EFFICIENCY

Notes

Efficiency is the ratio of useful energy or power produced to the total amount of energy or power used.

Efficiency is given by the formulae:

$$Eff = \frac{Energy\ output}{Energy\ input}$$

$$Eff = \frac{Power\ output}{Power\ input}$$

$$Eff = \frac{W_{out}}{W_{in}} \times 100$$

$$Eff = \frac{P_{out}}{P_{in}} \times 100$$

"The washing machine is very energy efficient. I just wish Frank was!"

Example 1: A 1500-Watt hair dryer has a thermal power output of only 1200 W because some energy goes to moving air and making sound. Find the efficiency of the hair dryer.

G: $P_{in} = 1500\ W$

$P_{out} = 1200\ W$

R: $Eff = ?\ [\%]$

A: $Eff = \frac{P_{out}}{P_{in}} \times 100$

S: $Eff = \frac{1200}{1500} \times 100$

$= 80\%$

S: The hair dryer has efficiency of 80%

Example 2: The annual natural gas consumption for heating a small house is equivalent to 1.2×10^{11}J. If the furnace has an efficiency of 85%, how much energy is transferred to the house? How much energy is wasted?

G: $W_{in} = 1.2 \times 10^{11}$ J

$Eff = 85\% = 0.85$

R: • $W_{out} = ?$ [J]

• $W_{wasted} = ?$ [J]

A: $Eff = \frac{W_{out}}{W_{in}}$

$\rightarrow W_{out} = Eff \cdot W_{in}$

S: $= (0.85)(1.2 \times 10^{11})$

$= 1.02 \times 10^{11}$ J

A: $W_{wasted} = W_{in} - W_{out}$

S: $= 1.2 \times 10^{11} - 1.02 \times 10^{11}$

$= 1.8 \times 10^{10}$ J

S: 1.0×10^{11} J of energy is transfered to the house and 1.8×10^{10} J of energy is wasted.

Efficiency of Machines

When comparing machines, we calculate their efficiency by:

$$Eff = \frac{work\ done\ by\ the\ machine}{work\ needed\ to\ operate\ the\ machine} \times 100$$

(work → energy)

Machines are never 100% efficient.

Any machine with moving parts loses some energy to friction in the form of heat, sound, or light.

$W = Fd$

$W = F\cos\theta d$

$W = \Delta KE$

$W = P\Delta t$

$W = Q = mc\Delta T$

$W = \Delta PE$

Example 3: A lift is able to carry a load of 1.0×10^3kg at a velocity of 1.5 m/s [up]. Given that the motor driving the lift has an input power of 20kW, calculate the efficiency of the lift.

G: $P_{in} = 20\,kW = 20\,000\,W$

$m = 1.0\times10^3\,kg$

$v = 1.5\,m/s$

R: $E_{ff} = ?\,[\%]$

A: $E_{ff} = \frac{P_{out}}{P_{in}} \times 100$

Step 1 : Find P_{out}

Step 2 : Find E_{ff}

S: ① $P_{out} = \frac{W}{\Delta t} = \frac{Fd}{\Delta t} = F\cdot v$

* F needed to overcome F_g

$P_{out} = mg\cdot v$

$= (1000)(9.8)(1.5)$

$= 14\,700\,W$

② $E_{ff} = \frac{14\,700}{20\,000} \times 100$

$= 73.5\%$

S: The lift's efficiency is 74%.

An Alternative Unit of Energy

- kW·h = kilowatt hour = a larger unit of energy

1 kW·h = 3.6×10^6J

- Physiologist, dieticians, and professionals in other health-related fields usually measure energy in **kilocalories [kcal]** =food calories. One kilocalorie is the amount of heat required to raise the temperature of 1 kg of water by 1°C: **1kcal = 4.187 kJ.**

G: $1\,kW = 1000\,W$, $\Delta t = 1\,h = 3600\,s$

$E = P\cdot\Delta t$

$E = (1000)(3600)$

$= 3600\,000 = 3.6\times10^6\,J$

Examples:

1. Calculate the energy consumed by a 150-Watt computer that is used for 2.0 hours and a 250-Watt laser printer that is used for 10 minutes. Give your answer in Joules and in kWh.

G: $P_{in_c} = 150\ W$

$P_{in_p} = 250\ W$

$\Delta t_c = 2.0\ h = 7200\ s$

$\Delta t_p = 10\ min = 600\ s$

R: $E_c = ?\ [J]$ and $[kW \cdot h]$

$E_p = ?\ [J]$ and $[kW \cdot h]$

A: $P = \frac{W}{\Delta t} = \frac{E}{\Delta t} \rightarrow E = P \Delta t$

S: $E_c = (150)(7200)$

$= 1.08 \times 10^6\ J$

$= 0.3\ kW \cdot h$

$E_p = (250)(600)$

$= 1.5 \times 10^5\ J$

$= 0.042\ kW \cdot h$

S: Energy consumed is $3.4 \times 10^{-1}\ kWh$ or $1.2 \times 10^6\ J$.

2. Calculate the energy consumed making a breakfast for one person: oatmeal (microwave oven, 1000W, 2.0 minutes), toast (toaster 1400 W, 1.0 minute), and a fruit smoothie (blender, 385W, 1.0 minute). Give your answer in Joules and in kWh.

G: $\Delta t_m = 2.0\ min = 120\ s$

$P_{in_m} = 1000\ W$

$\Delta t_t = 1.0\ min = 60\ s$

$P_{in_t} = 1400\ W$

$\Delta t_b = 1.0\ min = 60\ s$

$P_{in_b} = 385\ W$

R: $\Sigma E = ?\ [J]$ and $[kW \cdot h]$

A: $P = \frac{E}{\Delta t}$

$\rightarrow E = P \cdot \Delta t$

$\Sigma E = E_m + E_t + E_b$

S: $E_m = (1000)(120)$

$= 1.2 \times 10^5\ J$

$E_t = (1400)(60)$

$= 8.4 \times 10^4\ J$

$E_b = (385)(60)$

$= 2.3 \times 10^4\ J$

$\Sigma E = 2.3 \times 10^5\ J$

$= 0.063\ kWh$

S: Energy consumed is $2.3 \times 10^5\ J$ (OR $6.3 \times 10^{-2}\ kW \cdot h$)

3. A cell-phone charger rated at 5.0 W has an efficiency of 60%. If it takes 90 minutes to charge the phone, how much energy is transferred to the phone? How much energy is waste energy? Give your answer in Joules and in kWh.

G: $P_{in} = 5.0\,W$

$Eff = 60\% = 0.60$

$\Delta t = 90\,min = 5400\,s$

R: $E_{out} = ?$ [J] and [kWh]

$E_{wasted} = ?$ [J]; [kWh]

A: $Eff = \frac{W_{out}}{W_{in}} \times 100 \rightarrow W_{out} = \frac{Eff \cdot W_{in}}{100}$

S: $W_{out} = \frac{(60)(5.0)(5400)}{100}$

$W_{out} = 16200\,J$

Wasted energy: $W_{in} - W_{out}$

$= (5.0)(5400) - 16200$

$= 10800\,J$

S: $1.6 \times 10^5\,J$ ($4.5 \times 10^{-3}\,kW \cdot h$) of energy is transferred to the phone, while $1.1 \times 10^5\,J$ ($3.0 \times 10^{-3}\,kW \cdot h$) of energy is wasted.

4. The energy consumption for walking up the stairs is 0.1187 kcal/min (per 1kg of body mass). Calculate the power of a 75.0-kg person climbing the stairs.

G: $E = 0.1187\,kcal/kg$

$m = 75.0\,kg$

$\Delta t = 1.0\,min = 60\,s$

R: $P = ?$ [W]

A: $1\,kcal = 4.187\,kJ$

$= 4187\,J$

$P = \frac{E}{\Delta t}$

S: $P = \frac{(4187)(75)(0.1187)}{60}$

$P = 6.2 \times 10^2\,W$

S: the power of a 75-kg person climbing stairs is $6.2 \times 10^2\,W$.

OR 621 W.

365 days

5. Calculate the annual energy consumption in kWh, of a hair dryer that is rated at 1440W and is used for 7.0 minutes every day.

G: $P = 1440W$

$\Delta t = 7.0 \text{ min} = 420 s$

365 days

R: $E = ? \ [kW \cdot h]$ per year

A: $P = \frac{W}{\Delta t} = \frac{E}{\Delta t}$

$\rightarrow E = P\Delta t$

S: $E = (1440)(420)$

$E = 604800 \ J \ /day$

S: $(604800)(365) = 2.2 \times 10^8 J$

$\frac{2.2 \times 10^8 J}{3.6 \times 10^6 J} = 61.32 \ kWh$

S: the annual consumption of the hair dryer is 61 kWh.

6. A60.0-W incandescent light bulb runs continuously for 100 days.
   A) Calculate the amount of energy used in Joules and in kilowatt hours.
   B) How much heat is produced if the bulb has an efficiency of 5 percent?

G: $\Delta t = 100 \text{ days} = 8640000 \ s$

$P = 60.0 W$, $E_H = 5\%$

R: ① $E = ? \ [J]$ and $[kW \cdot h]$

② $E_{wasted} = ? \ [J]$

A: $E = P\Delta t$

S: $E = (60.0)(8640000)$

$= 5.2 \times 10^8 J$

$\Rightarrow 144 \ kWh$

A: $E_H = \frac{E_{out}}{E_{in}} \times 100$

$\rightarrow E_{out} = \frac{E_H \cdot E_{in}}{100}$

S: $E_{out} = \frac{(5.0)(5.2 \times 10^8)}{100}$

$E_{out} = 25920000 J$

$= 2.6 \times 10^7 J$

$= 7.2 \ kW \cdot h$

S: $E_{heat} = E_{in} - E_{out}$

$= 136.8 \ kW \cdot h$

$= 4.9 \times 10^8 J$

7. If you ran a washing machine (512W) and an electric clothes dryer (5000 W) for 1.5 h each day;
   A) How much energy do the two appliances use in one day?
   B) How much energy do the two appliances use in one year?
   C) How much is the cost of operating these two appliances a year if the current rate is 12.1cent/kWh?

G: $P_{in_m} = 512\ W$

$P_{in_d} = 5000\ W$

$\Delta t = 1.5 h = 5400\ s$

A) R: $E_{in} = ?\ [J]$

A: $P = \frac{E_{in}}{\Delta t}$

$\rightarrow E_{in} = P \Delta t$

$E_{in_m} = (512)(5400)$
$= 2.76 \times 10^6\ J$

$E_{in_d} = (5000)(5400)$
$= 2.7 \times 10^7\ J$

$\Sigma E = 3.0 \times 10^7\ J/day$
$= 8.268\ kW \cdot h/d$

B) R: E_{in} ? $[J]/year$

$\Sigma E = 3.0 \times 10^3\ kW \cdot h/year$ $\quad \Sigma E = 1.1 \times 10^{10}\ J/year$

C) R: ? cost [\$/year]

$Cost = (3.0 \times 10^3\ kW \cdot h)(12.1 c)$
$= \$363/year$

S: The two appliances consume $3.0 \times 10^7\ J$ (or $8.3 \times 10^1\ kW \cdot h$)/day $1.1 \times 10^{10}\ J$ (or $3.0 \times 10^3\ kW \cdot h$)/year and the cost of operating those two appliances in such a rate would cost \$363/year.