HEAT PUMPS

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A heat pump is essentially a backwards air conditioner, in that it extracts an amount of heat Q_c from the cold outside air using an amount W of electrical energy and dumps an amount $Q_h = Q_c + W$ of heat into an inside room in order to heat it. We can analyze its performance using the same logic as for a refrigerator. The coefficient of performance in this case is the amount of heat dumped into the room divided by the energy (work) needed to achieve this, so

$$\text{COP} = \frac{Q_h}{W} \tag{1}$$

From conservation of energy

$$\text{COP} = \frac{Q_h}{Q_h - Q_c} = \frac{1}{1 - Q_c/Q_h} \tag{2}$$

Thus the COP is always greater than 1.

In an ideal refrigerator (e.g. one working on a reversed Carnot cycle) the entropy gained in absorbing Q_c is equal to the entropy lost in expelling Q_h, so

$$\begin{aligned} \frac{Q_c}{T_c} &= \frac{Q_h}{T_h} && (3) \\ Q_c &= \frac{T_c}{T_h} Q_h && (4) \end{aligned}$$

The upper limit on the COP is therefore

$$\text{COP}_{max} = \frac{1}{1 - T_c/T_h} = \frac{T_h}{T_h - T_c} \tag{5}$$

A heat pump is more efficient than a purely electric heater (that is, a heater that generates heat by electrical resistance rather than by transferring heat from outside to inside) since in an electric heater, the work W is equal to Q_h, while in a heat pump, this work can be used to acquire an additional amount Q_c of heat which is expelled into the room along with the electrical work W. In other words, with a heat pump you have $Q_h = W + Q_c$ while with an electric heater, you have only $Q_h = W$.