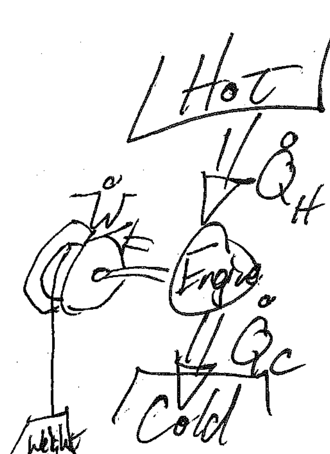
6.2 → 6.5

Yesterday we introduced the concept of direction, caused by irreversibilities. This led to the notion that real processes are inherently inefficient.

→ Kelvin-Planck Statement: "It is impossible to build an engine that will operate in a cycle (i.e. continuosly) that will provide no effect except the raising of a weight & cooling of a single thermal reservoir."



Thermal reservoir: infinite temperature source, provides thermal energy Q @ a constant temperature during the process under consideration: Lakes, rivers, atmosphere, buildings, etc.

For this system to work we have to add a cold reservoir, other wise there is no temperature gradiant for heat to flow.

Remember what Sadi Carnot said: $\dot{Q}_{in} \neq \dot{W}_{out}$ ← inefficient

How would we define the thermal efficient of the cycle above?

thermal efficiency: Ratio of the desired output (what you want) to the required input (what you payed):

$$\eta = \frac{\dot{W}}{\dot{Q}} \begin{matrix} \leftarrow \text{what you want} \\ \leftarrow \text{what you payed} \end{matrix} \Big\} \eta \overset{\text{always}}{<} 1$$

Therefore $\dot{W} < \dot{Q}_{in}$ so $\dot{Q}_{in} = \dot{W} + \dot{Q}_{out}$ ← Cold reservoir must exist.

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Similarly $\eta = \dfrac{\overbrace{\mathring{Q}_{in} - \mathring{Q}_{out}}^{\mathring{W}_{in}}}{\mathring{Q}_{in}}$ or $\eta = 1 - \dfrac{\mathring{Q}_{out}}{\mathring{Q}_{in}}$ For a heat engine

This means that the efficiency of a heat engine ~~is only~~ ~~dependent~~ must depend only on the heat transfer into & out of the system, What controls heat transfer? → temperature

→ Therefore we can ~~define~~ write the maximum, or best case efficiency of a system as just a function of temperature:

$$\eta_{\substack{Max\\thermal\\Heat\,Engine}} = \frac{\mathring{Q}_{in} - \mathring{Q}_{out}}{\mathring{Q}_{in}} \Rightarrow \frac{\mathring{Q}_{Hot} - \mathring{Q}_{cold}}{\mathring{Q}_{Hot}} \Rightarrow \frac{T_{Hot} - T_{cold}}{T_{Hot}}$$

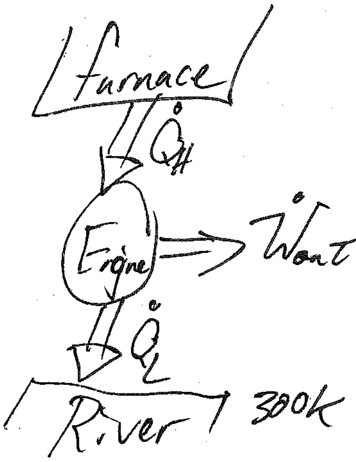
$$\underline{\eta_{Max} = \eta_{\substack{carnot\\for\,Heat\,engine}} = 1 - \frac{T_L}{T_H}}$$

does it matter which temperature scale we use here? Yes!!

You need to use an absolute temperature scale for 2nd Law analysis

This is the maximum possible efficiency for a heat engine, i.e. there are no irreversibilities (other than heat) affecting the engine, so a carnot engine or device ~~is~~ is reversible.

Example: Heat is transferred to a heat engine from a furnace at a rate of 80 MW. If the rate of waste heat rejection to a nearby river is 50 MW, determine the net power output, & the thermal efficiency, & the minimum temperature of the furnace for this to be possible.



$$\eta_{\substack{Thermal\\Heat\ Engine}} = \frac{\dot{W}_{out}}{\dot{Q}_H} = \frac{\dot{Q}_H - \dot{Q}_L}{\dot{Q}_H} = \frac{\boxed{30\,MW}}{80\,MW} \Rightarrow \eta = 0.375 \text{ or } 37.5\%$$

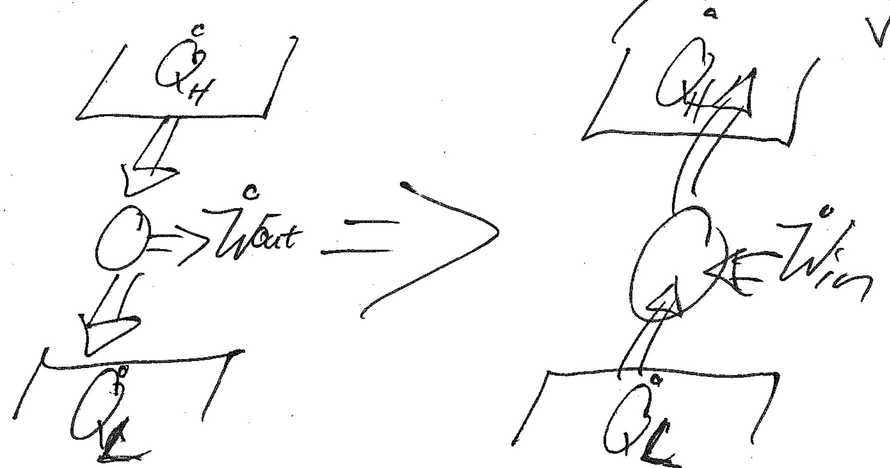
($\dot{W}_{out}$: what we want; $\dot{Q}_H$: what we payed)

How do we find minimum T_H? ← Carnot

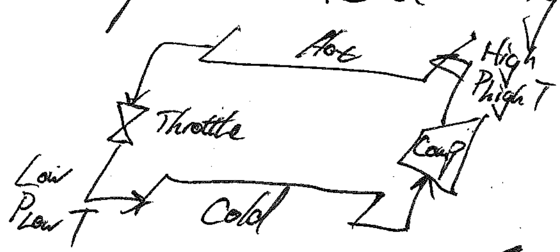
$$\eta_{\substack{Carnot\\Heat\ engine}} = 1 - \frac{T_L}{T_H} \Rightarrow 0.375 = 1 - \frac{300}{T_H} \Rightarrow T_H = \frac{300}{0.625}$$

$$T_H = 480\,K$$

What if I turned my heat engine around?



I could use this to cool a space like a refrigerator.



How would I define the thermal efficiency of this? $\frac{\text{What I want} = \dot{Q}_L}{\text{What I payed} = \dot{W}_{in}}$

This is called the Coefficient of Performance COP_R (for refrigerator) $= \frac{\dot{Q}_L}{\dot{W}_{in}} = \frac{\dot{Q}_L}{\dot{Q}_H - \dot{Q}_L} \Rightarrow \frac{T_L}{T_H - T_L}$ Ideal

$COP_R < 10.0$

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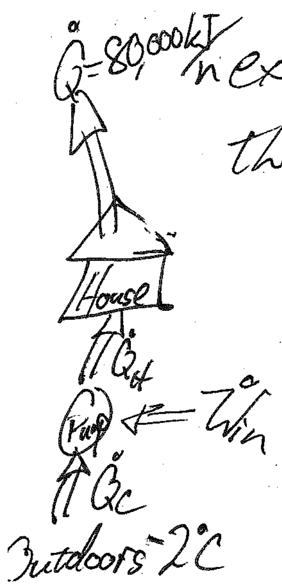
Can I do something with this system besides cool a space down? ← refrigeration ⇐ Yes! I can use it to heat up a space $\dot{Q}_H$, this is called a heat pump ← takes heat from colder temperature & moves it to a higher temperature.

<u>Example</u>: A heat pump is maintaining a house @ 20°C (293K). On a cold day the air temperature drops to −2°C & the house is estimated to loose heat at a rate of 80,000 kJ/h. If the heat pump has a COP of 2.5 under these conditions, find a) power required to drive pump β) the amount of heat extracted from the outdoor air $\dot{Q}_C$ & compare this finding to the amount of heat required if the house had electric heating.



Power Required?

$$COP_{HP}=\frac{\text{What we want}}{\text{What we payed}}=\frac{\dot{Q}_H}{\dot{W}_{in}} \Rightarrow \dot{W}_{in}=\frac{\dot{Q}_H}{COP_{HP}}=\frac{80,000\frac{kJ}{h}}{2.5}$$

$$\dot{W}_{in}=32,000\ kJ/h \text{ or } 8.9\,kW$$

How much heat came from the outside air?

Energy Balance: IN=OUT $\Rightarrow \dot{Q}_C+\dot{W}_{in}=\dot{Q}_H \Rightarrow$

$$\Rightarrow \dot{Q}_C=80,000\frac{kJ}{h}-32,000\frac{kJ}{h} \Rightarrow \underline{\dot{Q}_C=48,000\frac{kJ}{h}}$$

So we are only paying for 32,000 kJ/h! If we used electric base boards our electric bill would be <u>2.5 times higher</u>!