MEASURING ELECTRICITY

Measuring Electricity

Electricity makes our lives easier, but it can seem like a mysterious force. Measuring electricity is confusing because we cannot see it. We are familiar with terms such as watt, volt, and amp, but we do not have a clear understanding of these terms. We buy a 60-watt light bulb, a tool that requires 120 volts, or an appliance that uses 8.8 amps, but we don't think about what those units mean.

Using the flow of water as an analogy can make electricity easier to understand. The flow of electrons in a circuit is similar to water flowing through a hose. If you could look into a hose at a given point, you would see a certain amount of water passing that point each second. The amount of water depends on how much pressure is being applied—how hard the water is being pushed. It also depends on the diameter of the hose. The harder the pressure and the larger the diameter of the hose, the more water passes each second. The flow of electrons through a wire depends on the electrical pressure pushing the electrons and on the cross-sectional area of the wire.

Voltage

The pressure that pushes electrons in a circuit is called **voltage**. Using the water analogy, if a tank of water were suspended one meter above the ground with a one-centimeter pipe coming out of the bottom, the water pressure would be similar to the force of a shower. If the same water tank were suspended 10 meters above the ground, the force of the water would be much greater, possibly enough to hurt you.

Voltage (V) is a measure of the pressure applied to electrons to make them move. It is a measure of the strength of the current in a circuit and is measured in **volts (V)**. Just as the 10-meter tank applies greater pressure than the 1-meter tank, a 10-volt power supply (such as a battery) would apply greater pressure than a 1-volt power supply.

AA batteries are 1.5-volts; they apply a small amount of voltage for lighting small flashlight bulbs. A car usually has a 12-volt battery—it applies more voltage to push current through circuits to operate the radio or defroster. The standard voltage of wall outlets is 120 volts—a dangerous voltage. An electric clothes dryer is usually wired at 240 volts—a very dangerous voltage.

Current

The flow of electrons can be compared to the flow of water. The water current is the number of molecules of water flowing past a fixed point; electrical current is the number of electrons flowing past a fixed point.

Electrical current (I) is defined as electrons flowing between two points having a difference in voltage. Current is measured in **amperes** or **amps (A)**. One ampere is 6.25×10^{18} electrons per second passing through a circuit.

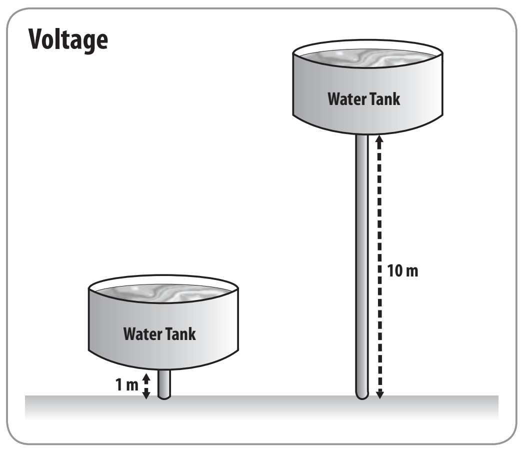
With water, as the diameter of the pipe increases, so does the amount of water that can flow through it. With electricity, conducting wires take the place of the pipe. As the cross-sectional area of the wire increases, so does the amount of electric current (number of electrons) that can flow through it.

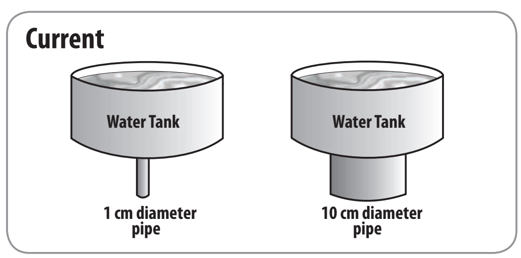
Resistance

Resistance (R) is a property that slows the flow of electrons. Using the water analogy, resistance is anything that slows water flow, such as a smaller pipe or fins on the inside of a pipe.

In electrical terms, the resistance of a conducting wire depends on the properties of the metal used to make the wire and the wire's diameter. Copper, aluminum, and silver—metals used in conducting wires—have different resistance.

Resistance is measured in units called **ohms (Ω)**. There are devices called resistors, with set resistances, that can be placed in circuits to reduce or control the current flow. Any device placed in a circuit to do work is called a **load**. The light bulb in a flashlight is a load. A television plugged into a wall outlet is also a load. Every load has resistance.





Ohm's Law

George Ohm, a German physicist, discovered that in many materials, especially metals, the current that flows through a material is proportional to the voltage. He found that if he doubled the voltage, the current also doubled. If he reduced the voltage by half, the current dropped by half. The resistance of the material remained the same.

This relationship is called **Ohm's Law** and can be described using a simple formula. If you know any two of the measurements, you can calculate the third using the following formula:

voltage = current x resistance
V = I x R or V = A x Ω

Electrical Power

Power (P) is a measure of the rate of doing work or the rate at which energy is converted. Electrical power is the rate at which electricity is produced or consumed. Using the water analogy, electric power is the combination of the water pressure (voltage) and the rate of flow (current) that results in the ability to do work.

A large pipe carries more water (current) than a small pipe. Water at a height of 10 meters has much greater force (voltage) than at a height of one meter. The power of water flowing through a 1-centimeter pipe from a height of one meter is much less than water through a 10-centimeter pipe from 10 meters.

Electrical power is defined as the amount of electric current flowing due to an applied voltage. It is the amount of electricity required to start or operate a load for one second. Electrical power is measured in **watts (W)**. The formula is:

power = voltage x current
P = V x I or W = V x A

Electrical Energy

Electrical energy introduces the concept of time to electrical power. In the water analogy, it would be the amount of water falling through the pipe over a period of time, such as an hour. When we talk about using power over time, we are talking about using energy. Using our water example, we could look at how much work could be done by the water in the time that it takes for the tank to empty.

The electrical energy that an appliance or device consumes can be determined only if you know how long (time) it consumes electrical power at a specific rate (power). To find the amount of energy consumed, you multiply the rate of energy consumption (measured in watts) by the amount of time (measured in hours) that it is being consumed. Electrical energy is measured in watt-hours (Wh).

energy = power x time
E = P x t or E = W x h = Wh

Another way to think about power and energy is with an analogy to traveling. If a person travels in a car at a rate of 40 miles per hour (mph), to find the total distance traveled, you would multiply the rate of travel by the amount of time you traveled at that rate.

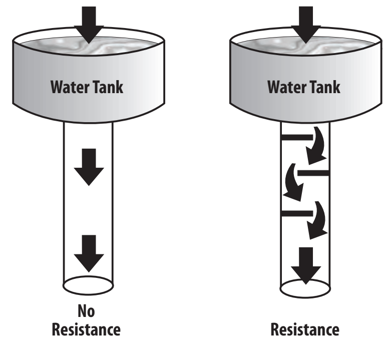
If a car travels for 1 hour at 40 miles per hour, it would travel 40 miles.

distance = 40 mph x 1 hour = 40 miles

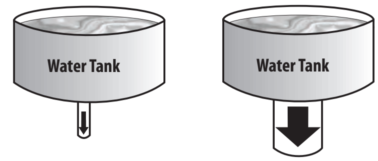
If a car travels for 3 hours at 40 miles per hour, it would travel 120 miles.

distance = 40 mph x 3 hours = 120 miles

Resistance



Electrical Power



The distance traveled represents the work done by the car. When we look at power, we are talking about the rate that electrical energy is being produced or consumed. Energy is analogous to the distance traveled or the work done by the car.

A person wouldn't say he took a 40-mile per hour trip because that is the rate. The person would say he took a 40-mile trip or a 120-mile trip. We would describe the trip in terms of distance traveled, not rate traveled. The distance represents the amount of work done.

The same applies with electrical power. You would not say you used 100 watts of light energy to read your book, because a watt represents the rate you use energy, not the total energy used. The amount of energy used would be calculated by multiplying the rate by the amount of time you read.

If you read for five hours with a 100-W light bulb, for example, you would use the formula as follows:

energy = power x time (E = P x t)
energy = 100 W x 5 hour = 500 Wh

One watt-hour is a very small amount of electrical energy. Usually, we measure electrical power in larger units called **kilowatt-hours (kWh)** or 1,000 watt-hours (kilo = thousand). A kilowatt-hour is the unit that utilities use when billing most customers. The average cost of a kilowatt-hour of electricity for residential customers is about $0.12.

To calculate the cost of reading with a 100-W light bulb for five hours, you would change the watt-hours into kilowatt-hours, then multiply the kilowatt-hours used by the cost per kilowatt-hour, as shown below:

500 Wh divided by 1,000 = 0.5 kWh
0.5 kWh x $0.12/kWh = $0.06

Therefore, it would cost about six cents to read for five hours with a 100-W light bulb.

Energy Consumption

To Save Energy at Home

- Maintain Heating and Cooling Systems Properly
- Use Programmable Thermostats to Control Indoor Temperature
- Make Sure There is Adequate Insulation in Walls and Attic Spaces
- Use Weatherstripping and Caulking to Reduce Air Infiltration

Residential and Commercial Sector

The residential and commercial sector—homes and buildings—consumes 41.6 percent of the energy used in the United States today. We use energy to heat and cool our homes and buildings, to light them, and to operate appliances and office machines. In the last 35 years, Americans have significantly reduced the amount of energy we use to perform these tasks, mostly through technological improvements in the systems we use, as well as in the manufacturing processes to make those systems.

Heating and Cooling

The ability to maintain desired temperatures is one of the most important accomplishments of modern technology. Our ovens, freezers, and homes can be kept at any temperature we choose, a luxury that wasn't possible 100 years ago.

Keeping our living and working spaces at comfortable temperatures provides a healthier environment, and uses a lot of energy. Forty-three percent of the average home's energy consumption is for heating and cooling rooms.

The three fuels used most often for heating are natural gas, electricity, and heating oil. Today, more than half of the nation's homes are heated by natural gas, a trend that will continue, at least in the near future. **Natural gas** is the heating fuel of choice for most consumers in the United States. It is a clean-burning fuel. Most natural gas furnaces in the 1970s and 1980s were about 60 percent efficient—they converted 60 percent of the energy in the natural gas into usable heat. Some of these furnaces could still be in use today, since they can last 20 or more years with proper maintenance.

New furnaces manufactured today can reach efficiency ratings of 98 percent, since they are designed to capture heat that used to be lost up the chimney. These furnaces are more complex and costly, but they save significant amounts of energy.

The payback period for a new high-efficiency furnace is between four and five years, resulting in considerable savings over the life of the furnace. **Payback period** is the amount of time a consumer must use a system before beginning to benefit from the energy savings because of the higher initial investment cost.

Electricity is the second leading source of energy for home heating and provides almost all of the energy used for air conditioning. The efficiency of air conditioners and heat pumps has increased more than 50 percent in the last 35 years.

In 1973, air conditioners and heat pumps had an average **Seasonal Energy Efficiency Rating**, or **SEER**, of 7.0. Today, the average unit has a SEER of 11.1, and high-efficiency units are available with SEER ratings as high as 18. These high-rated units are more expensive to buy, but their payback period is only three to five years.

Heating oil is the third leading fuel for home heating and is widely used in northeastern states. In 1973, the average home used 1,294 gallons of oil a year. Today, that figure is 833 gallons, a 35 percent decrease.

This decrease in consumption is a result of improvements in oil furnaces. Not only do today's burners operate more efficiently, they also burn more cleanly. According to the Environmental Protection Agency, new oil furnaces operate as cleanly as natural gas and propane burners. A new technology under development would use PV cells to convert the bright, white oil burner flame into electricity.

Saving Energy on Heating and Cooling

The four most important things a consumer can do to reduce heating and cooling costs are:

▪ Maintenance
Maintaining equipment in good working order is essential to reducing energy costs. A certified technician should service systems annually, and filters should be cleaned or replaced on a regular schedule by the homeowner.

▪ Programmable Thermostats
Programmable thermostats regulate indoor air temperature automatically, adjusting for time of day and season. They can be used with both heating and cooling systems and can lower energy usage appreciably.

▪ Insulation
Most heat enters and escapes from homes through the ceilings and walls. Adequate insulation is very important to reduce heat loss and air infiltration. The amount of insulation required varies with the climate of the region in which the house is located.

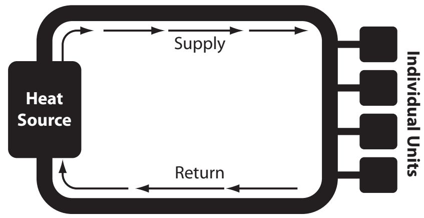
▪ Caulking and Weatherstripping
Preventing the exchange of inside air with outside air is very important. Weatherstripping and caulking around doors and windows can significantly reduce air leakage. Keeping windows and doors closed when systems are operating is also a necessity.

District Energy Systems

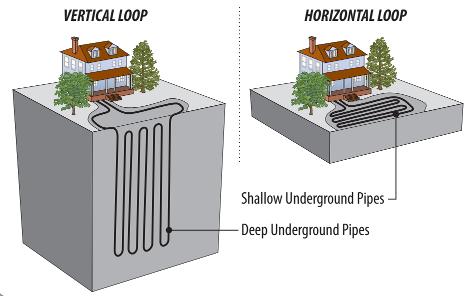
Where there are many buildings close together, like on a college campus, it is sometimes more efficient to have a central heating and cooling facility, which is called a **district energy system**. A district system can reduce equipment and maintenance costs, as well as produce energy savings.

If the system relies on a fossil fuel cogeneration plant for heat, the overall efficiency of the plant can increase from 30 to 90 percent. Cogeneration can also reduce emissions per unit of energy produced by 50 to 60 percent.

District Heating System



Residential Geoexchange Units



If the district energy system uses a renewable energy source, such as geothermal energy or waste heat, emission levels can be reduced even more. A major benefit of district heating is its ability to use materials as fuel that would otherwise be waste products. These fuels may include biomass, such as waste from the forest product industry, straw, garbage, industrial waste heat, and treated sewage. In the next 25 years, district energy systems will double their current output, using natural gas, as well as cogeneration from biomass and geothermal sources.

Geoexchange Systems

There are only a few areas in the country that have high temperature geothermal reservoirs, but low temperature geothermal resources are everywhere. Geothermal heat pumps, or **geoexchange units** as they are often called, can use low temperature geothermal energy to heat and cool buildings.

Geothermal systems cost more to install than conventional systems, but over the life of the system, they can save a significant amount of money and energy. They can reduce heating costs by 30-70 percent and cooling costs by 20-50 percent. It is estimated that the average homeowner can save $20,000 over the life of the system. Today, there are more than one million geothermal systems in homes and buildings. By the year 2023, the geothermal industry estimates that more than 10 million homes and businesses will be equipped with this new technology.

Building Design

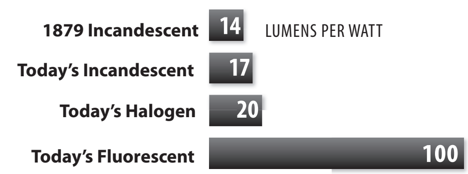
The placement, design, and construction materials used can affect the energy efficiency of homes and buildings. Making optimum use of the light and heat from the sun is becoming more prevalent, especially in commercial buildings.

Many new buildings are situated with maximum exposure to the sun, incorporating large, south-facing windows to capture the energy in winter, and overhangs to shade the windows from the sun in summer. Windows are also strategically placed around the buildings to make use of natural light, reducing the need for artificial lighting during the day. Using materials that can absorb and store heat can also contribute to the energy efficiency of buildings.

The Department of Energy's National Renewable Energy Lab has developed computer programs to design energy efficient buildings for any area of the country, taking into account the local climate and availability of building materials.

For existing houses and buildings, there are many ways to increase efficiency. Adding insulation and replacing windows and doors with high efficiency models can significantly reduce energy costs. Adding insulated draperies and blinds, and using them wisely, can also result in savings. Even planting trees that provide shade in the summer and allow light in during the winter can make a big difference.

Lighting Efficiency



Lighting

Lighting is essential to a modern society. Lights have revolutionized the way we live, work, and play. Today, about five percent of the energy used in the nation is for lighting our homes, buildings, and streets. Lighting accounts for about 11 percent of the average home's electric bill, but for stores, schools, and businesses, the figure is much higher. On average, the commercial sector uses about 38 percent of its electricity for lighting.

Most homes still use the traditional **incandescent bulbs** invented by Thomas Edison. These bulbs convert only 10 percent of the electricity they use to produce light; the other 90 percent is converted into heat. With new technologies, such as better filament designs and gas mixtures, these bulbs are more efficient than they used to. In 1879, the average bulb produced 14 lumens per watt, compared to about 17 lumens per watt today. By adding halogen gases, this efficiency can be increased to 20 lumens per watt.

Most commercial buildings have converted to fluorescent lighting, which costs more to install, but uses much less energy to produce the same amount of light. Buildings can lower their long-term lighting costs by as much as 50 percent with fluorescent systems.

Compact fluorescent bulbs (CFL) are more common in homes now. They are more expensive, but they last much longer and use much less energy, producing significant savings over the life of the bulb. New fluorescent bulb technology has made more dramatic advances in lighting efficiency. Some of the new fluorescent systems have increased the efficiency of these bulbs to as high as 100 lumens per watt.

Most light bulbs are used in some kind of fixture. The design of fixtures can have a major impact on the amount of light required in buildings. Good fixture designs that capture all of the light produced and direct it to where it is needed can reduce energy costs significantly.

Energy Consumption

Outdoor lighting consumes a lot of energy, too. Most of our major highways and residential streets have streetlights, as well as many parking lots. In the 1970s, most streetlights were inefficient incandescent and mercury vapor lights. It was at this time that the federal government began replacing these lights with high-pressure sodium lights, which produce four to five times as much light per watt. Automatic sensors also were installed to reduce energy use.

Consumers should make use of fluorescent bulbs wherever feasible and use only the amount of light they need for the task at hand. Most people use higher wattage bulbs than are necessary in most fixtures. Automatic turn-off and dimmer switches can also contribute to energy savings. Keeping light bulbs free of dust is an energy-saver, too. Some of the most important actions consumers can take is to turn off lights they aren't using, buy lamps that are suited to their needs in different rooms, and make energy conservation a priority in their daily lives. After CFLs have completed their lifespan, they can be recycled.

Appliances

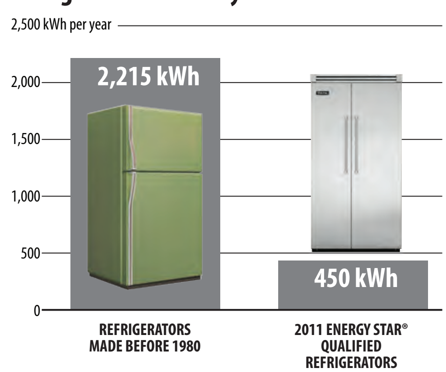
In the last 100 years, appliances have revolutionized the way we spend our time at home. Tasks that used to take hours are now accomplished in minutes, using electricity most of the time instead of human energy. In 1990, Congress passed the **National Appliance Energy Conservation Act**, which requires appliances to meet strict energy efficiency standards.

▪ Water Heating

Heating water uses more energy than any other task, except for home heating and cooling. Most water heaters use natural gas or electricity as fuel. New water heaters are much more energy efficient than earlier models. Many now have timers that can be set to the times when hot water is needed, so that energy is not being used 24 hours a day. New systems on the market combine high efficiency water heaters and furnaces into one unit to share heating responsibilities. Combination systems can produce a 90 percent efficiency rating.

In the future, expect to see water heaters that utilize heat that is usually pumped outside as waste heat. Systems will collect the waste heat and direct it into the water heater, resulting in efficiency ratings three times those of conventional water heaters.

Refrigerator Efficiency



Data: ENERGY STAR®

Most consumers set the temperature on their water heaters much too high. Lowering the temperature setting can result in significant energy savings. Limiting the amount of hot water usage with low-flow showerheads and conservation behaviors also contributes to lower energy bills.

▪ Refrigerators

Refrigerators have changed the way we live and brought health benefits to our lives. With these appliances, we can safely store foods for long periods of time. Since refrigerators involve heat exchange, they also consume a significant amount of electricity each year.

New refrigerators are many times more efficient than early models. Manufacturers have improved the insulation and the seals, or gaskets, to hold in the cold air better. The industry has also made technological advances in defrost systems, as well as in more energy efficient motors and compressors.

The appliance industry has worked with the chemical industry to develop refrigerants that are not harmful to the ozone layer, as the early CFCs were. As with all appliances, the most efficient models are more expensive to purchase but produce energy savings over the life of the refrigerator.

▪ Washers and Dryers

Before washers and dryers, doing the laundry meant hard physical work all day, no matter what the weather. Today, the most difficult thing about laundry is deciding which cycle to use. Today's machines have many innovations that save energy. Dryers with automatic sensors can tell when clothes are dry.

New washing machines are being designed with a horizontal axis, rather than the traditional top-load design. These machines use 40 percent less water and 60 percent less energy than the top-loading models. They also have higher capacity; they can wash large items such as comforters and sleeping bags.

▪ Appliance Efficiency Ratings

We use many other appliances every day. Some use less than 10 cents worth of electricity a year, while others use much more. Have you noticed that those appliances that produce or remove heat require the most energy?

When purchasing any appliance, consumers should define their needs and pay attention to the **Energy Efficiency Rating (EER)** included on the yellow label of every appliance. The EER allows consumers to compare not just purchase price, but operating cost as well, to determine which appliance is the best investment.

Usually, more energy efficient appliances cost more to buy, but result in significant energy savings over the life of the appliance. Buying the cheapest appliance is rarely a bargain in the long run.

In the next few years, consumers will have the choice of many smart appliances that incorporate computer chip technology to operate more efficiently, accurately, and effectively.

Measuring Electricity

Directions: Fill in the blanks in the tables below.

TABLE 1

VOLTAGE	=	CURRENT	X	RESISTANCE
1.5 V	=	______ A	x	3 Ω
______ V	=	3 A	x	4 Ω
120 V	=	4 A	x	______ Ω
240 V	=	______ A	x	12 Ω

TABLE 2

POWER	=	VOLTAGE	X	CURRENT
27 W	=	9 V	x	______ A
______ W	=	120 V	x	1.5 A
45 W	=	______ V	x	3 A
______ W	=	120 V	x	2 A

TABLE 3

APPLIANCE		POWER	=	VOLTAGE	X	CURRENT
TV		180 W	=	120 V	x	______ A
COMPUTER		40 W	=	120 V	x	______ A
PRINTER		120 W	=	120 V	x	______ A
HAIR DRYER		1,000 W	=	120 V	x	______ A

TABLE 4

POWER		TIME	=	ELECTRICAL ENERGY (kWh)	X	PRICE	=	COST
5 kW	x	100 h	=	____________	x	$ 0.127	=	$ ______
25 kW	x	4 h	=	____________	x	$ 0.127	=	$ ______
1,000 W	x	1 h	=	____________	x	$ 0.127	=	$ ______