AIR CONDITIONERS

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An air conditioner is an example of a refrigerator in which the cold reservoir is the room to be cooled and the hot reservoir is the outside atmosphere. On a hot day, the rate at which heat leaks into an air conditioned room from the outside is roughly proportional to the temperature difference $T_h - T_c$ between the outside and inside. In that case, the work done to remove an amount Q_c of heat in time Δt is

$$W = Q_h - Q_c = Q_h - K(T_h - T_c) \tag{1}$$

where Q_h is the heat expelled to the outside and K is a constant.

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

$$\frac{Q_c}{T_c} = \frac{Q_h}{T_h} \tag{2}$$

$$Q_h = \frac{T_h}{T_c} Q_c \tag{3}$$

$$= K\frac{T_h}{T_c}(T_h - T_c) \tag{4}$$

The work required to maintain a temperature of T_c is therefore

$$W = K\frac{T_h}{T_c}(T_h - T_c) - K(T_h - T_c) \tag{5}$$

$$= \frac{K}{T_c}(T_h - T_c)^2 \tag{6}$$

Thus lowering the inside temperature by a small amount can have a large effect on the work required to maintain this temperature, and thus on the cost of running the air conditioner. For example, suppose the outside temperature is 30° C = 303 K and the inside temperature is 22° C = 295 K. If we wish to lower the inside temperature by only one degree, the extra work required is

$$\frac{W_{294}}{W_{295}} = \frac{295}{294}\frac{9^2}{8^2} = 1.27 \tag{7}$$

We need to use 27% more power to achieve a single degree more cooling. This is one reason why it is much more economical to tolerate a slightly higher indoor temperature on a hot day.

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