

# H.V.A.C. Technology / Basic Training

- Heat and temperature
- Flow rate and pressure
- Heat Transmission
- Heat or cold Requirements
- Heating bodies
- Hydraulics
- Heating systems
- Temperature regulation

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# 1. Fundamental principles

## 1.1. Heat and Temperature

The notions at the base of all thermal activity are the definitions of temperature and heat.

**Temperature** is a physical value used to measure the degree of heat of a body or setting, and it is an indicator of thermal agitation; when the latter decreases, so does the temperature.

Conventionally, the absolute zero - where this molecular agitation is nil - is used as reference.

*Mention must be made of the significant difference between the feeling of hot and cold which one usually gets by touching an object and the temperature of the object itself. In fact, man can only perceive the differences in temperature especially with respect to his own body temperature (37°C) and, in addition, his feeling of the thermal condition is greatly influenced by the effects of heat transmission.*

**Heat** is a form of energy deriving from the agitation of the molecules that make it up; *The measurement unit is the kilocalorie (kcal). A calorie is the quantity of heat necessary to increase the temperature of 1 kg of water by 1 °C.*

## 1.2. Temperature scales

All the temperature scales are based on two invariable perfectly determined temperatures, which are assigned different values depending on the measurement system foreseen.

These two fixed temperatures are:

1. the temperature of distilled water during solidification (ice), which is taken as the lower limit.
2. the temperature of distilled water during boiling (steam), which is taken as the top limit.

**The Celsius scale** (the most common and well-known) assigns both fixed points (ice-steam) the conventional temperatures of 0° and 100° respectively; consequently, the range between these two temperatures is divided up into 100 equal parts, and for this reason, people often refer to the “centigrade scale” and the “centigrade temperature”. The symbol used is °C.

**The Fahrenheit scale**, commonly used in English-speaking countries, assigns both fixed points (ice-steam) the values of 32° and 212° respectively, dividing up the range between these values into 180 equal parts. The symbol used is °F.

**The Kelvin scale, also known as the “absolute scale” or “thermodynamic scale”,** is used in the international measurement system (SI) and assigns both fixed points the values of  $273.15^{\circ}$  and  $373.15^{\circ}$  respectively, dividing up the range between the two into 100 equal parts. This scale constitutes a consequence of the centigrade scale; in fact it is a known fact in physics that if one could remove from a body all the heat it possesses, then the same body would reach a theoretical value of  $-273.15^{\circ}$ . This limit is defined as the “absolute zero”. The symbol used is **K**.

Thermometer Scales	Celsius	Fahrenheit	Kelvin
Temperature of boiling water	$100^{\circ}$	$212^{\circ}$	373
Temperature of melting ice	$0^{\circ}$	$32^{\circ}$	273

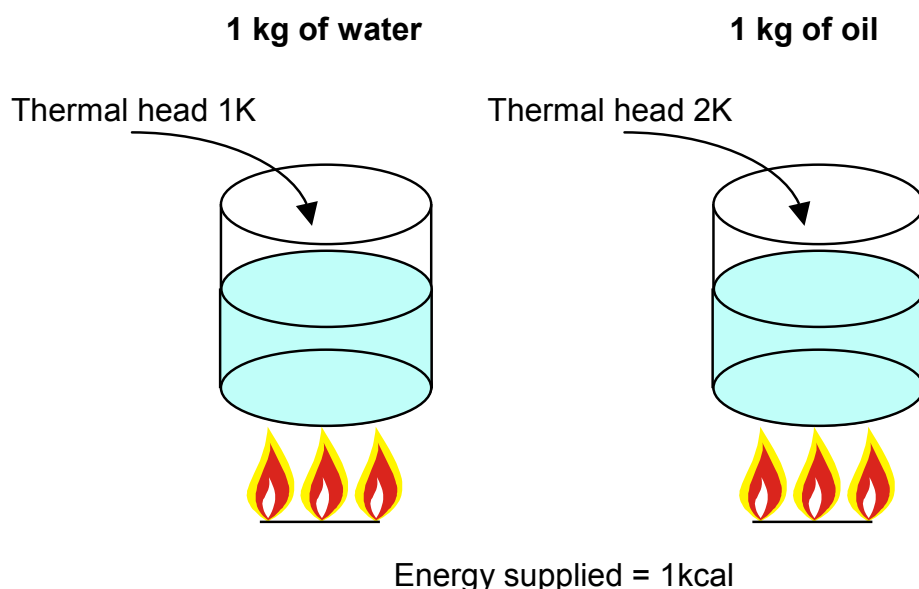
### 1.3. Specific heat

It can easily be seen that not all bodies heat in the same way when subjected to the same quantity of heat “Q” (under identical conditions), since each material has a different “**heat capacity**”, a characteristic which varies according to the nature and mass of the material itself.

When the mass is the same, the heat capacity exclusively depends on the nature of the body; the value which affects its absorption of the heat it is subjected to is called the “**specific heat**”.

**The specific heat (c) of a body (solid, liquid or gas) is therefore defined as the quantity of heat required to raise a unit mass of a body  $1^{\circ}\text{C}$  in temperature.**

For example, for water, 1 kcal is required to raise the temperature of 1 kg by 1 K ( $1^{\circ}\text{C}$ ) whereas for 1 kg of oil, with 1 kcal, the temperature will be raised by approximately 2 K ( $2^{\circ}\text{C}$ ) as illustrated below.



Formula:  $Q = M \times c \times (T_2 - T_1)$

where:

“Q” is the quantity of heat provided

“M” is the mass of the body expressed in kg

“c” is the specific heat of the body

“T<sub>2</sub>” is the final temperature

“T<sub>1</sub>” is the initial temperature

#### Specific heat of certain common materials

Material	Steel	Copper	Water	Steam	Oil	Air
c (kcal / kgK)	0.11	0.1	1.0	0.48	.47	0.23

## 1.4. Heat value

We will define the “heat value” of a material, and we will express it in kcal/kg, as being the quantity of heat developed by the perfect combustion of 1 kg of solid or liquid fuel or of 1 m<sup>3</sup> of gaseous fuel.

### Gross heat value

No fuel is ever completely dry; all fuels contain a certain quantity of water in the form of moisture; in addition, more water is formed in the combustion of the hydrogen contained. In the boiler furnace and ducts, this water is in the form of steam. If the flue gases were at a temperature of less than 100 °C, this steam would condense, releasing vaporisation calories which would consequently be used. This way, all the heat contained in the fuel would be used.

The “**gross heat value**”, is generally indicated by **H<sub>s</sub>**.

### Net heat value

If on the other hand, as is the case in boilers, the flue gases are at a temperature of more than 100 °C, the moisture is evacuated in the form of steam and the condensation heat is lost to the atmosphere. And so the heat actually used is in actual fact less.

The “**net heat value**”, is generally indicated by **H<sub>i</sub>**.

#### Average values of some fuels

Fuel	Gross heat value	Net heat value
<b>Naphtha</b>	<b>10,400 (kcal/kg)</b>	<b>9,800 (kcal/kg)</b>
<b>Diesel</b>		<b>10,200 (kcal/kg)</b>
<b>Methane</b>	<b>9,500 (kcal/m<sup>3</sup>n)</b>	<b>8,500 (kcal/m<sup>3</sup>n)</b>
<b>Ethane</b>	<b>16,800 (kcal/m<sup>3</sup>n)</b>	<b>15,300 (kcal/m<sup>3</sup>n)</b>
<b>Propane</b>	<b>24,000 (kcal/m<sup>3</sup>n)</b>	<b>22,000 (kcal/m<sup>3</sup>n)</b>
<b>Butane</b>	<b>32,000 (kcal/m<sup>3</sup>n)</b>	<b>29,000 (kcal/m<sup>3</sup>n)</b>

## 1.5. Energy and Power

### What is energy?

From a heat-related point of view, we could say that energy is tantamount to the heat required by the mass of a body (e.g. the quantity of water contained in the storage tank) to heat it from a lower temperature to a higher one.

From this practical definition, we can define the following formula:

$$Q = M \times c \times DT$$

where “**Q**” is the thermal energy supplied, “**m**” is the mass of the body (e.g. the quantity of water contained in a storage tank), “**DT**” is the difference in temperature (Final temperature - initial temperature), “**c**” is the specific heat of the body which varies from one material to the next (for water, the value is 1).

To illustrate the above formula, take a look at the example below:

How much thermal energy is necessary to heat 10 litres of water from 15 degrees to 40 degrees?

$$\begin{aligned}m &= 10 \text{ litres} \\c &= 1 \text{ for water} \\DT &= 40 - 15 = 25\end{aligned}$$

if you enter these values in the formula, this is the result:

$$Q = 10 \times 1 \times 25 \quad \text{so } Q = 250 \text{ kcal}$$

### What exactly is power?

The Heat output is simply the quantity of work (or energy) performed in a unit of time, i.e.:

$\text{Power} = \frac{\text{Energy}}{\text{Time}}$
--

In the majority of technical applications, the measurement unit used is the kilowatt (kW). The conversion from kW to kcal/h is as follows:

$$1 \text{ kW} = 860 \text{ kcal/h}$$

so what is the output required by an instantaneous water heater to supply 10 litres of hot water in one minute with a DT of 25 °C.

$$P = 10 \text{ (kg /min)} \times 1 \text{ (kcal/kgk)} \times 25 \text{ (K)}$$

$$\text{so } P = 250 \text{ kcal/min}$$

In fact, if you multiply the 250 kcal/minute by 60 minutes, you will get the heat output of the water heater expressed in kcal/h.

$$250 \text{ kcal/minute} \times 60 \text{ minutes} = 15,000 \text{ kcal/h} = 17.44 \text{ kW}$$

If you divide this value by 860, you will get the heat output, expressed in kW

$$P = 15,000 \text{ kcal/h} = 17.44 \text{ kW}$$

Another comment which can be made is that if you change the quantity of water, but with the same heat output “P” supplied, the relative “DT” will vary. E.g.:

$$m = 5 \text{ litres per minute}$$

$$c = 1 \text{ for water}$$

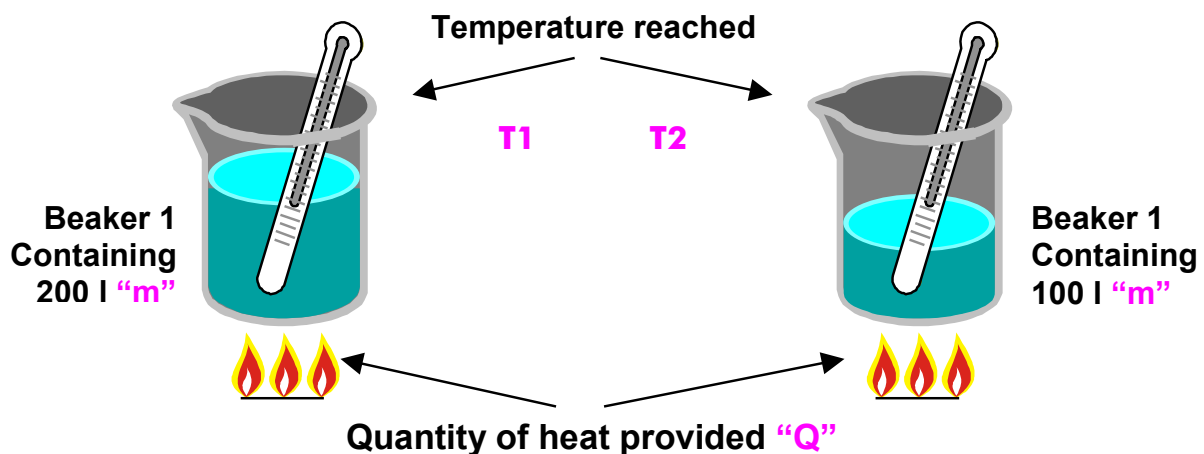
$$P = 250 \text{ kcal/minute}$$

$$DT = 250 \text{ kcal/minute: (1} \times 5 \text{ litres per minute)}$$

$$\text{so the } DT = 50 \text{ }^\circ\text{C}$$

the final temperature will be 65 degrees if the initial temperature was 15 degrees

The figure below illustrates another example:



Let us now suppose that we have to heat the water in both beakers, with an initial temperature of 15 °C, taking it to 60 °C in two hours.

What would the heat output required be?

<b>Beaker 1</b>	$Q = M \times c \times DT$	$Q = 200 \times 1 \times (60 - 15)$	$Q = 9000 \text{ kcal}$
	$P = \frac{Q}{t}$	$P = \frac{9000 \text{ kcal}}{2 \text{ h}}$	

$$P = 4500 \text{ kcal/h} \qquad P = 5.23 \text{ kW}$$

<b>Beaker 2</b>	$Q = M \times c \times DT$	$Q = 100 \times 1 \times (60 - 15)$	$Q = 4500 \text{ kcal}$
	$P = \frac{Q}{t}$	$P = \frac{4500 \text{ kcal}}{2 \text{ h}}$	

$$P = 2250 \text{ kcal/h} \qquad P = 2.62 \text{ kW}$$

## 1.6. Mixing energy

As we explained in the previous chapters, there is a strong link between heat and temperature, so we are now in a position to explain what happens when two liquids with a different quantity and temperature are mixed together.

**We can therefore state that the thermal energy reached will be obtained from the sum of the thermal energies of the two fluids mixed.**

Here is an example:

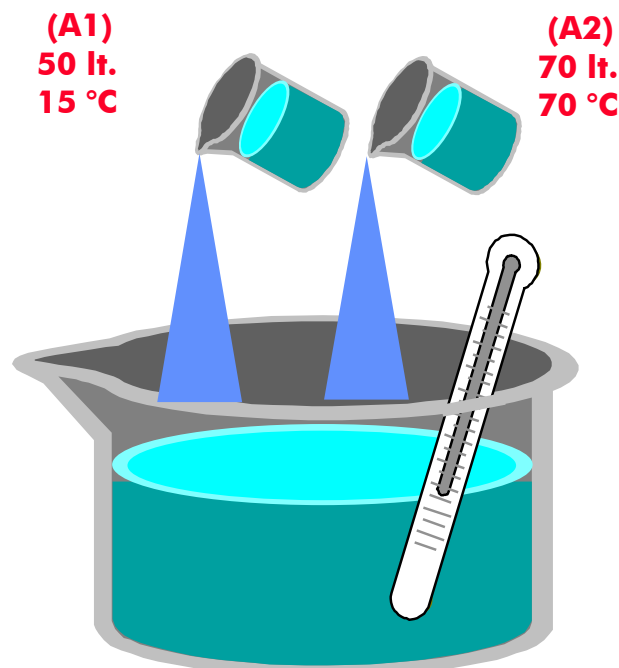
Let us consider two beakers, one containing 50 litres of water (beaker A1) at a temperature of (T<sub>1</sub>) 15 °C, and the other containing 70 litres of water (beaker A2) at a temperature (T<sub>2</sub>) of 70 °C.

Now let us pour the contents of the two beakers into another larger beaker (hence mixing them together) and analyse what happens:

**The final temperature is obtained by the equality between the thermal energy of the 120 litre beaker (sum of A1 + A2) and the sum of the thermal energies of each of the liquids poured, i.e.:**

$$M_t \times c \times T_t = M_1 \times c \times T_1 + M_2 \times c \times T_2 \quad M_t \times c \times T_t = A_1 \times c \times T_1 + A_2 \times c \times T_2$$

$$T_t = \frac{(M_1 \times T_1) + (M_2 \times T_2)}{M_t} = \frac{(50 \times 15) + (70 \times 70)}{120}$$



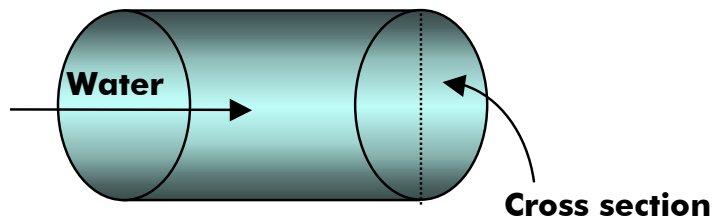
## 2. Flow rate and pressure

There are three fundamental values which characterise the flow of liquid. These are:

- Pressure
- Flow rate
- Speed

### 2.1 Flow rate

The flow rate is defined as the volume of fluid (water) which flows through the cross section S of the pipe in a unit of time, perpendicular to the direction of the water.



Measuring the volumes in  $m^3$  and the time in seconds, the flow rate is therefore expressed in  $m^3/s$

Measuring the volumes in  $m^3$  and the time in minutes, the flow rate is therefore expressed in  $m^3/min$

Measuring the volumes in  $m^3$  and the time in hours, the flow rate is expressed in  $m^3/h$ .

This last value is especially used for pumps.

Let us also remember that one  $m^3/h$  is tantamount to 1000 litres/h.

The concept of speed is well-known in mechanics, and represents the space covered by a car, for example, in a certain amount of time, and it is expressed in  $m/s$  or in  $km/h$ .

In our coverage of the flow of fluids, the concept of speed will incur a few limitations:

a) Firstly, mention must be made that in some parts of a river or channel where the width decreases, the speed of the current tends to increase; consequently, in our observations, we intend to refer always to an instantaneous speed taken in a specific section of the channel or pipe;

b) Moreover, please note that the speed on the riverbed is higher towards the centre of the current and slows down near the banks. As a consequence of these observations, in H.V.A.C. technology, reference is always made to the "average speed" of the fluid at a given cross section.

**The maximum speed which cold water can reach inside a pipe without any noise or turbulence being caused is 2.5 m/s, whereas it is 1.8 m/s for hot water.**

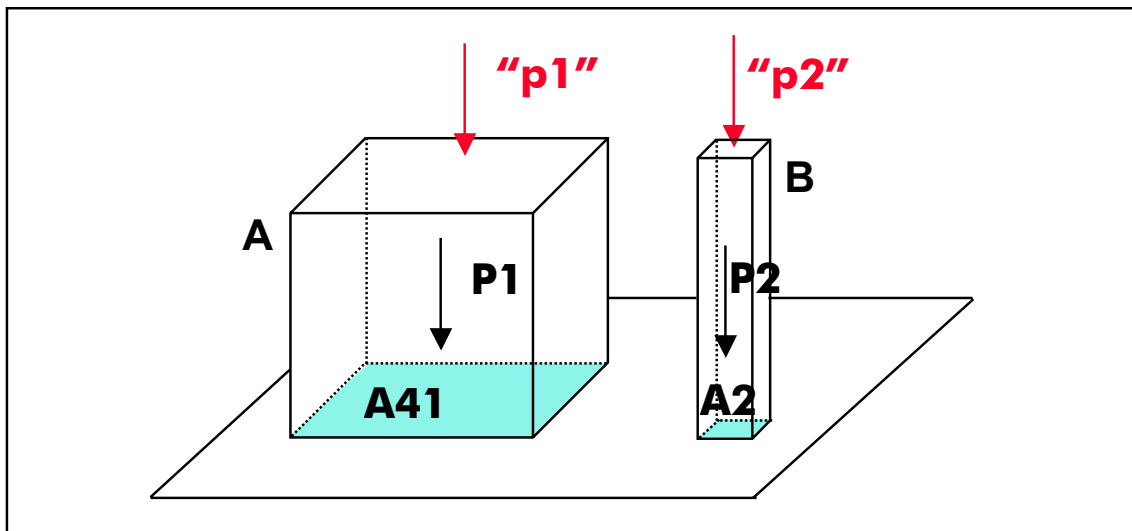
## 2.2. Pressure

Pressure “p” is defined as the stress exerted by a weight on a surface.

$$\text{Pressure} = \frac{\text{Weight}}{\text{Surface}} \quad p = \frac{P}{A}$$

Let us analyse the figure below: A cube “A” weighing 100 kg and a parallelepiped “B” also weighing 100 kg affect two different surfaces, one A1 of 50 cm<sup>2</sup> and the other A2 of 10 cm<sup>2</sup>. We can observe how the pressure is different; in fact:

$$p_1 = \frac{P_1}{A} \Rightarrow \frac{100}{50} = 2 \text{ kg/cm}^2 \quad p_2 = \frac{P_2}{A} \Rightarrow \frac{100}{10} = 10 \text{ kg/cm}^2$$



**Therefore, with the same weight, the pressure exerted on a smaller surface is higher.**

The measurement units used most commonly are: the Pascal, the bar, the mbar, the atmosphere (atm) and millimetres of water column (WC mm).

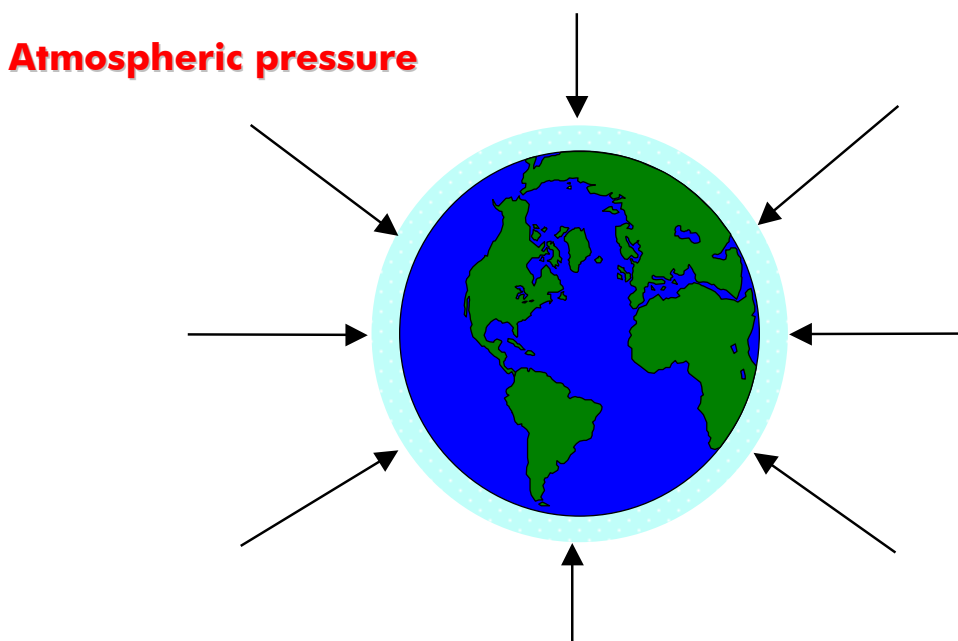
## 2.3. Atmospheric pressure

Every body on the Earth's surface is subject to a pressure (defined as the “**atmospheric pressure**”) due to the mass of air which surrounds the globe and makes life on earth possible.

The entity of the atmospheric pressure is not constant all over the Earth, and it even varies in the same point, depending on the temperature, the altitude and the meteorological conditions. However, in common problems, an average value is conventionally used, defined as the “**physical atmosphere**”.

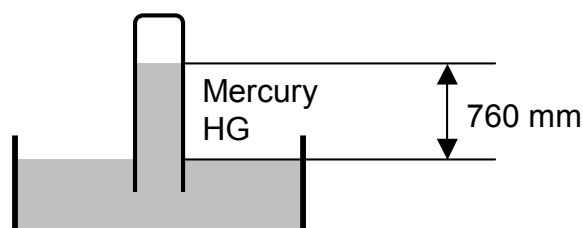
**A physical atmosphere corresponds to the average pressure exerted by the mass of air which surrounds the Earth, measured at sea level and at a temperature of 0 °C.**

The value of a “physical atmosphere” is equal to 10.33 metres of water column



In fact, if we dip a small vacuum tube (i.e. without any air in it) with a cross section of 1 cm<sup>2</sup> in a bucket of water, the result will be that the water tends to rise inside the tube up to a height of 10.33 m. This is thanks to the effect of the atmospheric pressure.

This test was carried out by the scientist Evangelista Torricelli, turning a tube full of mercury, sealed at one end, upside down in a container full of the same liquid.

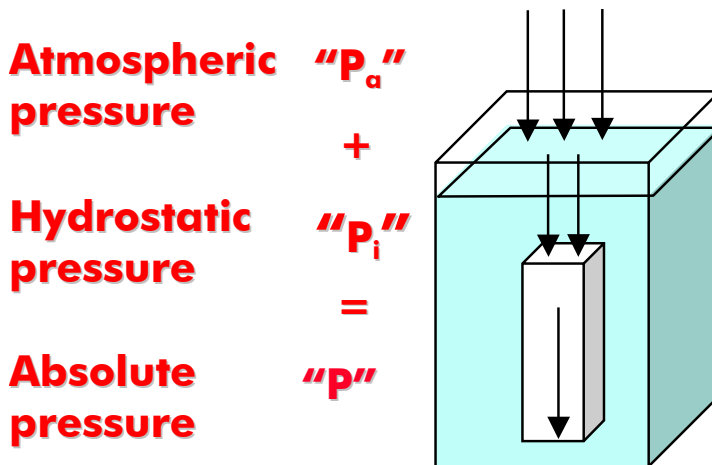


## 2.4. Absolute and relative pressure

If an object is dipped in a liquid, to a certain depth “h” under the free surface, it is subject not only to the atmospheric pressure “ $p_a$ ” (which affects the surface of the liquid) but also to the pressure “ $p_i$ ” due to the mass of the liquid above it; the latter is defined as “**hydrostatic pressure**”.

The total pressure “p” which affects the body submerged is called the “**absolute pressure**” and is obtained from the following formula:

$$p = p_i + p_a$$



For example, if we think of a pressure gauge placed on a water pipe in a heating plant and we read the value of 1, this means that the water contained is at a pressure of  $1 \text{ kg/cm}^2$  or 1 bar. However, if we read this value this way, we are not taking into account the atmospheric pressure. The pressure read is defined as the “**relative pressure**”.

## 2.5. Pressure scales

Previously, we mentioned the different measurement units used for pressure (Pascal, bar, etc.). Below is a table to use for the various conversions.

from/to	kg/cm <sup>2</sup>	Pascal	bar	atm	mm H <sub>2</sub> O
kg/cm <sup>2</sup>	1	$9.81 \times 10^4$	0.981	1.033	$10^4$
Pascal	$1.02 \times 10^{-5}$	1	$10^{-5}$	$0.987 \times 10^{-5}$	$1.02 \times 10^{-1}$
bar	1.02	$10^5$	1	1.013	$1.02 \times 10^4$
atm	0.968	$1.013 \times 10^5$	0.987	1	$0.968 \times 10^4$
mm H <sub>2</sub> O	$10^{-4}$	98.1	$9.81 \times 10^{-5}$	$1.033 \times 10^{-4}$	1

In everyday practice, we can state that:

1 atm = 1 bar = 1000 mbar

1 mbar = 10 mm H<sub>2</sub>O

## 2.6. Pressure in liquids and gas

As we know, all the materials in nature are made up of an enormous number of molecules subjected to stronger or weaker mutual forces of attraction (molecular cohesion) that characterise the “physical state” of the material itself with their intensity, so the material appears in the form of a **solid, liquid or aeriform** (gas).

### SOLIDS

In a solid, the cohesive strength between the various molecules which make it up is so great that it prevents their mutual separation as well as the sliding as an effect of their own weight or small external forces; consequently **a material in solid state has its own shape and an invariable volume.**

In fact, if we place an iron cube in a press, the cube will be warped, and take on the shape of a plate, but if we attempt to calculate its volume, the latter has not changed. In other words, solids are not compressible.

### LIQUIDS

Liquids benefit from a weaker cohesion strength compared to solids; this cohesion strength is enough to prevent the separation of the various particles but not the mutual sliding as an effect of the weight force, which can easily be observed when liquid is poured over a flat surface.

**Consequently, although materials in liquid state have their own volume, they do not have their own “shape”, but rather tend to take on that of the container housing them.**

**Liquids, like solids, are not compressible.**

### AERIFORMS

Finally, aeriforms have neither shape nor volume; there is no cohesion whatsoever between the various molecules, but instead repulsion, so they tend to separate increasingly from neighbouring molecules, and take up all the room available.

**An aeriform therefore takes on the shape and volume of the container housing it. Aeriforms, unlike solids and liquids, are easily compressible.**

However, please note that liquids feature tiny variations in volume when compressed by external forces, but these variations are so small that they can be deemed negligible at least in the majority of problems related to hydraulics and the relative machinery.

The volume of a given quantity of a material essentially depends on two factors:

- **Pressure**
- **Temperature**

## 2.7. Specific weight (or density)

The specific weight, or density of a body is the weight of the unit of volume of the body itself.

For reference, we take the weight of one  $\text{dm}^3$  (i.e. of one litre) of distilled water at a temperature of  $4^\circ\text{C}$ .

The specific weight is the ratio between the weight of one  $\text{dm}^3$  of a given material and the weight of  $\text{dm}^3$  of water at  $4^\circ\text{C}$ , taken as a unit.

The definition is valid for all materials and also for liquids, which may however feature appreciable variations as the temperature changes, so in many cases one must specify the temperature to which the density refers.

For gases, the specific weight referred in  $\text{kg per m}^3$  is evaluated, at a pressure corresponding to sea level.

**Table of some of the main specific weights**

<b>Solids</b>	<b>Specific weight</b>
<b>Silver</b>	<b><math>\text{kg/dm}^3</math></b>
<b>Iron</b>	<b><math>\text{kg/dm}^3</math></b>
<b>Gold</b>	<b><math>\text{kg/dm}^3</math></b>
<b>Copper</b>	<b><math>\text{kg/dm}^3</math></b>
<b>Liquids</b>	<b>Specific weight</b>
<b>Distilled water at <math>4^\circ\text{C}</math></b>	<b><math>\text{kg/dm}^3</math></b>
<b>Alcohol</b>	<b><math>\text{kg/dm}^3</math></b>
<b>Mercury</b>	<b><math>\text{kg/dm}^3</math></b>
<b>Petrol</b>	<b><math>\text{kg/dm}^3</math></b>
<b>Diesel</b>	<b><math>\text{kg/dm}^3</math></b>
<b>Gases</b>	<b>Specific weight</b>
<b>Air</b>	<b><math>\text{kg/dm}^3</math></b>
<b>Oxygen</b>	<b><math>\text{kg/dm}^3</math></b>
<b>Methane</b>	<b><math>\text{kg/dm}^3</math></b>
<b>Butane (gas)</b>	<b><math>\text{kg/dm}^3</math></b>
<b>Propane (gas)</b>	<b><math>\text{kg/dm}^3</math></b>

### 3. Heat transmission

A topic considered to be of vital importance is the transmission of heat from one fluid to another, through a wall which separates them.

The fluid releasing the heat must be at a higher temperature than the fluid receiving it, in accordance with Clausius' statement, according to which heat is transferred spontaneously from hotter to colder bodies.

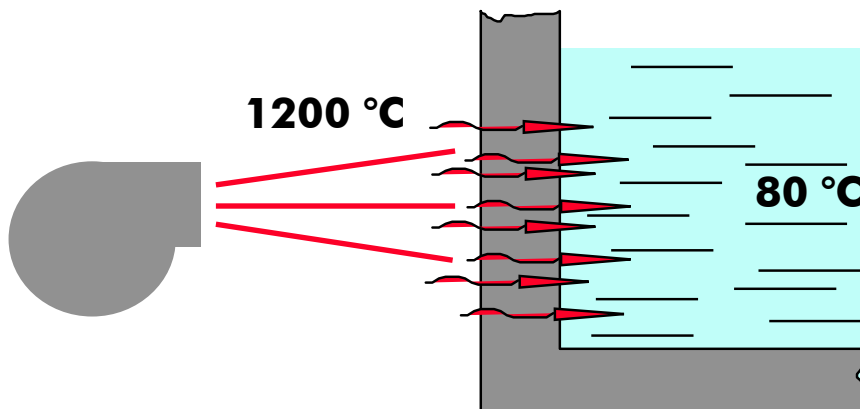
It is a well-known fact in physics that heat can be transferred in three ways:

1. By convection
2. By conduction
3. By radiation

#### 3.1. Convection

Heat is transmitted by “**convection**”, which means by transport, from one body to another by means of an intermediary fluid which transports the heat.

For example, the hot flue gases developed in the furnace of a boiler carry the heat, by convection, touching the metal sheets and release it to these sheets and from these to the water flowing through the heat exchanger.



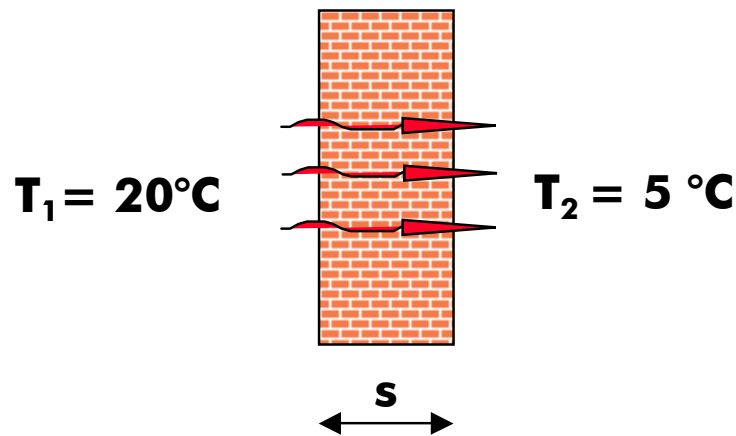
#### 3.2. Conduction

This is the name given to the transmission of heat obtained through molecular excitation, or internal vibratory movements. In other words, when the heat is transferred from one area of a solid to the next by means of molecular collisions.

The heat is transmitted by conduction more or less well depending on the type of material; in fact, it propagates well in metals, especially in Silver (Ag), Copper (Cu) and Aluminium (Al). It propagates less well in non-metal materials such as stone and bricks, and poorly in organic fabrics, wood, wool, etc.

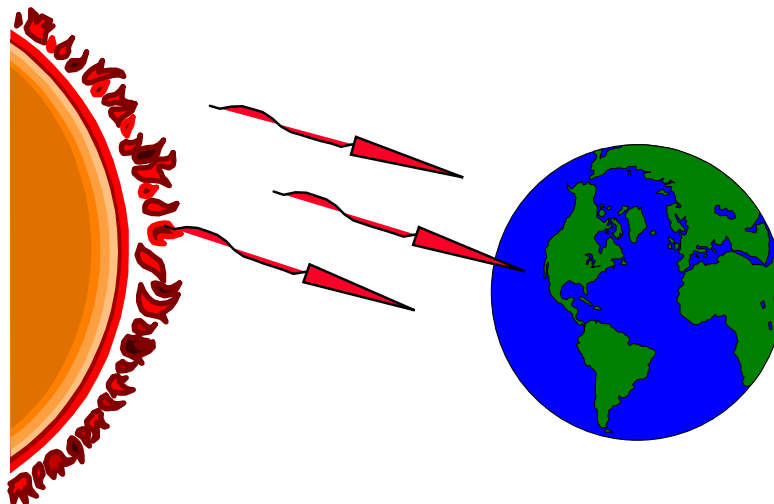
Let us imagine a flat surface (see fig.) of uniform material, such as a concrete wall, of thickness “s”.

Let us suppose we maintain the two sides of the slab at two different temperatures  $T_1$  and  $T_2$ . A flow of heat will move from the hotter side ( $T_1$ ) towards the colder one ( $T_2$ ). This flow occurs without any movement of material: in this case, the heat is said to be transmitted between the two flat sides by “**conduction**”.



### 3.3. Radiation

The heat is also propagated similarly to light, i.e. by radiation. In substance, the heat is transmitted to the surrounding bodies and without any connection to the heat source, but through the air or, in general, through space. Just like the sun conveys its heat to the Earth through space, or how a modest coal stove heats the people around it from a distance.



**If we wish to generalise things, we can say that a hot body emanates energy in all directions, energies which are propagated along straight lines at the speed of light. This energy is always intercepted by colder bodies than the emanating body.**

## 4. Heat or cold requirements

### 4.1. Premise - Why do we heat or cool a room?

The human body produces heat by metabolism.

This heat is continuously dissipated by radiation, by convection and through evaporation.

When, under normal circumstances, the body temperature is kept at around 37°C, the heat produced is balanced out by that lost.

So the room is heated or cooled to create a setting (temperature, air, walls, etc.) which ensures the thermal equilibrium of the human body, clothed in a certain way and at rest; i.e. it doesn't have to take any action to ensure its thermal equilibrium, so in actual fact it feels neither hot or cold.

As far as heat is concerned, every building is subject to constantly changing conditions which govern it both on the inside and the outside.

An understanding of these conditions will provide some practical help to determine the actual thermal requirement of the building or apartment, in order to evaluate:

- **the potential of the heat generator or cooling appliance**
- **Dispersion values for each room**

These depend on the following factors:

1. *The material of the outside walls.*
2. *The thickness of the outside walls.*
3. *The type of window, whether it is made of aluminium or wood, with single or double glazing, if the double glazing has an air space.*
4. *Type of outside door.*
5. *Type of flooring/slabs.*
6. *Type of ceiling.*
7. *Desired temperature of the various rooms.*
8. *If the top floor is heated.*
9. *If the lower floor is heated.*
10. *If the adjoining perimeter walls are with the outside or not.*
11. *The exposure of the outside walls (facing North, South, East or West).*
12. *Average outside temperature in winter and summer.*

## 5. Heating bodies

### 5.1. Premise

The heating bodies constitute the end elements of a central heating system. Their main purpose is to transfer the heat of the water heated by the heat generator to the various rooms.

In this case, the heating elements release their heat to the setting by convection.

The most important types of heating bodies used in hot water systems are called Fan coils

### 5.2. Fan coils

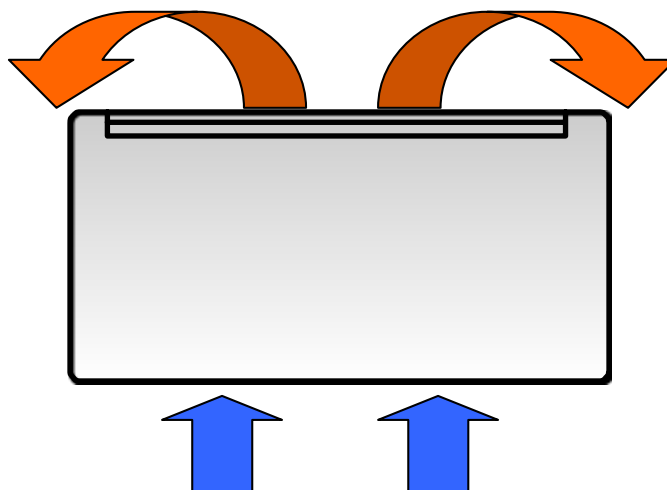
These are made up of a finned pipe coil which exchanges heat by forced convection (by means of a fan).

The thermal emission of the fan coils can be affected by the water flow rate.

The fins are designed to increase the heat exchange surface. Fan coils are made up of a cabinet which contains an air filter, one or two finned copper pipe coils, a single phase electric motor coupled directly to the centrifugal fan. A special commutator, built into the appliance, allows for three different operating speeds.

**Fan coils are very popular due to their versatility of use in both the heating and air conditioning sectors. In fact, the coil can be supplied with hot water or cooled water.**

Coil fans also offer an added bonus: high power ratings in compact dimensions, and thermal emission which are always closely related to the real requirements of the setting (automatic adjustment) with significant energy savings.



## 6. Hydraulics

### 6.1 Hydrostatics and Hydrodynamics

#### 6.1.1. Premise

Hydraulics is that area of engineering which concerns everything to do with liquids, be they still, flowing through various types of ducts or channels on the free surface; in the first case, the equilibrium of such a liquid depends on hydrostatics, whereas hydrodynamics are responsible for the laws regarding the flow of fluids.

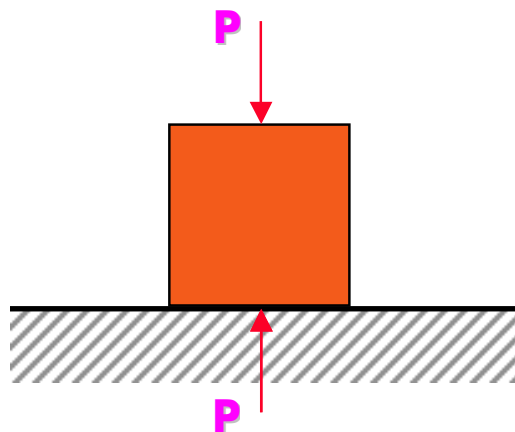
The brief explanations of hydrostatics and hydrodynamics given in this chapter are vital to understand fully this topic, to have a better grasp of the concepts of head and flow resistance in distribution systems. To determine the technical characteristics of a centrifugal pump in a central heating system, for example.

#### 6.1.2. Pascal's Law

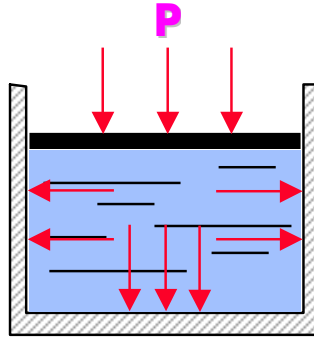
Pascal's law states that:

**“The pressure at any point of a liquid mass at rest is transmitted with the same intensity at every point of the liquid and in all directions”.**

This principle highlights the difference in the behaviour of solids and liquids; if we exert a force “P” on the top face of a solid (see figure below), it is transmitted to the lower face, whereas the lateral faces are free from any force;



consequently a liquid, sealed in a container (see figure below) and placed under a certain pressure compresses all the walls of the container equally and the pressure is normal at the surfaces, whatever the layout.



Pascal's law has countless practical applications; among the most common, we will mention the braking system used on vehicles, which allows for a uniform distribution of the braking force on all four wheels, something which is not possible with a mechanical drive.

### 6.1.3. Current regimes

Hydrodynamics studies the flow of liquids, whether this flow takes place as an effect of terrestrial gravity (runoff in water courses on the free surface) or as an effect of the energy communicated to the fluid by an operating machine (flow through piping or ducts caused by a pump, for example).

There are three fundamental values which characterise the flow of liquid. These are:

- **Pressure**
- **Flow rate**
- **Speed**

We have already dealt with the concept of pressure, so we will now concentrate on the flow rate and speed.

**The “Volumetric Flow Rate” (or simply flow rate) is defined as the volume of liquid which flows through the section in a unit of time.**

Measuring the volumes in  $\text{m}^3$  and the time in seconds, the flow rate is expressed in  $\text{m}^3/\text{s}$ ; however, in practice, small flow rates are evaluated in litres/s or even litres/min. To this end, please remember that:  **$1\text{m}^3/\text{s} = 1000\text{ dm}^3/\text{s} = 1000\text{ l/s}$**

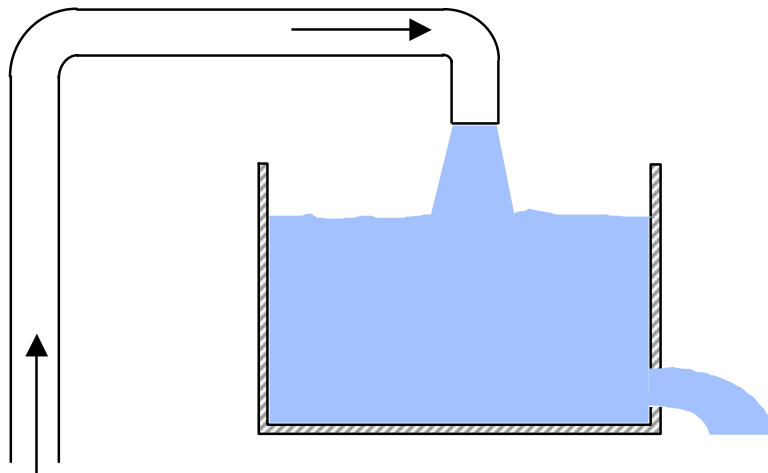
**“Speed” is defined as the space covered by a moving body in a unit of time and is expressed in m/s.**

If for example we observe a water course, we can see:

- a) that in the parts of a river or channel where the width decreases, the speed of the current tends to increase; consequently, in our observations, we intend to refer always to an instantaneous speed taken in a specific section of the channel or pipe;
- b) that the speed is higher towards the centre of the current and slows down near the banks.

As a consequence of the above, as we study the flow of liquids, we always intend to refer to the “**average speed**” of the fluid at a given cross section.

To illustrate how the three values defined above (pressure, speed and flow rate) characterise the flow of the fluid, we would like to refer to the tank in the figure, supplied by a pipe and featuring an opening through which part of the liquid inside it flows out.



At this stage, three different situations can arise:

- 1) if the supply pipe sends the tank more water than the amount which flows out of the opening (which means the supply flow rate exceeds the discharge flow rate), the level of the liquid in the tank tends to rise, increasing the hydrostatic pressure on the outflow section; this leads to an increase in the speed of the liquid that flows out and therefore a variation in the discharge flow rate.
- 2) If the supply flow rate is less than the discharge flow rate, the opposite occurs; the level of water tends to drop, the hydrostatic pressure decreases and the outflow is affected, decreasing in speed and flow rate.
- 3) If the supply flow rate is the same as the discharge flow rate, there are no variations in level, pressure or speed.

### 6.1.4. Flow resistance

The energy dissipation due to friction is commonly defined as “**Continuous flow resistance**” and it is expressed in metres of the liquid column in question.

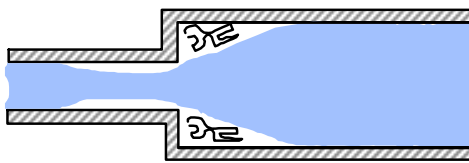
It essentially depends:

- on the speed of the liquid;
- on the extension of the walls and therefore on a dimension of the cross section;
- on the nature and roughness of the walls;
- on the length of the section of pipe considered.

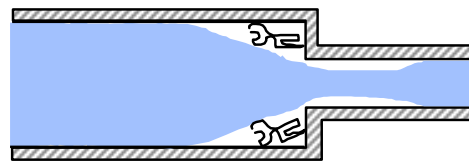
Continuous flow resistance is not the only reason for the drop in energy of the fluid, since any foreign element introduced inside the duct which alters the rectilinear flow of the current causes deviations, collisions or line vortices and will therefore lead to further energy dissipation.

Everyone knows that a piping network often features valves, branches, elbows and very often sudden changes in the pipe cross section; each one of these obstacles generates a flow resistance defined as “accidental” or “localised”.

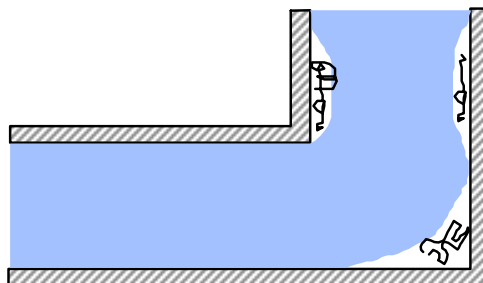
Figures A, B, C below highlight the abnormal behaviour of the fluid in the event of some flow resistance as described above (sudden expansion in cross section, constriction, 90° elbow).



**A) Sudden expansion**



**B) Sudden constriction**

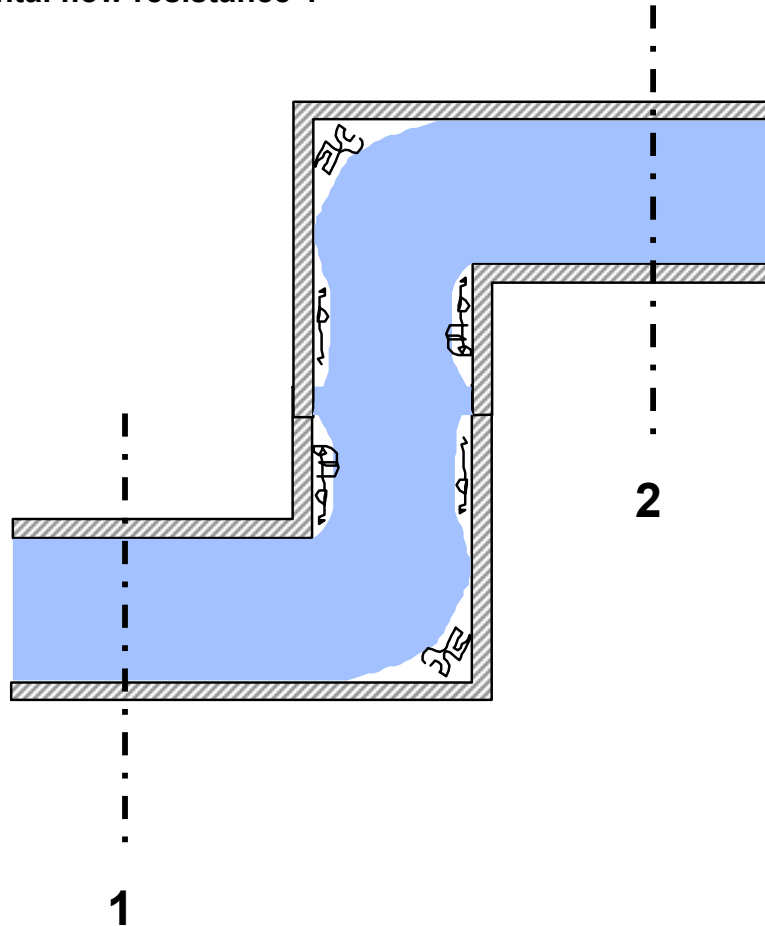


**C) Right angle elbow**

For these reasons, we try to avoid elbows which are too narrow, and any variations in cross sections are coupled using conical stub pipes.

We can therefore say that:

**“The total energy of a fluid at cross section 2 is equal to the energy such fluid has at cross section 1 minus the continuous flow resistance (in the section considered) and any accidental flow resistance”.**



## 7. Heating systems

### 7.1. Premise

To heat rooms, a certain thermal energy obtained by burning a specific fuel needs to be developed or transferred.

The thermal energy is produced in special generators (boilers), which are basically made up of:

- a main body (heat exchanger)
- a furnace (burner)
- a circulation pump
- a gas valve

The thermal energy produced by the generator is conveyed to the rooms to be heated using a carrier fluid, which could for example be water.

The remainder of this chapter will cover the various types of system available to convey our carrier fluid.

### 7.2. Forced circulation

Forced circulation central heating (air conditioning) systems are systems where the water is circulated by a pump.

In this case, the load available is established mainly by the pump and it is distributed equally throughout the entire system. This leads to the possibility of designing quick, multiform systems which use heating bodies with high flow resistance.

The pump, which is centrifugal as we shall see in point 4, is characterised by:

- a “**head (H)**” which defines the difference in height and the flow resistance which can be overcome;
- a “**flow rate (Q)**” which establishes the volume of water that can be set in motion.

To determine the diameter of the pipes in a system featuring a centrifugal pump, one can:

1. Estimate the pressure to supply the pump, which must be the same value as the resistances of the circuit (piping, Fan coils, valves, generator), with the help of abacuses or tables;
2. Set the maximum water circulation speed in the circuit.

It is not completely indispensable that you obtain a uniformly distributed flow resistance, but it would be better if it was variable, depending on the points of installation. This is because it is a good idea for the speed of the water to be faster in the long rectilinear sections rather than in the winding sections where the flow resistance is higher.

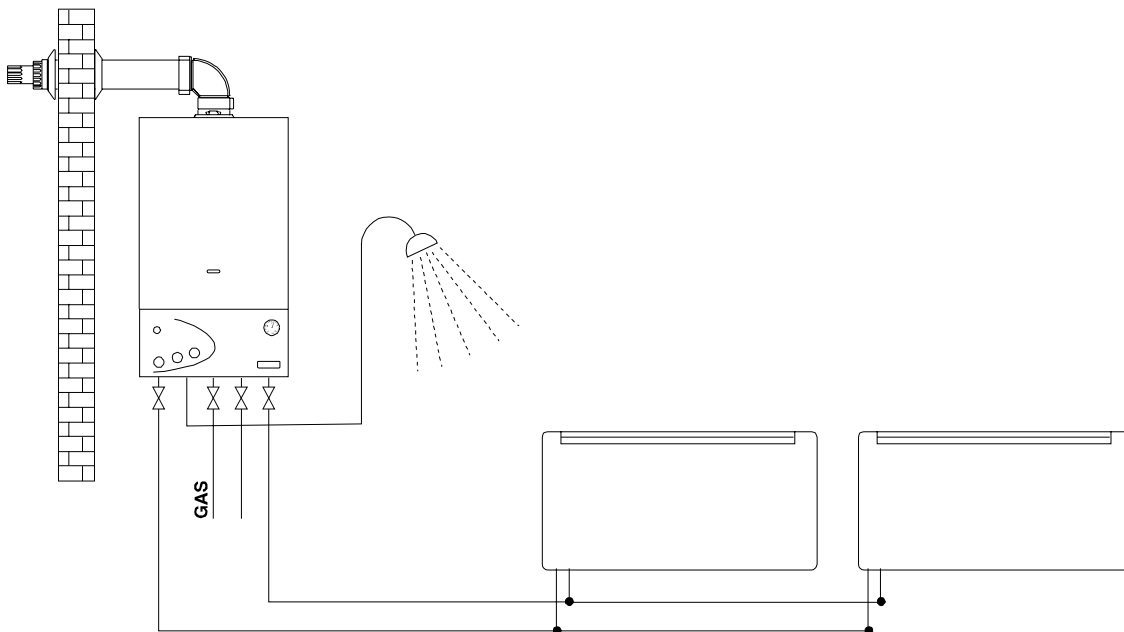
The maximum speed that the water in the circuit may have is 2 m/s. Faster speeds lead to a noisy system and very strong flow resistance. Below is a table for the general calculation of pipe diameters for water speeds of between 0.5 and 1 m/s, and with the relative hourly heat quantities transported these allow.

Diameter		Speed in m/s				
mm	inches	0,5	0,7	0,8	0,9	1
Kcal/h						
13	1/2	4780	6690	7560	8600	9560
19	3/4	10210	14290	16330	18370	20410
25	1	17700	24740	28270	31800	35340

However, for the correct sizing of the pipes, the designer should have considerable experience. The difficulty lies in the choice of the most suitable maximum speeds in the piping stub pipes with a different diameter.

Mention must however be made that in independent systems, the calculation is simplified considerably, given that the circulation pump is already built into the generator and the flow resistance in the circuit is usually limited.

Below is a diagram of a simple forced circulation system.



- **Pos 1:**  
Wall\_hung gas combination boiler
- **Pos 2:**  
Horizontal Coaxial Exhaust / Suction Pipe
- **Pos 3:**  
Fan coil Floor Standing

### 7.3. Distribution systems

A system can have the following characteristics:

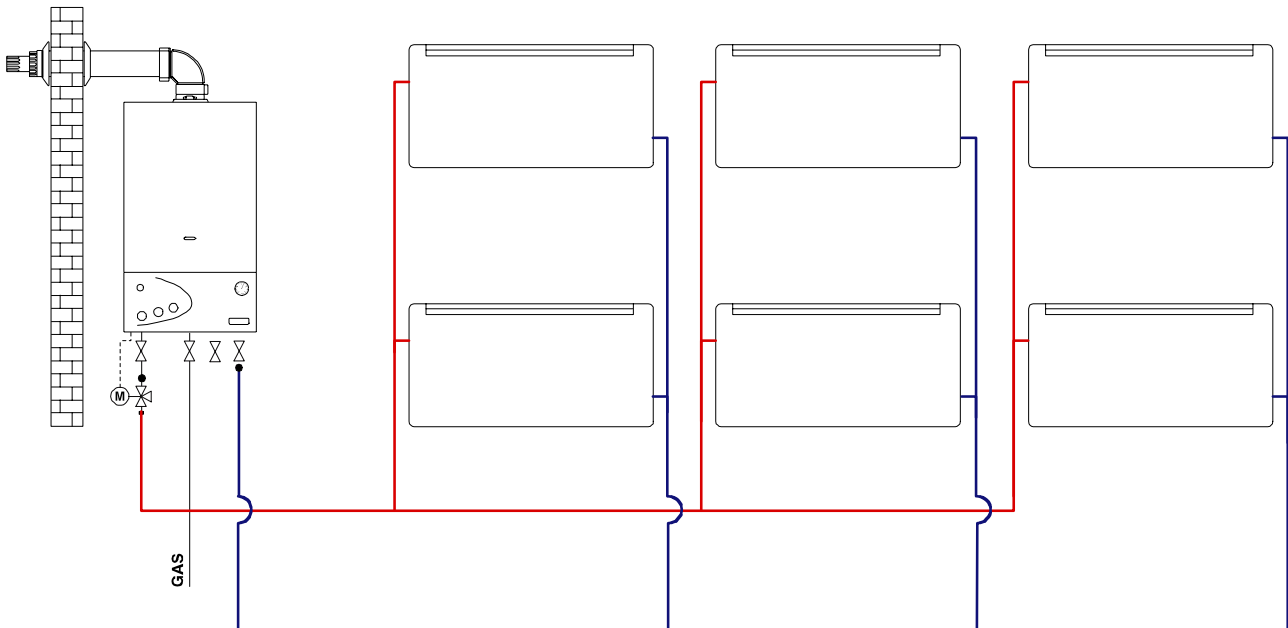
- **Flow and Return Distribution**
- **Modular Distribution**

#### Flow and Return

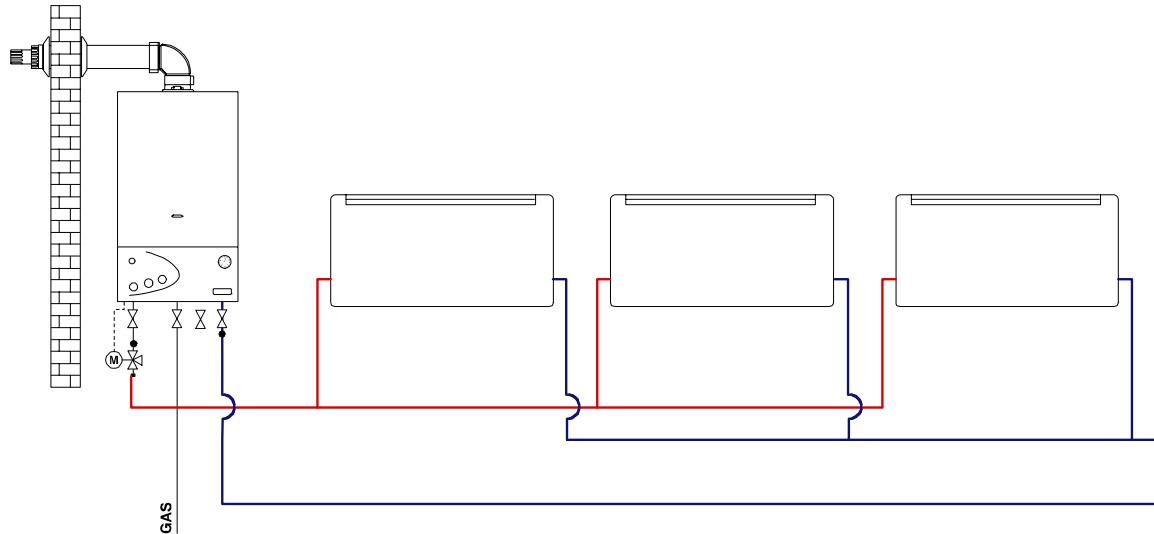
The “Flow and Return” systems, also referred to as dual pipe systems, mainly consist of a flow pipe which transports water from the generator towards the fan coils and a return pipe for the collection of the water returning from the fan coils to the boiler to regain the energy released.

In this case, there are several systems, summarised as follows:

- With the distribution from below, this is the most commonly used dual pipe system. The flow and return pipes are installed together at the lowest point of the system (see figure below)



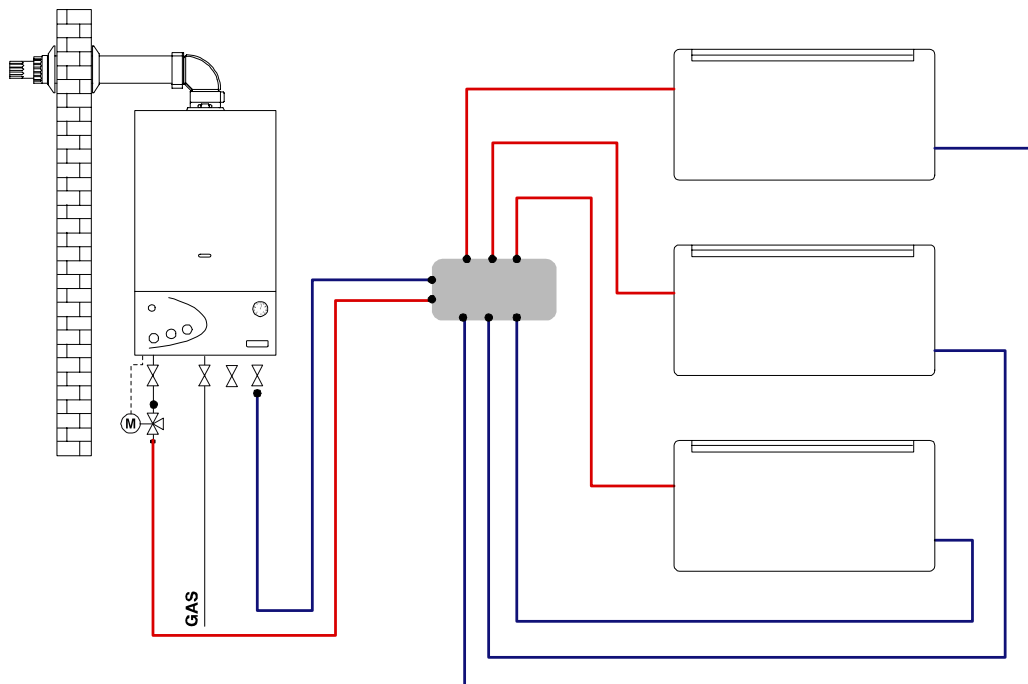
- Inverse return - it can be applied in the two previous cases to guarantee the perfect balance in individual circuits (see figure below);



- **Modular distribution**

The Modular distribution system consists of coplanar manifolds which are sized with a number of fittings corresponding to the heating bodies to be connected to each one. The columns supply a manifold on each floor, from which the connections to the various heating bodies branch out.

This particular system offers very low flow resistance and a relatively easy to install system. In fact, it can be installed with seamless pipe sections. The only connections to be made are between the manifold and the fan coil.



## 7.4. Centrifugal pump

### 7.4.1. Premise

We previously mentioned that there are various ways to design a heating system.

In actual fact, the most popular systems in use today are:

**“Independent forced circulation central heating systems with an expansion vessel (sealed system)”**.

In this chapter, we shall therefore analyse the concepts and problems linked to this type of system.

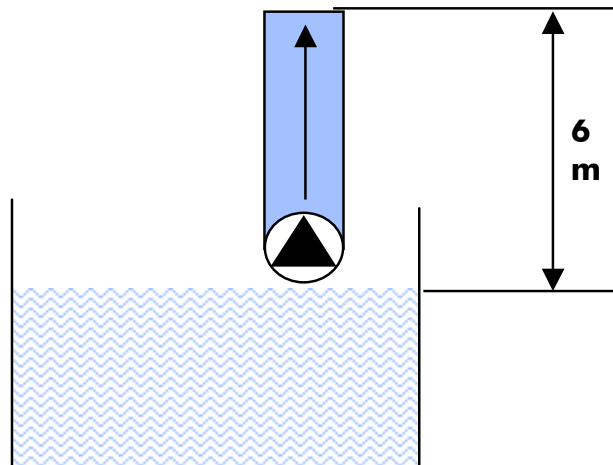
### 7.4.2. Pressure and head

In a hydraulic circuit, the pressure is determined by the weight of the column of water circulating through the piping. So at all the points which are positioned at the same level, we shall find the same hydrostatic pressure.

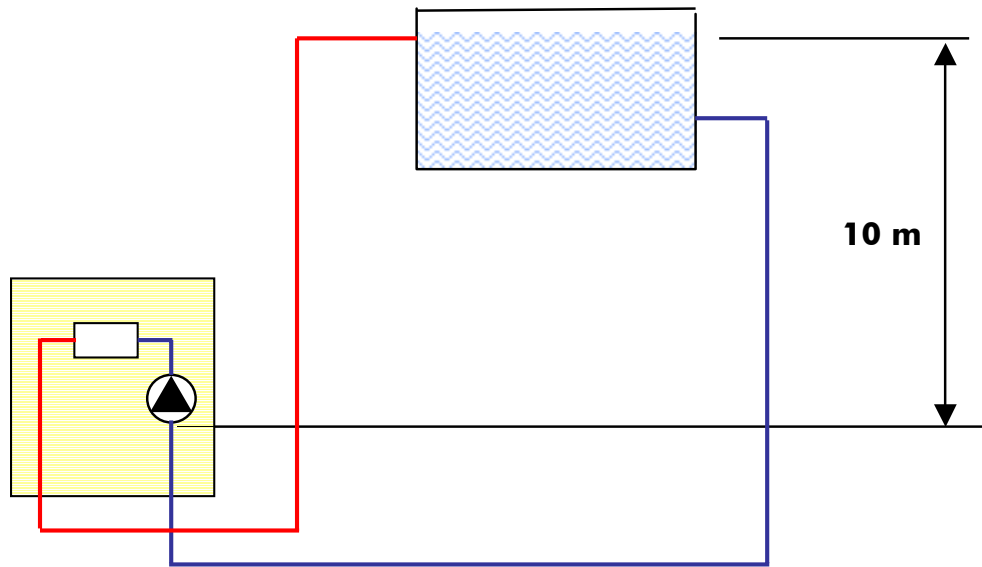
In a hydraulic circuit, as we saw earlier, there is some flow resistance due to the heating bodies, to the valves and to the pipes, i.e. the water finds some resistance along its path.

The sum of the flow resistance (continuous, accidental, localised) in a sealed system determines the head that the centrifugal pump will have to have in order to overcome such resistances. The symbol of the head is “H” and it is expressed in metres.

To illustrate the concept of head, take a look at the figures below.



**The pump has a head of 6 metres; this means that the water can be pushed vertically for up to 6 metres**



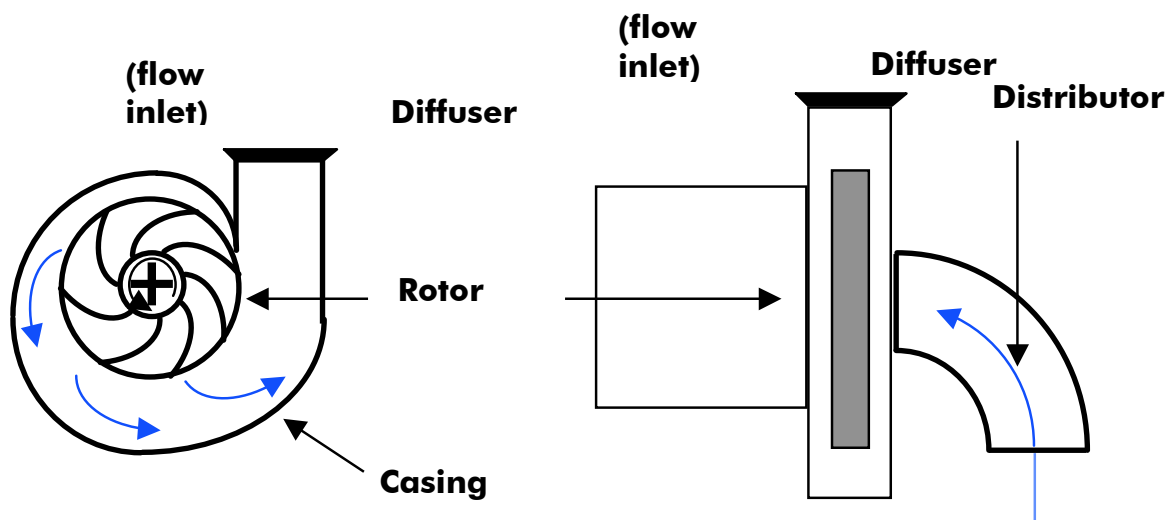
If the pump is instead included in a sealed circuit, the pressure that it supplies the water with is exactly the same as the inlet pressure, minus any flow resistance

We can therefore state that a pump is capable of pushing the water to a height even greater than its head in the event of sealed circuits.

### 7.4.3. Centrifugal pump

Centrifugal pumps, due to the exhaustive range of performance levels provided, their simple construction and operation, the possibility of coupling them directly to electric motors, have practically invaded all fields of application.

As far as our systems are concerned, however, especially independent systems, we always talk of small flow rates (around 1000 l/h) and low heads (around 5 m).



The operation of centrifugal pumps is mainly characterised by five parameters:

- Head
- Flow rate
- Number of revolutions
- Power
- Efficiency

**The head “H”** is the difference in height or the resistance (flow resistance) that the pump can overcome when it shifts a certain quantity of water; it is measured in meters of water column (WC m).

**The flow rate “q”** is the quantity of water that the pump can shift in a unit of time; it is measured in m<sup>3</sup>/h.

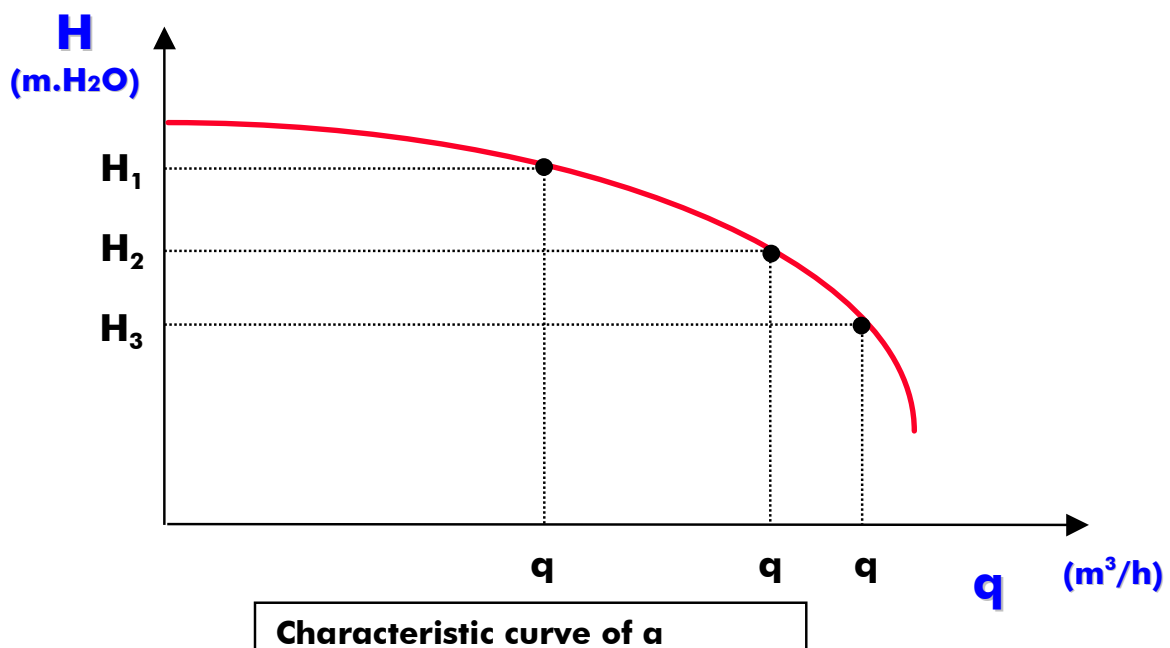
**The number of revolutions “n”** indicates the number of revolutions per minute of the rotor.

**The power “Pu”** is the useful power of the pump.

**The efficiency “h”** is obtained from the ratio between the useful power and the electric power absorbed.

### 7.4.4. Characteristic curve

In centrifugal pumps, the two characteristic elements “**Head and Flow rate**” are closely linked to one another, so much so that when one factor varies, so does the other. In actual fact, each flow rate value “**q**” corresponds to a specific head value “**H**” and this can be illustrated graphically by tracing a curve, defined as the “**Characteristic curve**” (see figure below).

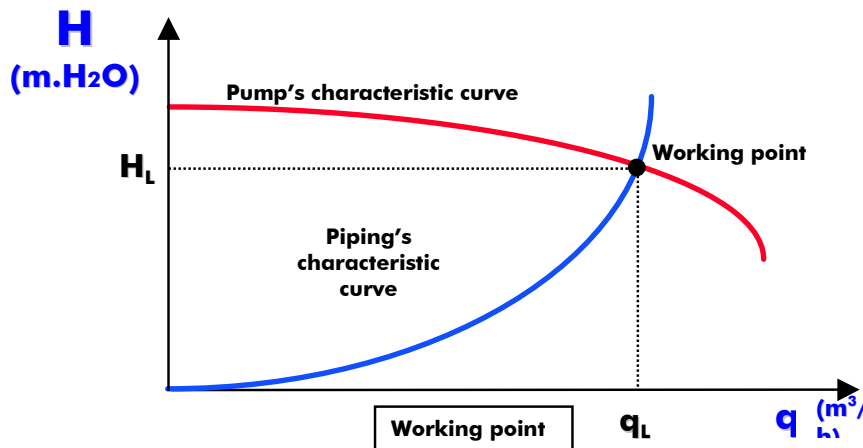


### 7.4.5. Working point

We mentioned previously that there are several resistances along a system due to the restrictions of pipes, the radiators, the valves, etc., which lead to a decrease in speed and therefore in the flow rate; we also said that to overcome these resistances, the centrifugal pump needs to have the right characteristics to provide for the flow resistance. In short, it must have a certain head.

The head necessary to overcome this flow resistance can be represented in the form of a graph, depending on the flow rate, obtaining the “**Characteristic curve of the piping network**” (see figure below).

The point where the pump’s curve and that of the piping cross is called the “**working point**”.

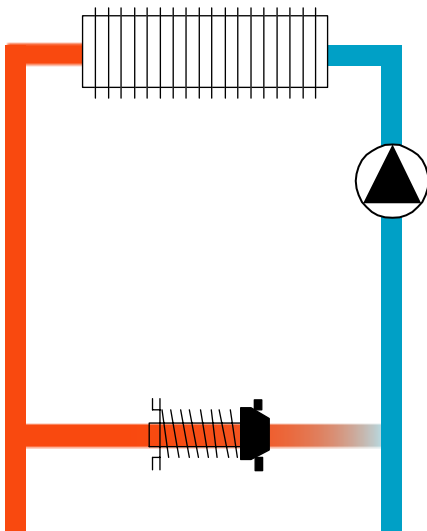


### 7.4.6. Using the By-pass

When a pump is fitted in a system, the circulation of water must be ensured at all times. Should this not be the case, the interior of the boiler may overheat.

This is why a **By-pass** valve is included in the circuit.

This by-pass valve is included as standard in all ARISTON wall hung boilers, so as to guarantee the minimum flow rate necessary to prevent any overheating and to avoid the installer having to create one on the system at a later stage.



## 7.5. Expansion vessel

### 7.5.1. Premise

When the temperature of liquid is varied, so does the liquid's pressure or volume, depending on whether the volume or the pressure is kept at a constant.

In the case of central heating systems, when we provide a certain energy, produced by the generator, this energy causes a variation in the temperature in the circuit, and in our case, the volume (since liquids are not compressible) and the pressure will also vary.

The pressure limit that our system can withstand is determined by the safety valve fitted in the system, and which is usually calibrated to 2.5 atm. If this limit is exceeded, the valve is designed to discharge pressure by opening (in practice, it works just like the valve on a pressure-cooker).

The opening of the valve would lead to a continuous refilling of water in the system, so we include an expansion vessel to compensate for any increases in volume, maintaining the pressure in the system almost constant, consequently avoiding the safety valve opening.

### 7.5.2. Expansion vessel

In a sealed system, the expansion vessel is airtight and the most commonly used type has a rubber diaphragm. It is designed to:

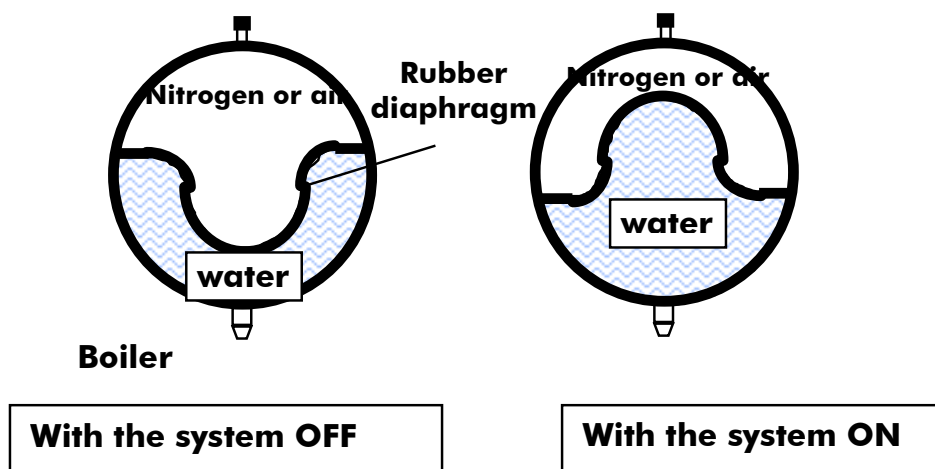
- **Absorb the increase in the volume of water;**
- **Maintain the pressure under any operating conditions at the highest points of the system;**

*All "ARISTON" wall hung boilers are fitted standard with an expansion vessel.*

The operating principle of an expansion vessel consists basically in the compression and decompression of the gaseous cushion when the water in the system incurs a variation in volume as it is heated.

The figure below represents the operating diagram of an expansion vessel:

#### Vessel inlet and control valve



## 7.6. Safety valve

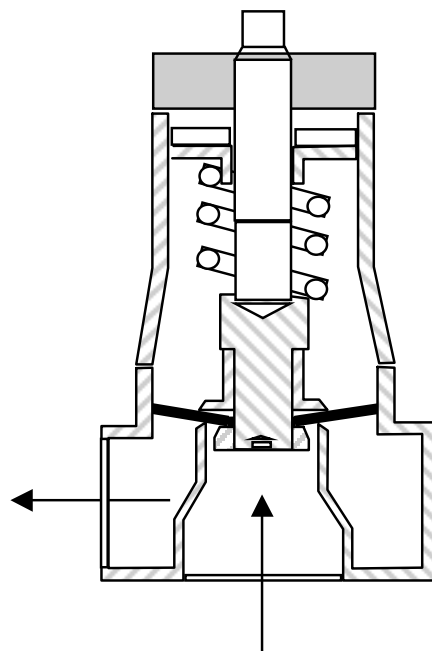
All systems with a sealed expansion vessel must be fitted with a safety valve. The calibration pressure must not exceed the boiler operating pressure.

The purpose of this valve is to reduce the pressure produced during heating, should the expansion vessel be faulty or empty.

These valves have a shutter that opens (as a consequence of the increase in the volume of the system caused by the increase in the temperature of the water) when the expansion vessel cannot absorb the volume of expansion due to a fault.

The shutter closes as soon as the condition of the system returns to normal.

**All “ARISTON” wall hung boilers are fitted standard with a safety valve.**



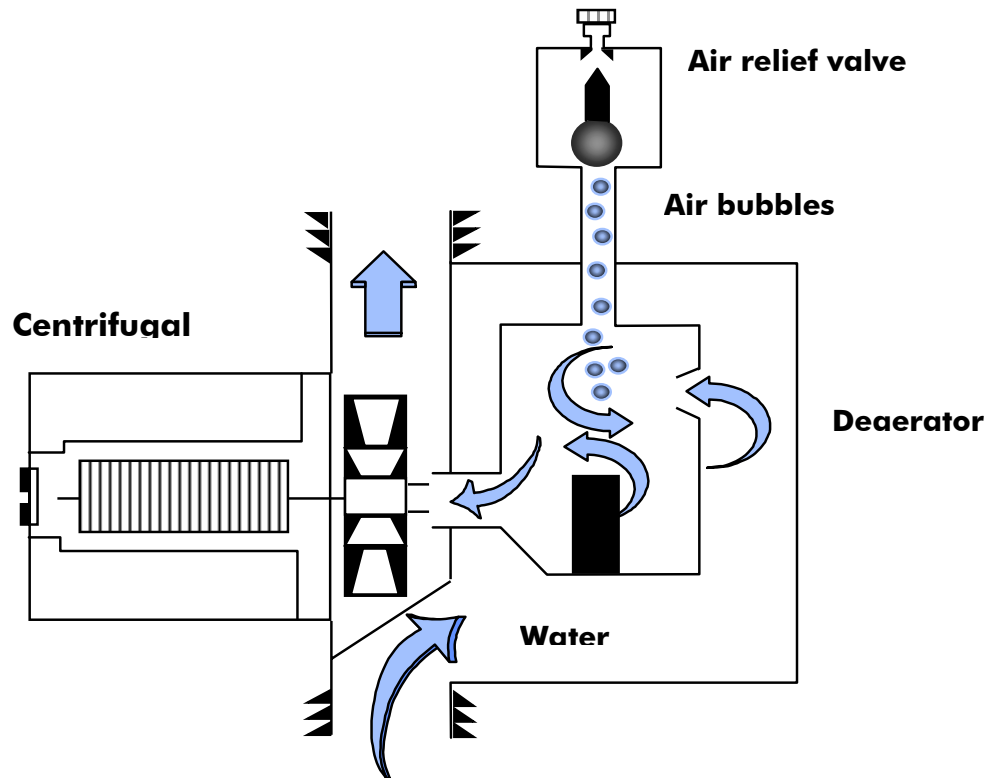
**Safety valve cross section**

## 7.7. Air relief valve

The automatic air relief valve (commonly referred to as a Utility valve) is designed to trap the air contained in the system and discharge it without the system losing any water.

It is usually positioned at the highest point in the system or on the distribution manifolds. In wall hung boilers and single family systems, the air relief valve is usually fitted in the centrifugal pump, as illustrated in the diagram below.

**All “ARISTON” wall hung boilers are fitted standard with an air relief valve.**



**Operating principle of the air relief valve fitted in the**

## 7.8. Filling the system

A few precautions should be taken when filling a system. First of all, the heat generator must be switched off, whereas the valves on the heating bodies must be open to allow any air to be released.

The system should be filled slowly to avoid large formations of air inside the pipes; however, any air bubbles will be discharged later by the air relief valve.

When the system is filled for the first time, we recommend you increase the pressure by 0.2 - 0.3 bar with respect to the static pressure to encourage the discharge of any air and to avoid any pressure drops in the circuit where this air is in fact discharged.

Once all the air has been removed, the pressure supplied must be equal to the expansion vessel load.

## 8. Heat regulation

### 8.1. Premise

In the previous chapters, we analysed the various types of systems which can be accomplished, and then we looked at the existing systems.

Now all we've got left to do is to determine the type of heat regulation to offer our central heating system, in order to complete the components that make it up.

#### First of all, what do we mean by heat regulation?

In technical jargon, heat regulation is the “**Automatic temperature regulation**”

In practice, we mean a temperature control system designed to make a setting or several settings more comfortable.

What are the main strengths of heat regulation?

- **Greater comfort;**
- **Energy savings;**
- **The opportunity to set the desired temperature.**
- **Programmable starting and stopping;**
- **The opportunity to set the temperature without having to physically be in the boiler room.**

The most common heat regulation system is:

**the “Room timer-thermostat”**

Note:

It is vital to choose an installation point well away from sources of heat or cold air draughts.

One factor that may affect the indoor temperature of a room is the temperature outside it.

### 8.2 “*Microcontrol*” timer-thermostat

The *Microcontrol* is a timer-thermostat with weekly programmes designed for use with “ARISTON” wall hung boilers

#### Technical Details

Dimensions:	128 x 85 x 31 mm
Power supply:	3 LR3 batteries
Boiler control:	via ON/OFF relays
Protection grade:	IP 30
Operating temperature	0 – 40°C
Seal of Approval	EC
(Complies with 89/336/EEC; 93/68/EEC)	

