EN 410
Energy Management

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Strategies of Net Zero Buildings - Space Cooling

- Reduce the room load
- Reduce the system load
- Meet the load by passive cooling methods

Vapor absorption system

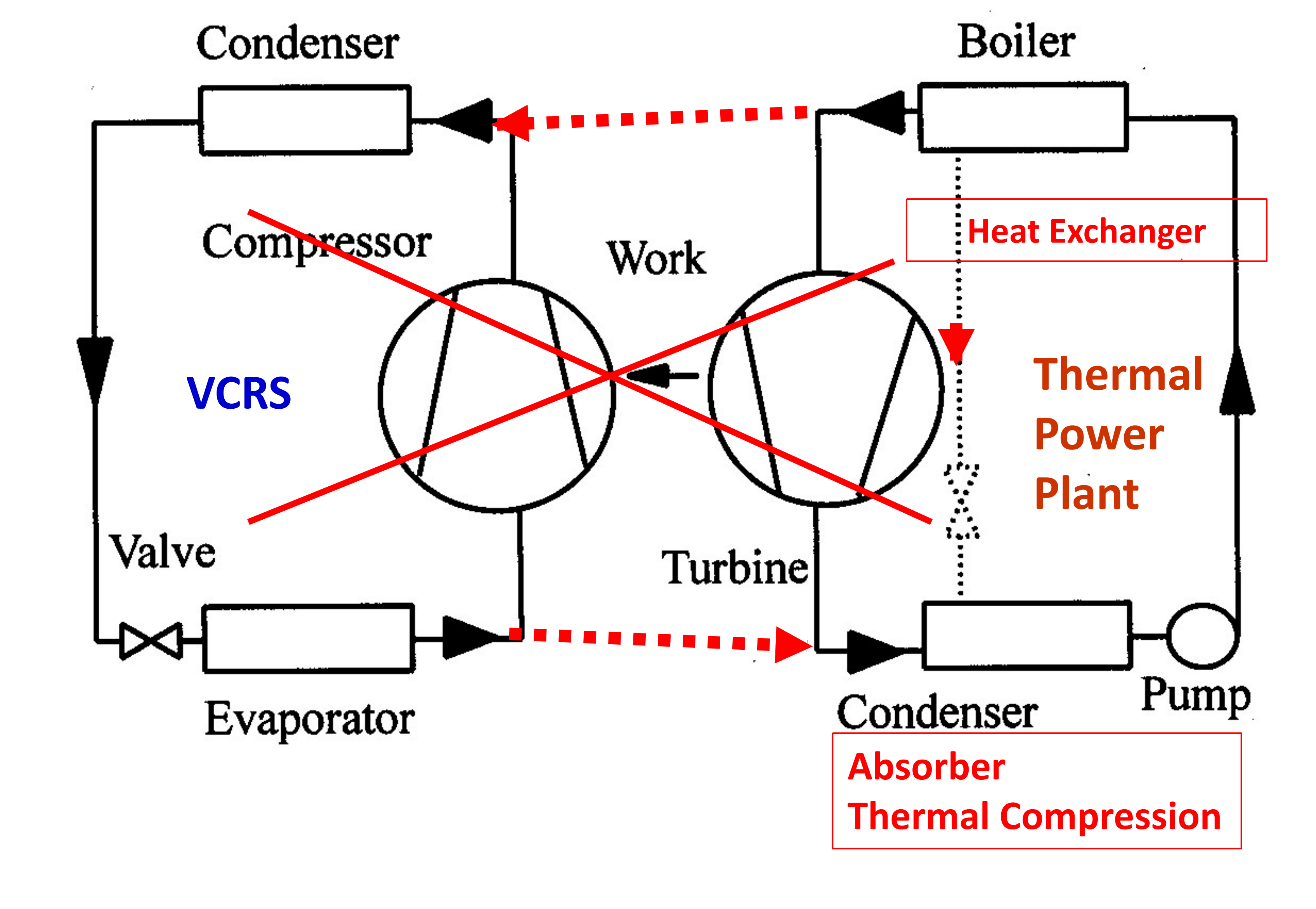
Passive cooling

Working Pairs:

LiBr – H_2O ,

NH_3 – H_2O,

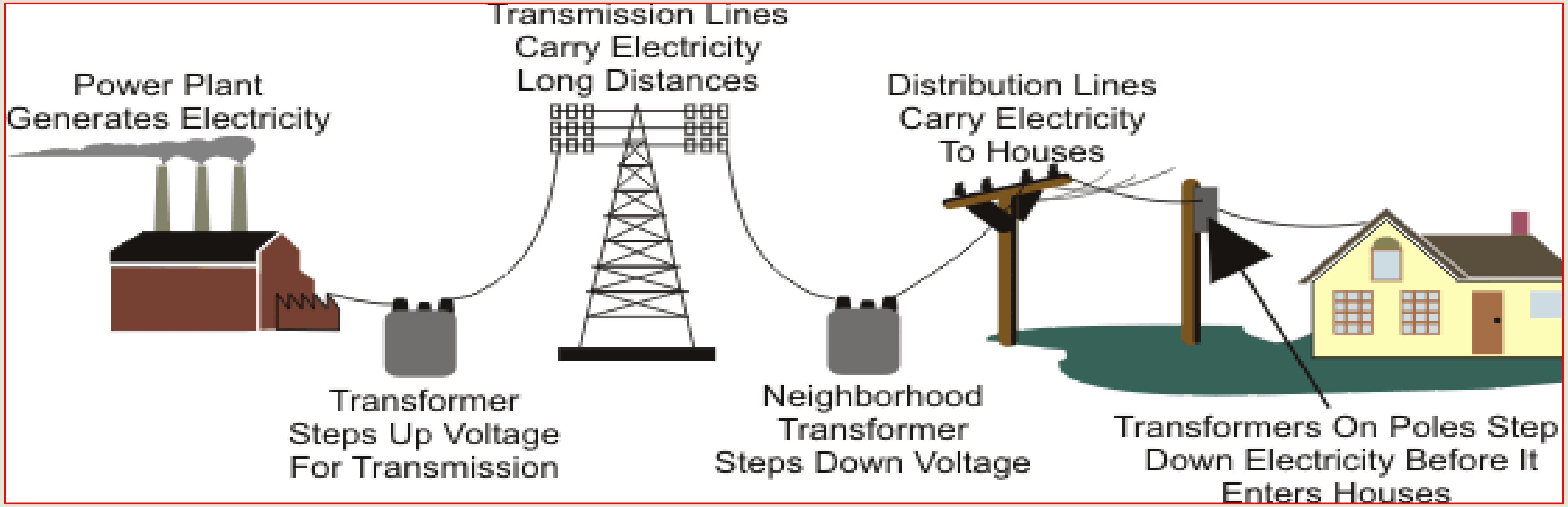
R134a - DMAC

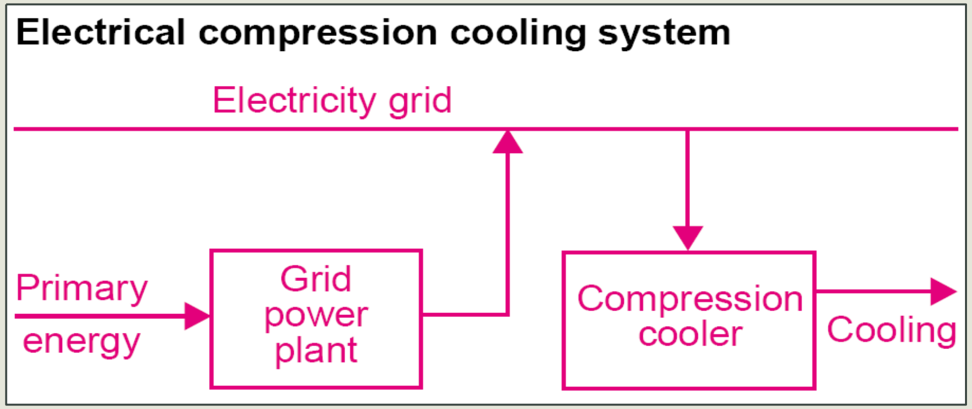


Vapor absorption system

Passive cooling

Power generation – Transmission – Compression Cooling





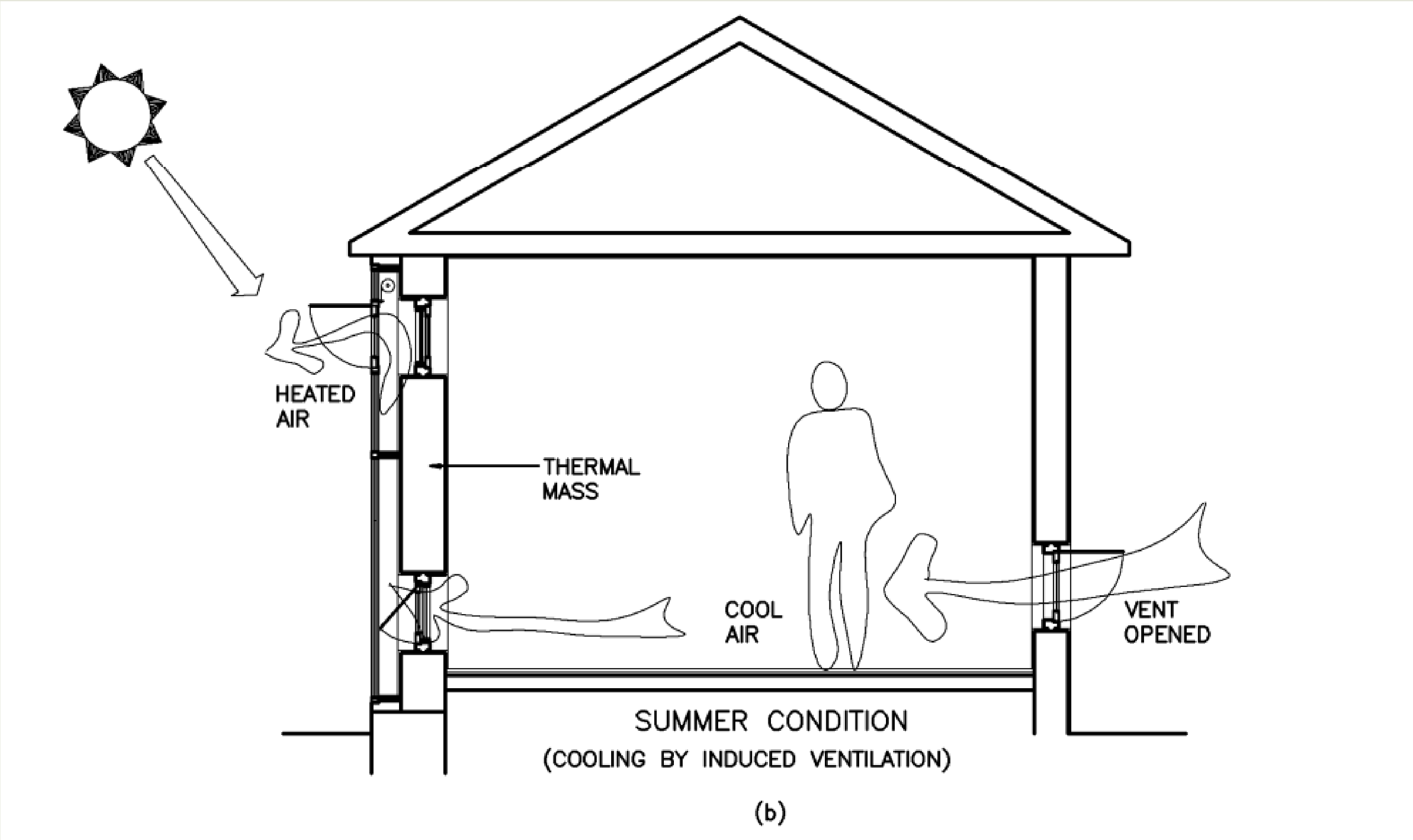
<u>Expected losses in power lines</u>

Power plant loss : 70%
(Efficiency = 30%)
Generator Loss : 5%
T &D Loss : 30%
End Equipment loss : 10%

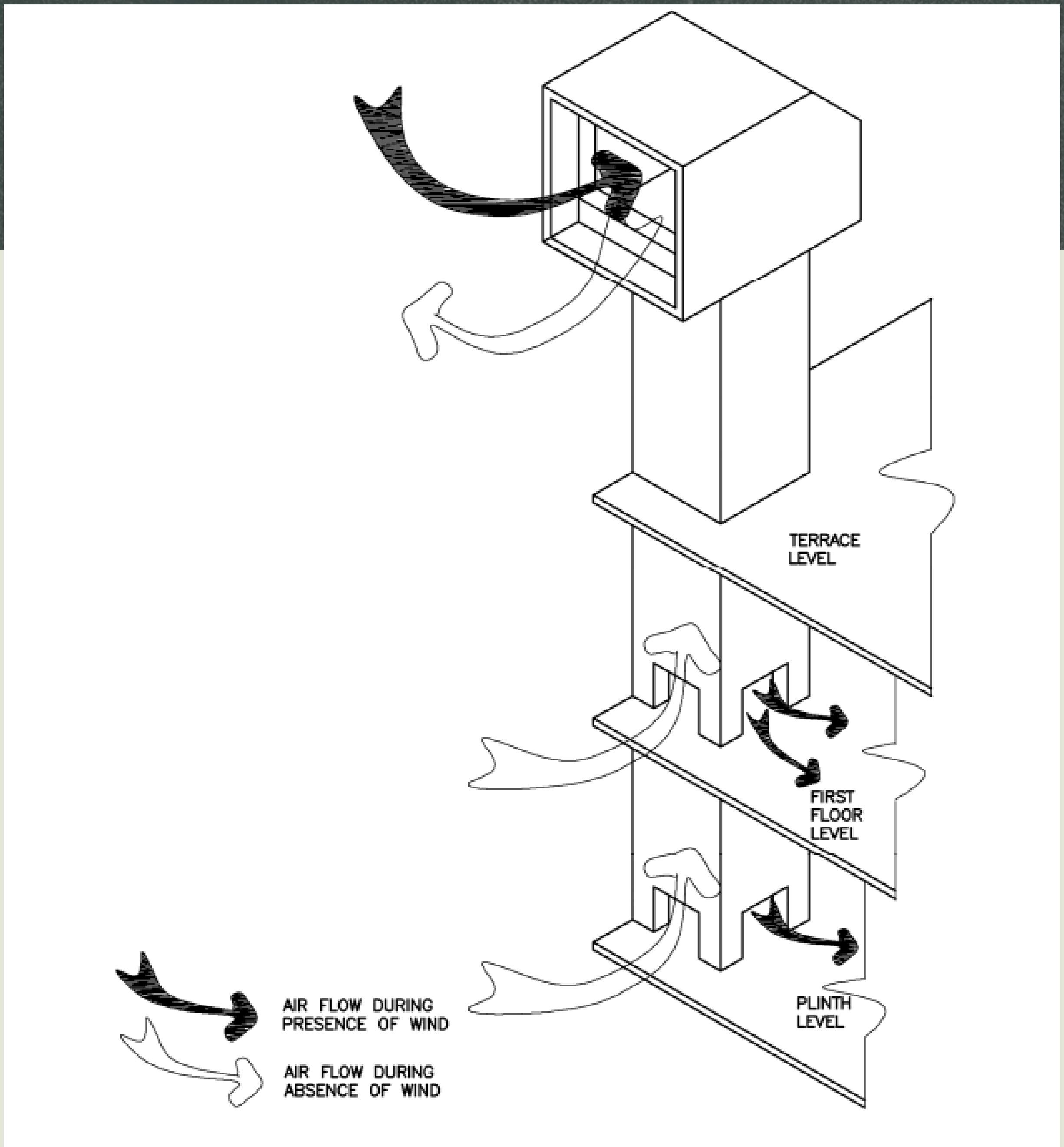
25 kW – 7.5 kW – 6.75 kW – 4.75 kW – 4.25 kW

Heat Source to Site Power Factor: 4.25/25 = 0.17

Trombe wall / Solar chimney



Wind tower


TERRACE
LEVEL
FIRST
FLOOR
LEVEL
PLINTH
LEVEL
AIR FLOW DURING
PRESENCE OF WIND
AIR FLOW DURING
ABSENCE OF WIND

Estimate the energy demand (EER) of an air-conditioner

Inlet condition: DBT=20°C, WBT=14°C

Outlet condition: DBT=12.7°C, WBT=11.3°C

Capacity = 20 TR

Air velocity = 2.5 m/s

Cross sectional area = 1.2 m^2

Power drawn by compressor = 10.69 kW

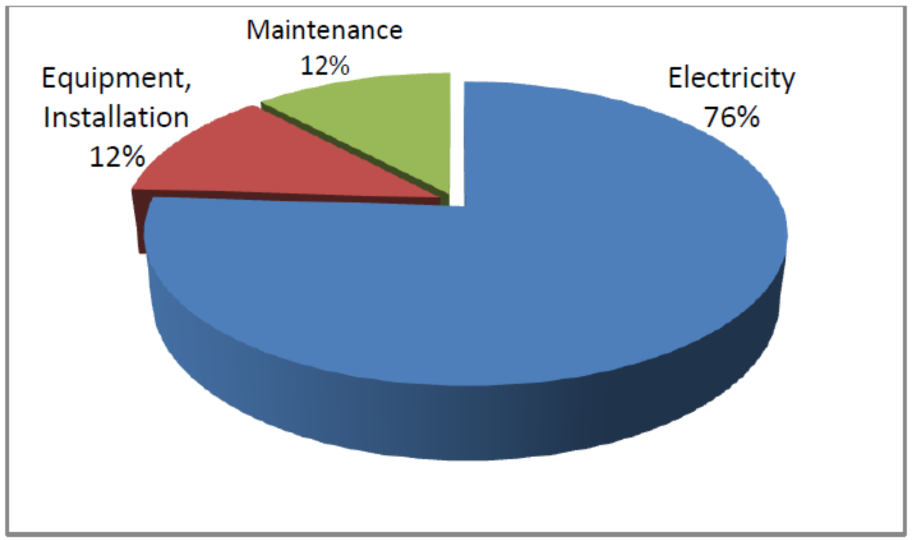
(Valid from the 1st July, 2023 to30th June, 2025)

Indian Seasonal Energy Efficiency Ratio(kWh/kWh)		
Star Rating	**Minimum**	**Maximum**
1 Star	2.70	3.09
2 Star	3.10	3.39
3 Star	3.40	3.69
4 Star	3.70	3.99
5 Star	>=4.00	

Compressor

- A compressor is capable of compressing the gas to very high pressures.
- Commonly used in industrial facilities to perform a wide variety of tasks such as cleaning, operating pneumatic equipment, and even refrigeration.
- It is often referred to as the fourth utility after electricity, water, and natural gas or oil.
- *Compressors are responsible for most energy consumption in many facilities.*
- The electricity consumption associated with compressors and compressed air systems may represent 70% of total consumption
- Refrigerant or Air Compressor

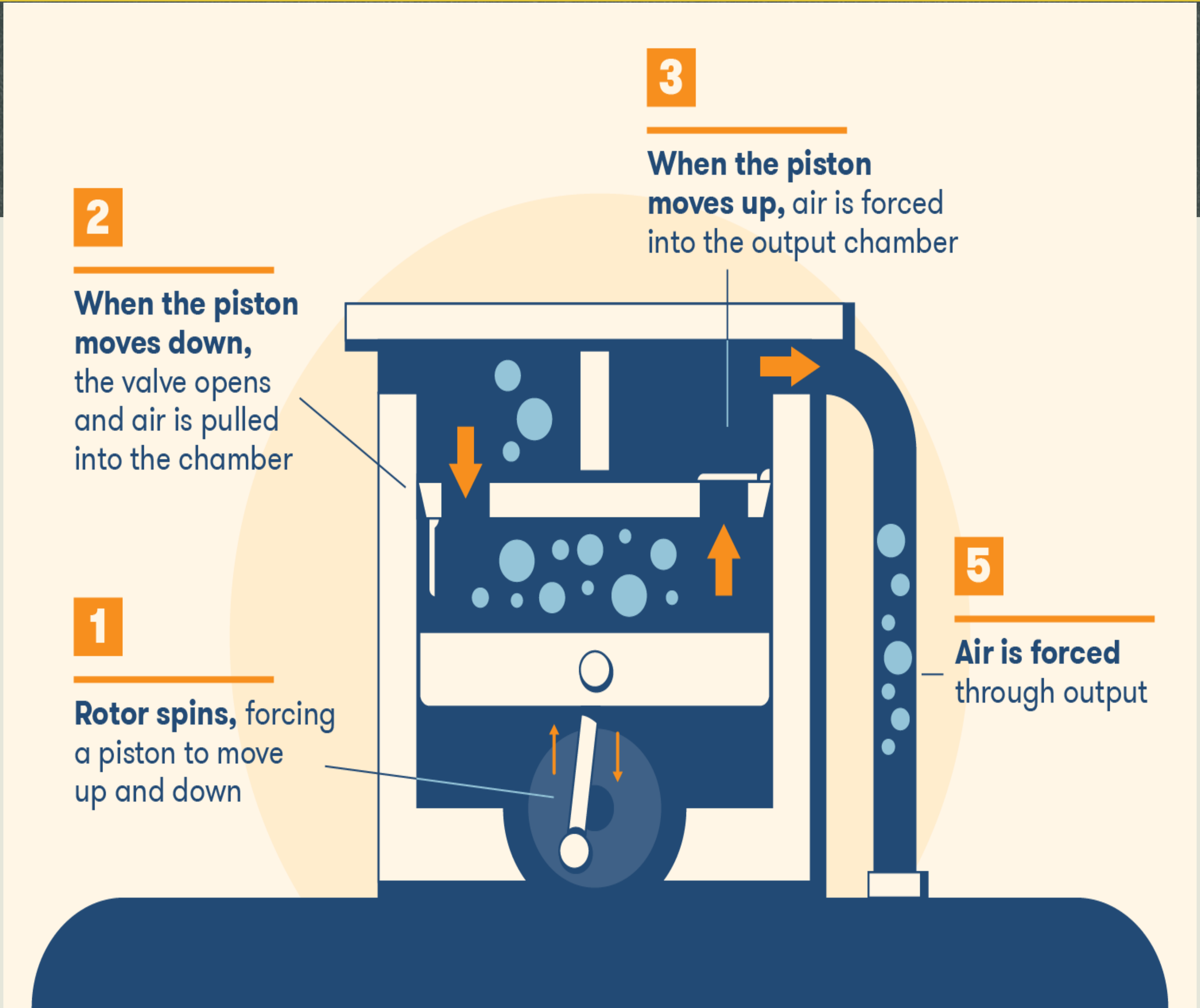
A typical distribution of costs associated with compressors



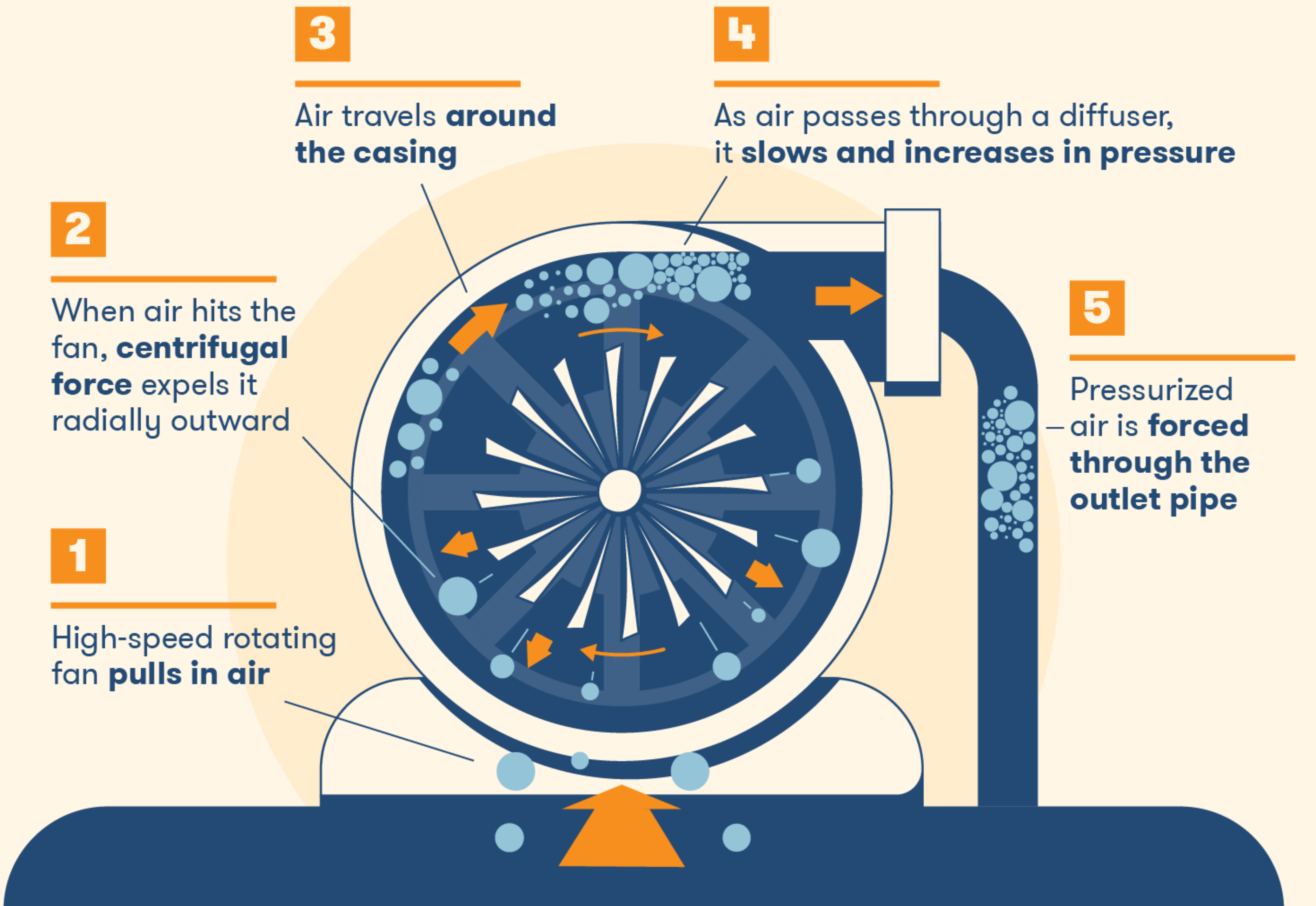
Classification

- Compressors are broadly classified as positive displacement (or displacement) and dynamic compressors.
- In **positive displacement compressors**, an application of shaft work decreases the volume of the fluid chamber, thus compressing it.
- In **dynamic compressors**, an application of external work allows the transfer of angular momentum to the fluid, and this result in an increase in fluid pressure.
- Positive displacement compressor: reciprocating and rotary.
  - Rotary compressor: vane, screw, roots, and liquid ring.
  - Reciprocating compressor: trunk, crosshead, free piston, labyrinth, and diaphragm.
- Dynamic compressor: radial or centrifugal, axial, and ejector.
- Classification according to lubricant/non-lubricant, Water/air cooled, Single/Multi Cylinder, Single/Multi stage

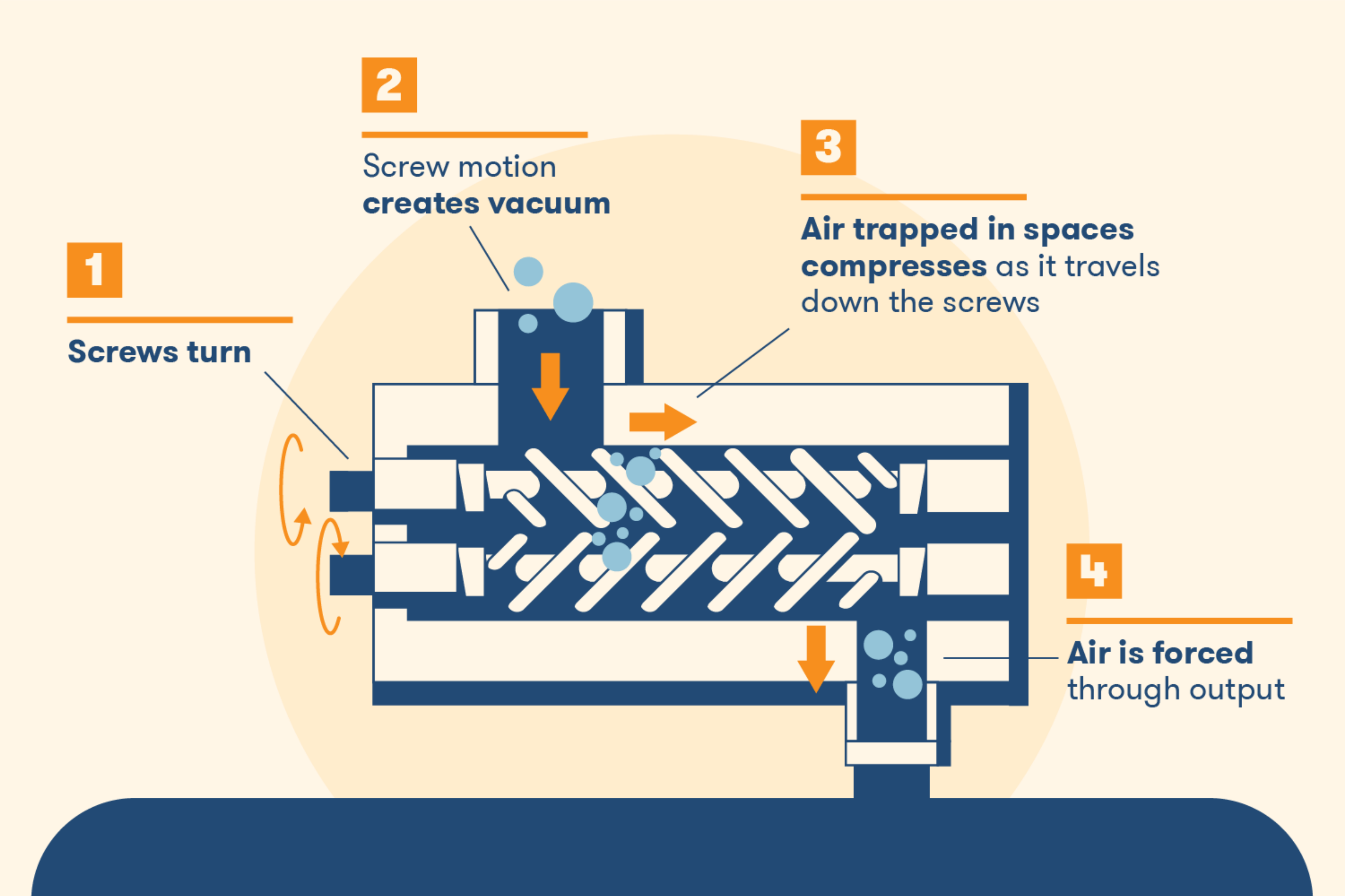
Reciprocating compressor



Centrifugal compressor



Screw compressor



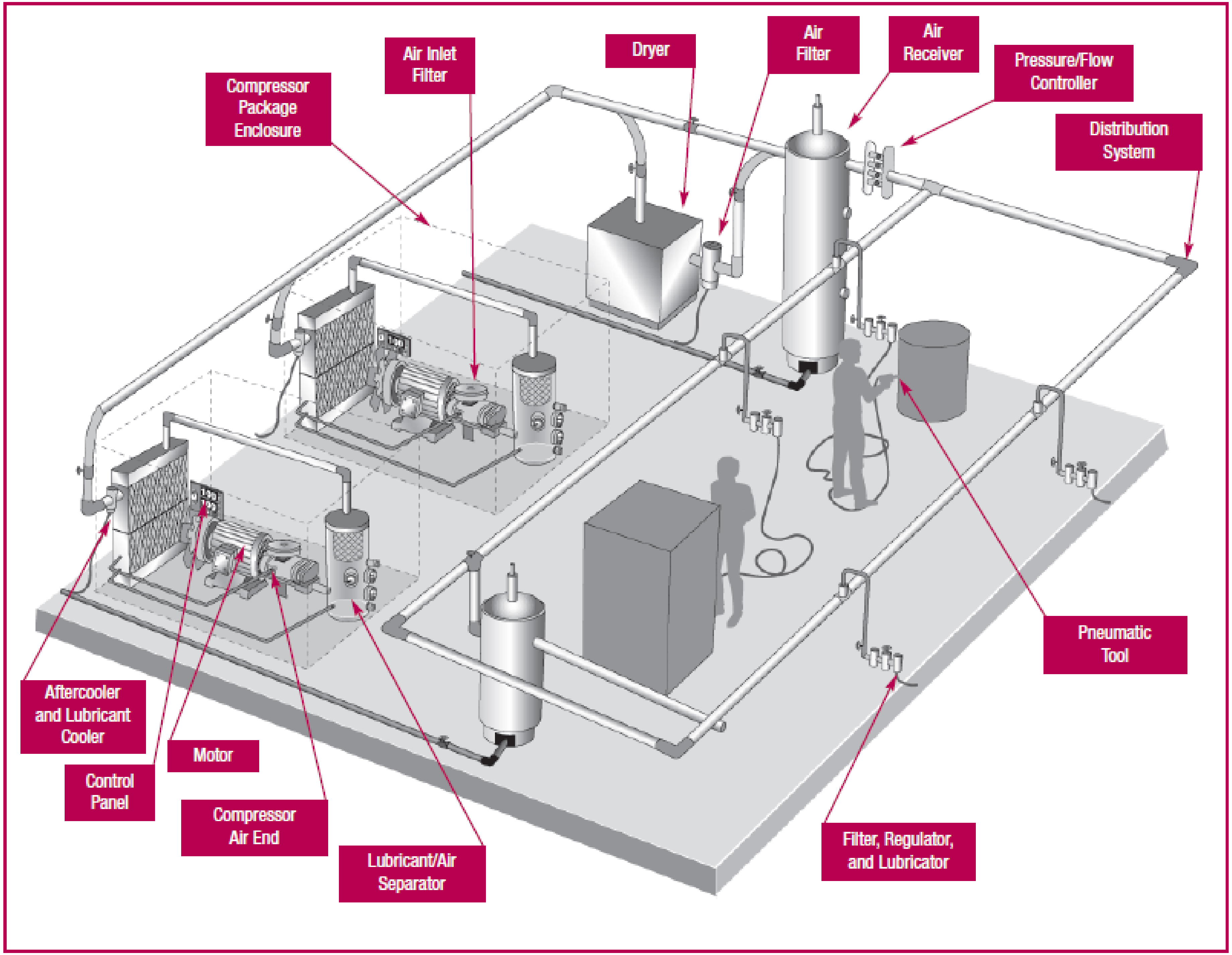
Selection of Compressor

Type of Compressor	Capacity (m^3/h)		Pressure (bar)	
	From	To	From	To
Roots blower compressor single stage	100	30000	0.1	1
Reciprocating				
- Single / Two stage	100	12000	0.8	12
- Multi stage	100	12000	12.0	700
Screw				
- Single stage	100	2400	0.8	13
- Two stage	100	2200	0.8	24
Centrifugal	600	300000	0.1	450

Comparison of Compressors

Item	Reciprocating	Rotary vane	Rotary Screw	Centrifugal
Efficiency at full load	High	Medium-high	High	High
Efficiency at part load	High due to staging	Poor: below 60% of full load	Poor: below 60% of full load	Poor: below 60% of full load
Efficiency at no load (power as % of full load)	High (10-25%)	Medium (30-40%)	High-poor (25-60%)	High-medium (20-30%)

Compressor air system



Compressor work

$$w_{\text{rev,in}} = \int_1^2 \upsilon \, dP$$

Isentropic (Pv^k = constant):

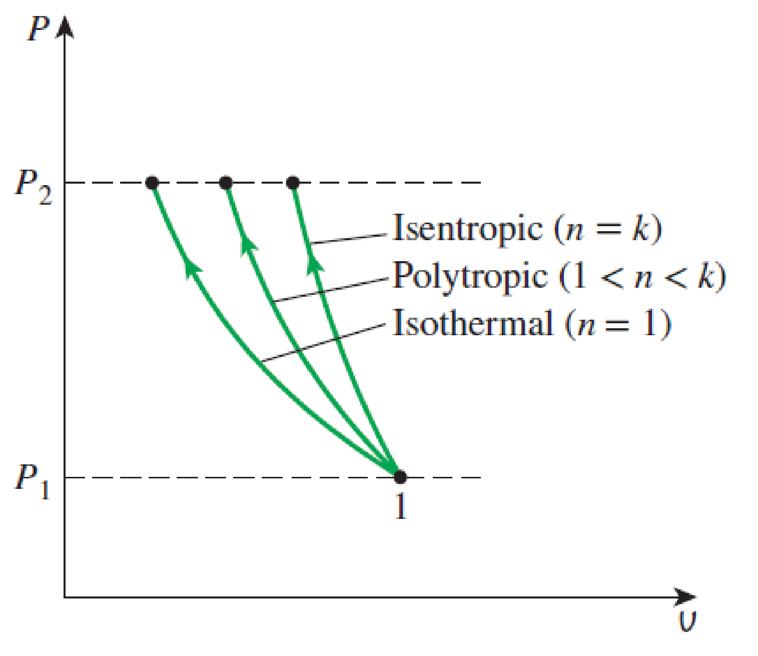
$$w_{\text{comp,in}} = \frac{kR(T_2 - T_1)}{k - 1} = \frac{kRT_1}{k - 1}\left[\left(\frac{P_2}{P_1}\right)^{(k-1)/k} - 1\right]$$

Polytropic (Pv^n = constant):

$$w_{\text{comp,in}} = \frac{nR(T_2 - T_1)}{n - 1} = \frac{nRT_1}{n - 1}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right]$$

Isothermal (Pv = constant):

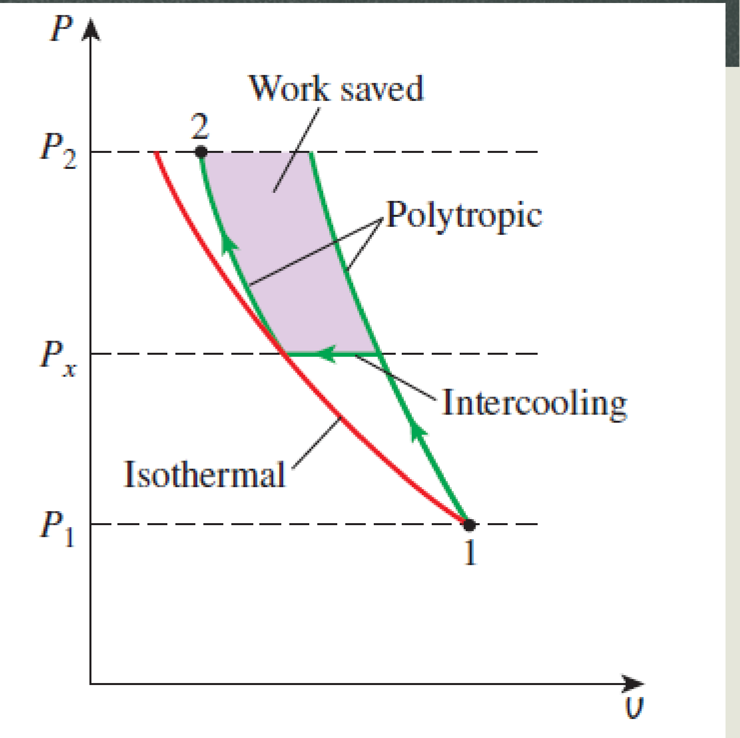
$$w_{\text{comp,in}} = RT \ln\frac{P_2}{P_1}$$



The adiabatic compression (Pv^k = constant) requires the maximum work and the isothermal compression (T = constant) requires the minimum.

Multistage Compression with Intercooling

The gas is compressed in stages and cooled between each stage by passing it through a heat exchanger called an *intercooler*.



$$w_{\text{comp,in}} = w_{\text{comp I,in}} + w_{\text{comp II,in}}$$

$$= \frac{nRT_1}{n-1}\left[\left(\frac{P_x}{P_1}\right)^{(n-1)/n} - 1\right] + \frac{nRT_1}{n-1}\left[\left(\frac{P_2}{P_x}\right)^{(n-1)/n} - 1\right]$$

$$P_x = (P_1 P_2)^{1/2}$$

To minimize compression work during two-stage compression, the pressure ratio across each stage of the compressor must be the same.

Multistage Compression with Intercooling

Multistage Compression

- Air is compressed steadily by a reversible compressor from an inlet state of 100 kPa and 300 K to an exit pressure of 900 kPa. Determine the compressor work per unit mass for (a) isentropic compression with k = 1.4, (b) polytropic compression with n = 1.3, (c) isothermal compression, and (d) ideal two-stage compression with intercooling with a polytropic exponent of 1.3.

Isentropic (Pv^k = constant):

$$w_{\text{comp,in}} = \frac{kR(T_2 - T_1)}{k - 1} = \frac{kRT_1}{k - 1}\left[\left(\frac{P_2}{P_1}\right)^{(k-1)/k} - 1\right]$$

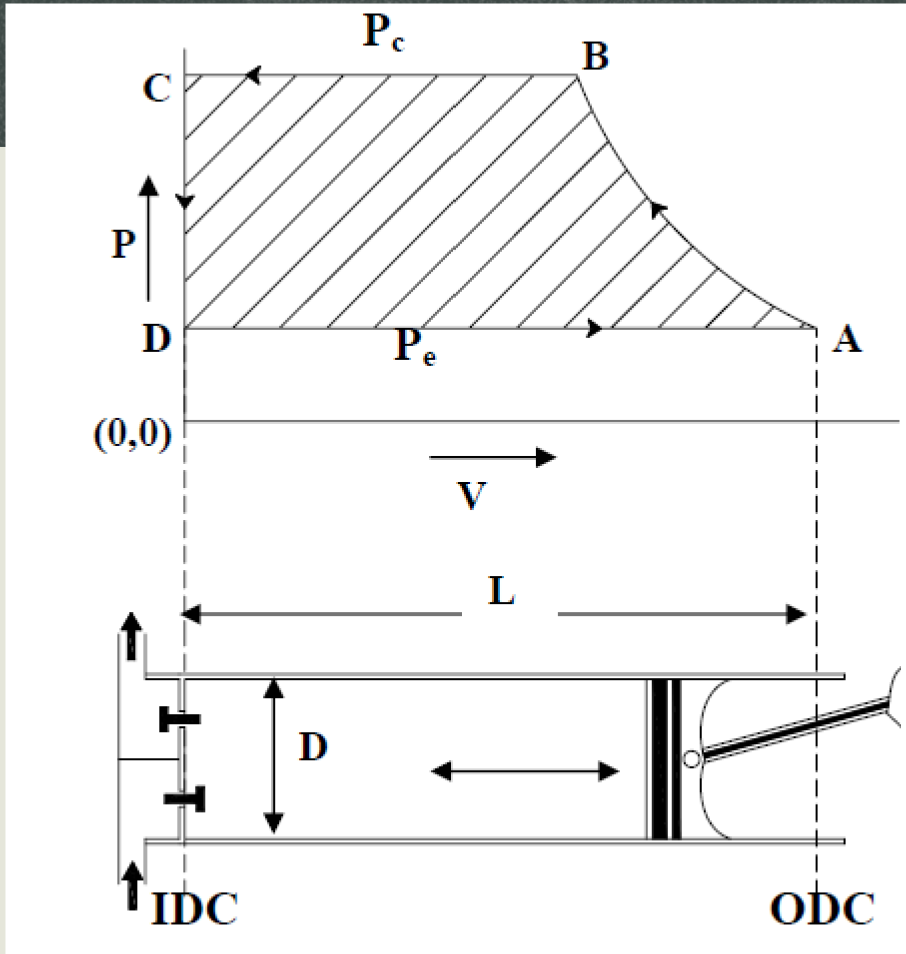
Polytropic (Pv^n = constant):

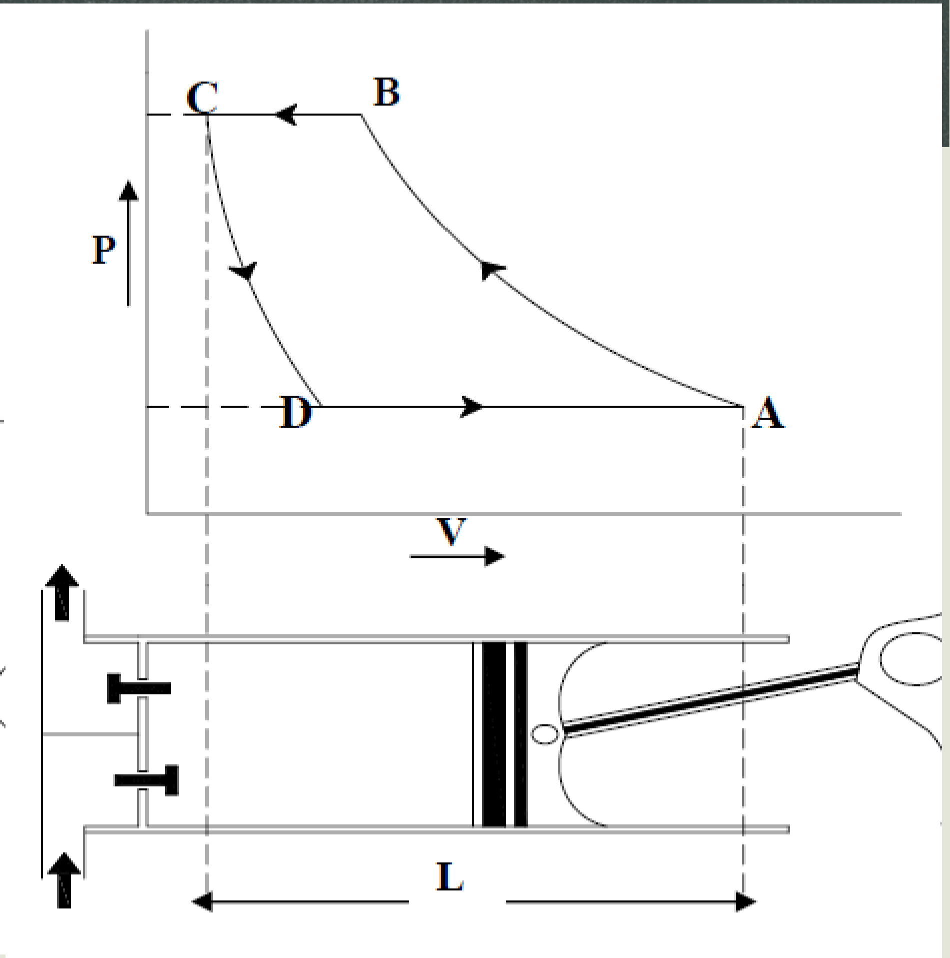
$$w_{\text{comp,in}} = \frac{nR(T_2 - T_1)}{n - 1} = \frac{nRT_1}{n - 1}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right]$$

Isothermal (Pv = constant):

$$w_{\text{comp,in}} = RT \ln\frac{P_2}{P_1}$$

Compressor Performance





$$\eta_{\text{comp}} = \frac{w_{\text{isothermal}}}{w_{\text{actual}}}$$

$$Volumetric\ Efficiency = \frac{Free\ Air\ Delivered}{Compressor\ Displacement}$$

Efficient Operation of Compressor

- Cool air intake – Compressor room always at a high temp – Every 4°C drop – 1% reduction in power – Fresh cool intake with less pressure drop
- Dust free intake – need of high eff filter, maintenance - Every 250 mm WC pressure drop due to choked filter increase the power consumption by 2%
- Dry air intake – moisture not suitable for pneumatics
- Location of compressor – Accessibility of clean, cold and dry air
- Adequate intercooler – approach the isothermal compression
- Adequate after-cooler – A high temp. and humid air enters the receiver which may lead to condensation – corrosion, pressure drop and leakage in pipe lines
- Reduced delivery pressure if possible – lesser the pressure ratio – lesser the power requirement

Efficient Operation of Compressor

- Segregate the low and high pressure requirements – don’t use reducing valves if possible
- Minimum pressure drop in the air lines – 0.3 bar in the main line – 0.5 bar in the distribution line
- Avoid misuse of compressed air – like body or floor cleaning – use blower air instead
- Elevation – higher the altitude and higher the power

Altitude Meters	Barometric Pressure milli bar*	Percentage Relative Volumetric Efficiency Compared with Sea Level	
		At 4 bar	At 7 bar
Sea level	1013	100.0	100.0
500	945	98.7	97.7
1000	894	97.0	95.2
1500	840	95.5	92.7
2000	789	93.9	90.0
2500	737	92.1	87.0

Avoid air leakage

- *Manufacturers are quick to identify energy (and thus money) losses from hot surfaces and to insulate those surfaces.*
- Not so sensitive to save compressed air since they view air as being free
- Attention is when the air and pressure losses interfere with the normal operation of the plant.
- Several studies at plants have revealed that up to 40% of the compressed air is lost through leaks.
- Eliminating the air leaks totally is impractical, and a leakage rate of 10% is considered acceptable.
- **Air leak locations:** Joints, flange connections, elbows, reducing bushes, sudden expansions, valve systems, filters, hoses, check valves, relief valves, extensions, and the equipment connected to the compressed-air lines.

Detecting air leaks

- Perhaps the simplest way of detecting a large air leak is to listen for it.
- The high velocity of the air escaping the line produces a hissing sound that is difficult not to notice except in environments with a high noise level.
- Another way of detecting air leaks, especially small ones, is to test the suspected area with soap water and to watch for soap bubbles.
- This method is obviously not practical for a large system with many connections.
- A modern way of checking for air leaks is to use an acoustic leak detector, which consists of a directional microphone, amplifiers, audio filters, and digital indicators.
- Pressure drop test

Capacity control

- ON/OFF control – using pressure switches – suitable for small compressors
- Load/Unload – Compressors may consume power even at unload conditions
- Multi-step control – High capacity compressor – 100, 75, 50 and 25%
- Vane / Speed control – Centrifugal type

References

- https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/education-training/engineers-newsletters/airside-design/admapn020en-0406.pdf
- https://nzeb.in/knowledge-centre/hvac-2/radiant-cooling-systems/
- NPTEL, Mechanical Engineering - Refrigeration and Air Conditioning
- https://archive.nptel.ac.in/courses/112/105/112105129/
- Karthik Panchabikesan, Kumaresan Vellaisamy, Velraj Ramalingam, Passive cooling potential in buildings under various climatic conditions in India, Renewable and Sustainable Energy Reviews, Volume 78, 2017, Pages 1236-1252,
- https://climate.earthathome.org/sunlight-stored-in-soil/
- https://fairconditioning.org/knowledge/passive-design/shading/
- https://www.sciencedirect.com/science/article/pii/S1364032116002665#f0010
- https://www.bigrentz.com/blog/how-air-compressors-work