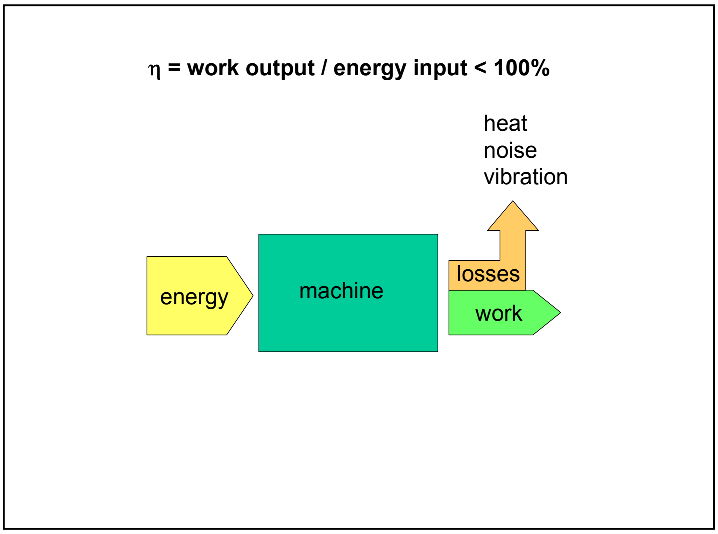
1 Basic Concept

"Energy is the ability of a system to cause an external effect" (Max Planck)

Thermodynamics is the branch of science that embodies the principles of energy transformation in macroscopic systems.
Is not the aim of this program to go deep on thermodynamics study but some concepts like **system, surroundings and boundary** are important to understand the main concept of energy transfers.
System is taken to be any object, any quantity of matter... selected for study and set apart (mentally) from everything else which is then called **surroundings**. The imaginary envelope, which encloses the system, is called **boundary** of the system.
A system has an identifiable, reproducible **state** when all its **properties** are fixed.
Temperature and pressure are examples of properties of a state that can be detected by measuring instruments such as thermometers and pressure gauges.
When a system is displaced from an equilibrium state, it undergoes a process during which its properties change until a new equilibrium state is reached. During a such process the system may be caused to interact with its surroundings so as to interchange energy in the forms of heat and work and so to produce in the system or surroundings changes considered desirable for one reason or another.
Heat - is the energy form crossing the system boundary under the influence of temperature difference or gradient.
Work – is also energy in transit between a system and its surroundings but resulting from the displacement of external force acting on the system.

In real systems the quantity of energy supplied to the system is always greater than the quantity of work and heat together coming from the system.
This ratio is called **efficiency**.



1-1 Figure

1.1 Units –SI

1.1.1 Base units

Length	1 m	Meter
Mass	1 kg	Kilogram
Time	1 s	Second
Electrical current	1 A	Ampere
Temperature	1 K	Kelvin
Material quantity	1 mol	Mol
Light intensity	1 cd	Candela

1.1.2 Derived

Force	1 N = 1 kgm/s²
Energy, work	1 J = 1 Ws = 1 Nm
Power	1 W = 1 J/s = 1 Nm/s
Pressure	1 Pa = 1 N/m² 1 bar = 105000 Pa

Specific Heat vCapacity	J/(kgK)
Spec. Gravity	-
Density	kg/m³
Thermal conductivity	W/(mKº)
Heat coefficient	W/(m²K)

1.1.3 SI-prefixes for decimal multiples and fractions

Prefix	Abbreviation	Meaning
Deca	Da	101
Hecto	H	102
Kilo	K	103
Mega	M	106
Giga	G	109
Tera	T	1012
Peta	P	1015
Exa	E	1018

Prefix	Abbreviation	Meaning
Deci	D	10-1
Centi	C	10-2
Milli	M	10-3
Micro	M	10-6
Nano	N	10-9
Pico	P	10-12
1.1.3.1.1.1	F	10-15
Atto	A	10-18

1.2 Energy & Power

Energy, Work

Work (W) = Power (P) x Time (t)

1 J (Joule) = 1 Ws = 1 Nm

	J	kJ	kWh	kcal	kpm	tep
1 J	1	0,001	0,278 x 10-6	0,239x10-3	0,102	0,024x10-9
1 kJ	1000	1	0,278 x 10-3	0.239	101.97	0,024x10-6
1 kWh	3,6x106	3600	1	860	367 000	86,0x10-6
1 kcal	4186,8	4.1868	0.001163	1	427	0,10x10-6
1 kpm	9,981	9,981x10-3	2.72 x 10-6	3,7x10-6	1	23,43x10-9
1 tep	41,87x109	41,97x106	11,63x103	10,0x106	4,26x109	1

Power

Power (P) = Work (W) / Time (t)

1 W (Watt) = 1 J/s = 1 Nm/s

	W	kW	kcal/h	kpm/s	PS
1 W	1	0,001	0.860	0.102	0.00136
1 kW	1000	1	860	102	1.35778
1 kcal/h	1.1628	0.0011628	1	0.119	0.00158
1 kpm/s	9.80665	0.0098067	8.43	1	0.01333
1 PS	736.498	0.7365498	632	75	1

(tep – equivalent petroleum tonne is listed as energy unit once portuguese energy legislation refers specific energy consumption in tep or kgep.
kpm – kilopond
PS – metric horse power)

1.2.1 Calculation example

For most physical constants, work is stated in kJ. However, for technical calculations work can be expressed, for example, in kWh.

Example:

1. Specific Heat capacity C_{Water} = 4.184 kJ/kg ºK
The conversion from kJ into kWh is arrived at as follows:

1kJ = 1 kWs = 1 kWs x 1h/3600s = 1/3600 kWh

Therefore Heat capacity C_{Water} in kWh:
C_{Water} = 4.184 kJ/kg Kº = 4.184 / 3 600 kWh/kg Kº = 1.1616x10^{-3} kWh/kg ºK or 1.16Wh/kg ºK

2. Specific Heat capacity C_{air} = 1.005 kJ/kg ºK
The conversion from kJ into kWh is arrived at as follows:

1kJ = 1 kWs = 1 kWs x 1h/3600s = 1/3600 kWh

Therefore Heat capacity C_{air} kWh:
C_{air}= 1.005 kJ/kg Kº = 1.005 / 3 600 kWh/kg ºK = 0.28 x10^{-3} kWh/kg ºK

1.3 Forms of Energy:

Two kinds of energy are kinetic and potential. Kinetic energy is the energy of motion. Potential energy is stored energy.

Energy is available in various forms:

Mechanical energy
Thermal energy
Chemical bound energy
Physical bound energy
Electromagnetic radiation energy
Electrical energy

1.4 Energy Levels

All these forms of energy can be broken down either into kinetic or potential.
Law of Conservation of Energy- Energy can neither be created nor destroyed.
Energy is always changing from one kind to another. The total energy of an object never changes.

Potential energy + Kinetic energy = Total energy and
Total energy - Kinetic energy = Potential energy and
Total energy - Potential energy = Kinetic energy

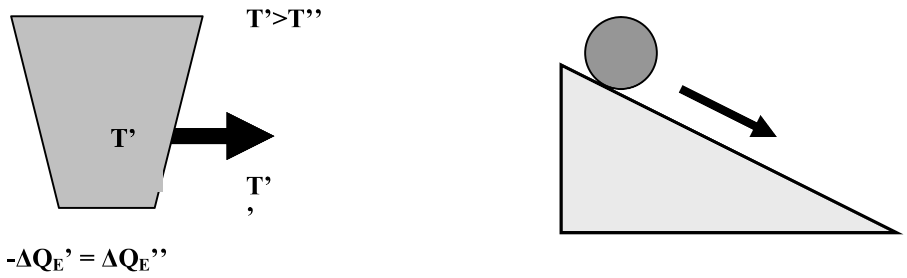


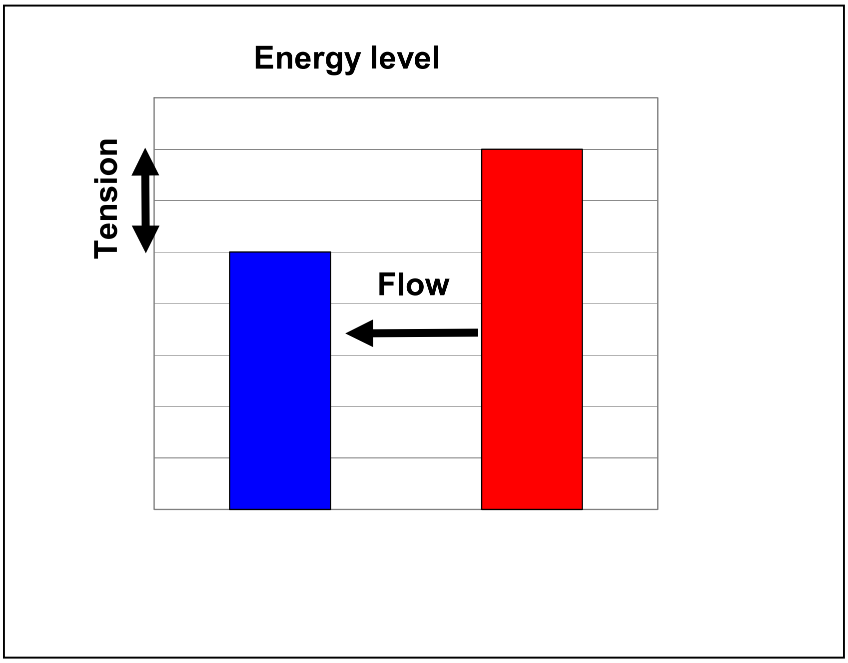
Figure1-2 Examples of potential that follow from non-equilibrium distributions of energy. Whenever energy (in whatever form) is out of equilibrium with its surroundings, a potential exists for producing change that, following the second law of Thermodynamics is spontaneously minimized.

Energy level: The same forms of energy can occur at different levels. An example is heat that can be perceived as being either cold or hot, depending upon the level.

Energy flow: If two different energy levels of the same kind of energy are present an energy flow from the higher to the lower level takes place caused by the tension or gradient between them. The transfer phenomena will continue until equilibrium is achieved. The transfer ratio depends on the physical and geometrical characteristics of the media through which energy flow occurs.

Energy flow = gradient / resistance

Figure 1-3



According to the level of transformation before last usage form, energy can also be classified as:

Primary energy: Energy that has not been subjected to any transformation in other form of energy:
E.g. water power, chemical energy in crude oil, natural gas, coal, wood, mechanical energy of the wind, radiant energy of the sun's radiation, ...

Secondary energy: Energy after the first transformation from raw form:
E.g. electricity after conversion in hydro-power stations, wind power stations, steam power stations or atomic power stations, petrol from the refinery, LPG from crude oil,...

Useful or net energy: Energy of a type used or utilized by the end consumer:
e.g. warmth, cold, force , pressure, light, sound, movement, ...;
Useful energy is energy after the last transformation.

Energy service: That which one obtains from the use of energy:
e.g.. a clean shirt after washing, mobility, entertainment, lighting, a pleasant temperature in the work area, ...;

Note that the same type of energy can be used in different forms, for example, wind energy can be used directly in a wind mill or indirectly if the mill is driven by an electrical motor using electrical energy produced by a wind generator.
Is a question of to have the suitable kind of energy available were the utilization is needed.

1.5 Ideal Gas Law

It is well known that compressing a gas increase its pressure and warming a gas increase its volume.

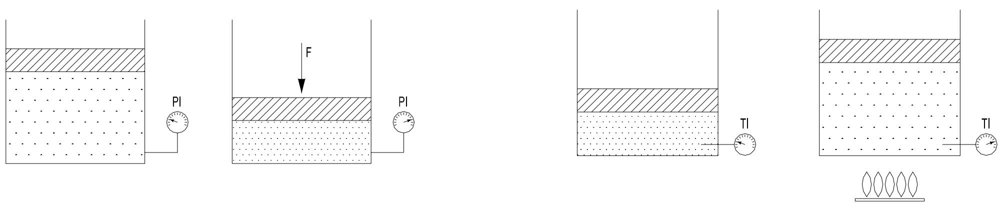


Figure 1-4

The opposite is also true.

These pressure and volume changes do not happens evenly, they happen according to a physical low known as **IDEAL GAS LAW**.

$$PV = RnT$$

Where:
P – pressure (bar)
V – volume (m^3)
T – absolute temperature ºK
R – perfect gases constant (=8.1334 J mol^{-1} $ºK^{-1}$)
n - number of moles

Applied to the same quantity of the same gas the variation of one of them can be computed once we know initial conditions for all and final conditions of the other two

$$V_c = V_m x \frac{P_m}{P_r} x \frac{T_r}{T_m}$$

Where:
V_c – gas volume at normal conditions, i.e. reference conditions (Nm^3)
V_m – gas volume at working conditions (m^3)
P_m – working pressure (bar)
P_r – reference or normal pressure 1.033 bar
T_m – working absolute temperature 273º K+T(ºC)
T_r – reference temperature = 273º K

This theoretical principle is very important to evaluate accurately the quantity of energy of a gaseous fuel like natural gas or propane.
The quantity of energy is related with quantity of mass, not volume, and the volume of a certain quantity of gas, as stated before, depends on the pressure and temperature conditions.
Energy manager must be aware about this to become sure that the volumes of the gaseous fuels considered in his calculations are properly corrected to normal conditions.

1.6 Energy Sources

Practically every substance and every body can be a source of energy in forms such as heat, light, movement, chemically bound, atomic or potential energy.

Oil	Water
Gas	Air
Coal	Wood
Uranium	Solar radiation

Fuel	Heat value PCI	Calorific value PCS	Max. CO2 emission (kg/kwh) as related to the: Heat value	Max. CO2 emission (kg/kwh) as related to the: Cal. value
Bituminous coal	8.14 kWh/kg	8.41 kWh/kg	0.350	0.339
Coke	7.50 kWh/kg	7. 53 kWh/kg	0.420	0.418
Brown coal (raw) 1	2.68 kWh/kg	3.20 kWh/kg	0.410	0.343
Brown coal briquettes1	5.35 kWh/kg	5.75 kWh/kg	0.380	0.354
Heating oil EL	10.08 kWh/l	10.57 kWh/l	0.312	0.298
Heating oil S	10.61 kWh/l	11.27 kWh/l	0.290	0.273
Natural gas L	8.87 kWh/Nm3	9.76 kWh/Nm3	0.200	0.182
Natural gas H	10.42 kWh/mn3	11.42 kWh/Nm3	0.200	0.182
Town gas	4.48 kWh/Nm3	5.00 kWh/Nm3	0.200	0.179

The calorific value of a fuel is the quantity of heat produced by its combustion, at constant pressure and under the conditions known as " normal " of temperature and pressure (i.e. to 0°C and under a pressure of 1.013 bar).
The combustion of hydrocarbons generates water vapour. Certain techniques make it possible to recover the quantity of heat contained in this water of combustion by condensing it (e.g. condensing boilers)

One thus distinguishes two calorific values:
The lower calorific value or Net calorific value (NCV) which supposes that the products of combustion contain the water of combustion to the vapor state. The heat contained in this water is not recovered.
The higher calorific value or Gross calorific value (GCV) which supposes that the water of combustion is entirely condensed. The heat contained in this water is recovered.

PCI : lower calorific value of gas. PCS : Gross calorific value

2 Optimizing strategies

Optimising the energy utilization means to organize a system that can ensure that the energy is used with best possible efficiency.

The most significant forms of energy used in industry are fuels and electricity.

2.1 Fuels

Fuels (natural gas, propane, gas oil and fuel oil) are mainly used in combustion processes in boilers and dryers.
To minimise losses and increase efficiency is necessary to guarantee:

- Control the combustion conditions
- Good insulation of production and distribution equipment and pipes.

2.2 Electricity

Electricity's main applications are power, cold and light.
In the electrical drives module, optimisations aspects of electrical power was already considered, regarding cold and light, some strategies should also be taken to ensure the best utilization efficiency.

Freezing chambers

- Insulation, proper design and good maintenance;
- Optimising the utilisation.

Light

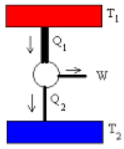
- More efficient lamps and lamps housing
- Automatic on and off switch.

3 Measurement and regulation

The objective of regulation is optimising the control equipment work that composes a process to the own process necessities.
The majority of the processes are sensible to internal and external variations so the control equipment must response in the better and quick possible way in order to prevent out of control situations.
In control systems there are two types of variables, the process variable (PV) and the control variable (CV).

3.1 Measurement equipment

For temperature measurement it is possible to use a thermocouple or a infrared radiation pyrometer. The choice of what kind of equipment should be done depends on application and the temperature range.



For pressure measurement it could be used simply pressure manometer or a pressure transmitter.

For mass measurement electronic or analogue scales are used.

Flow measurement: Liquid flow and gas flow measurements.
The former one could be done using various measuring principles, like electromagnetic, coriolis, ultrasonic, vortex, differential pressure flow or mechanical turbine flow meter. The right choice as to do with the application requirements and depends on the conductivity of the liquid and its viscosity.
The last depends of gas type, if it is clean or dirty, and could be done with the coriolis, Vortex, thermal or differential pressure flow principles.

3.2 Regulation system

The regulation systems must have the capacity of controlling the process variable even when unexpected variations occur.

Variable speed drives are one of the best examples of regulation system. This equipment has the capacity of control de velocity, current, torque of a electrical motor. It can be used to control a gas or liquid flow through a pipe when is applied to a fan or a pump. It can control the linear speed of a rubber conveyor by controlling angular speed of the electrical motor. It can control the depression inside a smelter adjusting the rotation speed of the draught fan.
Another type of flow regulator is the damper. This equipment could be controlled manually or by a servomotor.
Other examples are Multi speed motors, Pulse width modulation inverter

3.3 Controllers

Controllers are designed to eliminate the need for continuous operator attention. The set-point is where you would like the measurement to be. Controller receives the measurement and sends the error signal, which is the difference between set-point and measurement to the regulator in order to modify the process variable.

All these types of regulation could be used for stand alone controllers or centralise into a system that supervisor all the variables in a process.
This kind of approach is called CIM (Computer integrated Manufacturing). The computer receives all the information through network linking programmable logic controllers (PLC) or/and others controllers. This information could be saved in databases to keep a historical for the process.

Different types of controller:

Proportional controllers – pure gain or attenuation
Integral controllers – integrate error
Derivative controllers – differentiate error

P controller: termed proportional because output is not exactly linear in relation to input current. Despite their nonlinear response, an inexpensive way to control position, velocity, or force on equipment requiring high-speed response at high flow rates. The purpose of P controller is to decrease the steady-state error, but it has the side effect, that is, larger overshoot and could give rise to the oscillation.

I controller or Intregral controller: The purpose of I controller is to eliminate the steady-state error, since it increases one pole in origin.

The D controller is used to increase the stability, but it increases the noise in high frequency.

PID stands for Proportional, Integral, Derivative.

The variable being adjusted is called the manipulated variable which usually is equal to the output of the controller. The output of PID controllers will change in response to a change in measurement or set-point. Manufacturers of PID controllers use different names to identify the three modes.

System Control And Data Acquisition (SCADA) A process control application that collects data from sensors in remote locations and sends them to a central computer for management and control.
Direct Digital Control system (DDC): Use of digital computer to perform required automatic control operations in a total energy management system.
Programmable Logic Controller (PLC): These computers replace relay logic and usually have PID controllers built into them. PLCs are very fast at processing discrete signals (like a switch condition).