Hydronic systems – design principles

Heating, Ventilation and Air Conditioning Systems
A.A. 2022/23

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Expansion vessels

Scope

Expansion vessels (or chambers, or tanks) serve two functions:

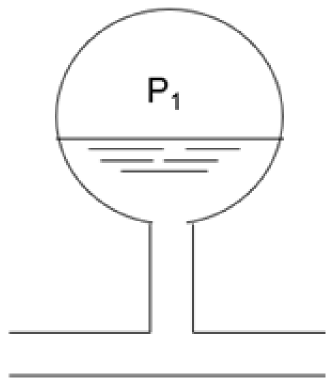
1. **Thermal function:** The tank provides a space into which the non-compressible liquid can expand or from which it can contract as the liquid undergoes volumetric changes.
2. **Hydraulic function**: The tank allows to control system pressurization by setting a «reference» pressure to the circuit.

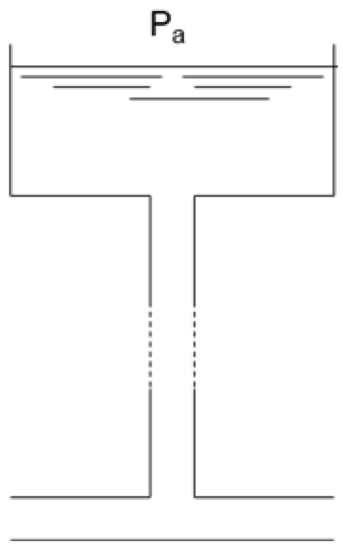
Expansion vessels

Types

There are two types of expansion tanks:

1. **Closed tank:** contains a captured volume of compressed air and water. It has either an air/water interface or a flexible membrane that separates the air from the water (diaphragm tank).
2. **Open tank**: the tank is open to the atmosphere.





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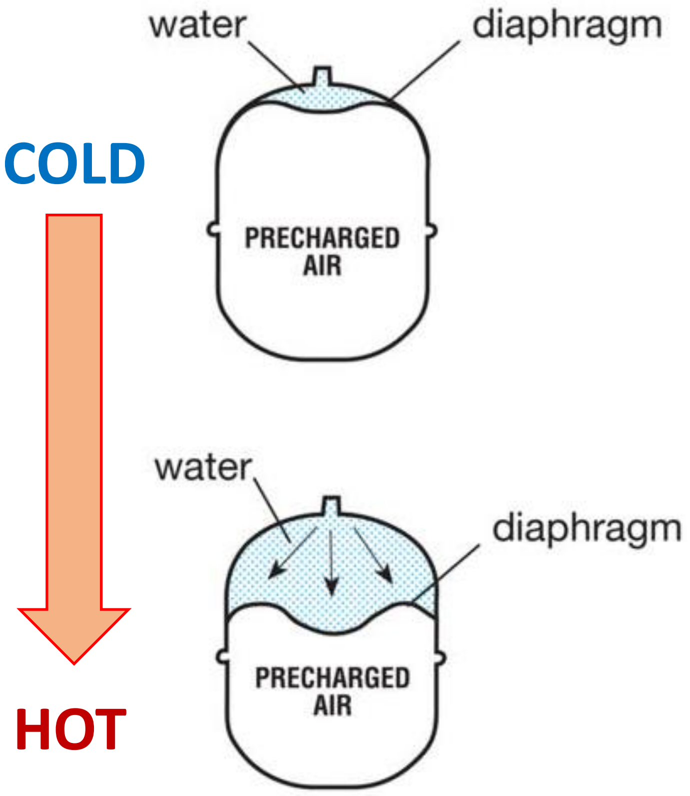

Expansion vessels

Sizing

For <u>closed tanks</u> with air/water interface:

$$V_t = V_w \frac{\left(\frac{v_2}{v_1} - 1\right) - 3\alpha\,(t_2 - t_1)}{\frac{p_a}{p_1} - \frac{p_a}{p_2}}$$

$V_w = volume\ of\ water\ in\ the\ system\ (m^3)$
$v = specific\ volume\ (m^3/kg)$
$\alpha = linear\ coefficient\ of\ thermal\ expansion\ (m/(m\ K))$

Expansion vessels

Sizing

For closed diaphragm tanks:

$$V_t = V_w \frac{\left(\frac{v_2}{v_1} - 1\right) - 3\alpha\,(t_2 - t_1)}{1 - \frac{p_1}{p_2}}$$

$V_w = volume\ of\ water\ in\ the\ system\ (m^3\,)$
$v = specific\ volume\ (m^3/kg)$
$\alpha = linear\ coefficient\ of\ thermal\ expansion\ (m/(m\ K))$

Expansion vessels

Sizing

For open tanks with air/water interface:

$$V_t = 2\,V_w \left[\left(\frac{v_2}{v_1} - 1 \right) - 3\alpha\,(t_2 - t_1) \right]$$

$V_w = volume\ of\ water\ in\ the\ system\ (m^3)$
$v = specific\ volume\ (m^3/kg)$
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Expansion vessels

Sizing assumptions

	Heating	Cooling
t_1	Design supply temperature (e.g. 60°C)	Ambient temperature (e.g. 35°C)
t_2	Ambient temperature at fill conditions (10°C)	Design supply temperature (e.g. 7°C)

The linear expansion coefficient depends on pipe material:

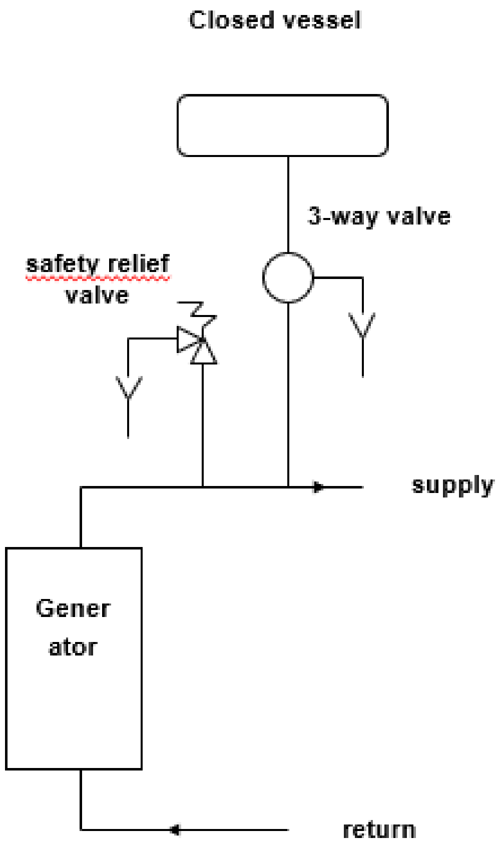
- for steel: $\alpha = 11.7 \cdot 10^{-6}\ m/(m\ K)$
- for copper: $\alpha = 17.1 \cdot 10^{-6}\ m/(m\ K)$

Expansion vessels

Sizing assumptions

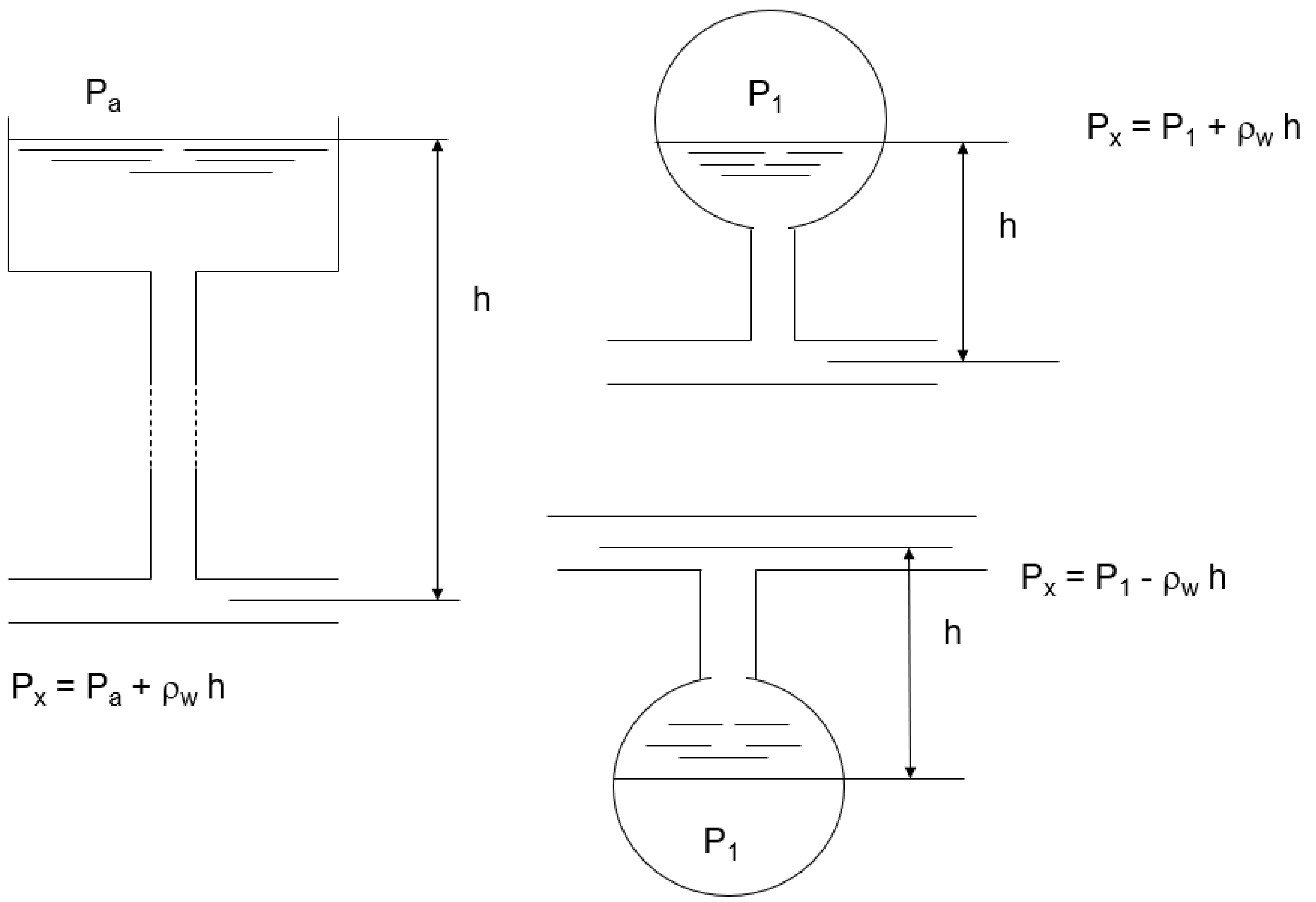
At the tank connection point, the pressure in closed-tank systems increases as the water temperature increases. Pressures are therefore designed such that:

- The lower pressure holds a positive pressure at the highest point in the system ($\cong 70\ \mathrm{kPa\ (gage)}$);
- The higher pressure corresponds to the maximum pressure allowable at the location of the safety relief valve(s) without opening them.



Expansion vessels

Sizing assumptions



Thermal expansion

Sizing assumptions

- When designing and constructing distribution networks, it is crucial to consider the thermal expansion of pipes carrying fluids –particularly when they are designed for high temperatures.
- These pipes must be able to expand without giving rise to forces capable of causing damage (permanent deformation or breakage) to the pipes themselves or to the anchoring supports.

Thermal expansion

Linear expansion coefficients

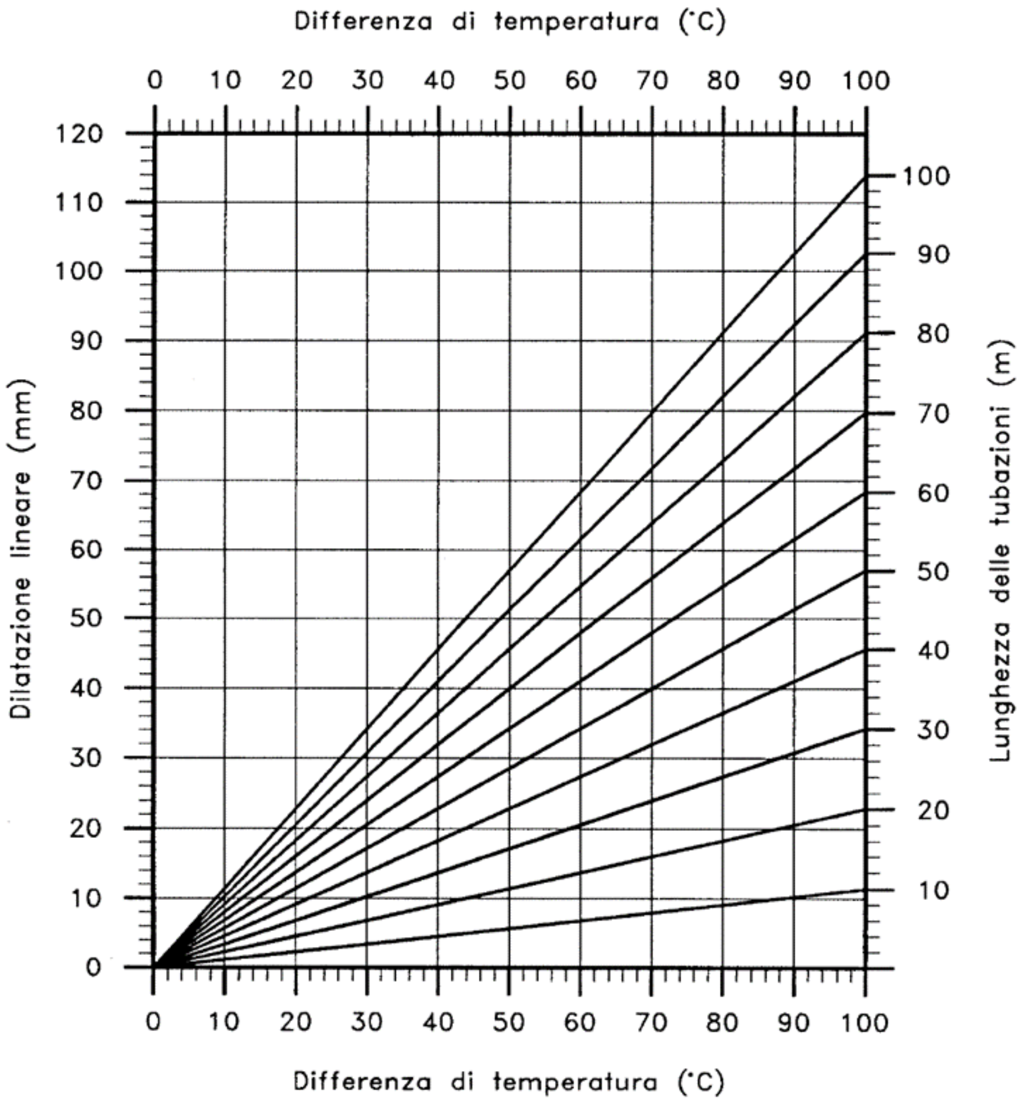
$$\Delta L = \alpha \cdot L \cdot \Delta T$$

Pipe material	α [mm / (m K)]
Steel	0.0114
Copper	0.0170
PEX	0.1400
HDPE	0.1300
PVC	0.0800
PP	0.1500

Thermal expansion

Linear expansion coefficients

$$\Delta L = \alpha \cdot L \cdot \Delta T$$



Thermal expansion

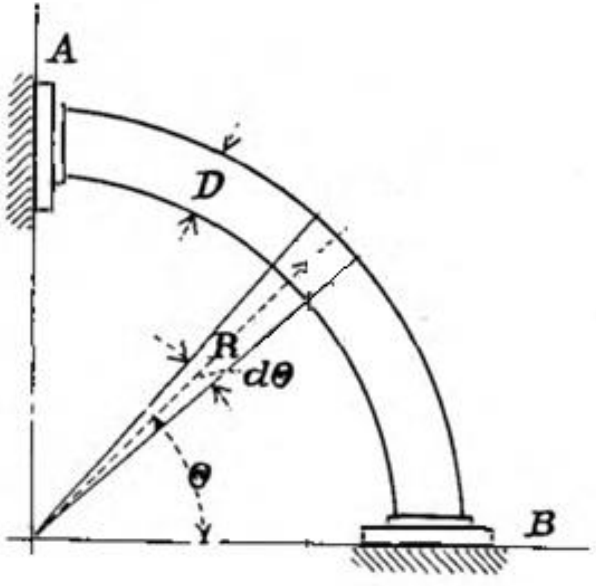
Pipe elasticity

- In systems with **limited distribution networks**, thermal expansion of the pipes is generally absorbed by the **“natural” elasticity** of the networks themselves.
- This elasticity depends mainly on the **number and type of bends in the network**. The bends, in fact, are easily deformed and can thus "naturally" absorb pipe elongation and shortening.

Thermal expansion

Pipe elasticity

The bends that best absorb thermal expansion of pipes are those that have **small diameter (D) and large bending radius (R)**.



Thermal expansion

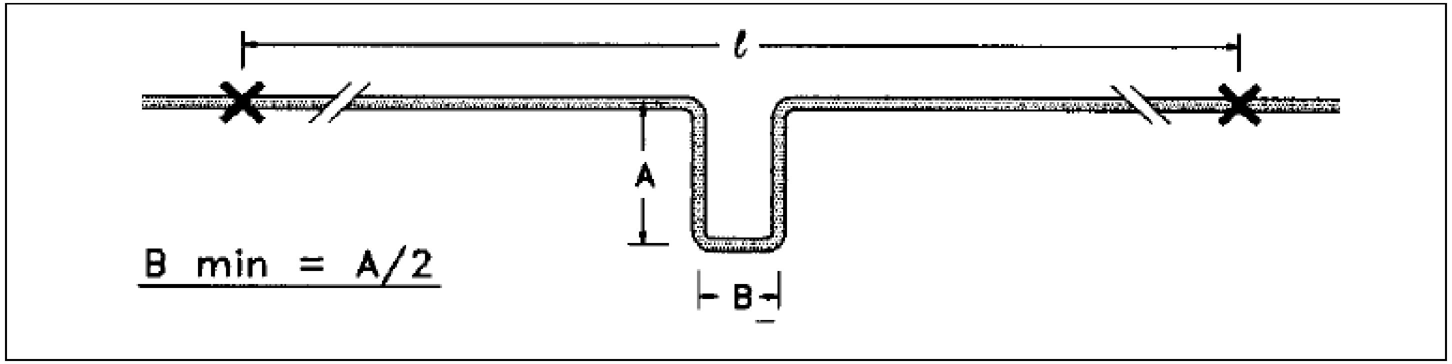
Pipe elasticity

On the contrary, in systems with **large extensions**, the inherent elasticity of the networks is generally **not sufficient** to guarantee the absorption of thermal expansion. In these cases, special compensators must be installed, which can be either natural or artificial.

Thermal expansion

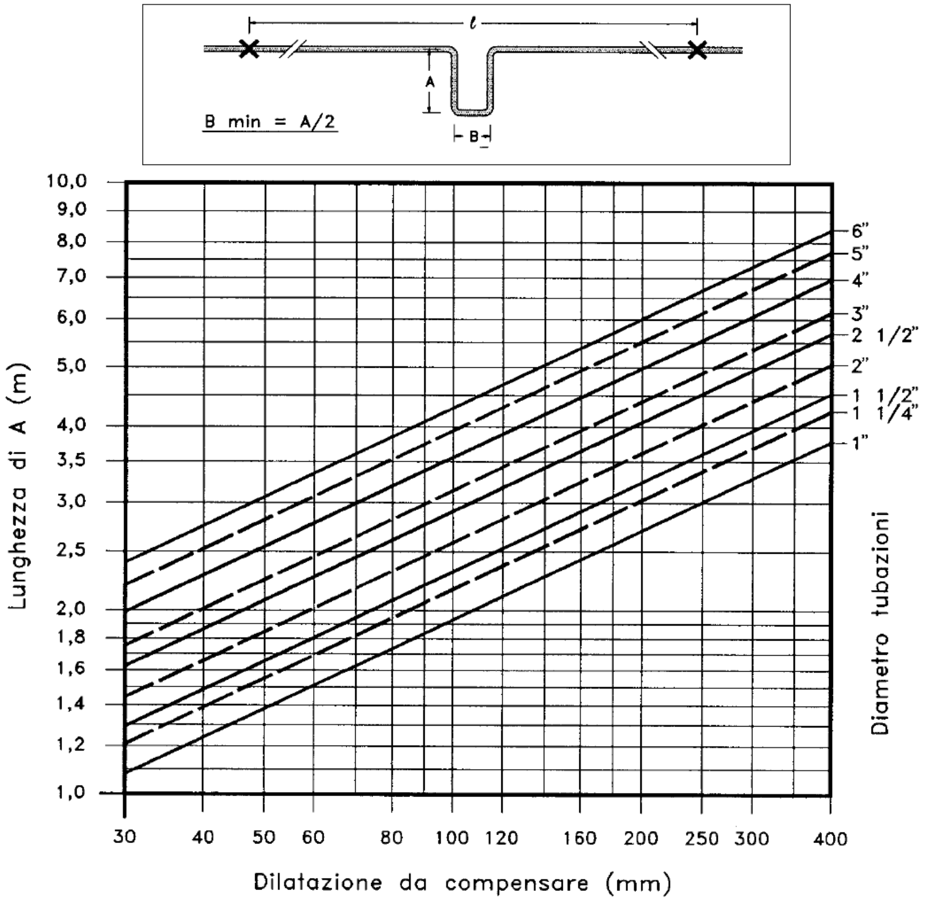
Natural expansion joints

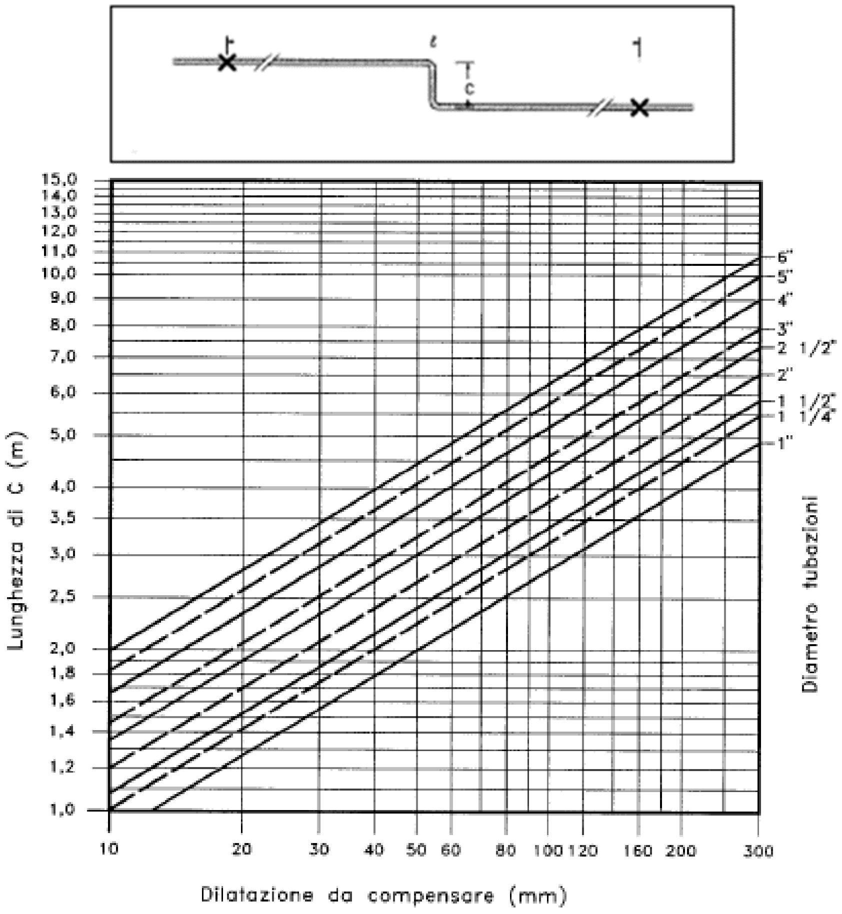
Compensators obtained with straight and curved sections of the same pipes that make up the distribution networks are thus defined. They are easy to make, inexpensive, and entail a high degree of safety. They can be installed with a slight pre-tensioning to limit reverse tensions.



Thermal expansion

Natural expansion joints

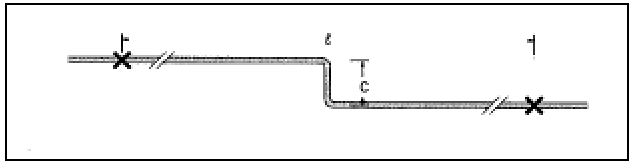




Thermal expansion

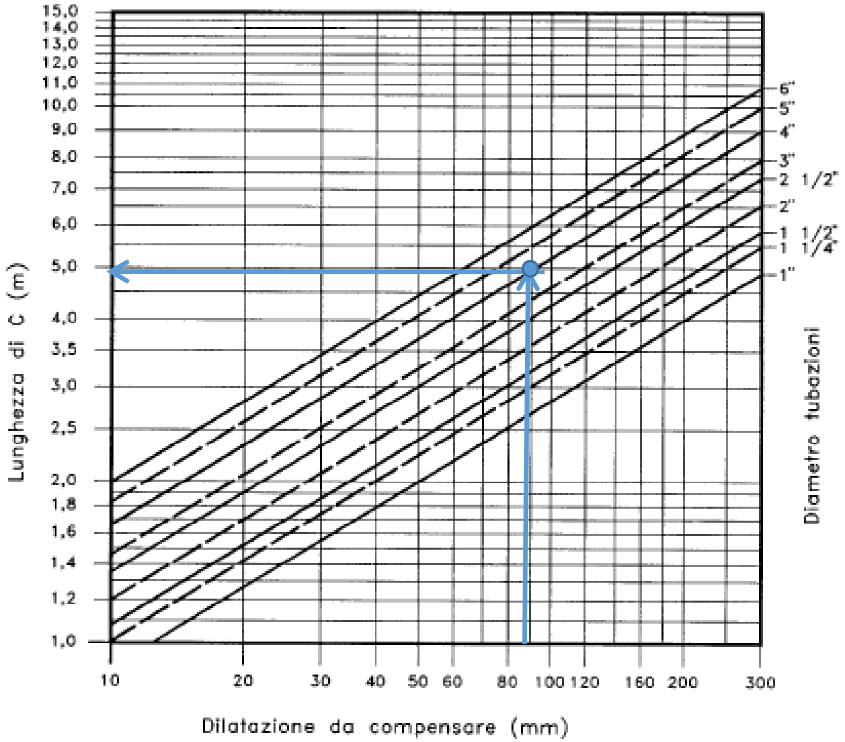
Example

Determine the size of a Z-shaped natural expansion joint for a 4'', 100-m-long steel pipe, installation temperature of 10°C, operating temperature of 90°C.



$$\Delta L = \alpha L \Delta T =$$
$$= 0.0114 \cdot 100 \cdot (90 - 10) = 91.2\, mm$$

$$C \cong 5.0\, m$$



Thermal expansion

Metal bellows

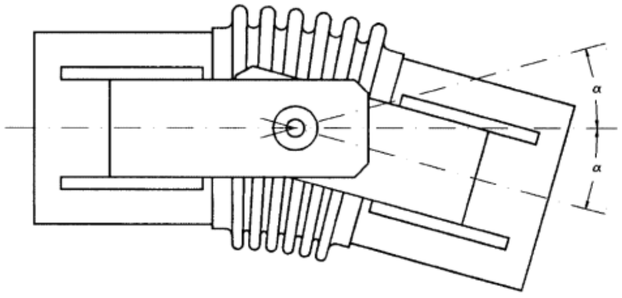
These are duct sections consisting mainly of a corrugated, deformable, bellows-like metal wall.

<u>Characteristics</u>

- Good tightness even at high pressures and temperatures
- Low bulk and wide range of movement
- Suitable for sanitary and heating installations

<u>Types</u>

axial, lateral and angular



Compensatore a soffietto metallico

Thermal expansion

Rubber expansion joints

They are compensating devices consisting essentially of a rubber duct section with a single or multiple 'wave' surface.

<u>Characteristics</u>

- Useful for absorbing vibrations and interrupting metal continuity.
- Unsuitable to high temperatures (>100÷105°C), high pressures (>8÷10 atm) and with those fluids that, due to their physical-chemical characteristics, cannot be conveyed in rubber ducts.

<u>Types</u>

axial, lateral and angular

Thermal expansion

Telescopic expansion joints

They are made from two coaxial tubes free to slide between them like the tube elements of a telescope. The hydraulic seal is achieved with one or more seals made of elastic material.

Characteristics

- Can only be used with limited pressure
- If the piping movements are not axial, the internal tubes of the compensators tend to 'stick', thus compromising the efficiency of the hydraulic seal.

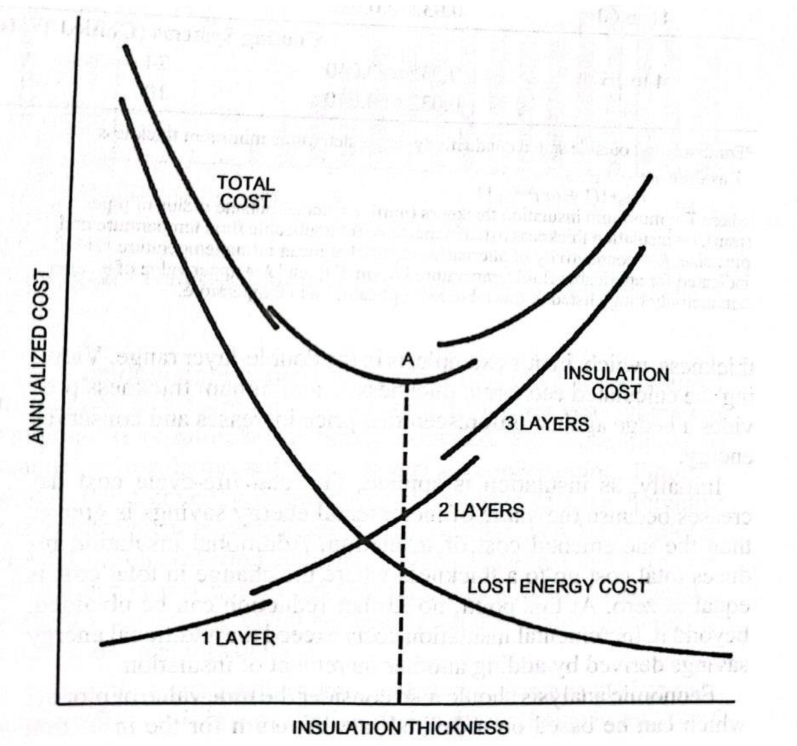
Types

Axial only

Thermal insulation

Thermal insulation of pipes in hydronic systems is not only needed to reduce energy consumption due to lower distribution losses. Indeed, insulating pipes helps in:

- **Energy conservation**
- Personnel protection
- **Condensation control**
- Process control
- Freeze protection
- Noise control
- Fire safety



Thermal insulation

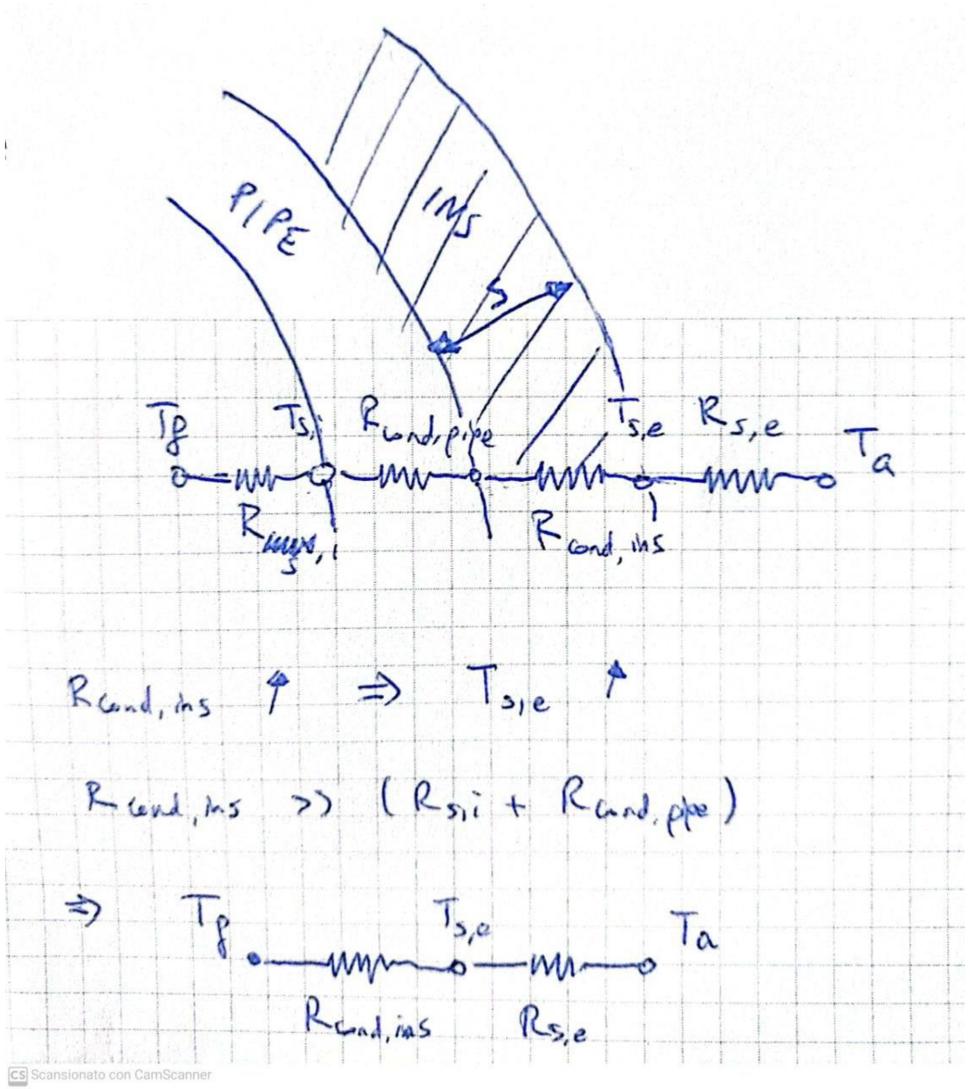
Condensation control

Often condensation control requirements are dominant in the design phase of hydronic systems for cooling applications.

$$q = \frac{T_a - T_f}{R_{se} + R_{ins}} = \frac{T_a - T_{s,e}}{R_{se}}$$

$$T_{s,e} = T_a - (T_a - T_f)\frac{R_{se}}{R_{se} + R_{ins}} \qquad R_{ins} = \frac{s}{\lambda}$$

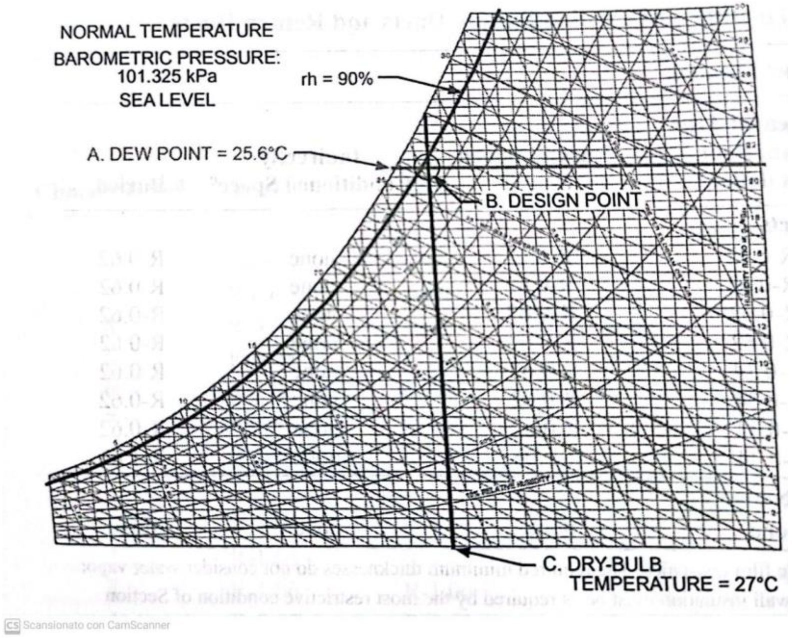
$$T_{s,e} > T_{dp} \qquad T_a - (T_a - T_f)\frac{R_{se}}{R_{se} + \frac{s}{\lambda}} > T_{dp}$$



Thermal insulation

Condensation control

$$T_a - (T_a - T_f)\frac{R_{se}}{R_{se}+\frac{s_{max}}{\lambda}} = T_{dp}$$



Example

$T_a = 30°C,\ T_f = 6°C,$

$R_{se} = 0.15\ (m^2\ K)/W\ ,\lambda = 0.043\ \frac{W}{m\ K}$

RH (%)	T_{dp} (°C)	s_{max} (mm)
75	25.1	25
80	26.2	34
85	27.2	49
90	28.2	80
95	29.1	166