ENERGY CONVERSION & ENERGY EFFICIENCY

Energy is 'used' by being degraded.

Mechanical energy >> Friction >> Heat >> Low grade heat

Electrical energy >> Mechanical energy >> Low grade heat

High grade heat >> Heat transfer >> Low grade heat

i.e. From the Second Law, energy tends to end up in the lowest level state and overall, the energy availability of our solar system is continuously decreasing.

From the First Law, the amount of energy in a closed system remains constant.

We have already seen that the conversion of thermal energy (heat) to mechanical energy by means of a heat engine is intrinsically limited. The best that can be done (a Carnot engine) gives an insight into how to maximise the conversion efficiency, but it can never be 100%.

Note: The Second Law only applies to heat engines. Other means of conversion (such as fuel cells) are not subject to the Second Law, but there are other reasons why they cannot convert energy with an efficiency of 100% either.

Even when we are converting energy from one type to the same type the conversion efficiency is never 100%.
e.g. A gear box - owing to friction, useful energy out is always less than energy in. The conversion efficiency = energy out / energy in is normally known as its mechanical efficiency.

A gas fired water heater - the heat transferred to the water is always less than that released by burning the fuel

Energy is categorised by: -

Source - Primary, Secondary (Delivered)

Type - Thermal, Mechanical, Electrical, Chemical, Nuclear etc

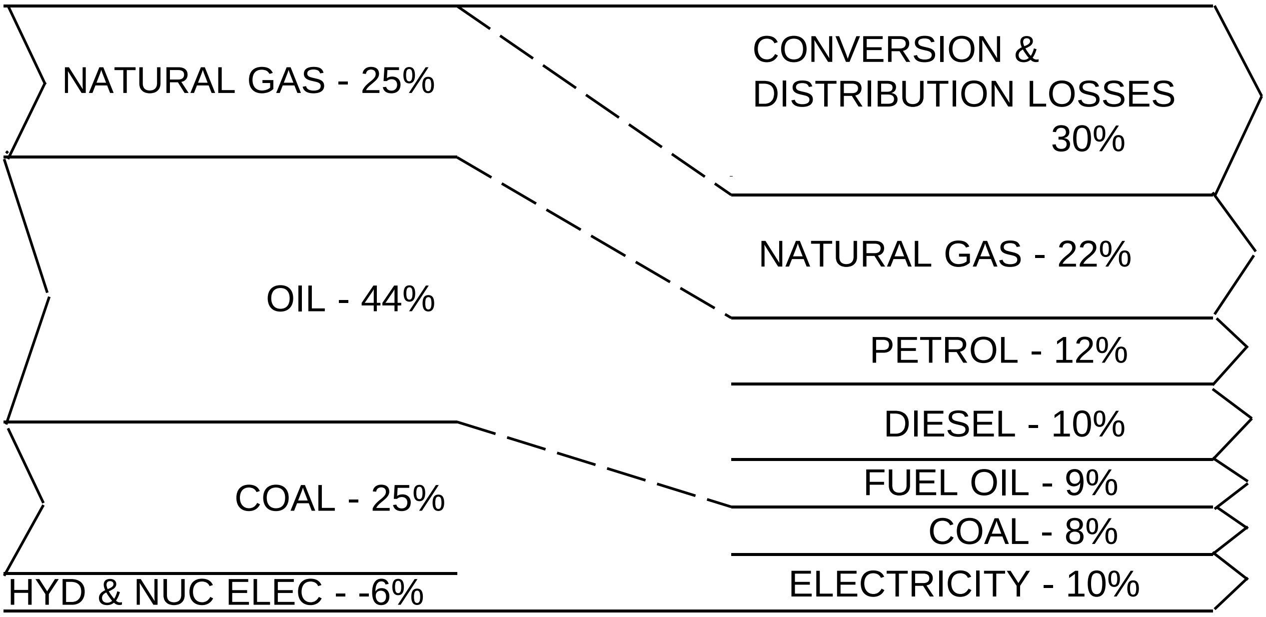
End Use - Heating, Lighting, Traction, Communication, etc.

PRIMARY		DELIVERED		USER
Coal Oil(Crude) Natural Gas Nuclear Ambient Solar Hydro Wind Wave Geothermal Bio-energy	Conversion & Distribution Industries	Heating Electricity Gas(N.G) S.N.G. C.N.G. Liquid Fuels	Energy Users	Heating Lighting Power Transport

Why the interest in energy?

The 'Oil Crisis' of the early and mid 1970's was a reminder that our main fossil fuel energy supplies are not inexhaustable. They formed over millions of years and now constitute of a STORE of energy - but it is a store where stocks are not replenished!

Renewable energy sources on the other hand are continuously replenished (by the sun) and therefore constitute very long term energy supplies. Fusion Reactors?



PRIMARY FUEL MIX SECONDARY FUEL MIX
(From Digest of U.K.Energy Statistics 1984)

Energy is used:

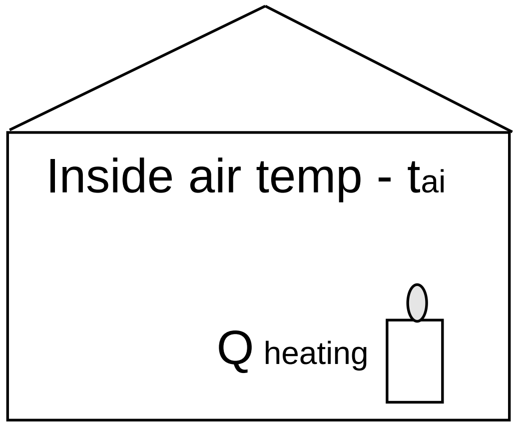
In buildings
- heating systems*
- lighting systems

In industry
- process heat
- processes
- compressed air systems*
- heat recovery
- electrical energy use

In transport*
- cars
- lorries
- ships
- trains
- aircraft etc.

HEATING SYSTEMS

In order to design a heating system, we need to know at what rate a building loses heat.



Outside air temp (OAT) - t_{ao}

Ventilation air flow - $\dot{m}$

Internal Heat production - Q_{total}

At **steady** conditions $\dot{Q}_{total} = \underbrace{\dot{m}C_p(t_{ai} - t_{ao})}_{\text{Ventilation or Infiltration losses}} + \underbrace{U_oA(t_{ai} - t_{ao})}_{\text{Fabric losses}}$

U_o = Overall heat transfer coefficient for the building

$\dot{Q}_{total} = \dot{Q}_{heating} + \underbrace{\dot{Q}_{occupants} + \dot{Q}_{solar} + \dot{Q}_{lights} + \dot{Q}_{elec.m/s} +}_{\text{Incidental or Casual gains}}$

(solar gain)

Incidental or Casual gains

$U_oA = UA_{roof} + UA_{walls} + UA_{floor} + UA_{windows} + UA_{doors}$

How do we find the thermal transmittance (or U-values) for given structures?

1) By reference to tables eg CIBSE guide A3
2) By calculation from thermal data for various materials

DESIGN HEAT LOAD

The heating requirement or 'load' of a building depends on the outside air temperature, so, for what OAT do we size a heating system?

If we choose 'too low' a temperature - the heating system will be oversized:-

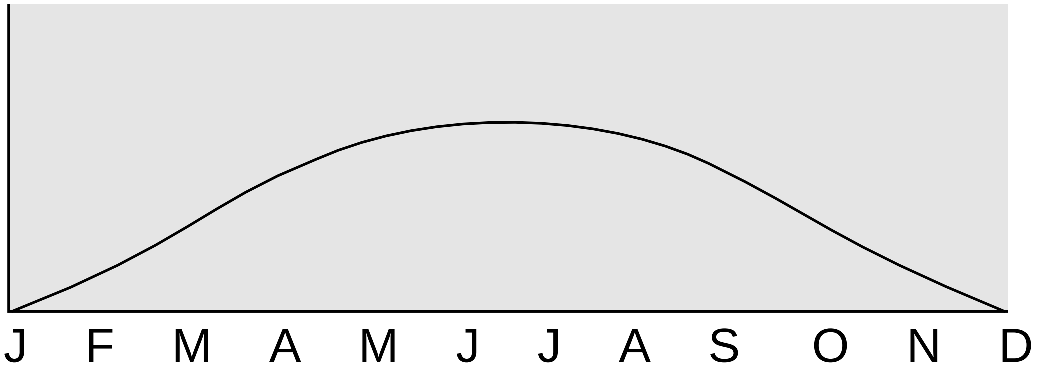
Higher capital cost than necessary

It will operate at part load for much of its life which often means inefficient operation.

If we choose 'too high' a temperature - the heating system will be undersized :-

Frequent periods of underheating leading to discomfort of occupants etc;

Annual Average Temperature Variation



We choose a design OAT which will enable the heating system to maintain the inside temperature at the desired level for a reasonable proportion of the time.

eg:	Hospitals -	99%
	Public Buildings-	95%
	Houses	90% etc;

The actual decision requires analysis of meteorological data.

For the U.K. a typical design temp. would be -1 °C

The design heat load must be provided by whatever heating system we choose.

This will often be dictated by what fuels are actually available.

In typical developed countries - oil, solid fuel, gas or electricity

In less developed countries it may be wood, solar, gas from a bio-digester or animal or human energy.

The fuel consumption of the heating system will depend upon its energy conversion efficiency.

e.g. typical 'traditional' gas boiler 60-80%

a condensing gas boiler 85-95%

direct electric convection 100%

oil fired boiler 65-85%

living flame gas fire ~40%

open fire ~5%

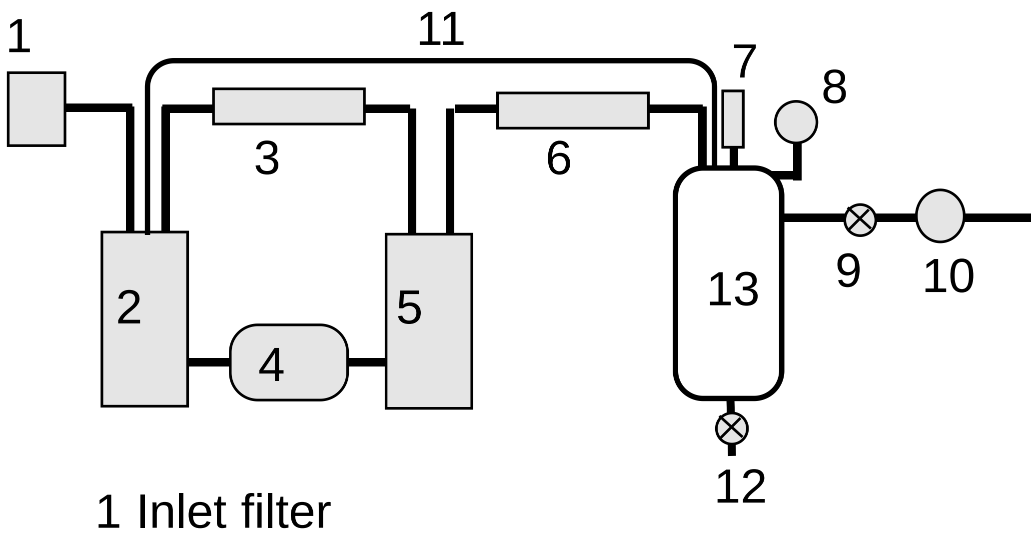
solar panels 40 - 80%

Conversion efficiencies are often very dependent on their delivery temperatures and operating conditions. Part load operation typically reduces efficiency.

COMPRESSED AIR SYSTEMS

We have already studied reciprocating compressors from a thermodynamic and mechanical design point of view, but how do they operate in a system?

A typical system may look as follows:



1 Inlet filter

2 First stage compressor

3 Intercooler

4 Motor

5 Second stage compressor

6 After cooler

7 Safety valve

8 Pressure gauge

9 Isolating valve

10 Presure regulator

11 Unloading pressure line

12 Drain valve

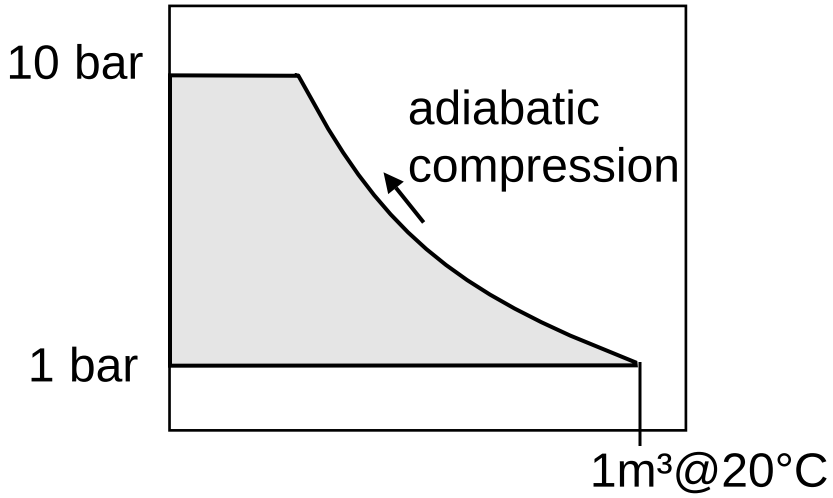
13 Receiver

Compressed air represents a useful source of energy. In many situations it is very safe (no sparks in explosive atmospheres e.g. mines), and can be very versatile compared with electricity especially in its ability to exert large forces in small volumes (riveters, clamps etc.)

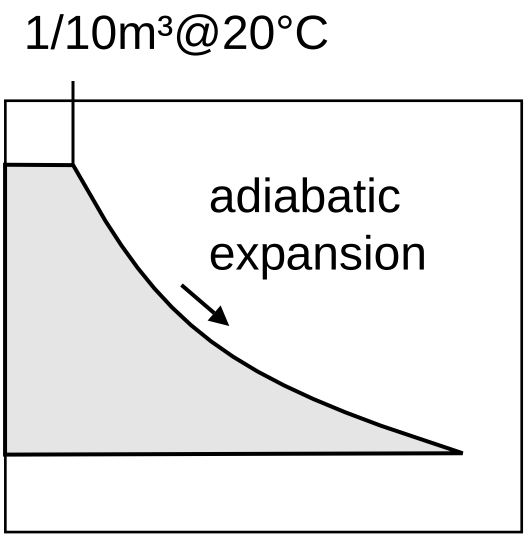
It is, however, very inefficient from an energy conversion point of view.

Losses occur in the motor (electrical & mechanical losses), the compression process itself dissipates energy in the form of heat which is lost in the inter and after coolers. Friction occurs in the air tools themselves.

We can estimate the energy efficiency assuming a compressor and expansion cylinder with zero clearance volume:



Compressor cylinder



Work cylinder

The compression work equals the shaded area:

$$W_{comp} = \int_{p_1}^{p_2} V\,dp$$

$$If \quad pV^{\gamma} = const\ (k)$$

$$W_{comp} = \int_{p_1}^{p_2} k^{\frac{1}{\gamma}} p^{\frac{-1}{\gamma}} dp$$

$$= \left[k^{\frac{1}{\gamma}} p^{1-\frac{1}{\gamma}} \right]_{p_1}^{p_2}$$

$$W_{comp} = \frac{1}{\gamma - 1}\left[p_2V_2 - p_1V_1\right]$$

Finding V_2 from pV^{γ}=const and substituting the result in the above gives the compression work equal to 325.7 kJ/m³

If we take this same cubic meter when it has been compressed to 10 bar and cooled to 20°C we can calculate its expansion work from a similar formula. Doing this we obtain: V_2=0.518m³ (nearly half of the volume it started off at!), and the expansion work = -168.7 kJ

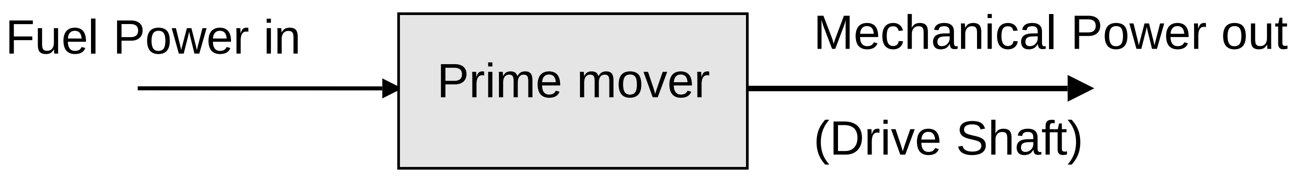
Ignoring the + and - signs the energy efficiency =168.7/ 325.7 = 0.52

and this is before we factor in the motor efficiency, compressor mechanical efficiency and air tool efficiency which may reduce it by a further 50%. i.e. to ~ 25%.

Compressed air is very energy inefficient source - use it only when nothing else will do.

IC ENGINES AS PRIME MOVERS

A prime mover is a device which typically converts available energy (often thermal energy) into mechanical energy for subsequent direct use or further conversion.



Fuel Power in is given by : mass flow rate x calorific value

Note: it is normal to measure the <u>volume</u> flow rate of fuel, therefore mass flow rate has to be calculated from volume flow rate x density of fuel

Mechanical power out = torque x rotational speed

Torque is twisting effect measured in Nm, and rotational speed, normally measured in RPM, must be converted to radians/sec.

$$\text{Energy efficiency} = \frac{\text{mechanical power out}}{\text{fuel power in}}$$

Typical figures:

SI (petrol engine) ~ 25%

CI (diesel engine) ~ 40%

In module THER204B we shall find that these efficiencies are very much lower than what a simple analysis (called an air-standard analysis) would indicate.

The 'basic' energy efficiency of the prime mover is further reduced by transmission losses, the need for power to drive auxiliary devices such as oil pumps, water pumps, radiator fans, air conditioning systems, alternators, etc. The exact definition of energy efficiency is therefore not straightforward. Various codes are adopted.