

Activity – Efficiency of a Water Heating System

Goal: Participants gain a sense for how much energy is consumed in a daily activity and how the efficiency varies based on method used

Learning objectives. By the end of the activity the participants:

1. can theoretically calculate the energy required to heat water to a boil
2. are competent in using the Watt-meter and basic measuring tools (thermometer, graduated cylinder)
3. can calculate energy consumed to heat water based on experimental measurements
4. can convert energy units between kWh, kJ, Btu
5. can calculate the efficiency of water heating devices.

Key concepts:

Power vs. energy
Energy units / conversions
Energy efficiency (ratios, percent calculations)
Measuring/calculating energy consumption

Supplies:

Graduated cylinders (one per group)
Thermometers (one per group)
Hotpot (could have a couple of different models)
Microwave
Watt meter (one per group)
Calculators

Background:

The theoretical amount of energy needed to heat a substance such as water can be calculated based on the mass, temperature rise and specific heat of the substance:

$$Q = m C_p \Delta T$$

Where:

Q is the energy required (joules, J);
m is the mass of the substance (g);
 C_p is the specific heat (J/g/°C); The specific heat of water is 4.186 J/g/°C.
 ΔT is the change in temperature (°C).

When we actually heat a substance, however, there are inefficiencies in the process and some heat energy is lost to the surroundings. We can measure the actual energy consumed by electrical appliances to heat water with a watt meter. The electrical

energy is generally expressed in units of kWh. It is determined as the product of the power consumed by the appliance and the time of heating:

$$\text{energy (kWh)} = \text{power (W)} \times \text{time (h)} \times \frac{\text{kW}}{1000\text{W}}$$

The energy units of kWh and J can easily be interchanged through the definition of a watt: $W=J/s$. The English unit of Btu (British thermal unit) is also used for expressing quantities of energy. Burning one wooden match releases approximately one Btu. There are 1055 joules in a Btu. Thus, a kJ (1000 J) is approximately equal to a Btu.

Procedure:

1. Heat 500 mL of water to a temperature to $\sim 80^{\circ}\text{C}$ with either the hot pot or the microwave. Create a data table to record initial temperature, final temperature and energy or power consumed.
2. Calculate the actual energy required to heat the water (J or Btu)
3. Calculate the theoretical amount of energy required to heat the water and use this to quantify the efficiency of the appliance (efficiency = theoretical energy / actual energy)

Discussion questions:

1. What are your thoughts on the efficiency of the appliances? How could this information be used to help you chose how to heat water?
2. Identify any potential mechanisms by which heat energy was “lost” in the appliance and technique used to heat water. Discuss ways that these losses could be reduced to increase the efficiency of the appliance.