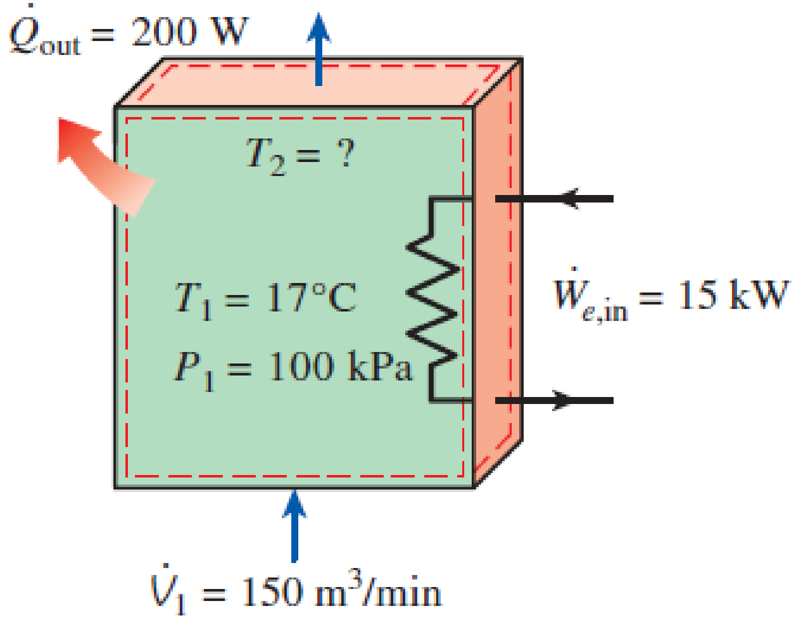
Problems on pipe and duct flow :

The transport of liquids or gases in pipes and ducts is of great importance in many engineering applications. Flow through a pipe or a duct usually satisfies the steady-flow conditions and thus can be analyzed as a steady-flow process. This, of course, excludes the transient start-up and shut-down periods. The control volume can be selected to coincide with the interior surfaces of the portion of the pipe or the duct that we are interested in analyzing.

Problems on pipe and duct flow :

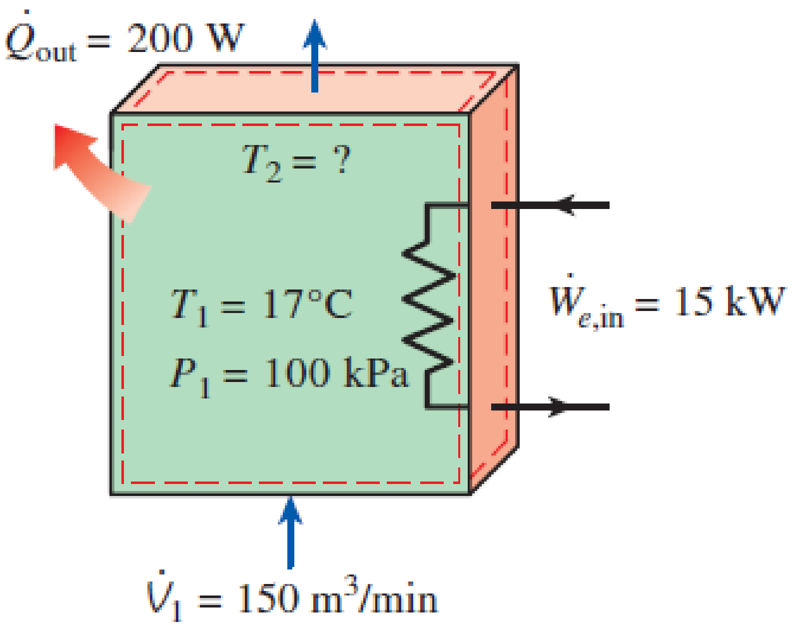
The electric heating systems used in many houses consist of a simple duct with resistance heaters. Air is heated as it flows over resistance wires. Consider a 15-kW electric heating system. Air enters the heating section at 100 kPa and 17°C with a volume flow rate of 150 m^3/min. If heat is lost from the air in the duct to the surroundings at a rate of 200 W, determine the exit temperature of air.



Problems on pipe and duct flow :

SOLUTION The electric heating system of a house is considered. For specified electric power consumption and air flow rate, the air exit temperature is to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time at any point and thus $\Delta m_{CV} = 0$ and $\Delta E_{CV} = 0$. **2** Air is an ideal gas since it is at a high temperature and low pressure relative to its critical-point values. **3** The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$. **4** Constant specific heats at room temperature can be used for air.



Control volume is taken as denoted by dotted red line in the figure.

The conditions at the inlet and outlet are denoted by subscripts “1” and “2”, respectively.

Problems on pipe and duct flow :

$$\dot{W}_{e,\text{in}} + \dot{m}h_1 = \dot{Q}_{\text{out}} + \dot{m}h_2 \quad (\text{since } \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

$$\dot{W}_{e,\text{in}} - \dot{Q}_{\text{out}} = \dot{m}c_p(T_2 - T_1)$$

From the ideal-gas relation, the specific volume of air at the inlet of the duct is

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287 \text{ kPa·m}^3/\text{kg·K})(290 \text{ K})}{100 \text{ kPa}} = 0.832 \text{ m}^3/\text{kg}$$

The mass flow rate of the air through the duct is determined from

$$\dot{m} = \frac{\dot{V}_1}{v_1} = \frac{150 \text{ m}^3/\text{min}}{0.832 \text{ m}^3/\text{kg}}\left(\frac{1 \text{ min}}{60 \text{ s}}\right) = 3.0 \text{ kg/s}$$

Substituting the known quantities, the exit temperature of the air is determined to be

$$(15 \text{ kJ/s}) - (0.2 \text{ kJ/s}) = (3 \text{ kg/s})(1.005 \text{ kJ/kg·°C})(T_2 - 17)\text{°C}$$

$$T_2 = \mathbf{21.9°C}$$

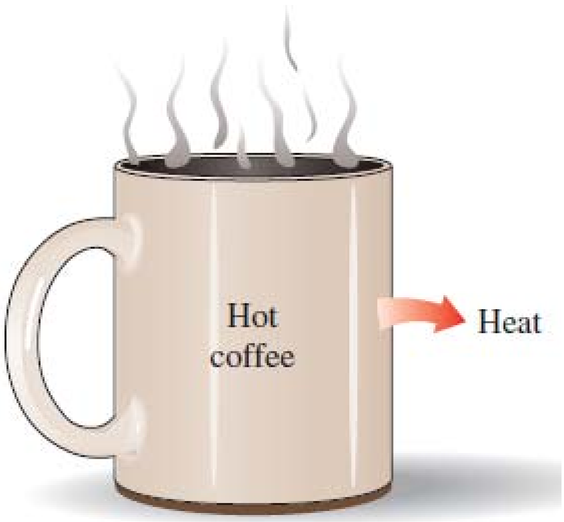
Discussion Note that heat loss from the duct reduces the exit temperature of air.

Natural or spontaneous processes are irreversible :

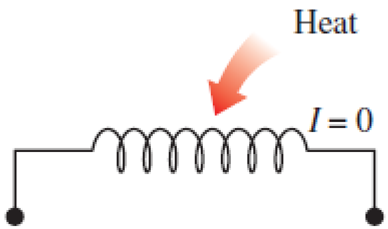
It is observed that processes occur only in a certain direction

Processes occur in a certain direction, and not in the reverse direction.

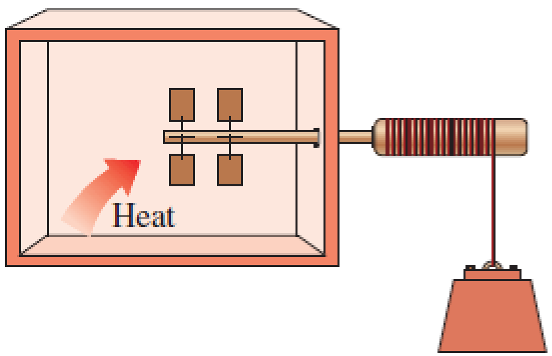
Examples :



A cup of hot coffee does not get hotter in a cooler room.



Transferring heat to a wire will not generate electricity.



Transferring heat to a paddle wheel will not cause it to rotate.

Factors causing irreversibility :

Friction

Volume change due to finite pressure difference

Heat transfer due to finite temperature difference

Inelastic deformation of solids

Resistance to flow of electrical current

Chemical reactions

Introduction to Second law of thermodynamics :

In reversing of the processes (see slide 5) first law is not violated.

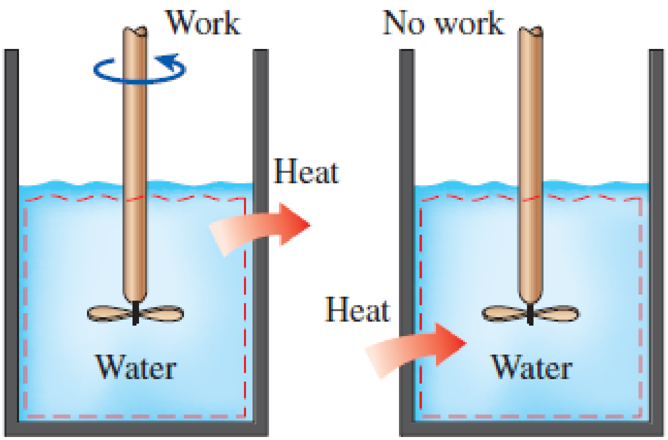
Still these processes are never observed to occur in reverse direction !

Natural (or spontaneous) processes are **irreversible**

This suggests that there exists a general principle which governs the direction of a natural process

This principle is called "Second law of thermodynamics".

Heat engines :

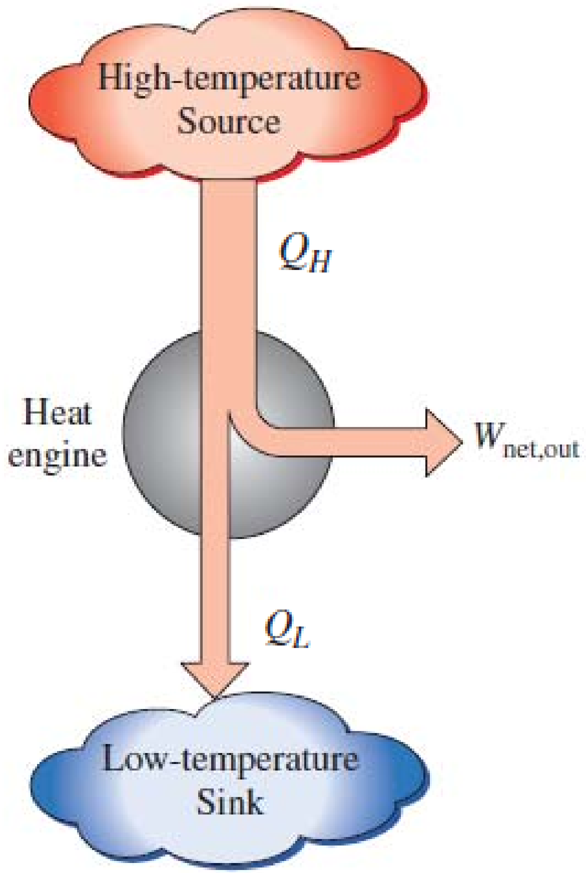


As can be seen in the above example, work can be converted into heat directly and completely, but the reverse is not true

Converting heat into work requires special devices known as “**Heat engines**”

Heat engine employs a “working fluid” which undergoes a cyclic process

Heat engines :



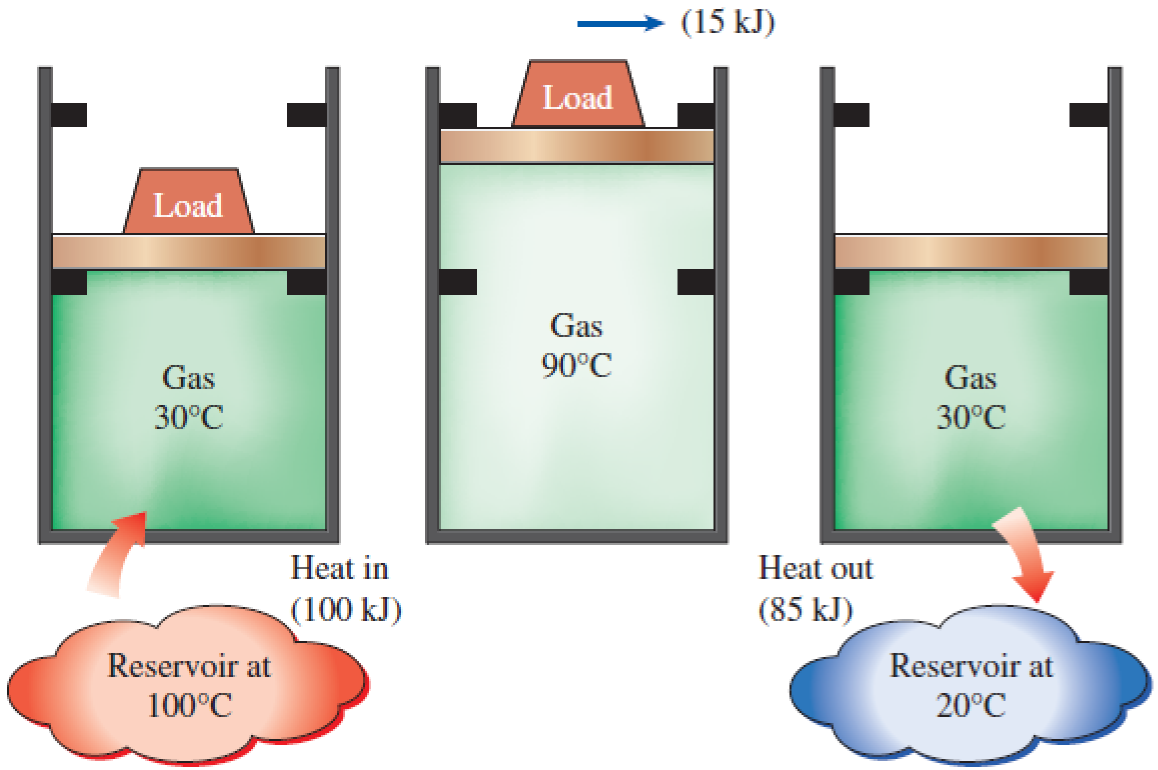
Why heat must
Be rejected in a cyclic
Process, even when there
is no friction, i.e., process
is ideal ?

Why $Q_L \neq 0$?

1. They receive heat from a high-temperature source (solar energy, oil furnace, nuclear reactor, etc.).
2. They convert part of this heat to work (usually in the form of a rotating shaft).
3. They reject the remaining waste heat to a low-temperature sink (the atmosphere, rivers, etc.).
4. They operate on a cycle.

Cyclic processes :

State of the gas
is characterized by
internal energy
and volume

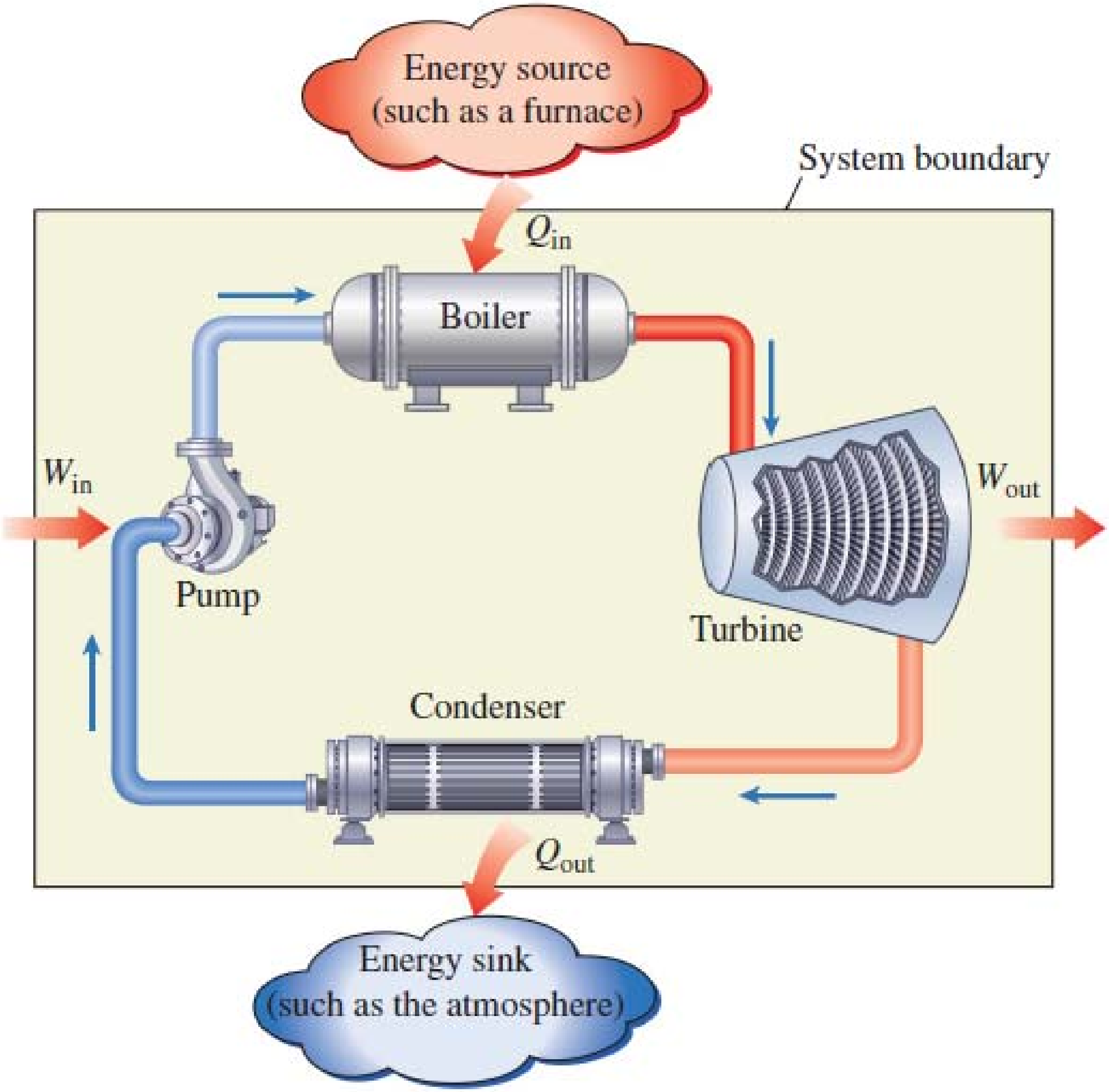


<u>Step 1</u>: Gas is heated by contacting with a high temperature reservoir. Some work is done in lifting the weight (U1 , V1) → (U1+85, V2)

<u>Step 2</u>: Load is removed and gas is returned to the original state by contacting with a low temperature reservoir (U1+85, V2) → (U1, V1)

Rejection of heat to low temperature reservoir is necessary to complete the cycle by returning the working fluid to original state

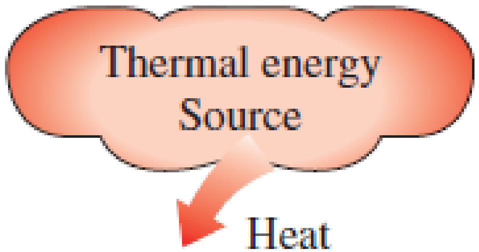
Heat engine : Coal based power plant



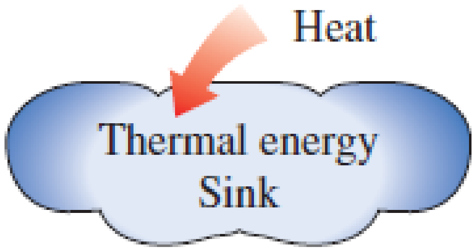
Thermal energy reservoirs :

These are large bodies which absorb or lose heat with negligible changes in temperature. Thus the temperature of thermal energy reservoirs can be taken as constant during heat transfer with other systems. Examples : Atmospheric Air, rivers, lakes

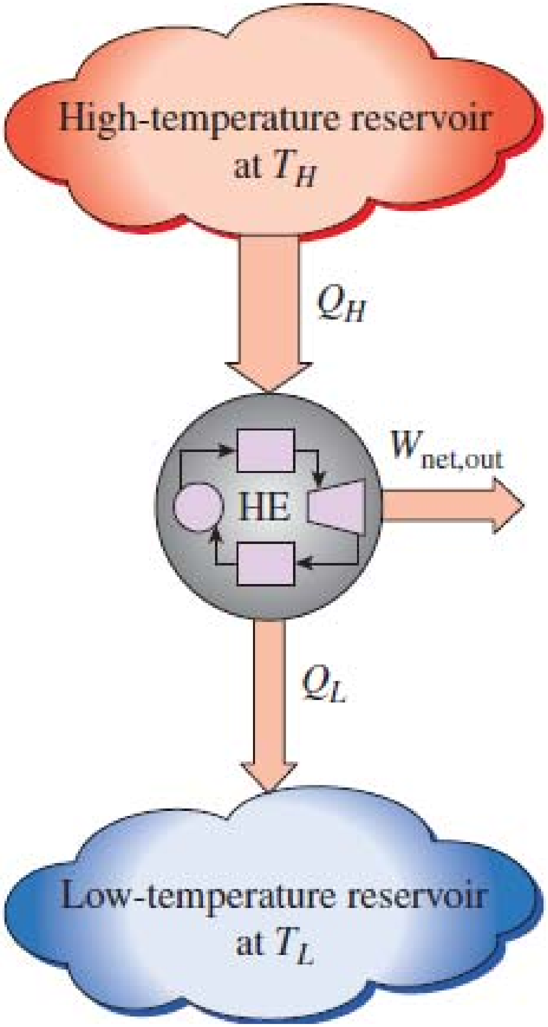
Thermal energy reservoir that supplies energy in the form of heat is called as a “source”



Thermal energy reservoir that absorbs energy in the form of heat is called as “sink”



Thermal efficiency of heat engine :



$$W_{\text{net,out}} = Q_H - Q_L$$

It is not possible to have Q_L **= 0**

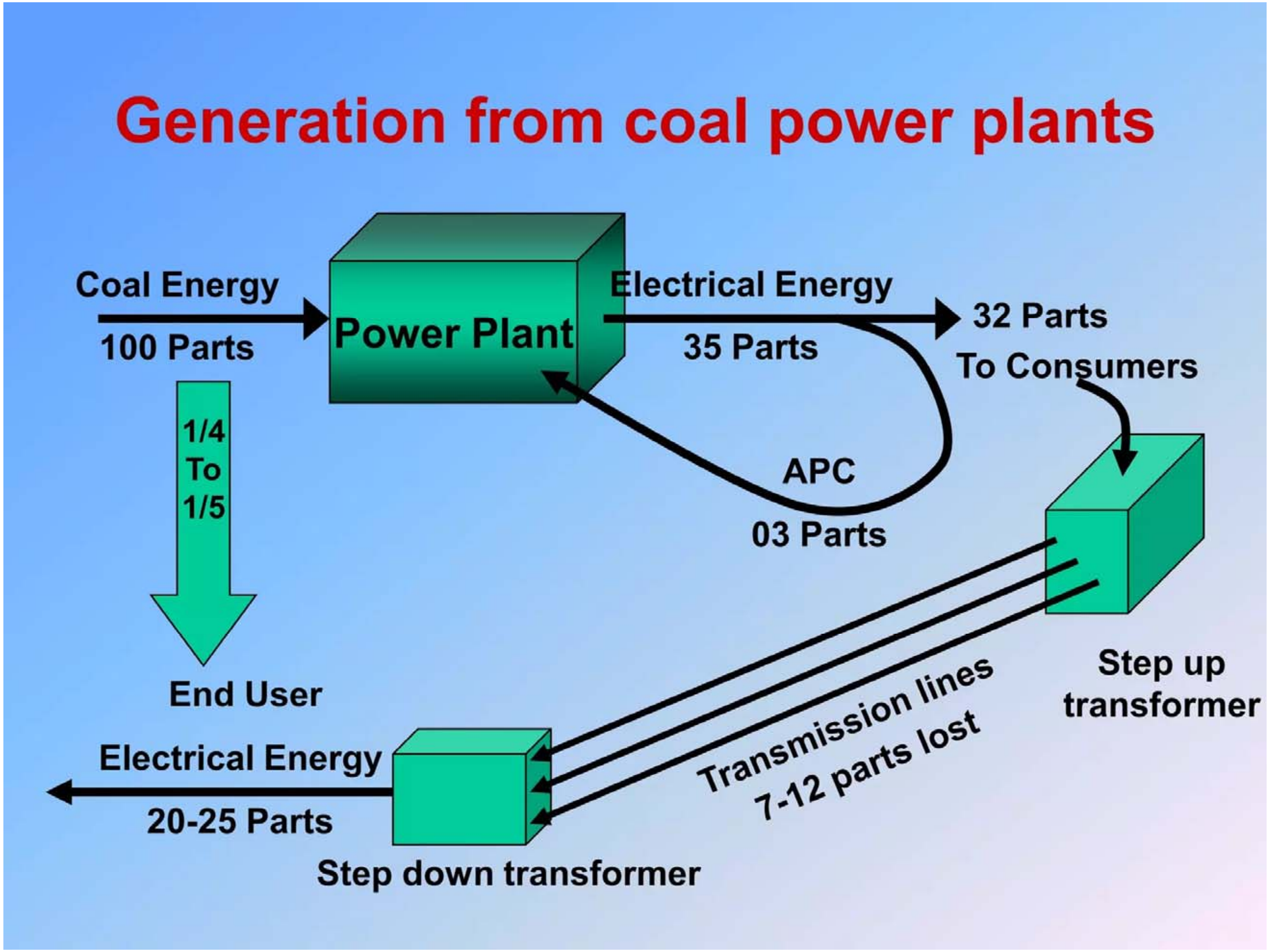
Some heat must be rejected !!

Thermal efficiency of a heat engine is

$$\eta_{\text{th}} = \frac{W_{\text{net,out}}}{Q_H} \quad \text{or} \quad \eta_{\text{th}} = 1 - \frac{Q_L}{Q_H}$$

Q_H = magnitude of heat transfer between the cyclic device and the high-temperature medium at temperature T_H

Q_L = magnitude of heat transfer between the cyclic device and the low-temperature medium at temperature T_L



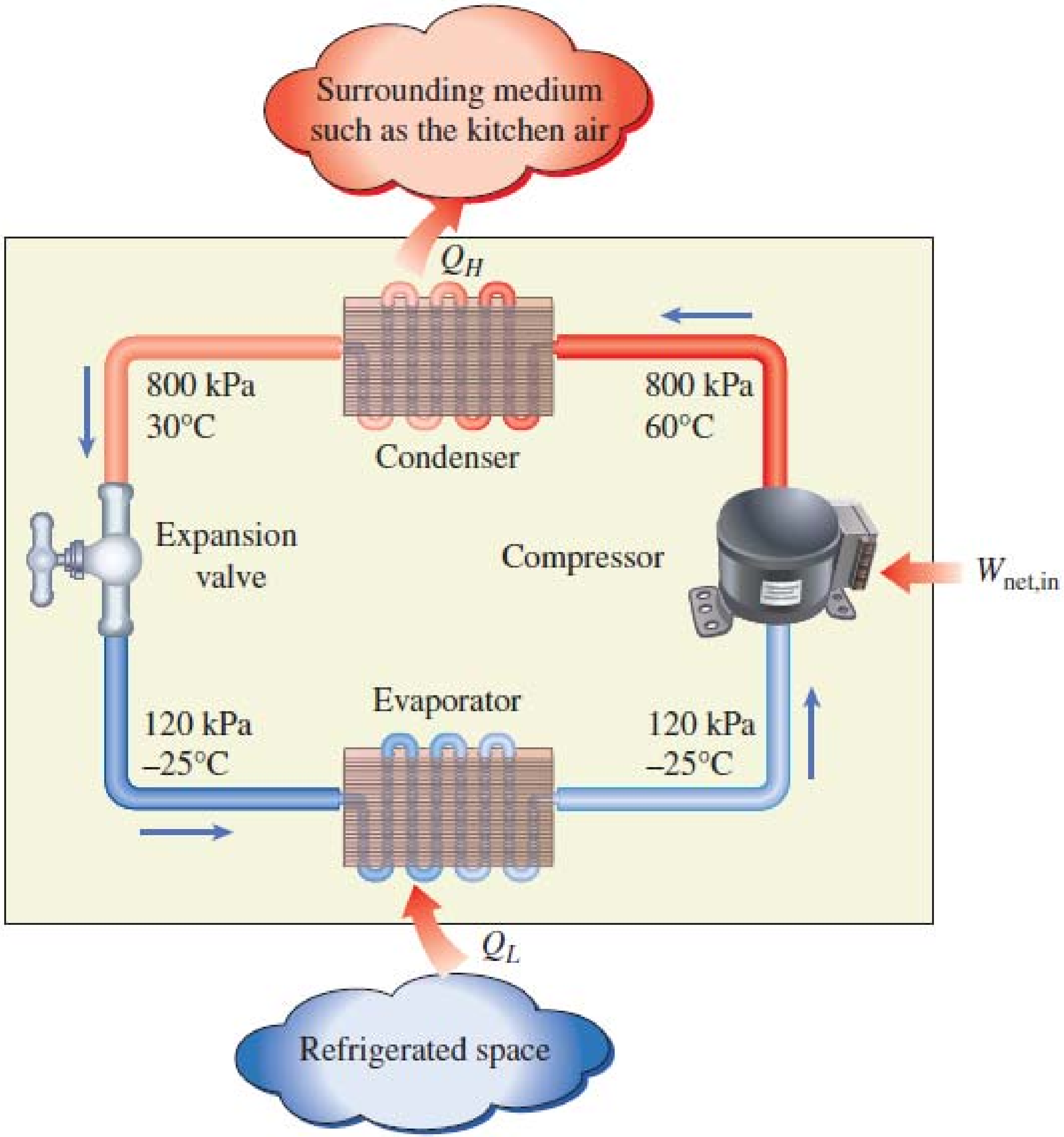
$$\eta_{th} \approx 32\ \%$$

Kelvin—Planck statement (Second law of thermodynamics):

It is impossible for any device that operates on a cycle to absorb heat from a single reservoir and produce a net amount of work

Heat must be rejected

Refrigerators :



Vapor compression refrigeration cycle and typical operating conditions

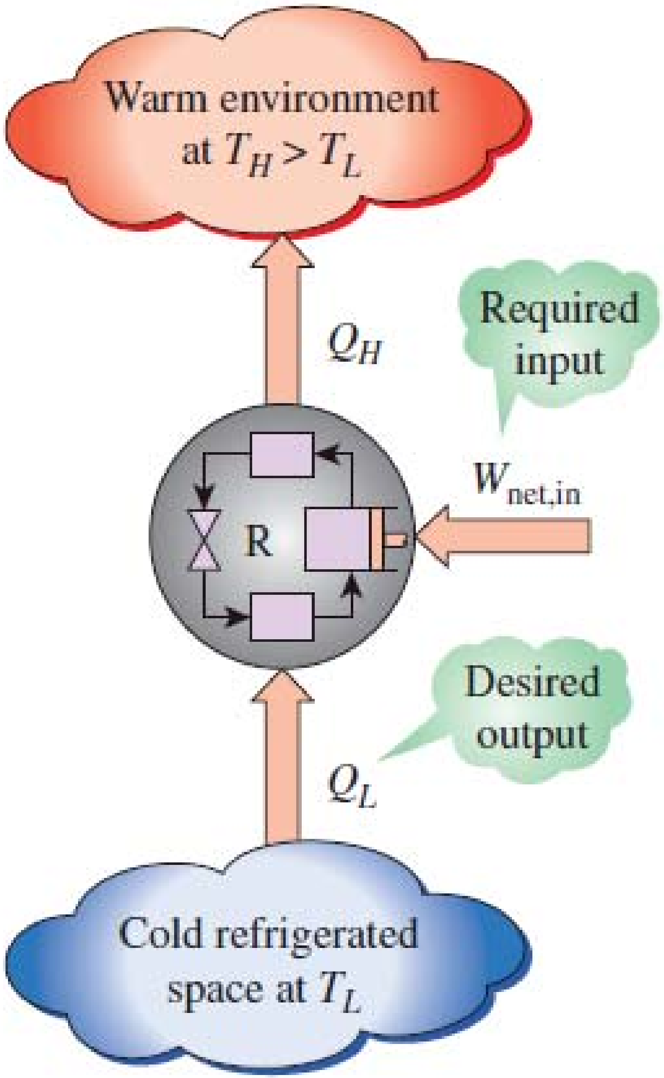
Refrigerators :

Coefficient of performance (COP_R)

$$COP_R = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_L}{W_{\text{net,in}}}$$

$$W_{\text{net,in}} = Q_H - Q_L$$

$$COP_R = \frac{Q_L}{Q_H - Q_L} = \frac{1}{Q_H/Q_L - 1}$$



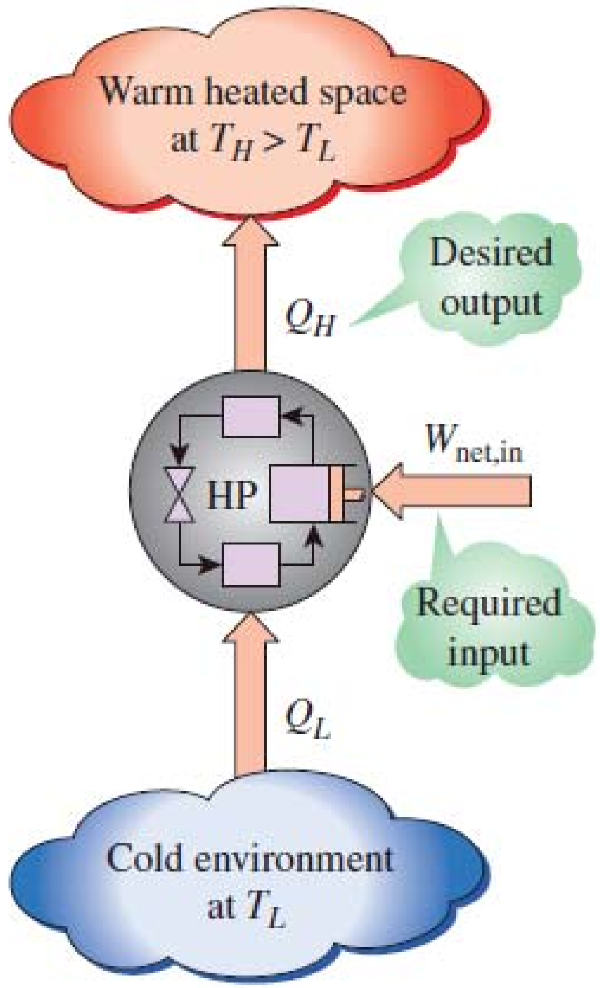
Heat pumps :

Coefficient of performance (COP_{HP})

$$\mathrm{COP_{HP}} = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_H}{W_{\mathrm{net,in}}}$$

$$W_{\mathrm{net,in}} = Q_H - Q_L$$

$$\mathrm{COP_{HP}} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - Q_L/Q_H}$$

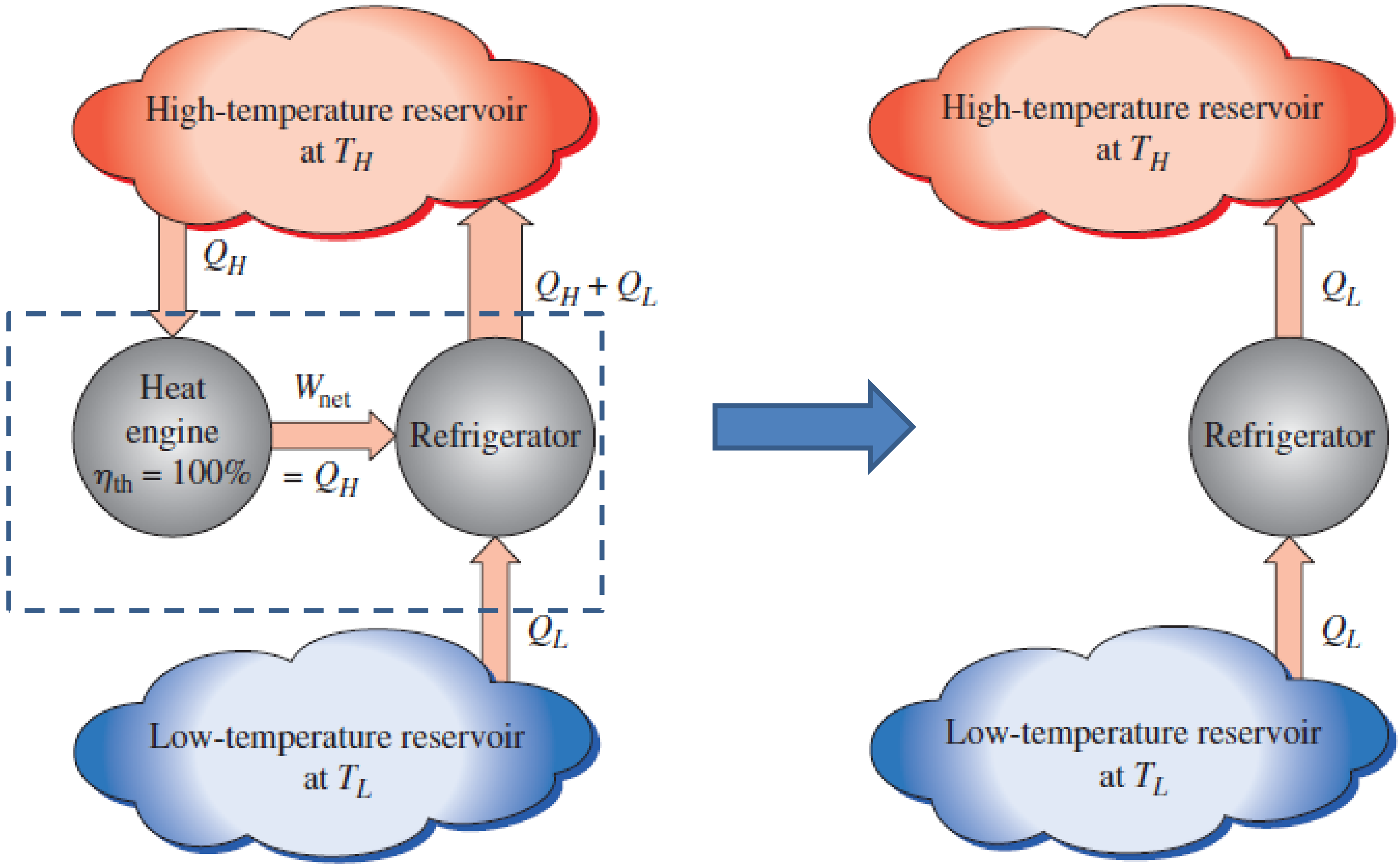


Clausius statement (Second law of thermodynamics) :

It is impossible to construct a device that operates on a cycle and produces no effect other than the transfer of heat from a low temperature body to a higher temperature body.

This is consistent with our experience that energy transfer in the form of heat does not occur from a low temperature body to a high temperature body.

Equivalence of Kelvin-Planck and Clausius statements :



(*a*) A refrigerator that is powered by a 100 percent efficient heat engine

(*b*) The equivalent refrigerator]

Heat engine in (a) violates Kelvin-Planck statement. In (a) we use a refrigerator that takes in the work output of heat engine. The combined equipment inside the dashed box in (a) is equivalent to a refrigerator as shown in (b). This refrigerator in (b) violates Clausius statement.

Equivalence of Kelvin-Planck and Clausius statements :

The last slide shows that **violation of Kelvin-Planck statement leads to violation of Clausius statement.**

Similarly, it can be shown that **violation of Clausius statement leads to violation of Kelvin-Planck statement.**

Hence the two statements are **equivalent.** Both of these statements are different ways of expressing the same general principle in nature which is **"Second law of thermodynamics".**