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## A primer on energy

Generally speaking, all energy on earth comes from the sun. Energy exists in different forms, such as chemical, nuclear, sound, light, mechanical, heat, etc. Energy can be converted from one form to another, and all energy eventually converts into heat when being expended.

### What energy is

Energy can be defined as the ability to do work, and work is defined as expending of a force through a distance, for example, lifting an object to a higher elevation. If a box weighing 10 lb is lifted from the floor onto a table which is 3 ft above the floor, the work required is 10 lb times 3 ft or 30 ft-lb. To do this work, it will theoretically require 30 ft-lb of energy.

### Conversion of energy

A law of physics known as the law of conservation of energy states that energy can neither be created nor destroyed. This law is very important in understanding how energy is used and how it can be conserved. The 30 ft-lb of energy that was required to lift the box onto the table is not used up and lost; rather it is stored at the box as "potential energy." If at a later time, the box were lowered from the table back to the floor, the 30 ft-lb of stored potential energy would be available to do some other work, such as lifting an object to another height assuming box and object are connected to a system of cords and pulleys. An example of such a device is the double hung window with counterweights in the window jamb. When the upper window is pulled down, counterweights rise within the jamb; force expended by the person to pull down the window is stored as potential energy onto the

counterweights. When the window is again raised, energy stored in the counterweights provides most of the required work to lift the sash.

Aside from the direct work energy, there are other forms of energy. Most people have heard of the Boy Scout's technique of starting a fire by rubbing two sticks together. This technique uses different forms of energy. It takes work (and thus energy) to rub the sticks together because of a resistance to the "rubbing" called friction. That is, the sticks are not completely free to move against one another when they are pressed together; it takes energy or work to make them slide. But this energy is not stored as was the energy used to lift the box. What happens is that the sticks get hot, and work energy is thus converted to heat energy. Heat energy is measured not in foot-pounds, but in British thermal units called Btu. It requires 778 ft-lb of work to convert to 1 Btu of heat energy. In this manner, the work energy of rubbing sticks is converted to heat energy. When the heat energy accumulated becomes hot enough, it could ignite some combustible materials, such as wood chips, and the fire is started by a process of combustion. In the combustion process, chemical energy which is stored in the wood chips combines with oxygen in the air and releases thermal or heat energy. The chemical energy stored in the wood is useless until it is released through this combustion process into the form of heat. Once the heat is released, energy can be utilized for space and water heating, cooking, and other processes.

Gasoline used in an automobile engine ignited by spark plugs in a mixture with air (containing 21 percent oxygen) converts chemical energy to heat and work energy providing the mechanical force to move the car.

**Table 15-1. Energy value of common fuels.**

Fuel	Approximate high heat value
Natural gas	1,000 Btu/cu ft
Propane	93,000 Btu/gal
Oil	140,000 Btu/gal
Coal	10,000 Btu/lb
Wood (12 percent moisture)	8,000 Btu/lb

### Fuels classified

The materials used to release stored chemical energy by combustion are called fuels; most common fuels contain as basic ingredients carbon and hydrogen, or hydrocarbons. There are two common classifications of fuels—bio-fuels and fossil fuels.

a) Bio-fuels are products of growing matter such as trees and plants. This matter receives energy from the sun which is combined with other chemicals of the earth as they grow over a relatively short time span. At some stage of growth, these bio-fuels can be harvested and used for fuel with replacements planted for a later harvest.

b) Fossil fuels are generally considered as nonreplenishable and therefore depleting. Fossil fuels also derive their energy from the sun, but it took millions of years for them to form to their present state. Common fossil fuels are natural gas, petroleum, and coal.

The amount of energy in the form of heat that can be obtained by the burning of fuel is called the high heat value of fuel; some of the most common fuels and their approximate high heat values are shown in Table 15.1.

### Electrical energy

Another familiar form of energy is electrical energy. Electrical energy provides a very useful method or means of moving energy from one place to another, or of transferring from one form to another. Electrical energy can be transformed from chemical energy (fuel cell and batteries), nuclear energy, heat energy (thermoelectric and thermionic), magnetohydrodynamic mechanical energy (hydro), and thermal-mechanical energy. Over 90 percent

of the electrical energy generation in this country is by thermal-mechanical method where electrical energy is produced by driving a rotation electrical generator with a steam turbine. The steam turbine derives its energy from expanding steam produced by burning fossil fuel. In this energy conversion process, chemical energy is converted into heat energy, to mechanical energy, and then finally to electrical energy. Electrical energy is then sent through transmission lines to distant locations where it is converted to other useful forms, such as running a fan (to mechanical energy), heating a space (to heat energy), and lighting a task (to lighting energy).

Electrical energy is usually measured in kilowatt-hours (kW-hr or KWH) where 1 KWH is equivalent to 3413 Btu. Another energy unit commonly used is "horsepower-hour" (hp-hr) where 1 hp-hr is the equivalent of 2545 Btu.

### Energy units

Common forms of energy used or found in building systems and their units of measurement are shown in Table 15-2.

The British thermal unit (Btu) is the most commonly used unit for energy measurement or for a common base of energy conversion; however, it is a very small unit (when compared to the amount usually required in building systems). In building energy evaluation, one must constantly deal with astronomically large numbers. Frequently, hundred-thousand Btu (therm), million Btu (mega-Btu), billion Btu (giga-Btu), or quadrillion-Btu (quad-Btu) are used for expressing annual energy consumption.

### Power and energy

Power has often been confused with energy. In trying to understand energy conservation and energy management, it is very important to understand the difference between these two terms.

Power is the rate of consumption or conversion of energy; that is, power is an expression of how long or how quickly a given amount of energy is consumed or converted. An example: if 100 hp-hr of energy is used in 1

**Table 15.2. Energy equivalent.**

Form	Unit of measurement	Btu equivalent
Heat	British thermal unit (Btu)	—
Electrical	Kilowatt-hour (kW-hr)	3413
Mechanical	Horsepower-hour (hp-hr)	2545
Chemical (fuel)	Pounds, gallons, cubic feet	See Table 15-3

hr, the power required would be 100 hp-hr divided by 1 hr, or 100 hp. Thus a motor or engine to provide energy at this rate would be a 100 hp motor; however, if the same amount of energy were used over a 10 hr period, it would require only a 10 hp motor. Expressed in a mathematical equation, the relation between power and energy is:

$$\text{power} = \frac{\text{energy}}{\text{time}}$$

### Power units defined

If each energy term discussed previously is divided by time, then the power unit for heat, mechanical, and electrical energy will be Btu/hr, hp, and kW, respectively.

If a building is being cooled, it is necessary to remove heat (energy) from the space. This cooling procedure is more commonly called "air conditioning." The rate at which this heat is removed can be expressed as Btu/hr cooling, or tons of refrigeration. Common power

units and their equivalent values in Btu/hr are shown in Table 15.4.

### The effect of power on costs

Consider the case of the 100 hp-hr of energy consumed in the earlier example. If it is feasible to use a 10 hp motor for 10 hr per day, it would certainly be better than using a 100 hp motor for only 1 hr per day because the investment cost of a 100 hp motor is much higher than the 10 hp motor even though they both consume the same amount of energy (100 hp-hr) per day. It can therefore be said that power is related to investment cost, and energy is related to operating cost.

Electrical usage for a building is generally charged by the amount of energy (kW-hr) consumed per month. However for large users, the utility company may also base its charge on power (kW) demand which is normally determined by the maximum demand during any 15 min interval in a month or year. In this case, power demand is also related to operating cost for the user. The

**Table 15.3. Energy unit (EU) value of common sources.**

Type of energy	Unit of measure	Approximate value*	
		English unit (Btu)	Metric unit (kcal)
Electricity	Kilowatt-hour (kW-hr)	3,413	860
Gasoline	Gallon (gal)	128,000	32,000
Fuel oil (no. 2)	Gallon (gal)	140,000	35,000
Residual oil (no. 6)	Gallon (gal)	147,000	37,000
Natural gas	Cubic feet (cu ft)	1,000	250
	Therms (tm)	100,000	25,000
LP gas (butane)	Gallon (gal)	102,600	25,600
LP gas (propane)	Gallon (gal)	93,000	23,300
Steam (at 14.7 psia)	Pound (lb)	1,150	290
Steam (at 200 psia)	Pound (lb)	1,200	300
Coal (average)	Pound (lb)	10,000	2,500

\*Btu—British thermal unit; kcal—kilocalorie. Energy values shown in the table may vary with source.

**Table 15-4. Value of units.**

Form	Unit of measurement	Btu/hr equivalent
Heat	Btu per hr	—
Electrical	Kilowatt	3,413
Mechanical	Horsepower (hp)	2,545
Cooling	Tons of refrigeration	12,000
Chemical (fuel)	Btu per hr	—

utility company, however, must charge for the demand (power) to offset their investment cost in the generating plant and distribution network.

### Energy required in buildings

Energy is generally used in buildings to perform functions of heating, lighting, mechanical drives, cooling, and special applications. The energy is available to the building in limited forms, such as electricity, fossil fuels, and solar energy, and these energy forms must be converted within the building to serve the end use of the various functions. A loss of energy is associated with any conversion process. In energy conservation efforts, there are two avenues of approach—reducing the requirement of the end use, and/or reducing conversion losses. The latter is an unfortunate situation inherent in most conversion processes. For example, the furnace which heats the building produces unusable and toxic flue gas which must be vented to the outside of the building, and thus part of the energy is lost. (The “lost” energy is not destroyed, it simply ends up as heat energy.)

### Conservation of depletable energy

The ultimate source of energy, as stated earlier, is the sun. It is plentiful and nondepletable for million of years; however, from the perspective of current technology and social systems, the vast majority of energy resource is still fossil fuel, which is a depletable commodity. Even though electricity can be converted within buildings to other forms of end use with relatively low losses, it has already undergone a conversion process in which approximately two-thirds of the fossil fuel energy was lost, unless electricity is generated by hydroelectric plants where energy is converted by controlled water fall (potential energy).

Solar energy, the only continually nondepleting source available, is not easily converted to the form needed for the end use, and the investment cost of solar energy conversion systems is quite high compared to more conventional sources. In achieving the goal of energy conservation, efforts must be directed toward minimizing consumption of depletable energy resources.