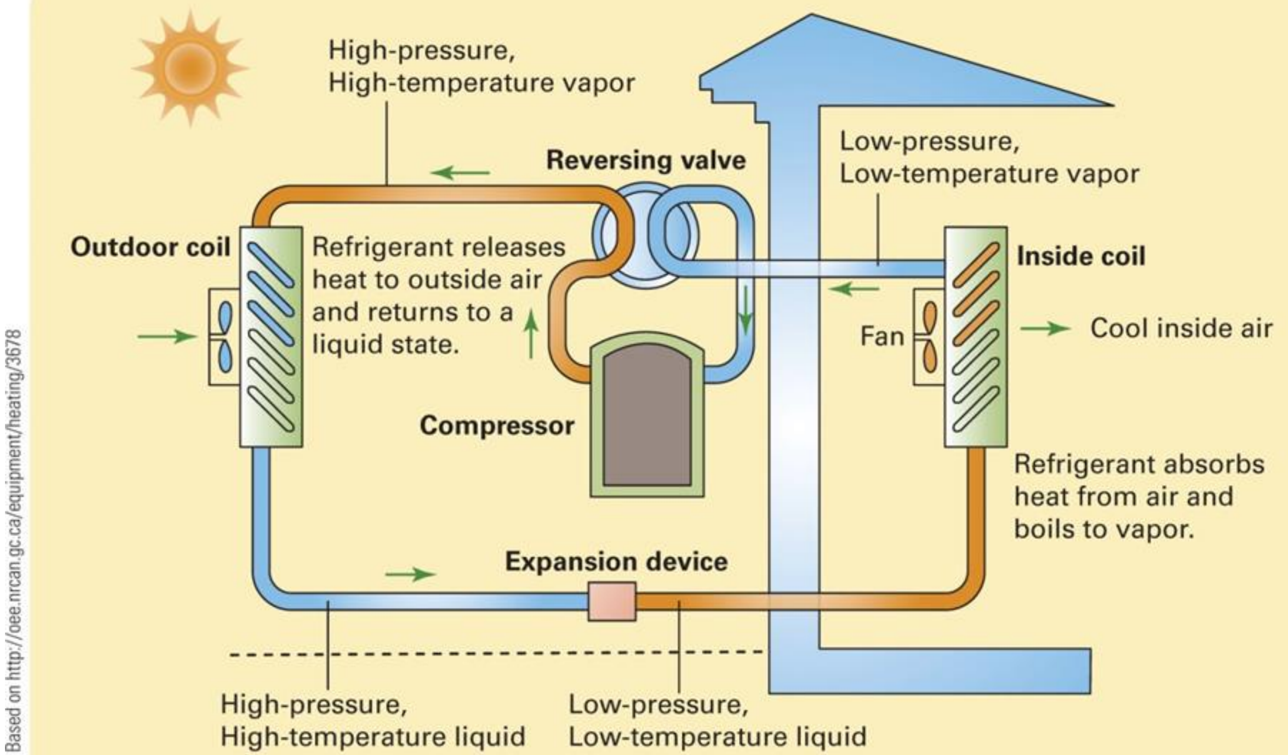


Figure 17.12: Heat pump in the cooling configuration (air conditioner). The flow of fluid is opposite to that of the heat pump in Figure 17.8.

©2015 Cengage Learning Engineering. All Right Reserved.

Integrated heat pump and furnace

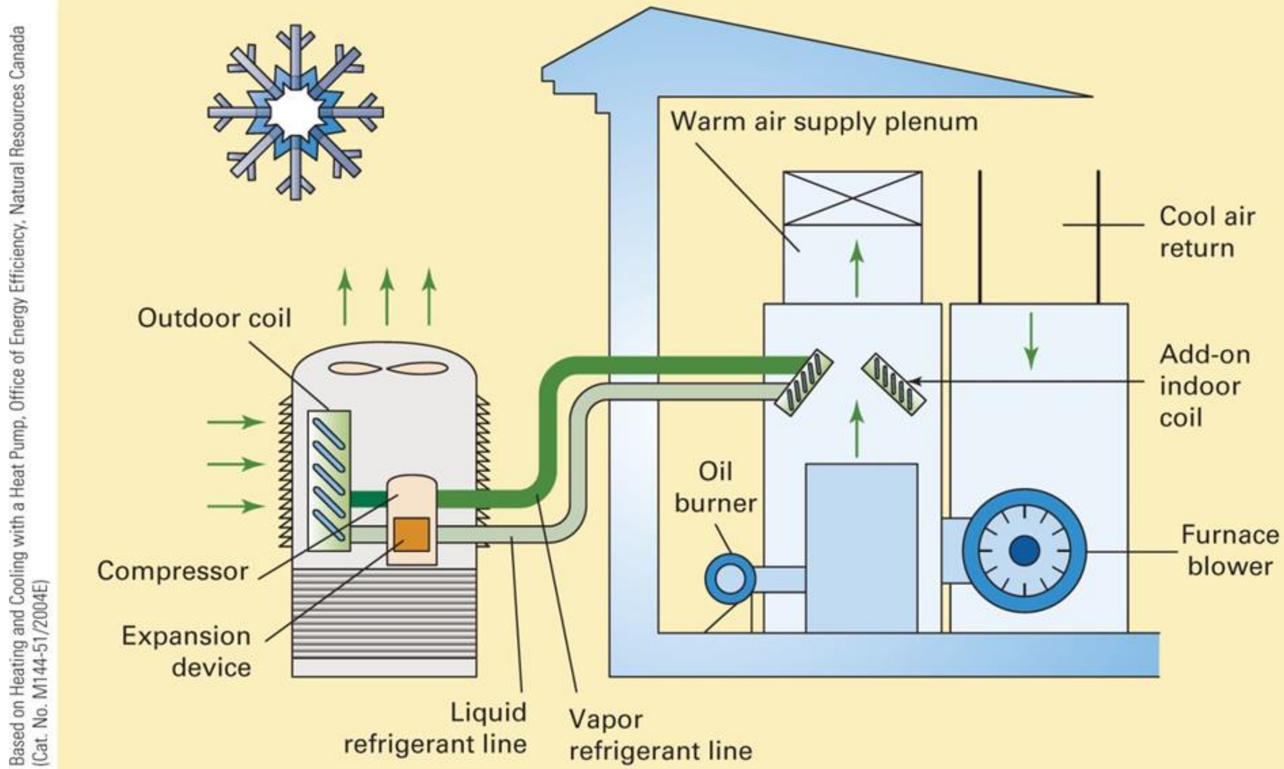


Figure 17.15: Schematic illustrating the operation of an air source heat pump in conjunction with an oil-fired furnace for residential heating.

©2015 Cengage Learning Engineering. All Right Reserved.

Integration of alternative energy sources

Alternative energy such as solar can be integrated with other heating technologies and heat storage

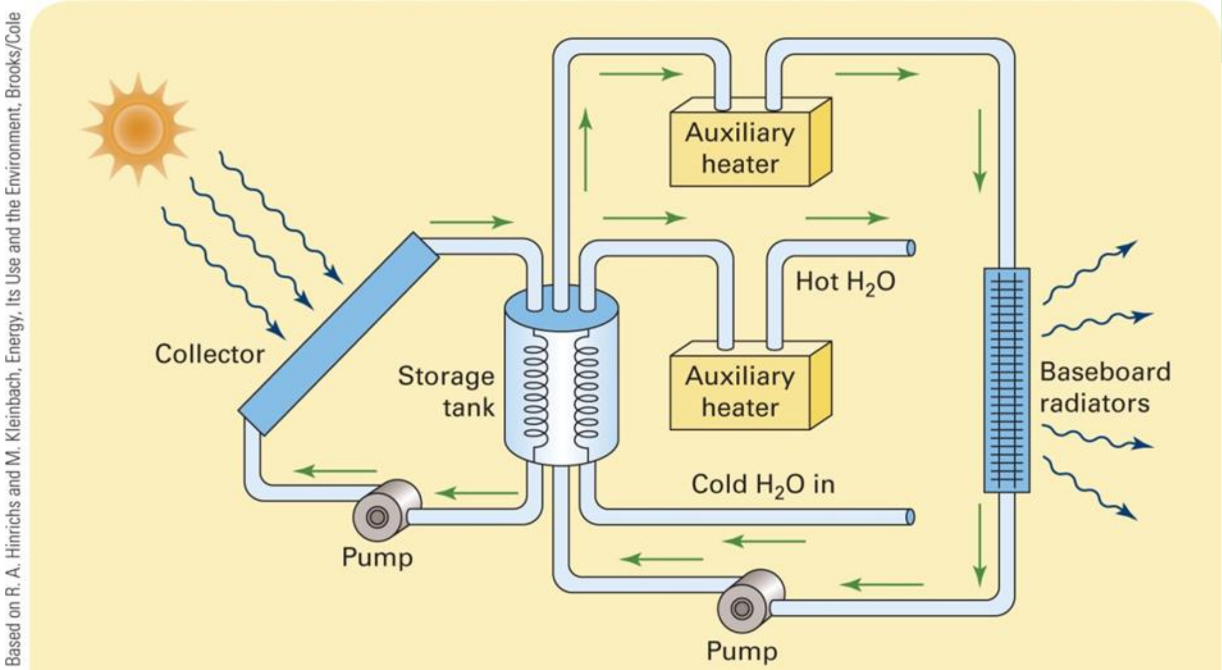


Figure 17.16: Design of an integrated solar space heating system. The system provides heating and hot water. Back-up heating is provided by an auxiliary system (e.g., fossil fuel-fired boiler).

©2015 Cengage Learning Engineering. All Right Reserved.

Minimizing residential heat loss

It is important to minimize heat transfer from the heated interior of the building to the cold outside in the winter,

and to minimize heat transfer from the warm outside to the air conditioned interior of the building in the summer.

©2015 Cengage Learning Engineering. All Right Reserved.

Three important aspects of minimizing heat loss in buildings

- utilizing effective insulation
- minimizing heat loss through windows
- minimizing air leaks

©2015 Cengage Learning Engineering. All Right Reserved.

Insulation

Occupies space between interior and exterior walls and in ceiling or under roof

Limits heat transfer by

- limiting air circulation in the space between walls
- can also have a reflective layer to minimize radiative losses

©2015 Cengage Learning Engineering. All Right Reserved.

Typical forms of insulation include

- Blankets - flexible material such as fiberglass that comes in a roll
- Rigid insulation - fibrous or foam material that comes in sheets
- Foam insulation - sprayed on material that adheres to walls etc.
- Loose fill - pellets that are blown into spaces between walls etc.

©2015 Cengage Learning Engineering. All Right Reserved.

R-values of some common insulating materials

Table 17.1 Approximate *R*-values per unit thickness of some insulating materials.

material	*R*-value $(h \cdot ft^2 \cdot °F)/Btu$ per inch thickness	R_{SI}-value $(s \cdot m^2 \cdot °C)/J$ per cm thickness
vermiculite loose fill	2.2	0.15
fiberglass loose fill	3.1	0.21
polyicynene spray foam	3.6	0.25
fiberglass wool	3.7	0.26
polystyrene foam rigid sheet	5.0	0.35
polyurethane spray foam	6.0	0.42
polyisocyanurate spray foam	6.5	0.45

© Cengage Learning 2015

©2015 Cengage Learning Engineering. All Right Reserved.

Some important aspects of effective insulation

- The effectiveness of insulation is reduced if the insulation is compressed.
- Air spaces between the edges of the insulation and the wall studs reduces effectiveness of insulation.
- The *R*-value of the wall is always less than the *R*-value of the insulation because studs from thermal bridges between the inside and outside.

©2015 Cengage Learning Engineering. All Right Reserved.

Heat loss through windows

Windows typically have a lower *R*-value than an insulated wall.

The *R*-values of windows can be improved by several design features

- Using double or triple glazed windows
- Adding a low emissivity coating to the glass surfaces
- Replacing the air between the panes with argon

©2015 Cengage Learning Engineering. All Right Reserved.

Heat loss through air leaks

Common locations for air leaks in a residential building

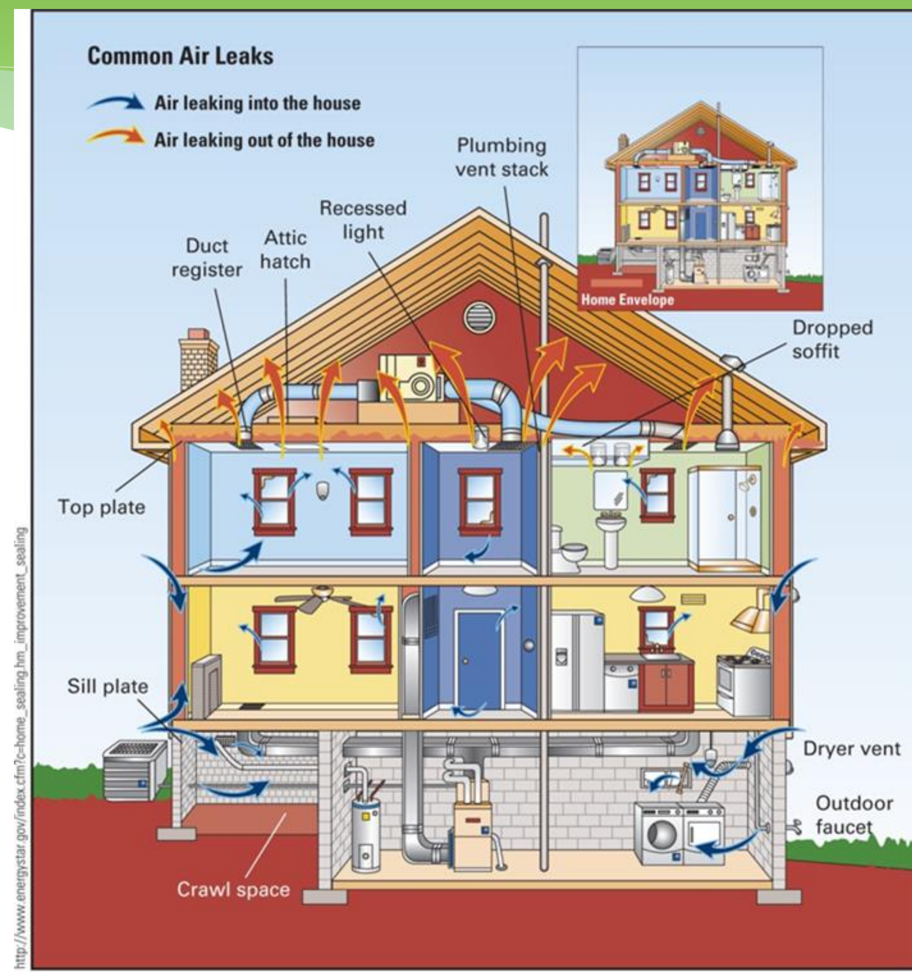


Figure 17.19: Common air leaks in a house.

©2015 Cengage Learning Engineering. All Right Reserved.

Residential lighting

- Traditional incandescent light bulbs produce more heat than light.
- Fluorescent lights and LEDs produce mostly light and a small amount of heat.

©2015 Cengage Learning Engineering. All Right Reserved.

Properties of light bulbs

The ratio of the light output (in lumens) to the electrical energy input (in W) for different types of light bulbs

Table 17.2: Typical light output per electrical input in lumens per watt (lm/W) for some light-producing devices.

light source	output/input (lm/W)
incandescent bulb	15
compact fluorescent lamp (CFL)	60–70
light-emitting diode (LED)	100–150

© Cengage Learning 2015

©2015 Cengage Learning Engineering. All Right Reserved.

Compact fluorescent lights

Compact fluorescent lamps (CFLs) are a popular and economical alternative for incandescent bulbs and have a screw of bayonet base that allows for direct replacement.

A 13 W CFL produces as much light as a 60 W incandescent.

©2015 Cengage Learning Engineering. All Right Reserved.

Some common CFL geometries

Figure 17.21: Compact fluorescent lamps. Front left to right: 9-W spiral, 13-W spiral, 23-W spiral, 26-W spiral, and 9-W tube, with light output equivalent to incandescent bulb with ratings of 40 W, 60 W, 100 W, 120 W, and 40 W, respectively. Lamps shown have the standard North American Edison base.

©2015 Cengage Learning Engineering. All Right Reserved.

LED lighting

LEDs are more efficient than CFLs but typically have a longer payback period due to a greater initial cost

Richard A. Dunlap

Figure 17.24: A 7-W LED lamp with Edison screw base.

©2015 Cengage Learning Engineering. All Right Reserved.

Actual energy savings

Actual energy savings using a CFL or LED bulb instead of an incandescent bulb can be more or less than expected.

The extra energy used by an incandescent bulb is given off as heat.

- In a building that is heated this heat contributes to the heat requirements and is not wasted.
- In a building that is air conditioned the incandescent bulb not only uses more electricity per light output but produces heat that puts an additional load on the air conditioning system.

- In the former case energy savings are minimal.
- In the latter case energy savings are greater than expected.

©2015 Cengage Learning Engineering. All Right Reserved.

Vehicle fuel economy

Government regulations (such as CAFE regulations in the U.S.) have led to improved fuel efficiency

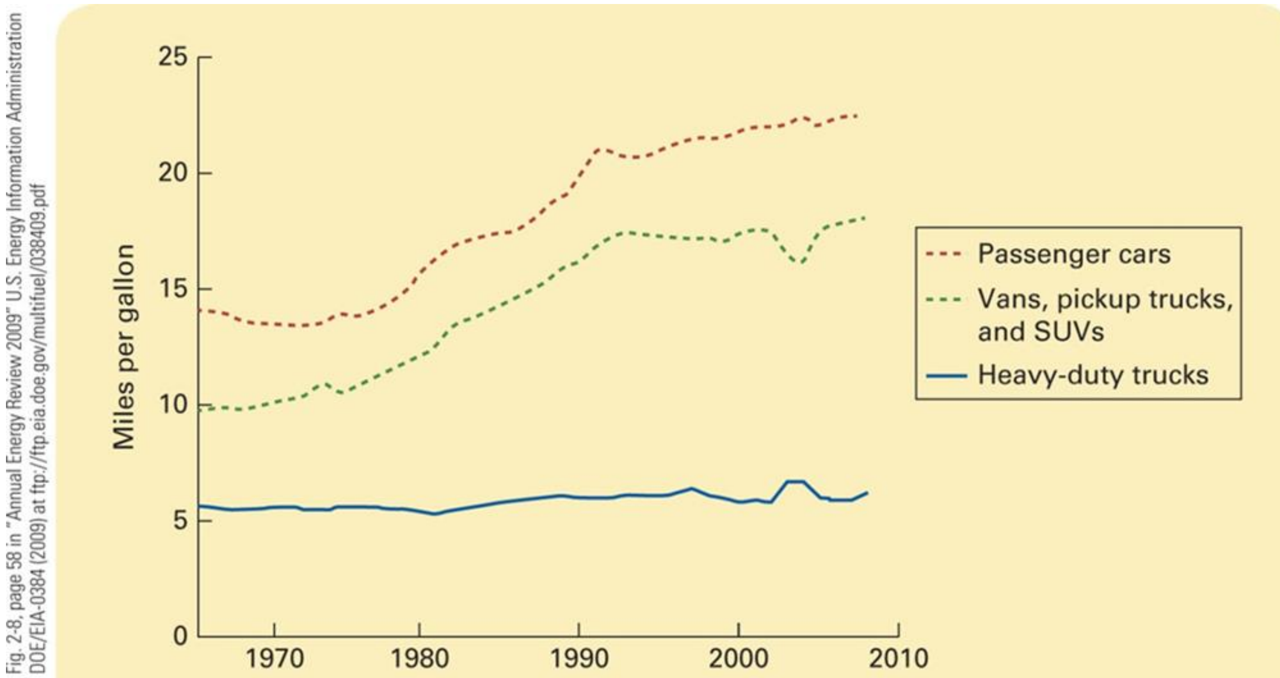


Figure 17.28: Fuel economy of vehicles in the United States, 1966–2008.

©2015 Cengage Learning Engineering. All Right Reserved.

Fuel economy worldwide

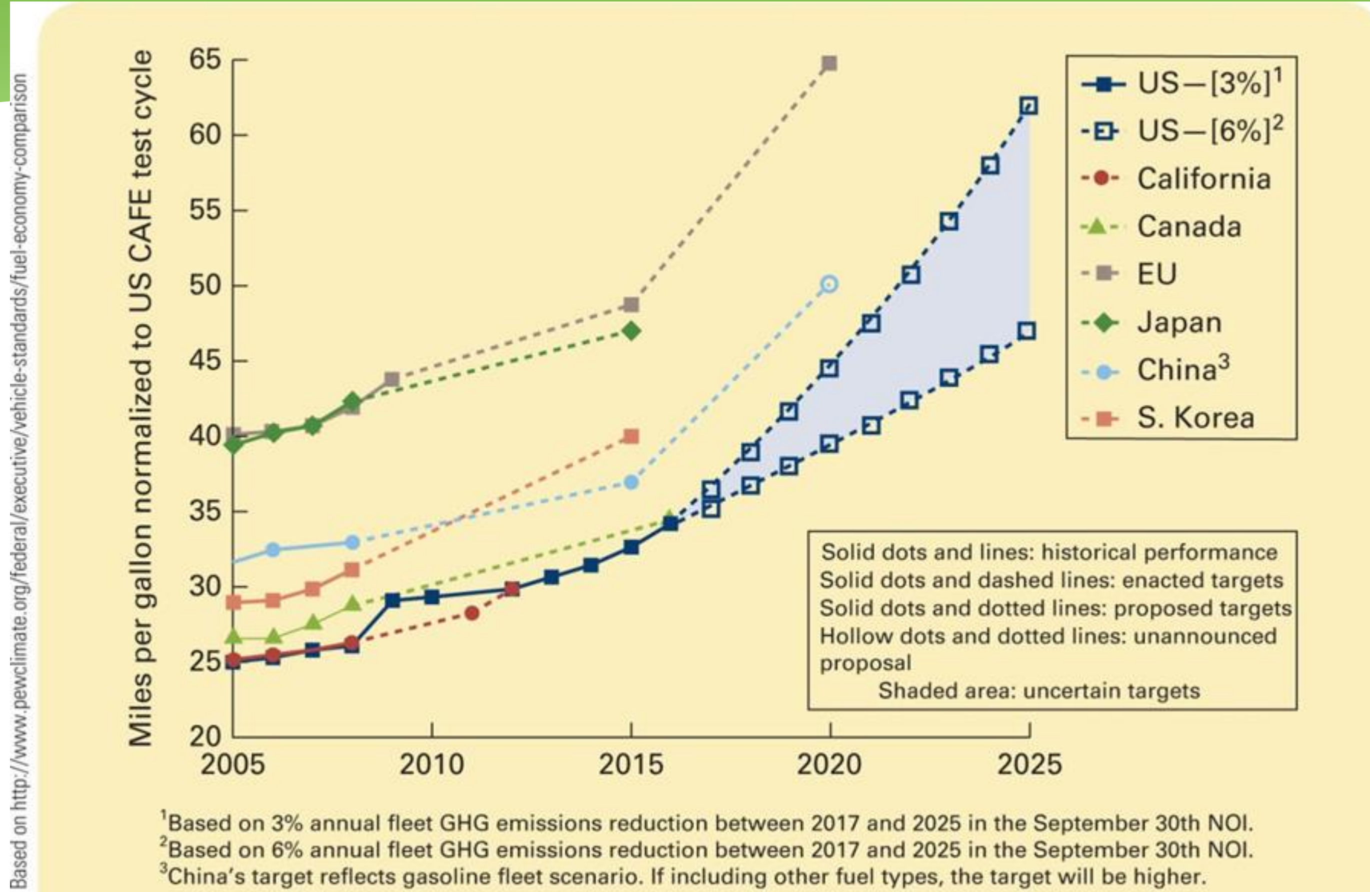


Figure 17.30: Average fuel economy for passenger vehicles in different countries. Historical data for 2005 to 2010 and projected data until 2025.

©2015 Cengage Learning Engineering. All Right Reserved.

Effects of per capita GDP

More expensive vehicles burn more fuel

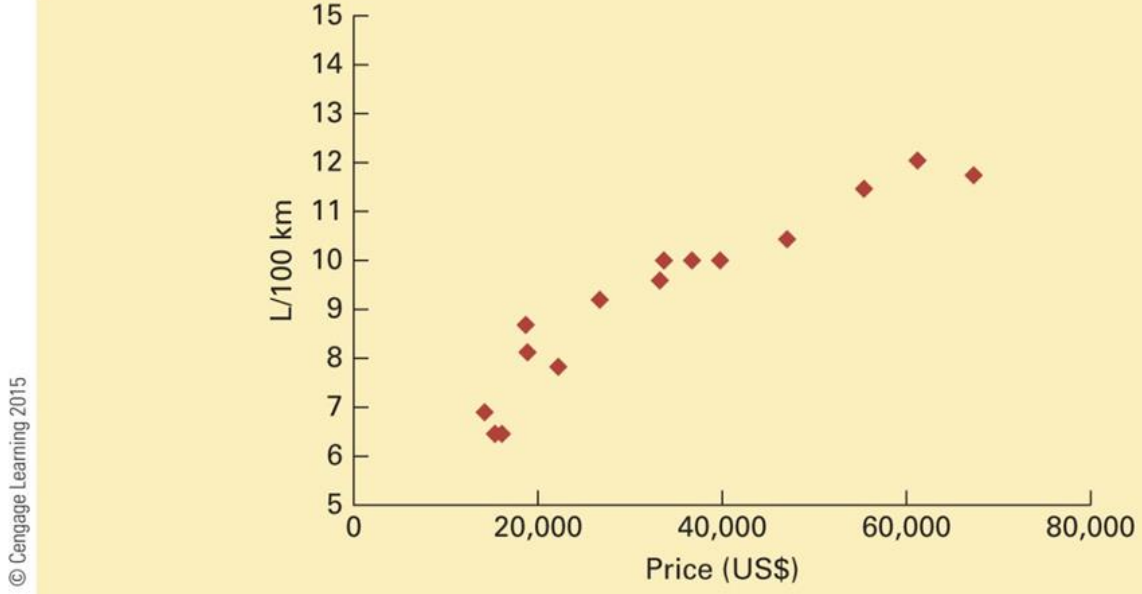


Figure 17.26: Fuel consumption in L/100 km average city/highway from U.S. Environmental Protection Agency (EPA) estimates as a function of model base price (in US$) for all nonhybrid passenger automobiles marketed in North America by Toyota (Scion/Toyota/Lexus) in 2012.

©2015 Cengage Learning Engineering. All Right Reserved.

Hybrid vehicles

Gasoline-electric hybrid vehicles have both a traditional internal combustion engine and batteries that power an electric motor.

The electric motor provides supplemental power to the drive system.

The batteries are recharged by the gasoline engine and store energy produced by regenerative braking.

©2015 Cengage Learning Engineering. All Right Reserved.

The first mass produced hybrid vehicles

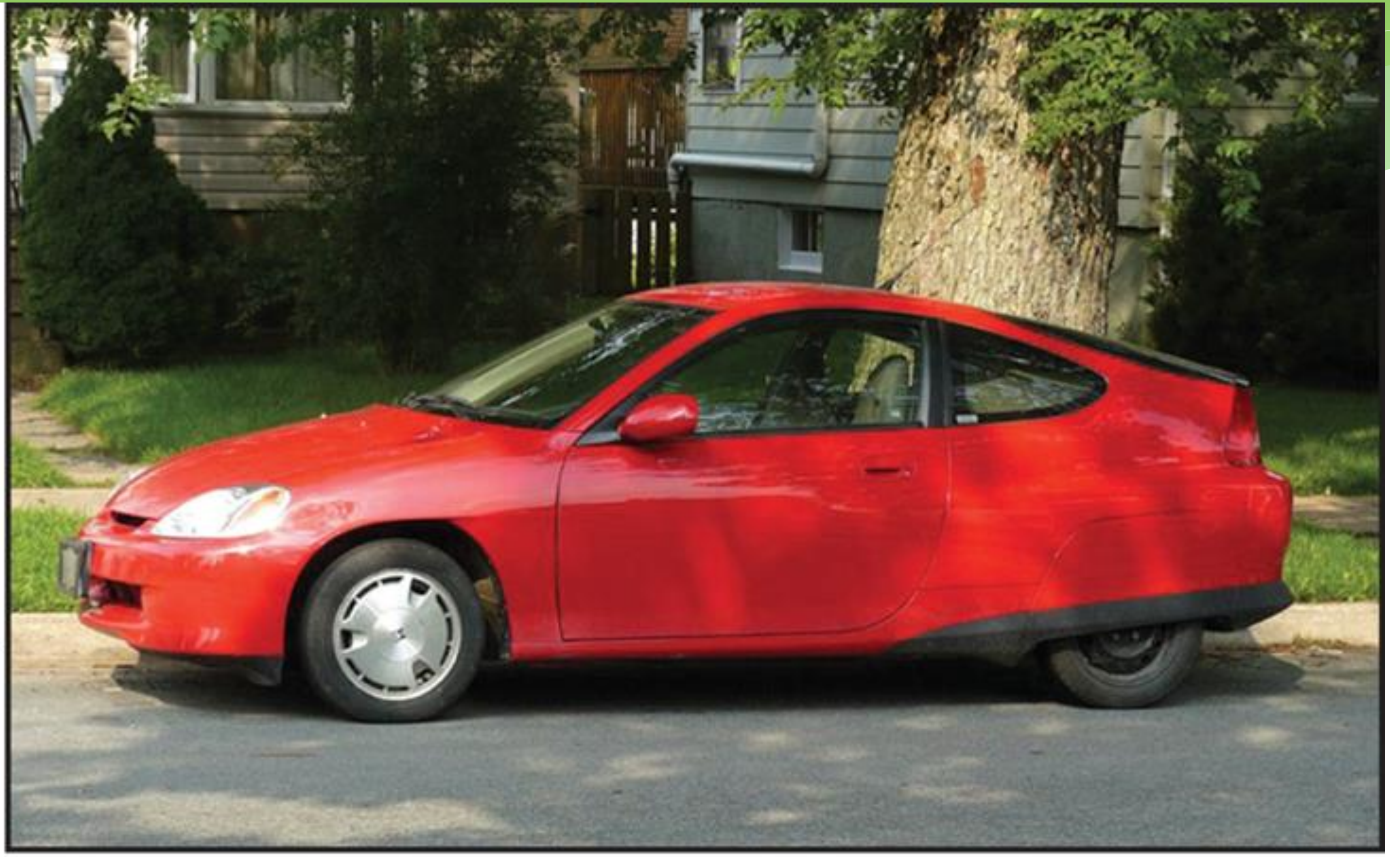
Table 17.3: Power output of the first-generation Toyota Prius and Honda Insight.

vehicle	years	mass kg (lbs)	gasoline power kW (hp)	electric power kW (hp)	fuel consumption L/100 km (mpg)
Toyota Prius	1997–2001	~1200 (2640)	43 (58)	30 (40)	5.6 (42)
Honda Insight	1999–2006	838 (1840)	52 (70)	9.7 (13)	3.7 (64)

© Cengage Learning 2015

©2015 Cengage Learning Engineering. All Right Reserved.

First-generation Honda Insight



Richard A. Dunlap

Figure 17.31: A first-generation Honda Insight hybrid.

©2015 Cengage Learning Engineering. All Right Reserved.

Series hybrids

Series hybrids are vehicles which use only the battery operated electric motor to drive the wheels and the gasoline engine is only used to recharge the batteries.

This arrangement allows the gasoline engine to run at constant speed under constant load in order to achieve optimal efficiency.

©2015 Cengage Learning Engineering. All Right Reserved.

Chevrolet Volt series hybrid

Figure 17.32: Chevrolet Volt (series hybrid).

©2015 Cengage Learning Engineering. All Right Reserved.

Summary

- Energy conservation can be practiced on a variety of different levels
- Cogeneration is an effective means of using waste heat from thermal electricity generation
- Smart grid technology is needed to effectively utilize alternative energy production and storage
- LED streetlights are an effective means of conserving municipal energy
- Residential energy conservation can include the use of efficient HVAC systems, minimizing heat loss and efficient lighting technologies
- Government regulations have improved fuel economy of passenger vehicles
- Hybrid vehicles allow for energy recovery through regenerative braking.
- Series hybrids have improved gasoline engine efficiency due to constant speed and load conditions

©2015 Cengage Learning Engineering. All Right Reserved.