Lecture 9
April 26, 2011

Pre Midterm Review

Mechanics: Force, Work done, energy, power
each term has a dimension and a precise meaning and a standard unit

Energy=> Joule, watt hour, BTu, calorie, foot pound
Force=> Newton, pound
power=> Watt, horse power

Types of energy: Chemical, Potential, Heat,Mass,...

First law implies we can convert between different forms of energy.

a) Chemical energy : Combustion (Burning of coal, wood, gas..) Sources: carbon and hydrogen based, batteries

b)Heat energy: Heat = energy (Thermodynamics)

c)Mass energy: $E= M c^2$ Einstein: nuclear energy 1.gm lead is 9×10^{14} J (enormous!!)

d) Kinetic energy   (energy of kinetic motion can be converted to heat) $1/2\ mv^{2}$:

e)Potential energy: Dams Hydroelectric, gravity

f) Solar energy= Electromagnetic energy

g) Electrical energy: Invisible yet powerful: motors, DC (direct current) and AC (alternating current):

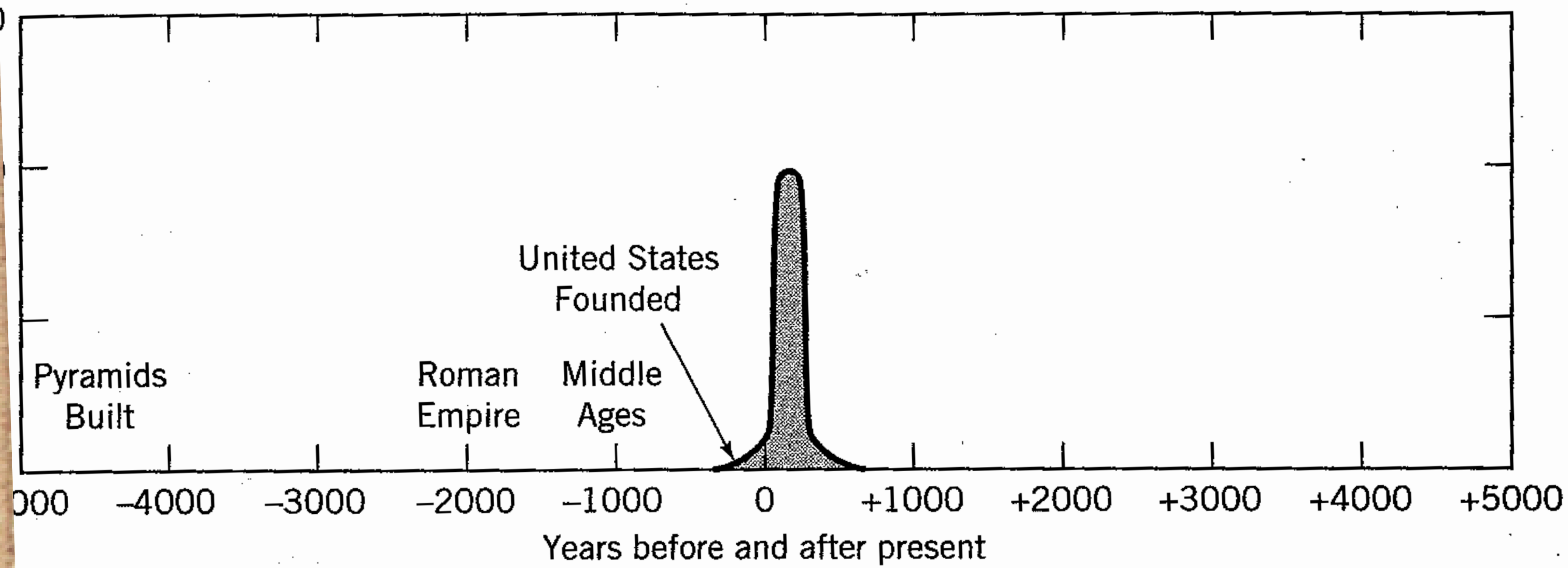
AC related to time dependent fields,

DC related to PE: Q V = PE in a battery; partly chemical

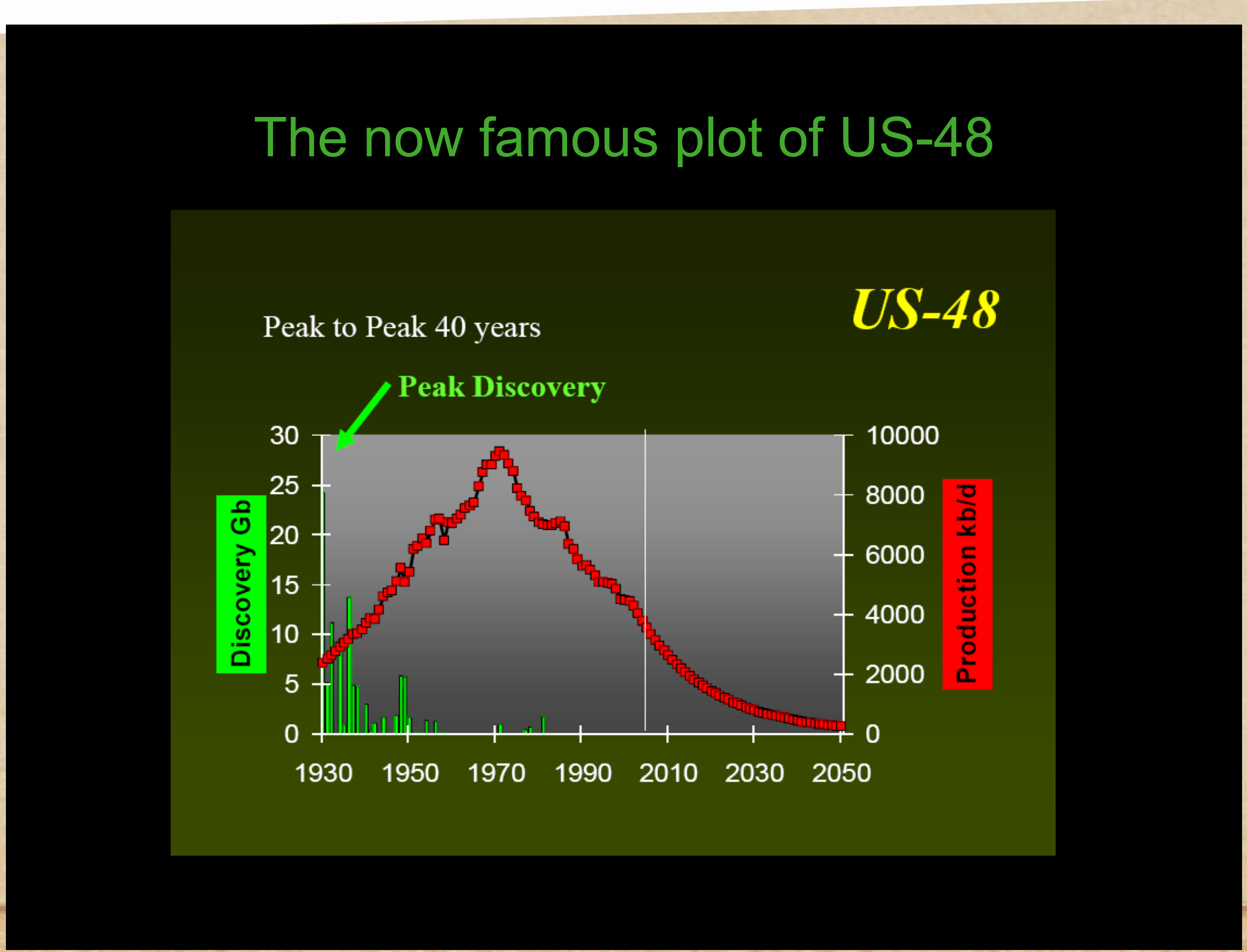
Table 1.3: Energy Content of Fuels

Type of Fuel	Energy in joules/kg	Type of Fuel	Energy in joules/kg
Coal	2.9×10^7	Garbage and Trash	1.2×10^7
Crude Oil	4.3×10^7	Bread	1.0×10^7
Gasoline	4.4×10^7	Butter	3.3×10^7
Natural Gas	5.5×10^7	Nuclear fission with Uranium 235	8.0×10^{13} = $8{,}000{,}000 \times 10^7$
Wood	1.4×10^7		

	Numbers useful on a bigger scale				
	Total energy consumption in USA				
	(1 QBtu ~ referred to as a Quad)			1 Quad=172.4	Million Barrels
	1 Quad = 293 TWh		1000TWh=3.41 Quad		
2003	98.3 Quad		$2.88\text{x}10^{16}$	watt hours	28800 TWh
2007	101.6 Quad		$2.97\text{x}10^{16}$ watt hours		29700 TWh
	Annual electricity production in USA in 2010				
	3992 TWh		(China 3715 TWh)		
	Energy Consumption per capita in US = 101.6x 172.4 Mill/290 Mill =				60.4 barrels per person



1.2 The complete exploitation of the world's fossil fuels will span only a rela-
brief time in the 10,000 year period shown centered around the present. (*Source*:
ted with permission from M. K. Hubbert, *Resources and Man*, Washington,
National Academy of Sciences, 1969. Historical events added.)



Hint: (1) Identify the formula needed (2) Plug in the numbers.

Some occasionally used special energy units

Toe Tonne equivalent of energy obtained by burning 1 metric tonne of a standard crude. 1000 MToe= 40 Quads	1 Toe	6 Giga Joule or 40×10^6 BTU
Therm Unit used e.g. in power and utilities bills for homes.	1 Therm	10^5 BTU = 29.3 KWh

PG&E Bills

Electricity Usage (July 2010): 405 Kwh Charges: $54.84 (@).1188 / Kwh (first 215) then @ .2902 /Kwh

Gas charges :29 Therms Charges: $4.22 @1.09 /Therm

- Petroleum- History and production information
- Petroleum Resources and their depletion: M K Hubbert’s thesis
- Petroleum Refining: some facts.
- Natural gas:
- Coal:
- Shale Oil
- Tar Sands

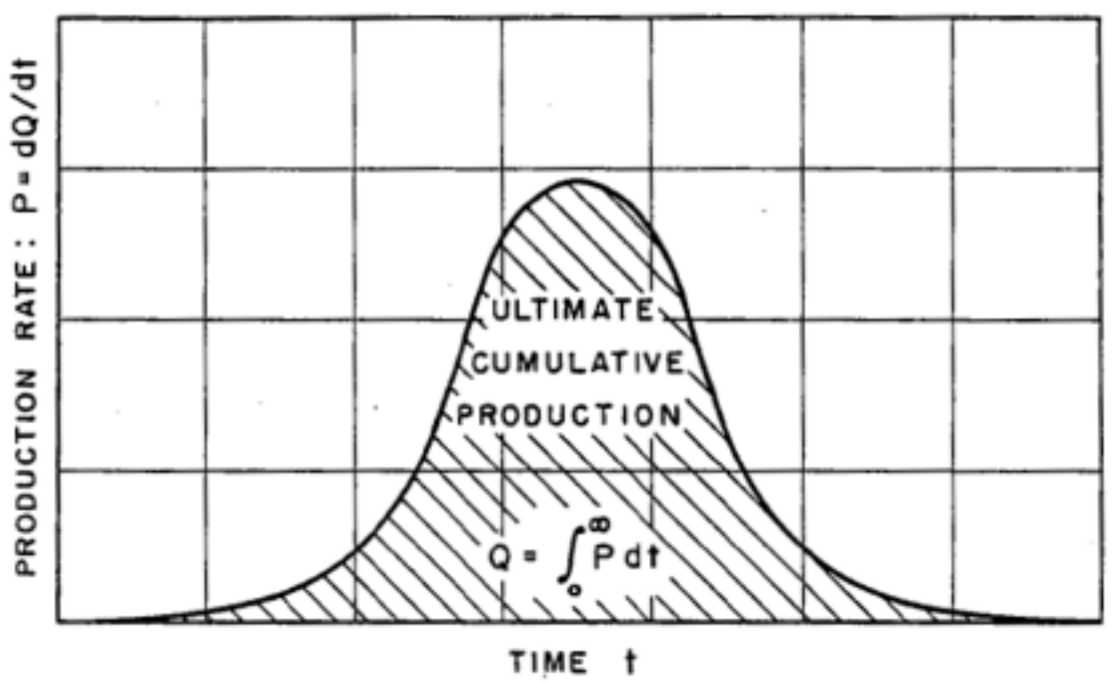
P = production rate

Example a single well may produce 1 Million barrels per day in 1975 changing to .95 in 1976,.... and .75 in 2011.

We will then say that P(t) = 1,.95,..., .75

Actual number

P ~ 5.7 Million barrels per day 2003 (USA) ~9 MB/day Saudi: ~70 MB/day world



For any finite resource we may define

Q(t) is the quantity of the produce upto time "t".

$$Q_\infty = Q(t);\ t \to \infty$$

This represents the grand total of the produce.

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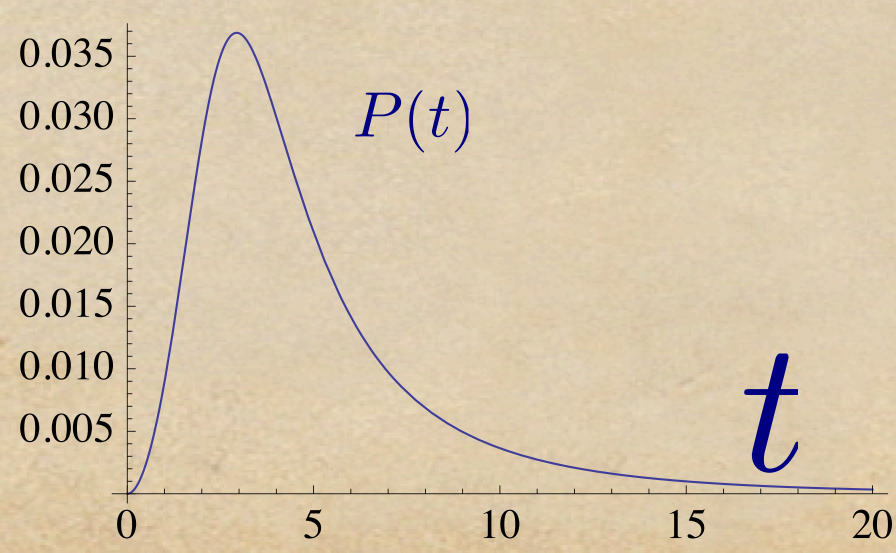

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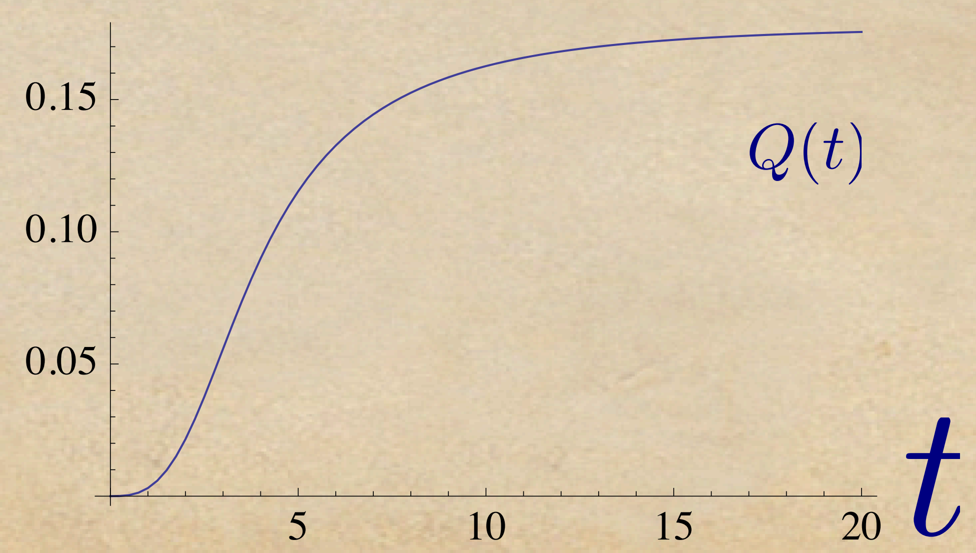


Concepts:

Temperature T, Heat ΔQ, Specific heat C, Latent heat L, Pressure

Laws of Thermodynamics 0,1,2,3

Mixtures and resulting temperatures

Carnot Cycle for efficiency

Quality of Heat and 2nd law efficiencies

Mixing problems

specific heat

$$\Delta Q_1 = M_1 c_1 \Delta T_1 \qquad \Delta T_1 = T_1 - T_f$$

$$\Delta Q_2 = M_2 c_2 \Delta T_2 \qquad \Delta T_2 = T_f - T_2$$

$$\Delta Q_1 = \Delta Q_2 \qquad T_f = \frac{M_1 c_1 T_1 + M_2 c_2 T_2}{M_1 c_1 + M_2 c_2}$$

Summarizing the difference between
Specific heat versus Latent Heat

$\Delta Q = M c \Delta T$

(State is fixed but T changes)

$\Delta Q = M L$

(T is fixed but state changes)

Example combing the two

Find the heat needed to heat 10 kG water at 90°C to steam at 110°C

A) There is heating of water from 90 to 100 C,

B) change of state to steam at 100 C

C) heating of steam from 100 C to 110 C

Data given: Latent heat for boiling 2.25 MJ/kG
Specific heat of water 4.2 kJ/kG
Specific heat of steam 1.996 kJ/kG
Specific heat of ice 2.18 kJ/kG

$\Delta Q = Q_a + Q_b + Q_c$

$Q_a = 420$ kJ, $Q_b = 22.5$ MJ, $Q_c = 199.6$ kJ

2nd Law of thermodynamics

- It is impossible for a machine to take heat from a reservoir at T, produce work and exhaust heat into a reservoir at same T .
- Systems isolated from the environment will move towards equilibrium with their surroundings.

Second Law says:
There is an intrinsic limit
on how good our engine can get

$$\eta(Carnot) = \frac{T_{Hot} - T_{Cold}}{T_{Hot}} \times 100\%$$

$$\text{Efficiency(Carnot)} = \frac{T_{Hot} - T_{Cold}}{T_{Hot}} \times 100\%$$

Heat Pump≈Refrigerator

≈ Heat Engine Run backwards

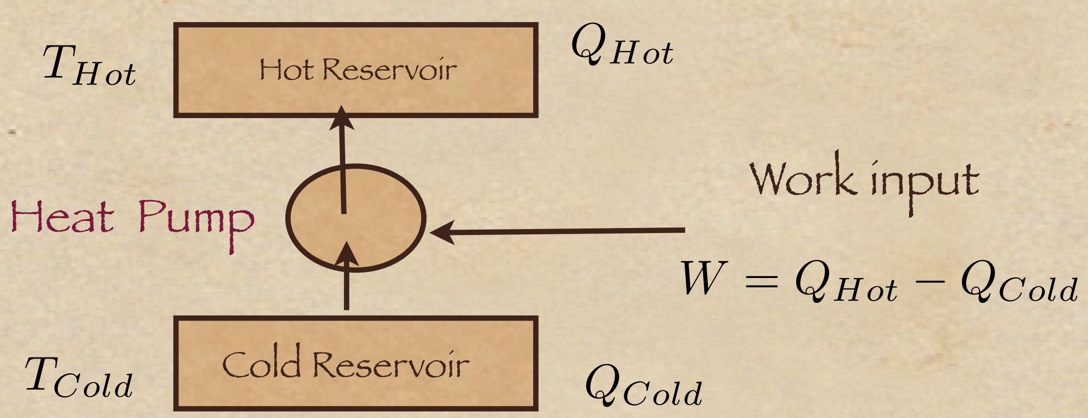
Coefficient of Performance:

$$COP = \frac{Q_{Hot}}{Q_{Hot} - Q_{Cold}} \times 100\%$$

Often COP > 500% or 600%

Outside temperature of room containing the refrigerator

Warm bedroom inside house



Cold outside air in winter

Cold milk in refrigerator

Remarkable fact is that $W < Q_{Hot}$, i.e. we are getting Q_{Hot} amount of heat although putting in only W by our external agencies.

Good alternative to space heaters.

Summary:

Given T_H and T_L we may define three functions

Heat Engine Efficiency = $(T_H - T_L)/T_H$

Refrigerator COP = $T_L/(T_H - T_L)$

Heat pump COP = $T_H/(T_H - T_L)$

COP= coefficient of performance

Second law efficiencies:

Carnot efficiency refers to an ideal reversible engine, in reality we must deal with losses, friction etc. Hence it is useful to define a second law efficiency of an engine as;

second law efficiency=
first law efficiency/Carnot efficiency for best process for task

$$w = cW$$

$w =$ Available work

$W = Q_H - Q_C$

$$\eta_S = c = \frac{w}{W}$$

Losses make c<1

$$\eta_{Second\ Law} = \frac{\eta_{First\ Law}}{\eta_{Carnot}}$$

$$\frac{w}{W} = \frac{w/Q_H}{W/Q_H} = \frac{\eta_{Firstlaw}}{\eta_{Carnot}}$$

Problems:

HW4

1. calculate the three efficiencies given T_{hot} and T_{cold}

Formula?

2. Work is less than the ideal amount by 10% second law efficiency? Heat pump?

Practice Midterm exam solutions

A coal burning power plant burns coal at 706^0C and exhausts heat into a river with average temperature 19^0C. What is the minimum possible rate of thermal pollution (i.e. heat exhausted into the river) if the station generates 125 MW of electricity?

The best possible machine for this purpose is a reversible one, i.e. a Carnot engine.

The first calculation we need to do is to figure the efficiency of this engine. Since the operating temperatures (T_H, T_L) are given as

$$T_H = 706^0\ C = 979^0\ K$$

$$T_L = 19^0\ C = 292^0\ K$$

Since the power station produces power at the rate of 125 MW, we infer that in a small time interval Δt the work done is $Q_H - Q_L = \Delta W = 125\ \Delta t$ MJ.

From the definition of efficiency, we find

$\eta = (Q_H - Q_L)/Q_H = 1 - Q_L/Q_H$.

Hence $Q_L = (1-\eta)\, Q_H$, as well as $Q_H = \Delta W/\eta$. Therefore $Q_L = \Delta W\, (1/\eta - 1) = 125\ \Delta t\ (1/.702 - 1) = 53.1\ \Delta t$ MJ. This is the amount of heat discharged by the plant, in a time interval Δt, and hence the rate of pollution is 53.1 MW.

2. A jeweller needs to melt a .5 kg block of silver at 20 °C, in order to pour into her molds. How much heat is needed to achieve this in kJ?

We view this in two stages: one is to heat silver to its melting temperature T_B= 960.8 °C from 20°C, using the known heat capacity of silver C_H= .235 kJ/(kg °C, and the second to melt it using the latent heat of fusion (melting) 88.3 kJ/kg. The answer can be summarized in a neat formula

$$Q = L_{melting}\ m + C\ m\ (T_B - T_{room})$$

Plugging in the various values, we find in units of kilo Joules

Q= 0.5 kg x 88.3 kJ/kg + .235 kJ/(kG °C) x 0.5 kg x 940.8°C = 155 kJ.

3. Solar energy is incident on a parking lot with intensity 1000 W/m², and 75 % of it is absorbed. After 8 hours of exposure, how much energy per squared meter has been absorbed? Express your answer in Btu/m² and in calorie/m².

If 50 % of the solar energy (again with intensity 1000 W/m²) incident on a 3 m x 3 m surface for 30 minutes is used to heat up 10 kg of water, how much is the increase in the water temperature?

First part: After 8 hours of exposure the energy absorbed per squared meter will be (remember that W=J/s)

$$0.75 \times \frac{1000 \text{ J}}{\text{s m}^2} \times \frac{3600 \text{ s}}{1 \text{ hr}} \times 8 \text{ hr} = 2.16 \times 10^7 \text{ J/m}^2$$

Convert this to Btu/m²

$$2.16 \times 10^7 \frac{\text{J}}{\text{m}^2} \times \frac{1 \text{ calorie}}{4.183 \text{ J}} = 5.16 \times 10^6 \text{ calorie/m}^2$$

Second part: On a surface of 3 x 3 = 9 m^2, the solar energy deposited in 30 minutes is

$$\frac{1000 \text{ J}}{\text{s m}^2} \times \frac{60 \text{ s}}{1 \text{ min}} \times 30 \text{ min} \times 9 \text{ m}^2 = 1.62 \times 10^7 \text{ J} = 1.62 \times 10^4 \text{ kJ}$$

where we used 1 kJ = 1000 J. Now, 50% of this energy is used to heat up the water:

$$Q = 0.5 \times 1.62 \times 10^4 \text{ kJ} = 8.1 \times 10^3 \text{ kJ}$$

To find the increase in the water temperature, use Q=m C ΔT, where C is the heat capacity of water, m the mass and ΔT the increase in temperature. Solve for ΔT.

$$\Delta T = \frac{Q}{mC} = \frac{8.1 \times 10^3 \text{ kJ}}{10 \text{ kg} \times 4.2 \text{ kJ/kg}^0\text{C}} = 193\ ^0\text{C}$$

4. An ideal heat pump takes in work at the rate of 3000 Btu/second and delivers heat at the rate of 5000 Btu/second. What is the power that it absorbs from the environment? What is its coefficient of performance? If the pump is non ideal, would its coefficient of performance decrease or increase?

Let's call P_{input} the input power (3000 Btu/s), P_C the power absorbed from the environment and P_H the power delivered. In terms of W, Q_C, $Q_H$$ these powers are simply P_{input}=W/time, e.g. P_C=Q_C/time, P_H=Q_H/time. We find

$$P_C = P_H - P_{input} = 2000 \text{ Btu/s}$$

The coefficient of performance is

$$\text{C.O.P.} = \frac{Q_H}{W} = \frac{P_H}{P_{input}} = \frac{5000}{3000} = \frac{5}{3}$$

If the pump were not ideal, the coefficient of performance would decrease