Lecture 17, Oct 18, 2022

Refrigerators

- A refrigerator is a device that takes heat from a low-temperature region to a higher temperature region, when being supplied with work
  - Essentially a heat engine working in reverse
- Heat Q_C is taken from the cold reservoir T_C and heat Q_H is rejected to the hot reservoir T_H, while work W is going in
- A liquid absorbs latent heat when it evaporates, and rejects heat when condensing
  - Using a low-pressure evaporator and high-pressure compressor, we can make the condensation temperature higher than the evaporation temperature since T_{sat} is dependent on P

Carnot Refrigerator

- A Carnot refrigerator is the theoretical maximumly efficient refrigerator
- Condenser $T = T_H + \Delta T$ feeds into a turbine, then an evaporator with $T = T_C - \Delta T$, then a compressor and back into the condenser

Definition

The Coefficient of Performance for a refrigerator: $\text{cop}_R = \dfrac{Q_C}{W_{net}}$

- Energy balance: $W_{net} = Q_H - Q_C \implies \text{cop}_R = \dfrac{Q_C}{Q_H - Q_C} = \dfrac{1}{\frac{Q_H}{Q_C} - 1}$
- Entropy balance for Carnot cycle: $\dfrac{Q_H}{T_H} - \dfrac{Q_C}{T_C} = 0 \implies \dfrac{Q_H}{Q_C} = \dfrac{T_H}{T_C}$
- Therefore $\text{cop}_R = \dfrac{1}{\frac{T_H}{T_C} - 1}$
  - Since $T_H > T_C$, $\text{cop}_R > 0$, i.e. you always need to supply work to a refrigerator
    - This is stated in the Clausius statement
  - Typically it is greater than 1
    - For typical domestic refrigeration it is 2-3
  - Note $\lim\limits_{T_H \to T_C} \text{cop}_R = \infty$; i.e. the smaller the temperature difference, the better the performance
- Notice that as $T_C \to 0, \text{cop}_R \to 0$, so as T_C approaches absolute zero, we need more and more work; we can never reach absolute zero because that would require infinite work
  - This is the counterpart to how thermal efficiency $\eta_{th} \to \infty$ as $T_C \to 0$
- Heat pumps use refrigerators as heating devices
  - The heat added is $Q_H = Q_C + W_{net}$ for heat pumps while regular heating has $Q_H = W_{net}$, so heat pumps are significantly more efficient
- Define the coefficient of performance for a heat pump to be $\text{cop}_{HP} = \dfrac{Q_H}{W_{net}}$, which works out to $\dfrac{1}{1 - \frac{T_C}{T_H}}$
  - Since $\dfrac{T_C}{T_H} < 1$, $\text{cop}_{HP} > 1$
  - As $T_C \to T_H$, the performance increases – this is why heat pumps are less effective in colder climates
  - A solution is ground-coupled heat pumps, which draw heat from inside the ground instead of the outside air
- We can design refrigerators/heat pumps such that they can be easily reversed, so in the summer we can use it as an AC, and in the winter as a heater

Carnot Principles

1. The efficiency of a reversible heat engine is always greater than that of an irreversible engine operating between the same temperatures
    - Consider two engines, one reversible and one irreversible, connected to the same temperatures
    - If work from the reversible engine, W_R, is less than the work from the irreversible engine, W_I, then $Q_{C,I} < Q_{C,R}$
    - Consider if we ran the reversible engine as a refrigerator, and put the resulting heat into the irreversible engine, and use the irreversible engine to drive the reversible engine
    - This gives us a device that interacts only with one thermal reservoir and gives us work directly, which makes it a perpetual motion machine
2. The efficiency of all reversible engines operating between the same two temperatures are the same
    - Efficiency depends only on temperatures, not engine design, in a reversible engine
    - This can be proven in exactly the same way