MINISTRY OF
INDUSTRY AND TRADE

EU - VIET NAM SUSTAINABLE ENERGY TRANSITION PROGRAMME (SETP)

Global Gateway

Funded by the European Union

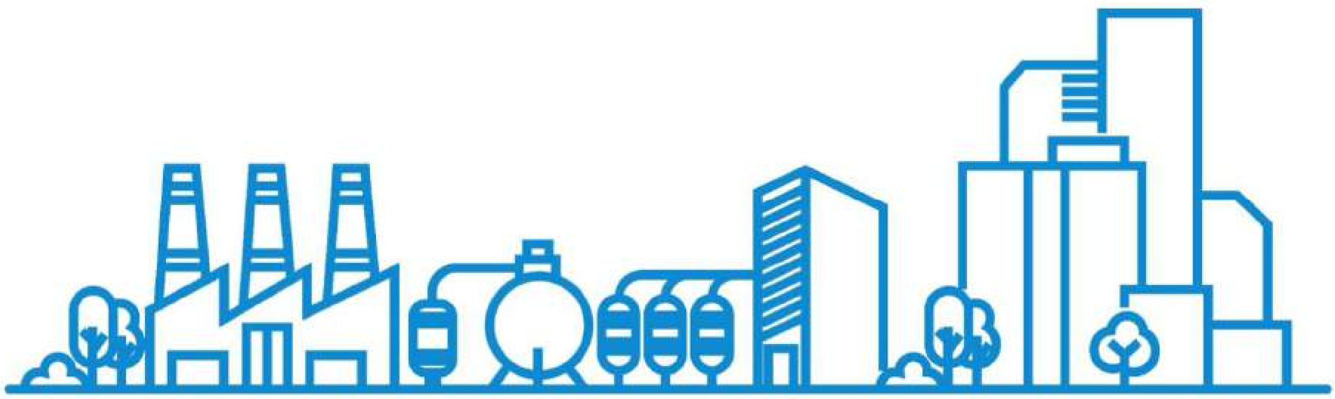
UNIDO
UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Project "Accelerating energy efficiency (EE) in large industries through energy management system, system optimisation and the promotion and adoption of EE in SMEs" (IEEP)

EXPERT TRAINING PROGRAMME

COMPRESSED AIR SYSTEM OPTIMISATION (MODULE 1)

Ha Noi, 09 - 10/05/2024



AGENDA
TRAINING ON "COMPRESSED AIR SYSTEM OPTIMIZATION"
09 – 10/05/2024

Adonis Hotel, 55 Quang Trung, Hai Ba Trung, Ha Noi

Day 1

Time	Contents	Speakers
8.00-8.30	Registration and welcome	
8.30-8.40	Participants Introduction	Representative of UNIDO Project Office
8.40-8.50	Opening speech	Representative of the Project Management Board
8.50-10.00	**Section 1** – The fundamentals of a compressed air system	Mr. Ian David Moore
10.00-10.15	**Tea break**	
10.15-12.00	**Section 1** – The fundamentals of a compressed air system (continued)	Mr. Ian David Moore
12.00-13.15	**Lunch at the Hotel**	
13.15-15.00	**Section 2** – Analyze and audit compressed air systems	Mr. Ian David Moore
15.00-15.15	**Tea break**	
15.15-17.00	**Section 2** – Analyze and audit compressed air systems (continued)	Mr. Ian David Moore

Day 2

Time	Contents	Speakers
8.00-8.30	Registration and welcome	
8.30-10.00	**Section 3** – Optimization opportunities - Optimization and minimize waste - Control air compressors - Compressed air systems - Distribution – Heat recovery - Maintenance...	Mr. Ian David Moore
10.00-10.15	**Tea break**	
10.15-12.00	**Section 3** – Optimization opportunities (continued)	Mr. Ian David Moore
12.00-13.15	**Lunch at the Hotel**	
13.15-15.00	**Section 4** – Economic analysis - Analyze compressed air saving projects - Examples of optimization and energy savings - Recent developments	Mr. Ian David Moore
15.00-15.15	**Tea break**	
15.15-16.45	**Section 4** – Economic analysis (continued)	Mr. Ian David Moore
16.45-17.00	- Wrap-Up - Closing speech	Mr. Ian David Moore Representative of the Project Management Unit

Compressed Air Systems

Ian Moore CEng FIMechE
UNIDO Compressed Air System Expert

Part 1 – Compressed air basics

Course Agenda

- Introduction
- Components of a compressed air system
- Carrying out a compressed air survey
- Typical opportunities for optimisation
- Evaluation of new equipment
- Recent developments

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Why use compressed air?

When asked people often say it is:

- Cheap
- Safe
- Convenient
- New equipment can easily be connected anywhere on the existing system

Most of these statements can be true but are often not. During this course we look at the facts and how best to make the above statements true.

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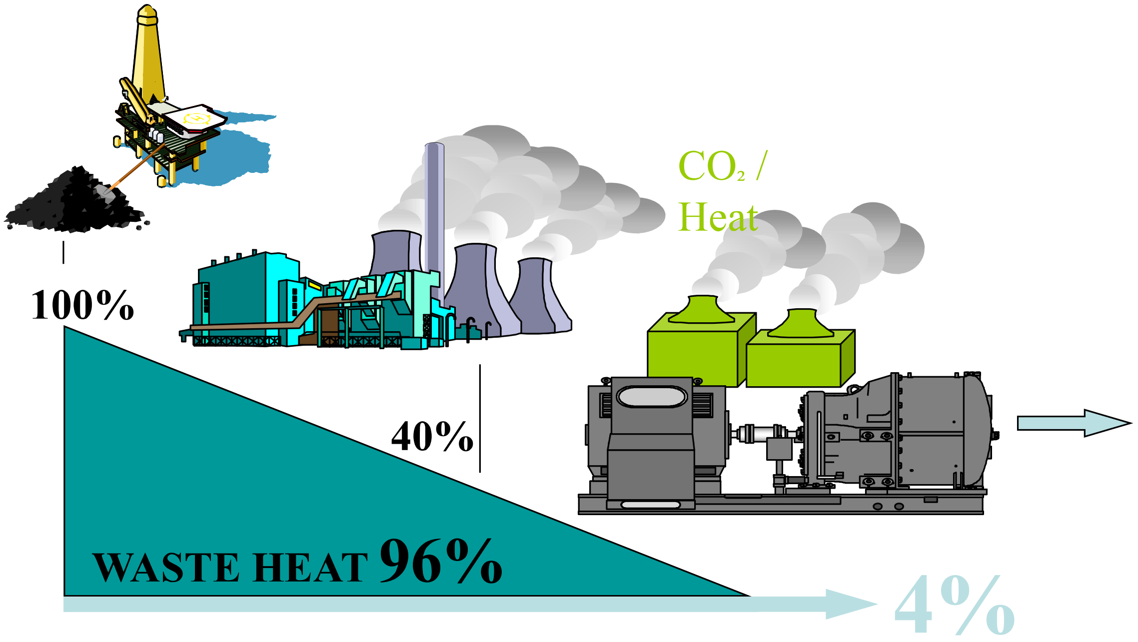
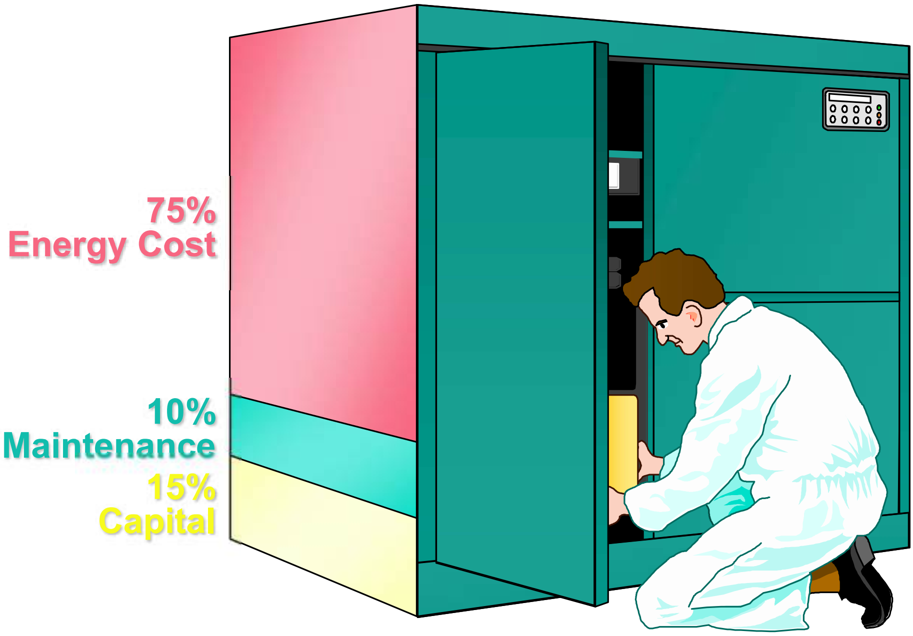
Compressed Air - The Facts

- 10% of industrial electricity is typically used to produce compressed air
- In Vietnam this equates to around VND 31,836,105,000,000
- On average 30% can be saved some at little or no cost this equates to 1,228,864 Tonnes CO_2
- Compressed Air is NOT free - it's an expensive resource - don't waste it

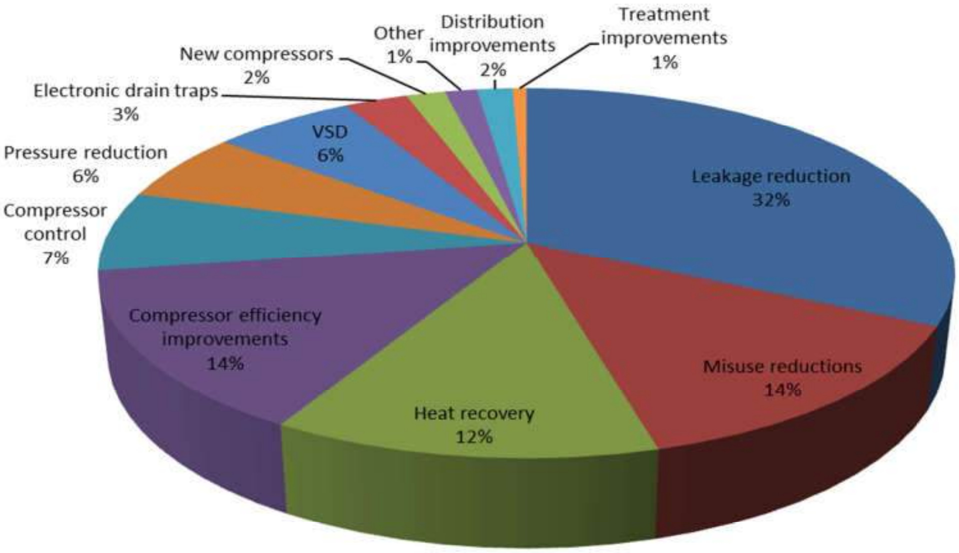
THE ENERGY TRAIN



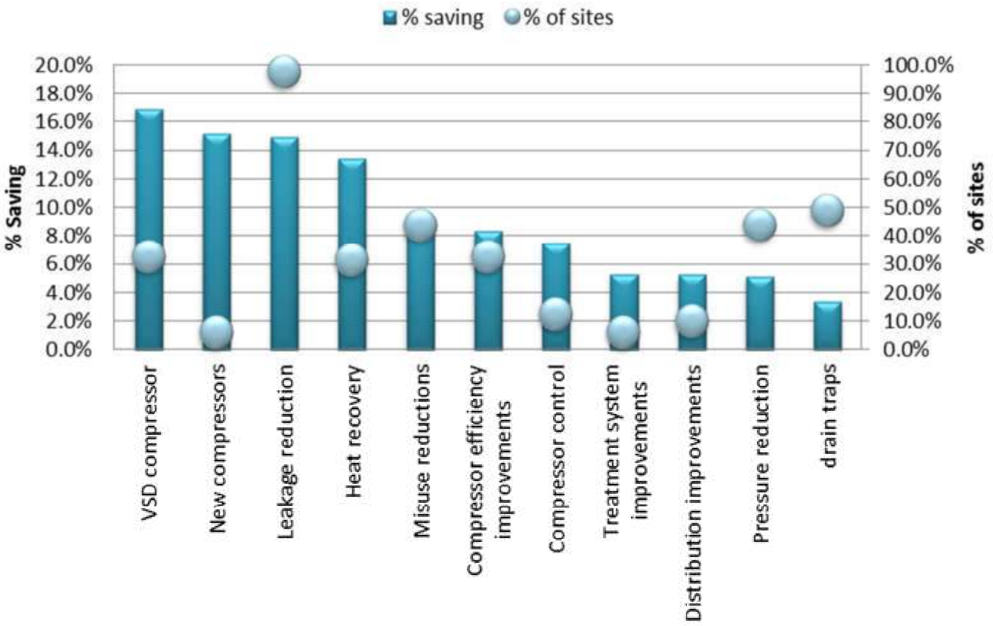
Compressor life cycle costs



Compressed Air Key Savings Areas



Compressed Air Key Savings Areas



Note applications eg new compressors give good saving but were only economical at 6% of sites – 33% for VSD

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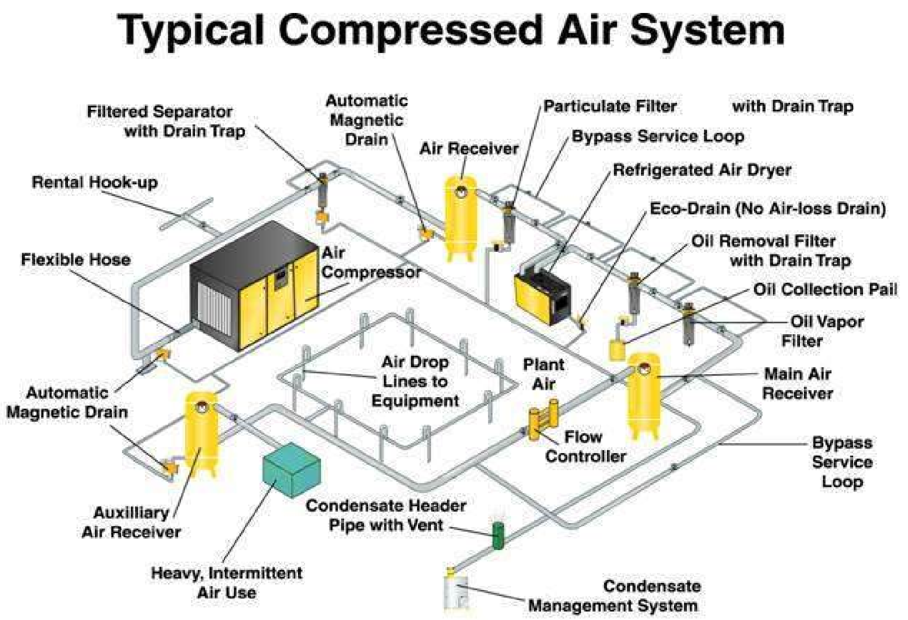
Compressed Air Systems



A typical compressor house?

Common problems in practice

The symptoms

- High running cost
- High pressure drops
- Wet air
- High purge or drain losses
- Poor reliability

The causes

- Incorrect sizing
  - Compressors
  - Dryers
  - Filters
  - Receivers
  - Pipework
- Poor control
- Inadequate cooling
- Poor maintenance

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What constitutes a best practice system?

- Compressors well matched to the demand and well controlled
- Compressors efficient and well maintained
- Treatment to the minimum required standard
- Dryers running efficiently
- Condensate collected and treated correctly
- Piping correctly sized in all areas
- Operating pressure minimum required
- Pressure drop <0.5 bar in compressor house
- Pressure drop <0.2 bar in system
- Leakage <10% of mean demand
- Air on only when required

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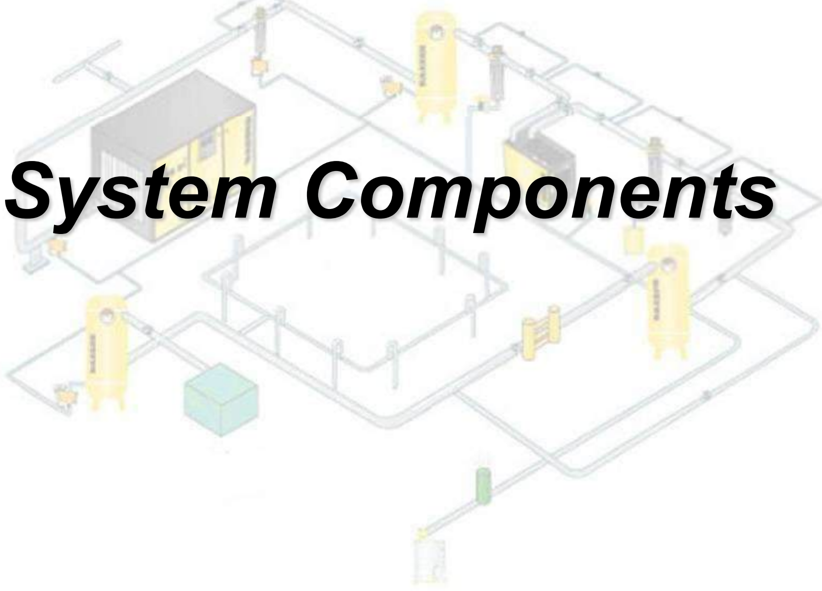
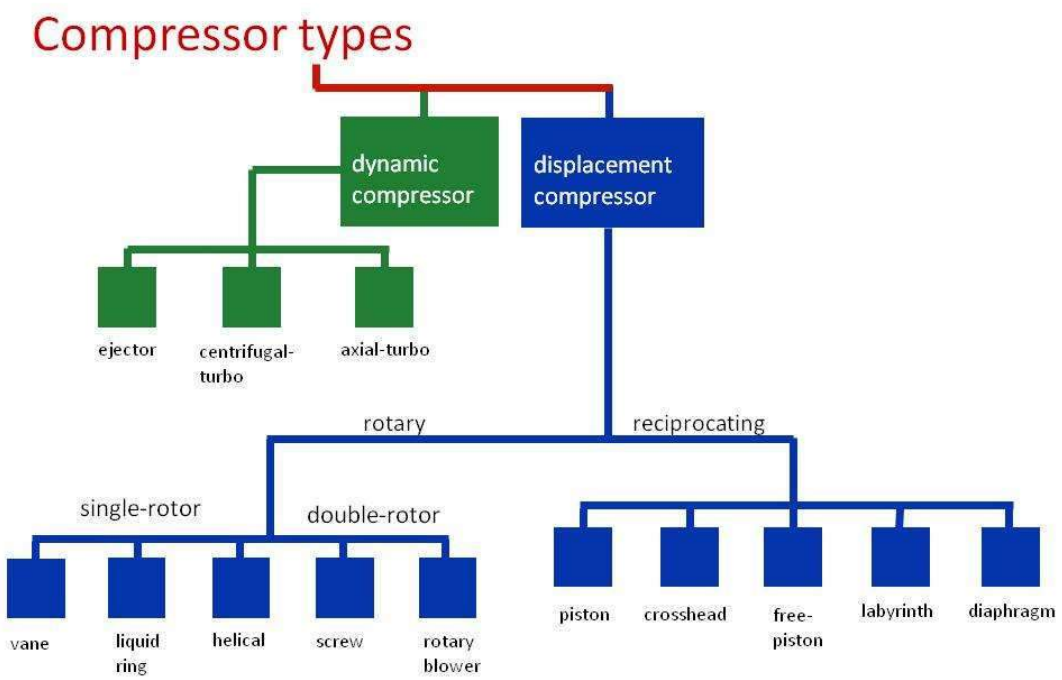
Compressed Air Systems

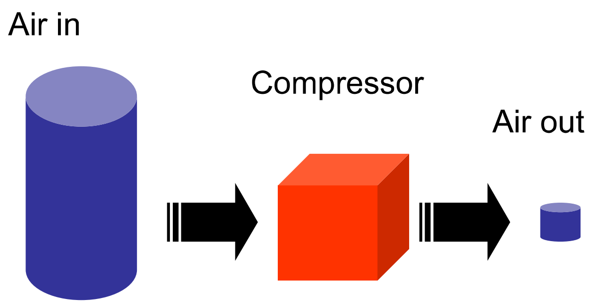
System Components





Compressed air – The basics

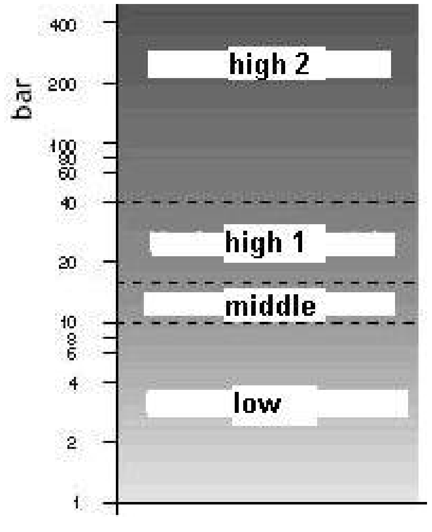
- Compressors are rated at their inlet conditions
  - 500 cfm = 500 cfm at compressor inlet
  - 250 m^3/hr = 250 m^3/hr at compressor inlet



Ambient air
Pressure: 1000 mbarA
Volume: 8m^3
Mass: 10 Kg

Compressed air
Pressure: 7 barg (8 barA)
Volume: 1m^3
Mass: 10 Kg

Pressure ranges



High pressure 2: Leak testing, power stations and rolling plants, oxygen compression. Compressors:
3-4 stage piston compressors
High pressure 1: Pipe pressure testing, blow moulding of plastic containers. Compressor: 3-stage piston and screw compressors
Mid. pressure: Heavy vehicle tyres, special machinery
Low pressure: Most applications in industry and trade lie within this pressure range. Compressor:
1-2 stage piston, screw, vanes and centrifugals.

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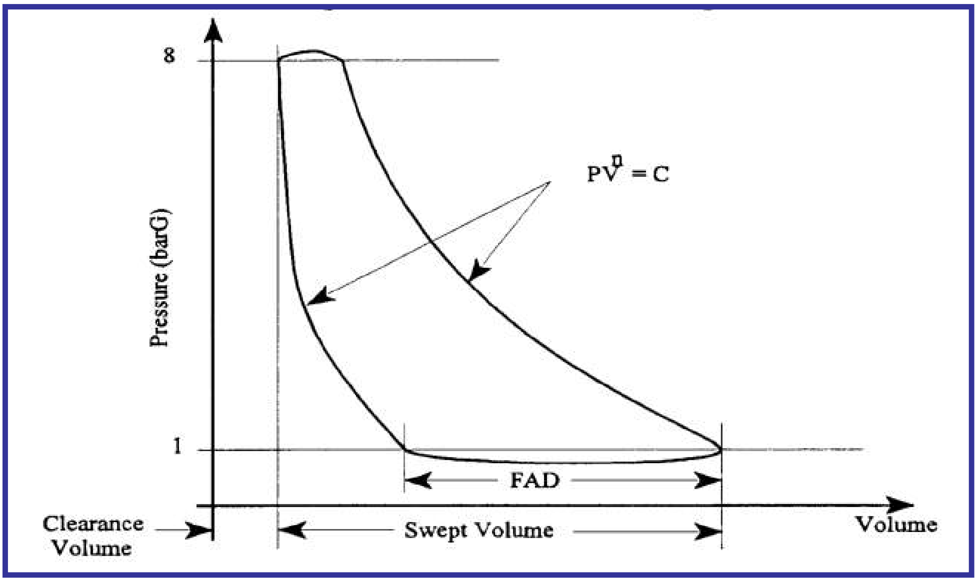
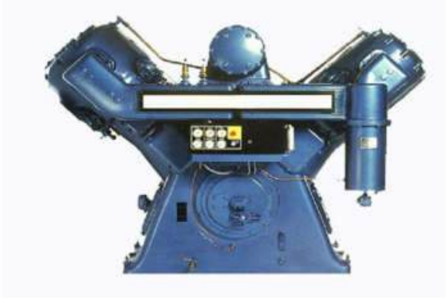
Pressure Volume Diagram

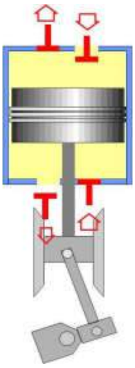


Reciprocating compressors

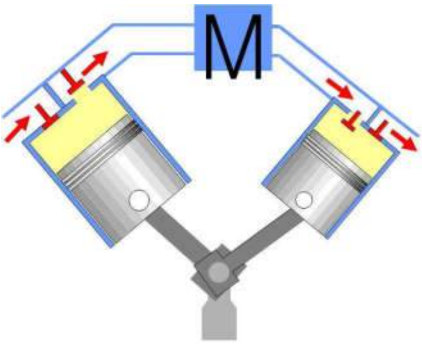


Single-acting, single-stage

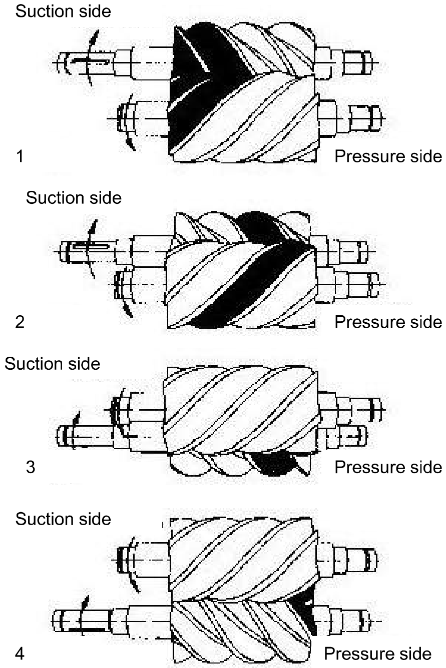
Double-acting, single-stage



Single-acting, two-stage

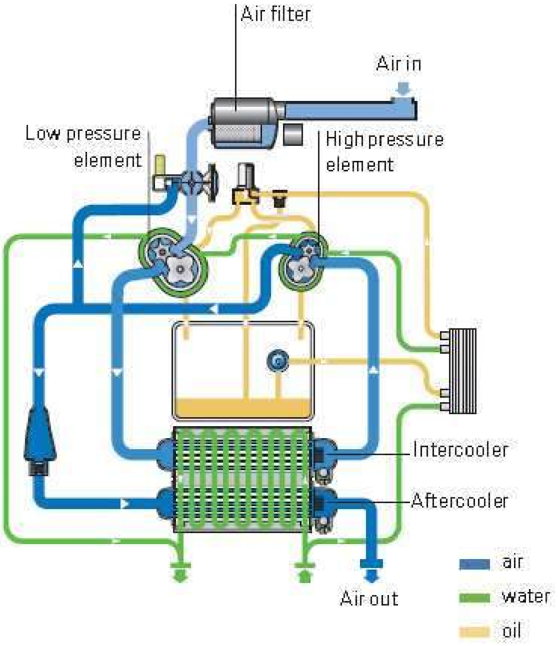


The screw compressor



Oil injected – single stage
Oil free – two stage

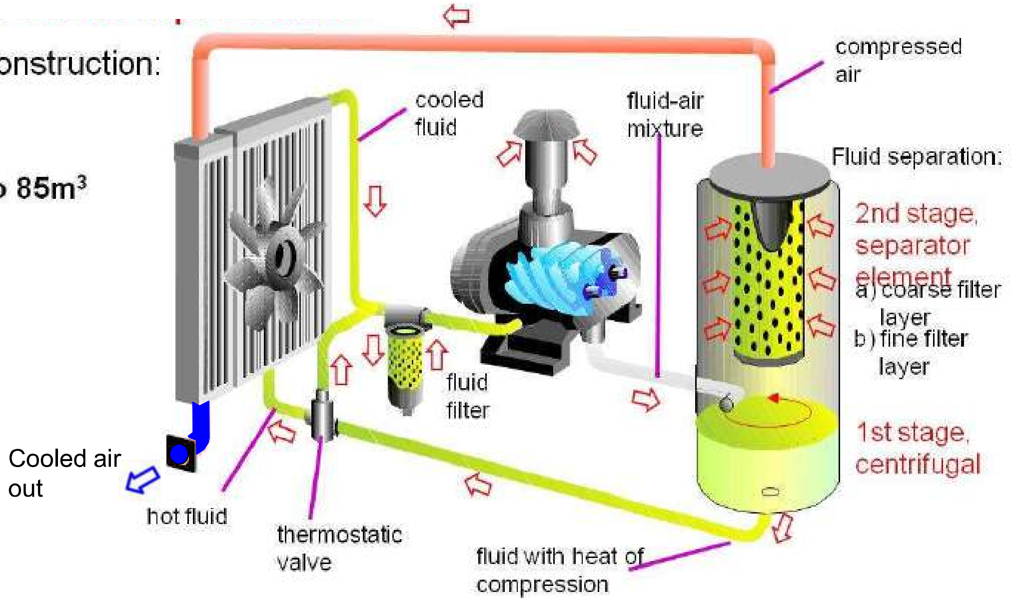
Oil free screw compressor



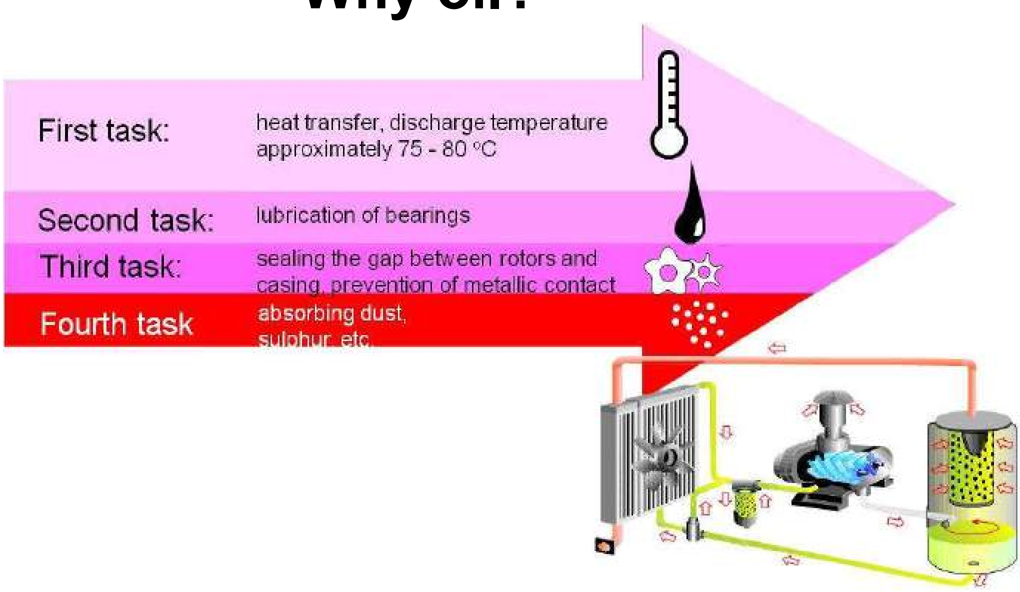
Oil injected screw compressor

Construction:

Up to 85m³



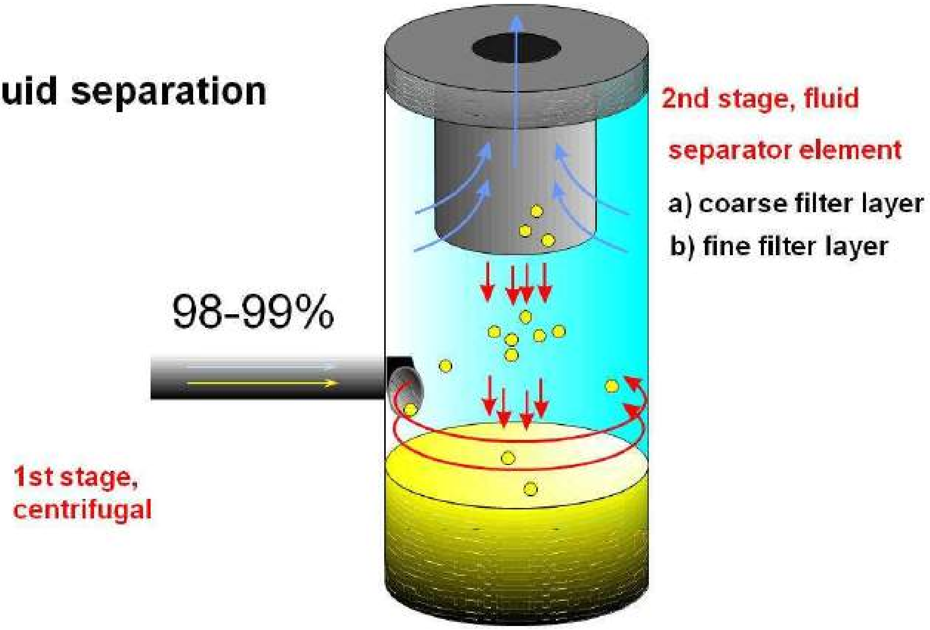
Why oil?



- **Cooling effect allows higher pressures in one stage**
- **Cheaper than oil free (2 stage)**
- **Higher risk of oil contamination downstream**

Oil separation

Fluid separation



Compressed Air Systems

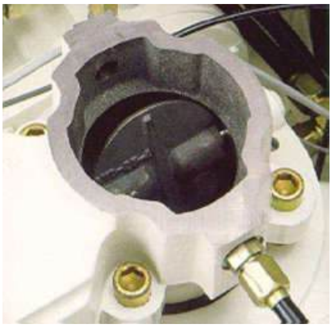
Applying rotary screw compressors

- Sized by flow, pressure, demand
- Back-up compressor(s)
- Undersized: Low pressure
- Oversized compressors:
  1) Inefficient – part load
  2) Water damage
  3) Increased wear

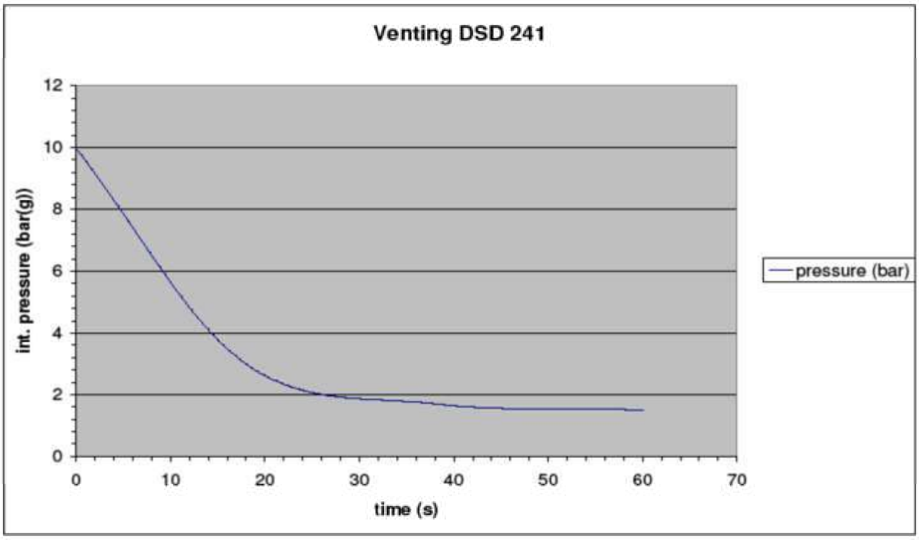
Multiple compressor installations:

- Sequencer
- Trim w/ smallest compressor
- Dual control

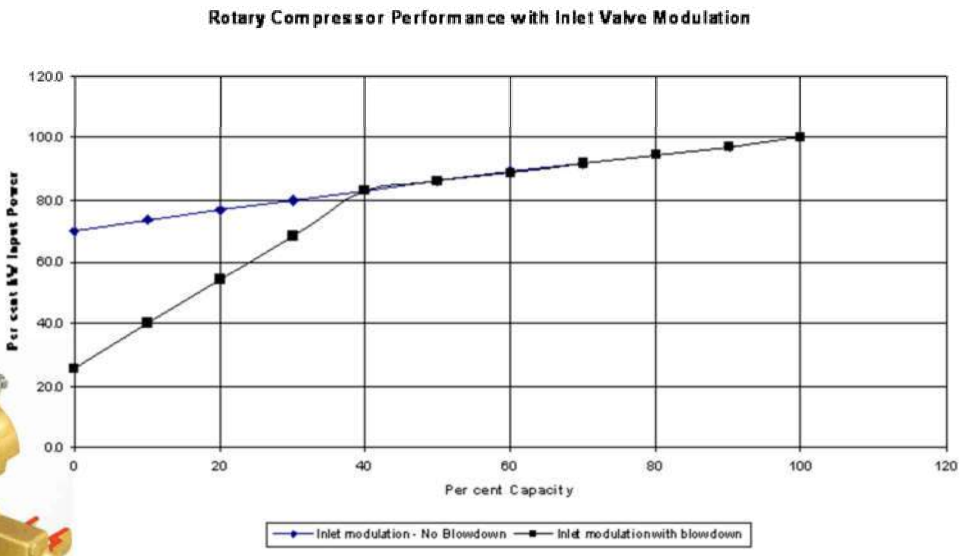
Compressor control – on/off load

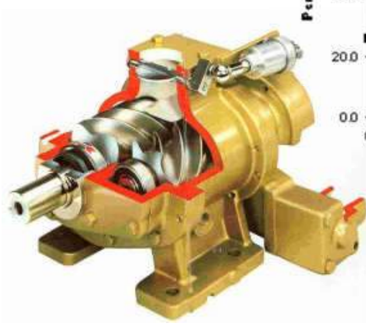


Unloading Power Time

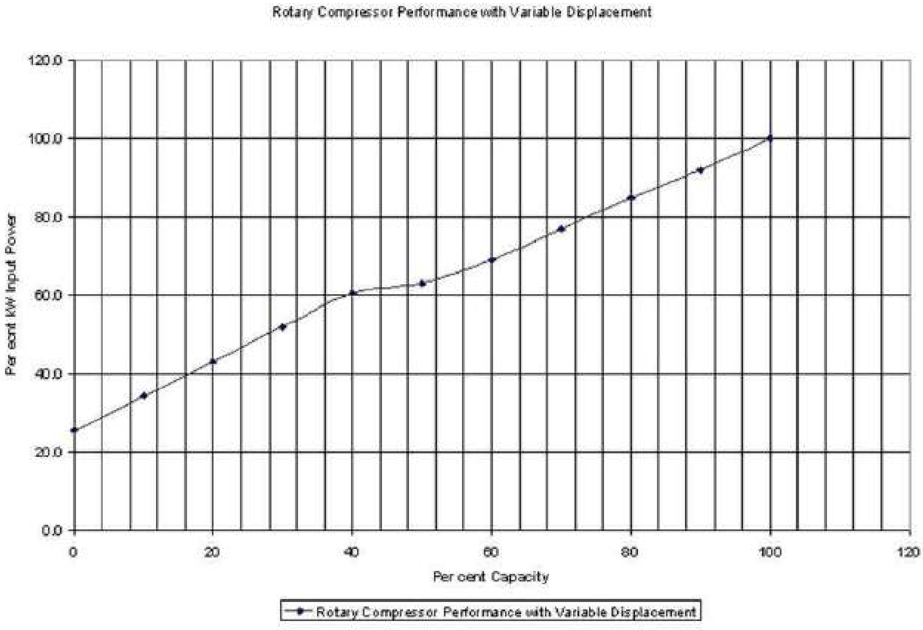


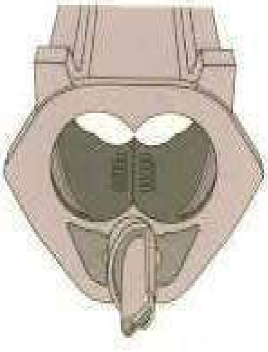
Compressor control – inlet modulation



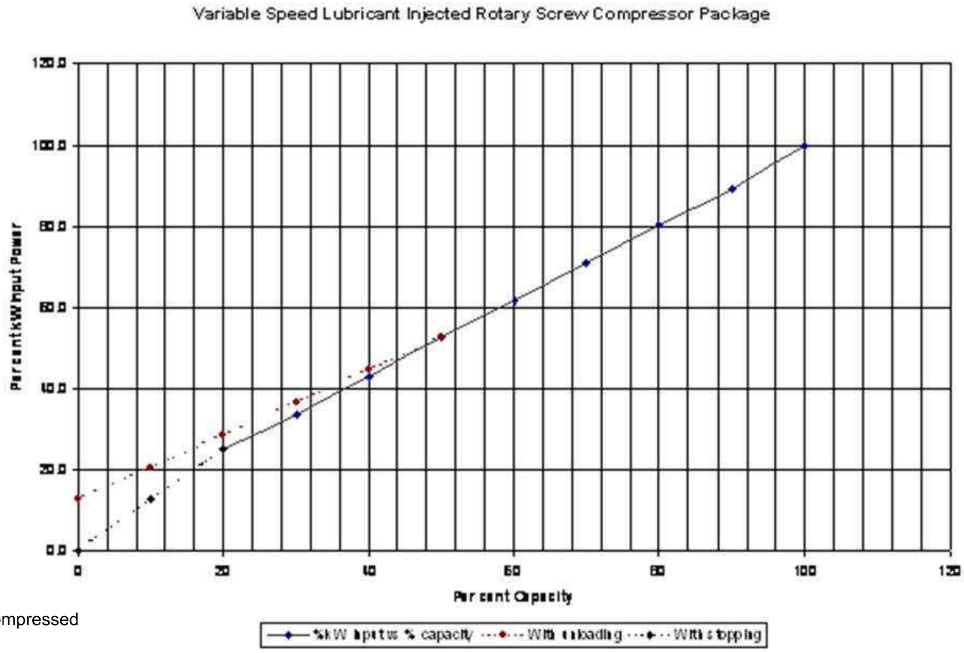


Compressor control – variable displacement



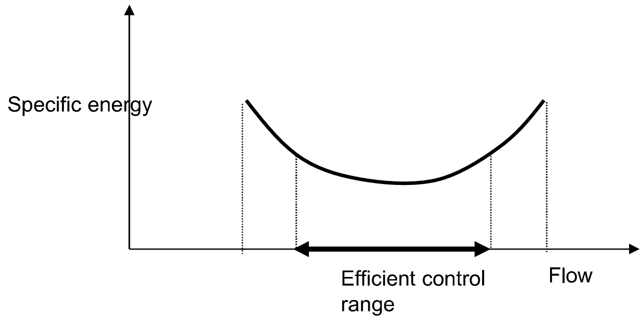


Compressor control – variable speed drive

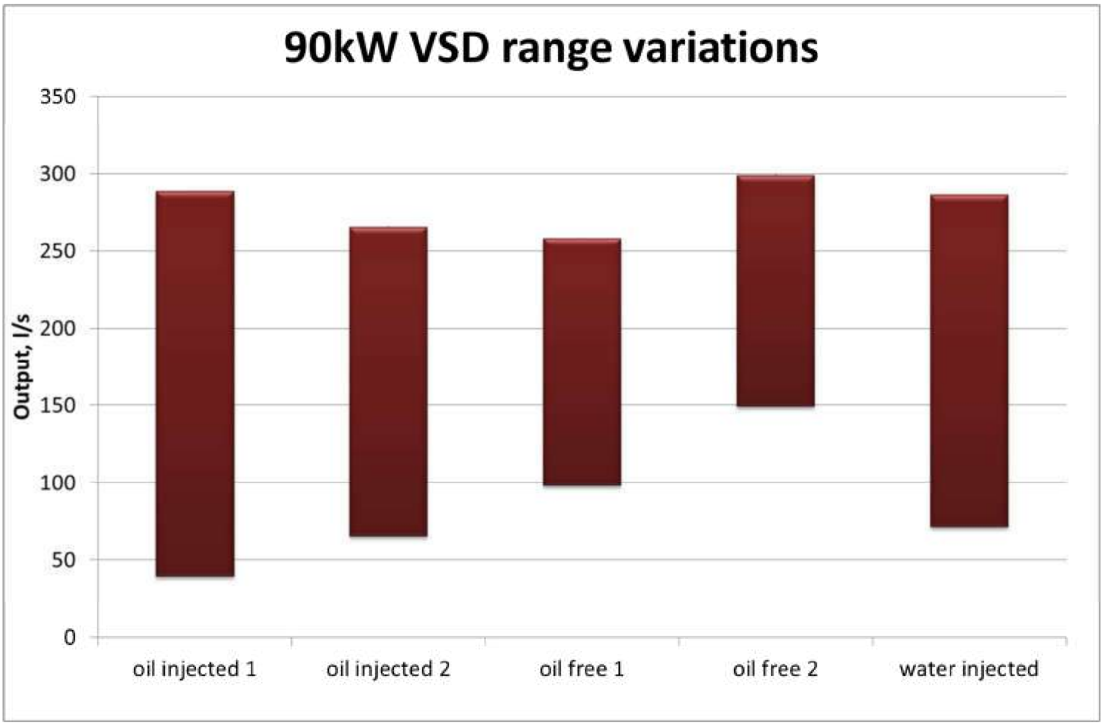


Variable speed drive limitations

Screw with variable speed Drive

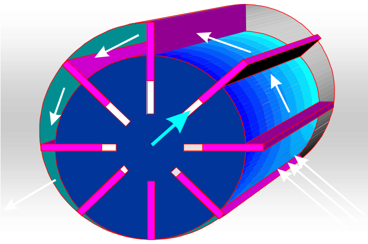


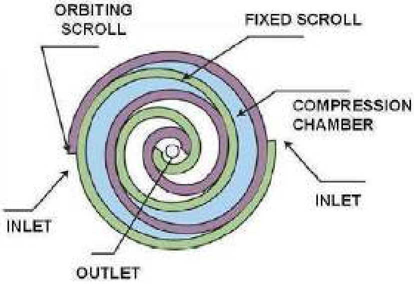
- Different sizes have different control ranges
- Oil injected has larger turndown than oil free
- Not all manufacturers are the same

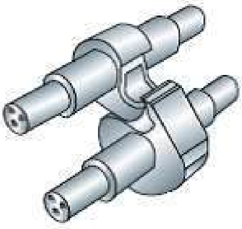


Other Displacement Compressor types

- **Rotary vane**
- **Scroll**
- **Toothed Rotor**







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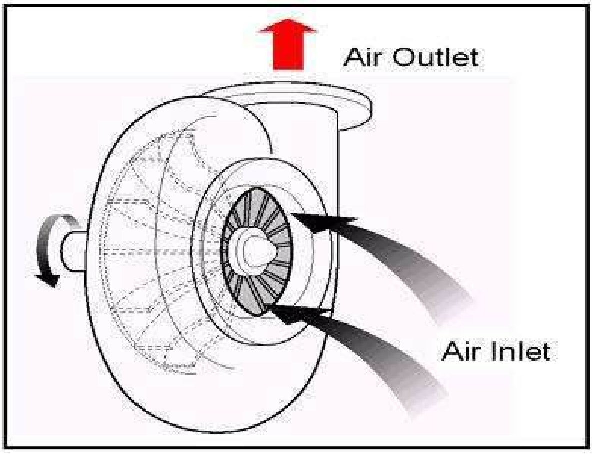
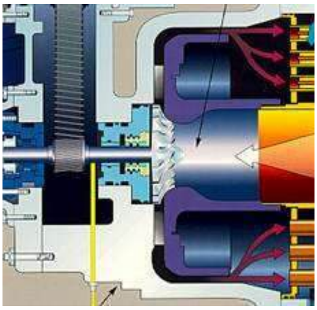
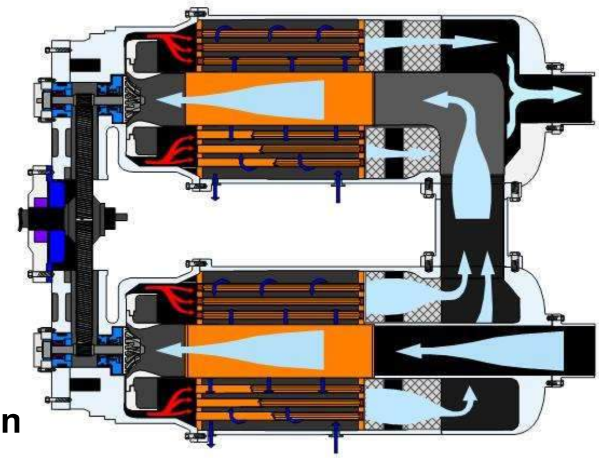
Centrifugal Compressors



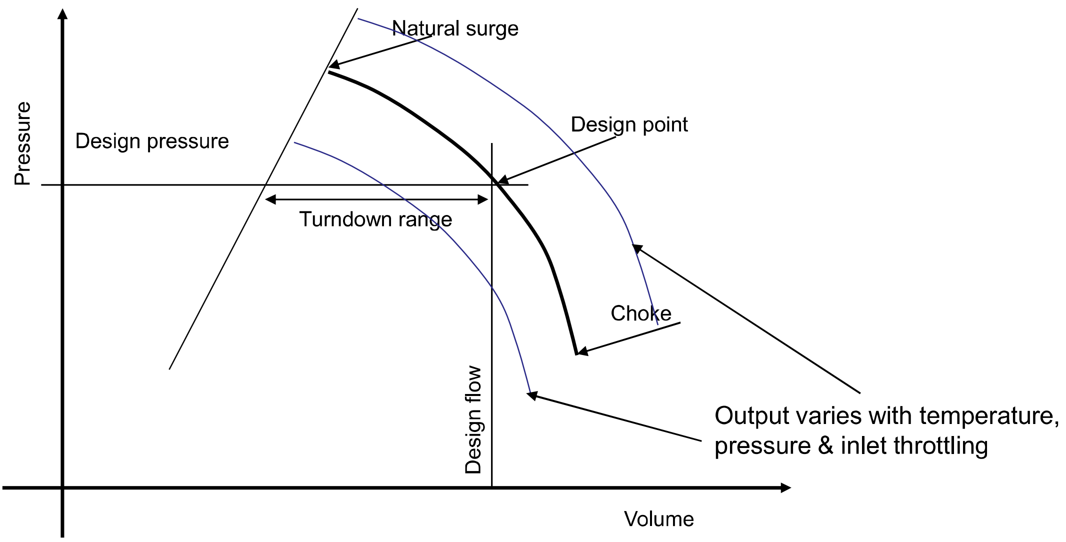
Centrifugal Turbo compressors



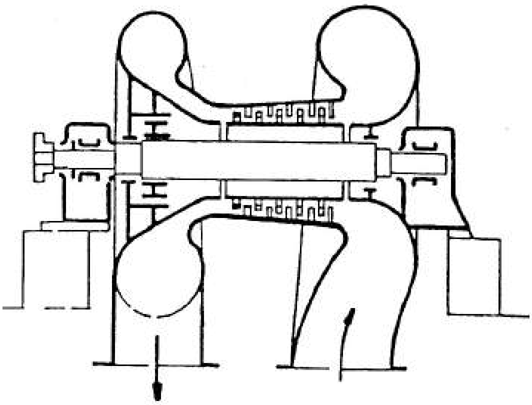


Characteristics:
Capacity: 35 - 1200 m^3/min
Stages: 1 - 6
Pressure range: 3 - 40 bar (g)
Speed range: 3000 - 80000 min^{-1}

Centrifugal Compressor control range



Axial compressor



Characteristics:
Capacity: 600 - 30000 m^3/min
Stages: 10 - 25
Pressure range: 0 - 6 bar (g)
Speed range: 6000 - 20000 min^{-1}

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Compressed Air Treatment

- Treatment is essential to reduce water, dust and oil in the delivered air
- Treat the main supply of air to minimum quality then upgrade at point of use where required
- Use ISO8573.1 air quality specification

Compressed air quality classes ISO8573.1:2010

Technology: **Filtration** (particulate) · **Drying** (dewpoint) · **Filtration** (oil carry over)

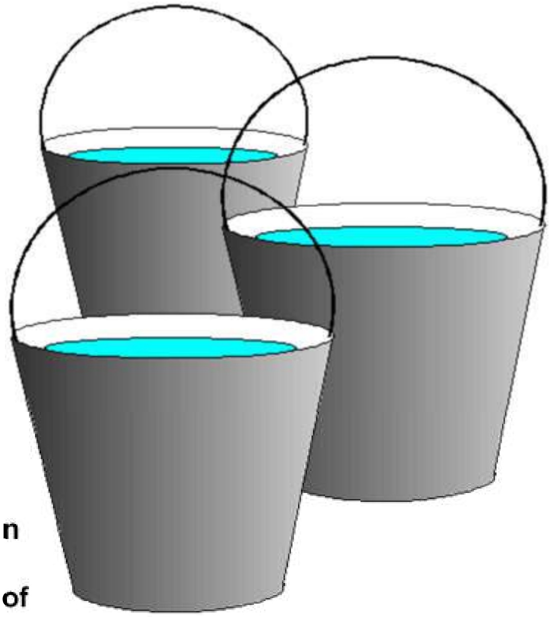
Summary of ISO8573.1-2010

Class	Particulate - Maximum number of particles per m³				Dewpoint	Oil carry over
	Particle size					
	≤0.1	0.1<d≤0.5µm	0.5<d≤1.0µm	1.0<d≤5.0µm	°C	Mg/m³
0	As specified by the equipment user or supplier and more stringent than class 1					
1	Not specified	20,000	400	10	≤-70	≤0.01
2	Not specified	400,000	6,000	100	≤-40	≤0.1
3	Not specified	Not specified	90,000	1,000	≤-20	≤1
4	Not specified	Not specified	Not specified	10,000	≤+3	≤5
5	Not specified	Not specified	Not specified	100,000	≤+7	
6	≤5 Mg/m³				≤+10	
7	5>Cp≤10 Mg/m³				Cw≤0.5g/m³	
8					0.5<Cw≤5	
9					5<Cw≤0.5	
X	Cp>10				Cw>10	>5

Impurities in the air

Compression concentrates impurities
In atmospheric air there are around 150 million dust particles/m^3
At 7 barg there are 1.2 billion dust particles/m^3

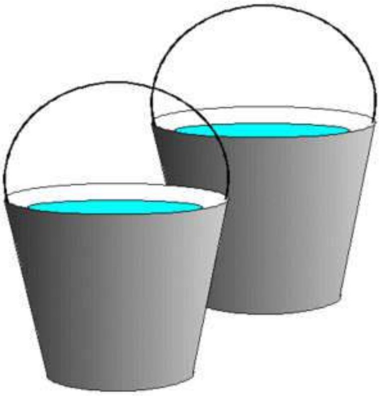
Condensate:



This compressor with an air delivery of 5 m^3/min (referred to +20° C, 70 % moisture carry-over and 1 bar absolute) transports around 30 litres of water into the air main during an 8 hour day. At 30°C this increases to 50 litres.

Condensate

About 20 litres of this water accumulates in the aftercooler in the form of condensate (at 7 bar gauge working pressure and an outlet temperature of +30° C at the aftercooler)



Condensate

As the air cools down further the remaining 10 litres accumulate at convenient points in the air main

(15 litres at 40C delivery temperature)

The results are expensive maintenance, repairs and defects in production

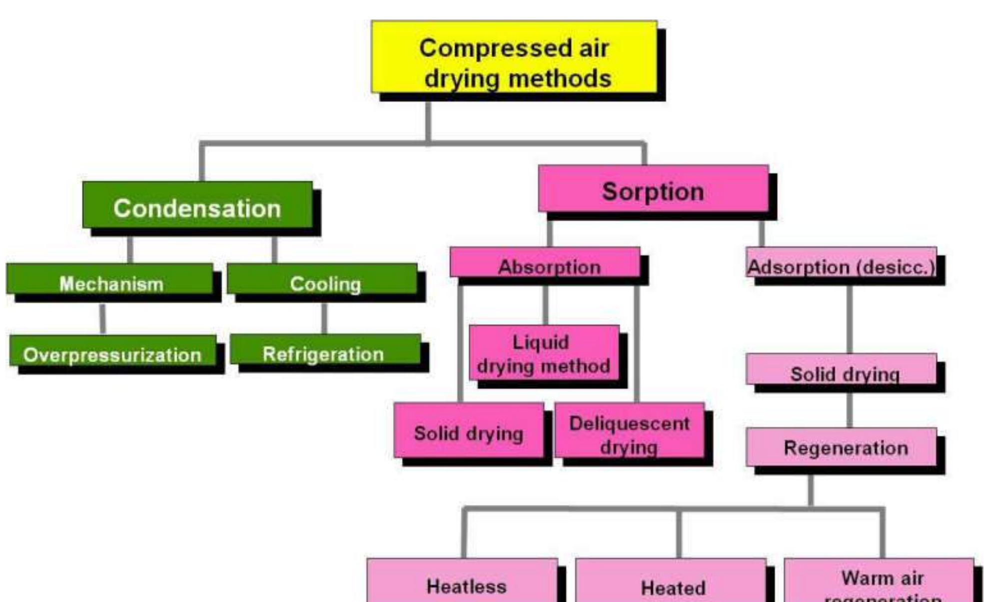
The effect of untreated air

Corrosion in pipework

Abrasive condensate sludge

Damaged tools

Compressed Air Drying



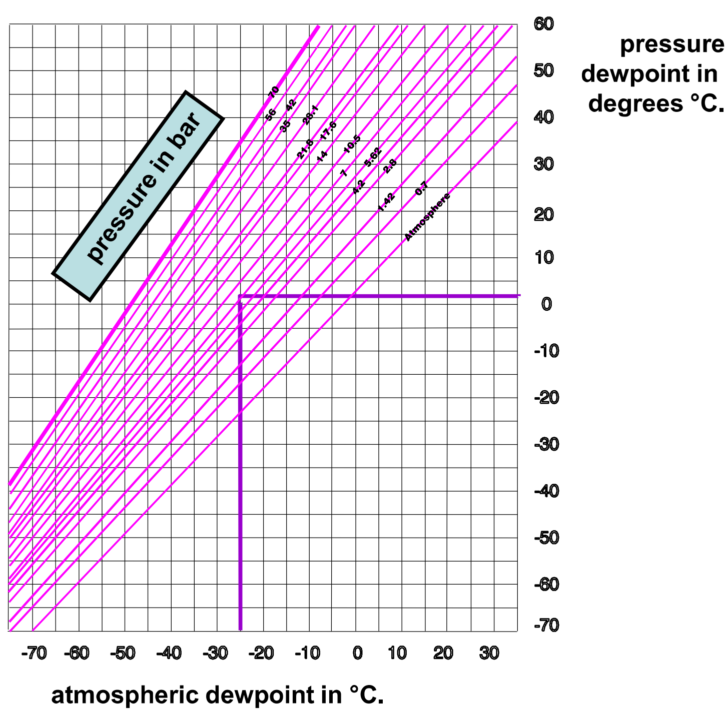
Additional Cost of Treatment

Pressure dewpoint, C	Dryer type	Filtration	Additional cost
+3	Refrigerant	General purpose	3%
-20	Waste heat regenerated	None	<1%
-40	Air regenerated	Pre & After	10-15%
-40	Heat regenerated	Pre & After	5-12%
-70	Air regenerated	Pre & After	15-21%

Incorrect sizing can significantly increase costs

Pressure dewpoint - atmospheric dewpoint

Example:
Pressure dewpoint: 2-3 °C.
Working pressure: 7 bar
Atmospheric dewpoint: - 25 °C.



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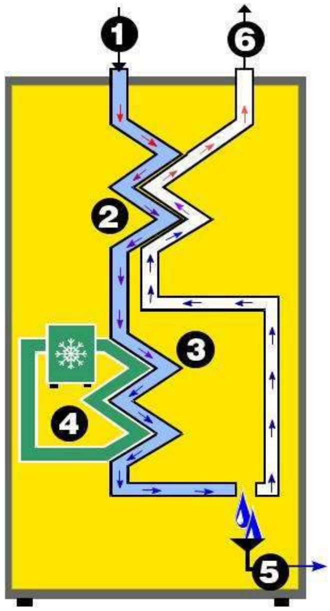
Water Content of Ambient Air

Dewpoint	g/m³	Dewpoint	g/m³
+100	588.208	+6	7.246
+90	417.935	+4	6.359
+80	290.017	+2	5.570
+70	196.213	+0	4.868
+60	129.020	-10	2.156
+50	82.257	-20	0.88
+40	50.672	-30	0.33
+30	30.078	-40	0.117
+20	17.148	-50	0.038
+10	9.356	-60	0.011
+8	8.342	-70	0.0033

Refrigeration drying

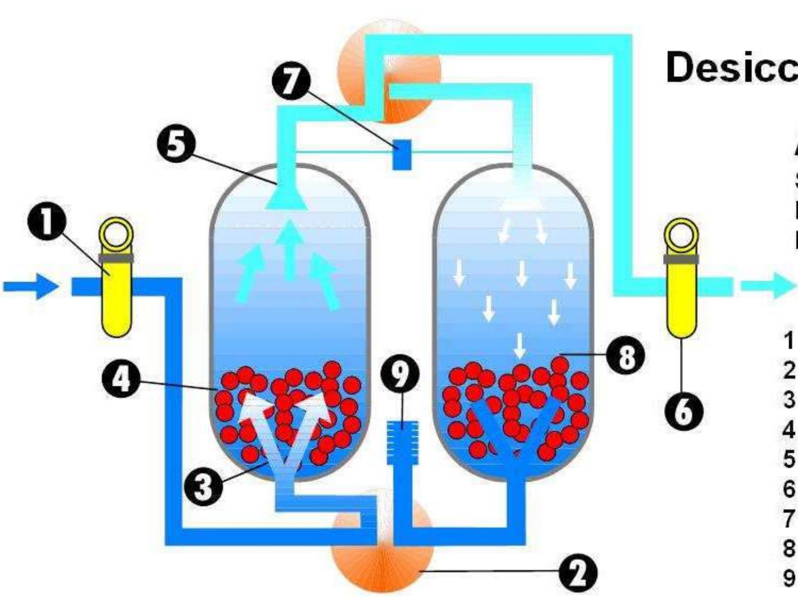
1. Air inlet
2. Air to air heat exchanger
3. Refrigerant to air heat exchanger
4. Refrigerant compressor
5. Condensate separation, automatic condensate drain
6. Compressed air outlet



Refrigerant Dryers

- Rated at about 35° C, 7 bar, 100% RH inlet air
- Refrigerated dryers:
  1) 3° C pressure dew point
  2) Non-cycling feature stable pressure dew point
  3) Cycling feature improved part-load power cost with fluctuating dew point
  4) Typical pressure drop – 0.3 bar

Desiccant dryers



Desiccant drying - heatless

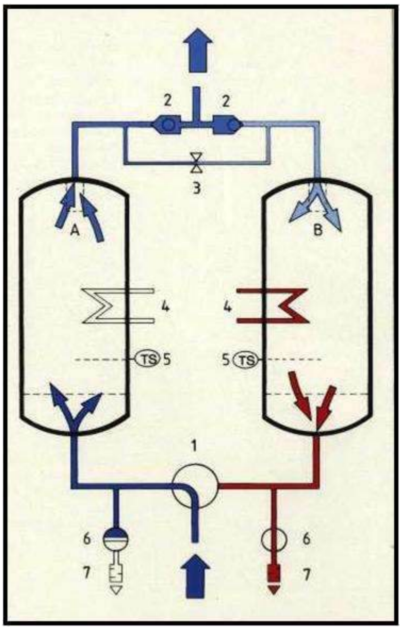
Application:

Systems subjected to freezing.
High ambient temperatures.
Extreme requirements of air quality.

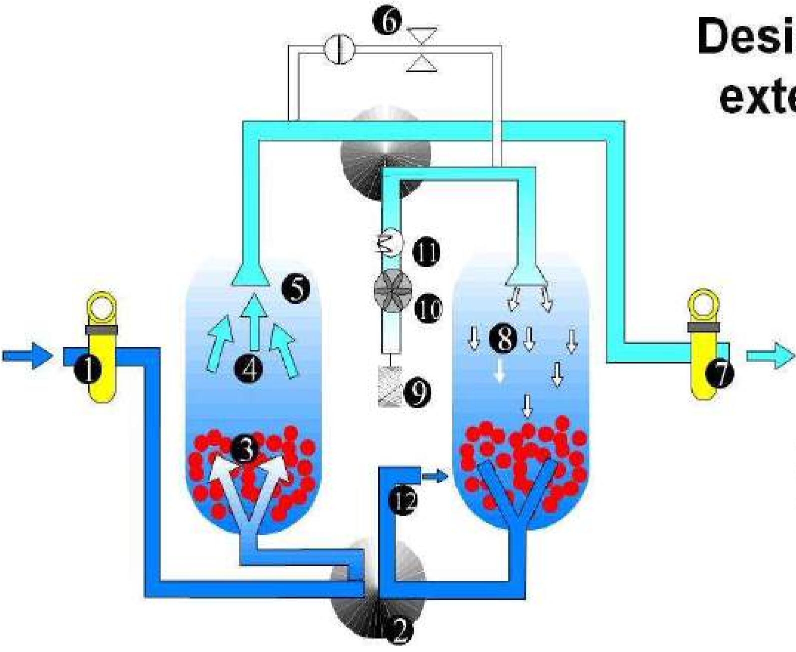
1 microfilter (0.01 µm, 0.01 ppm)
2 changeover valve
3 flow diffuser
4 desiccant bed: moisture adsorption
5 outlet collector
6 particulate filter 1 µm
7 purge (regeneration) air valve
8 desiccant bed: regeneration
9 purge air exhaust silencer

Desiccant drying - internally heated

- integrated heating rods (desiccant not heated evenly during regeneration)
- low purge air requirement (cooling, pressure build-up)
- constant dry, oil-free and clean compressed air



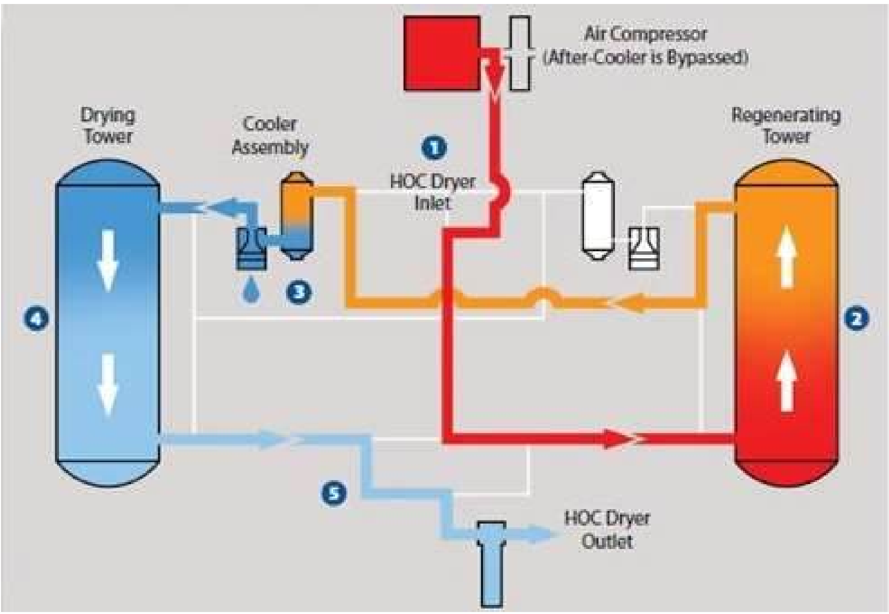
Compressed Air Systems



Desiccant drying - externally heated

1 microfilter (0.01 µm, 0.01ppm)
2 changeover valve
3 flow diffuser
4 desiccant bed: adsorption
5 outlet collector
6 regeneration (purge) valve
7 particulate filter
8 desiccant bed: regeneration
9 purge air inlet
10 purge air blower
11 purge air heating
12 purge air outlet

Heat of compression desiccant dryer



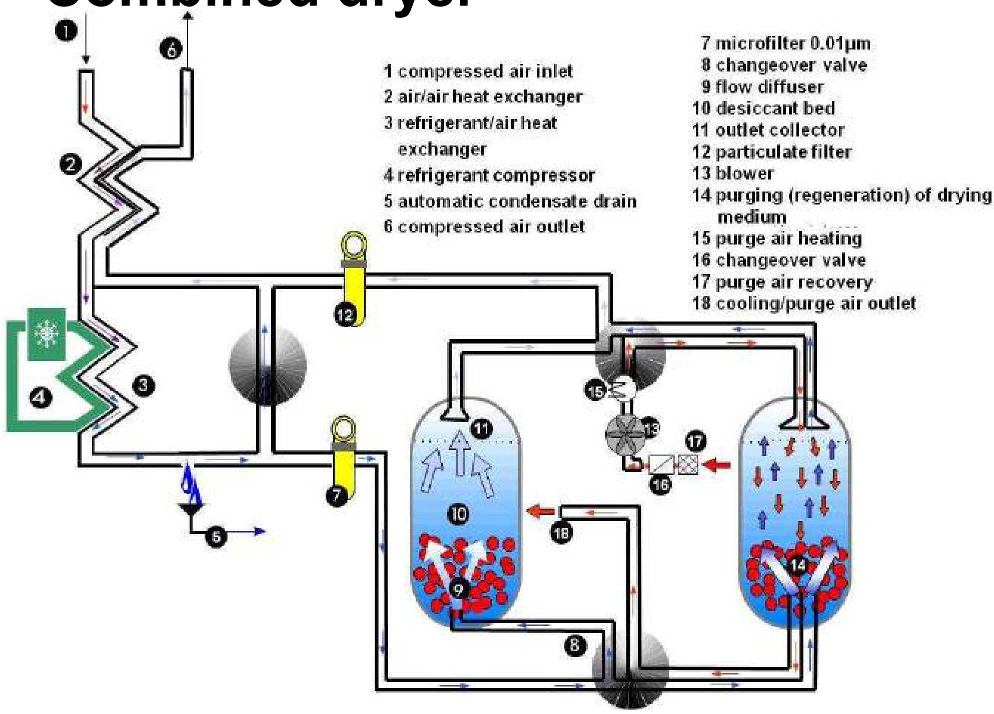
Compressed Air Systems

Applying Desiccant Dryers

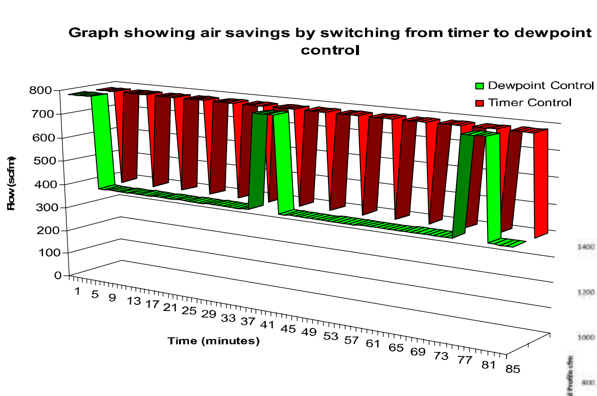
Desiccant dryers:

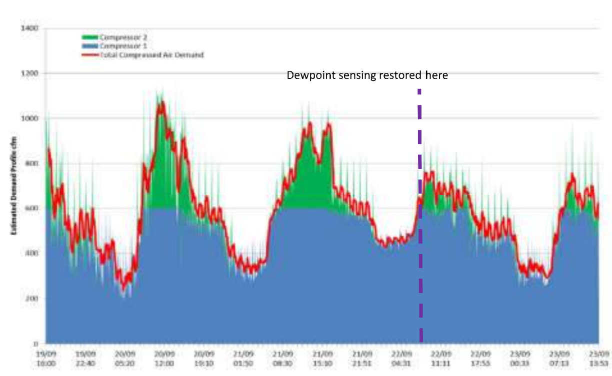
1) Pressure dew point to –70° C
2) Non-heated units require 15 – 17% purge air
3) Heated units require 7% purge air
4) Blower purge units require 0 - 2% purge air
5) Typical pressure drop – 0.2 to 0.3 bar

Combined dryer



Air dryers with dewpoint sensing control





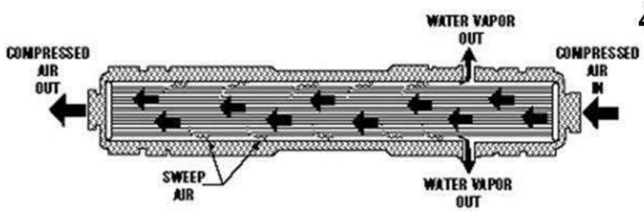
- Savings up to 70%
- Systems can often be retrofitted to existing dryers

Compressed Air Systems

Applying Membrane Dryers

Membrane dryers:

1) Pressure dew point to – 40° c
2) Require particulate and coalescing filters as pre-filters
3) Up to 30% purge air required
4) Excellent for point of use, very dry applications



Heat of compression drum dryers

- Specific to Atlas Copco
- Can only be used on oil free compressors, low energy cost can produce dewpoints to -25°C
- Electric heaters may be needed at low loads
- Very low operating cost

Compressed Air Filters

Applying Filters

- Sized for demand side air quality and air flow
- Under-sized filters:
  1) High pressure drop
  2) Reduced air quality
  3) Possible filter damage
- Grossly over-sized: May reduced air quality

Applying Filters

Liquid Separator:

- Liquid removal: 99%+ of water
- Maximum liquid loading: 30,000 ppm w/w
- Solid particle removal: 10 microns
- Oil carryover: N/A
- Pressure drop: Wet – 0.055 bar
- Located downstream of aftercooler

Applying Filters

Filtered Liquid Separator:

- Liquid removal: 99%+ of water
- Maximum liquid loading: 25,000 ppm w/w
- Solid particle removal: 3 microns
- Oil carryover: 5 ppm w/w
- Pressure drop: Dry – 0.07 bar, Wet – 0.1 bar
- Located downstream of aftercooler

Applying Filters

Particulate Filter:

- Liquid removal: 100% of water
- Maximum liquid loading: 2,000 ppm w/w
- Solid particle removal: 1 micron
- Oil carryover: 1 ppm w/w
- Pressure drop: Dry – 0.07 bar, Wet – 0.145 bar
- Located downstream of refrigerated dryer and heatless desiccant dryer – upstream of coalescing filters

Compressed Air Systems

Applying Filters

Coalescing Filter:

- Liquid removal: 99.99% of oil
- Maximum liquid loading: 1,000 ppm w/w
- Solid particle removal: 0.01 micron
- Oil carryover: 0.008 ppm w/w
- Pressure drop: Dry – 0.07 bar, Wet – 0.2 bar
- Located downstream of refrigerated dryer – upstream of desiccant dryer

Applying Filters

Extra Fine Coalescing Filter:

- Liquid removal: 99.999% of oil
- Maximum liquid loading: 100 ppm w/w
- Solid particle removal: 0.01 micron
- Oil carryover: 0.0008 ppm w/w
- Pressure drop: Dry – 0.14 bar, Wet – 0.4 bar
- Located downstream of refrigerated dryer – upstream of desiccant dryer or vapor adsorber filter

Applying Filters

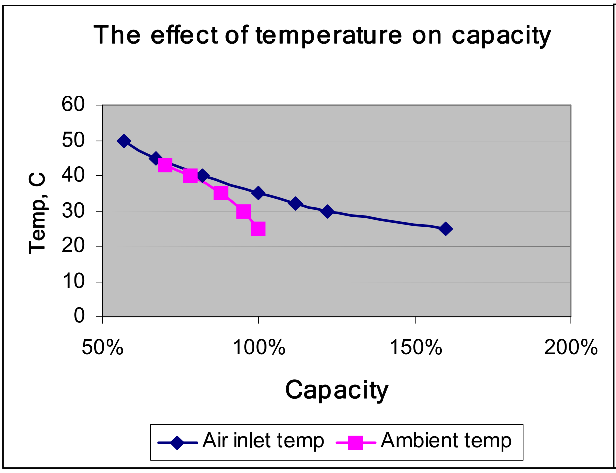
Vapor Adsorber Filter:

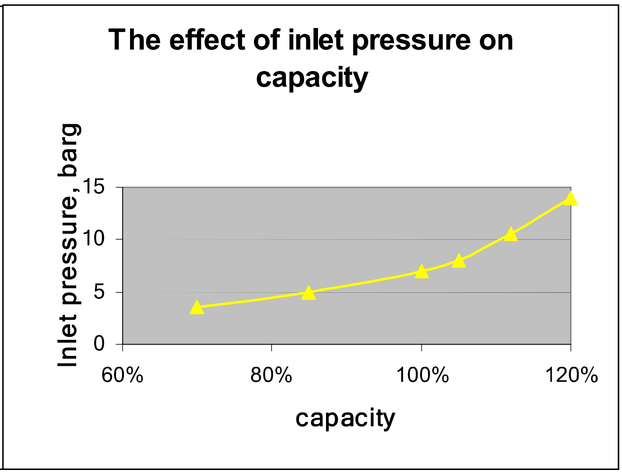
- **Liquid removal: 0%**
- **Maximum liquid loading: 0 ppm** w/w
- **Solid particle removal: 0.01 micron**
- **Vapor carryover: 0.003 ppm** w/w
- **Pressure drop: Dry – 0.07 bar, Wet – N/A**
- **Located downstream of coalescing filters**

The effect of operating conditions

- Dryer capacities normally based on 7 barg 35C inlet temperature
- Low pressure or high temperature reduces capacity and can affect performance
- Filters are tested at specified inlet conditions (7 barg 20C inlet, 20C ambient)
- Manufacturers claims for ISO classification are based on specified conditions
- Change in conditions/performance may affect performance and ISO classification

The effect of conditions on capacity

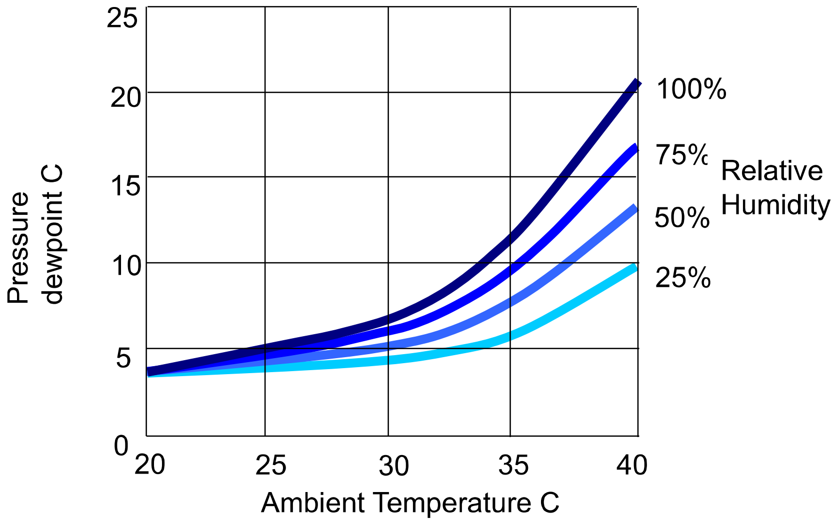




- **Multiply factors where several conditions vary**
- **Eg 100 cfm dryer at 7 barg, 35C, 25C ambient**

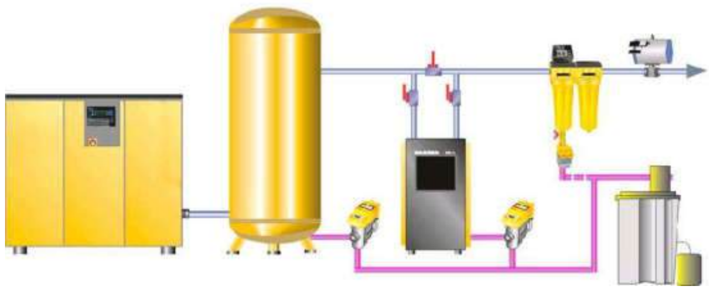
= 70 cfm at 6 barg, 40C inlet, 30C ambient

The effect on performance



Based on an air cooled integrated refrigerant dryer

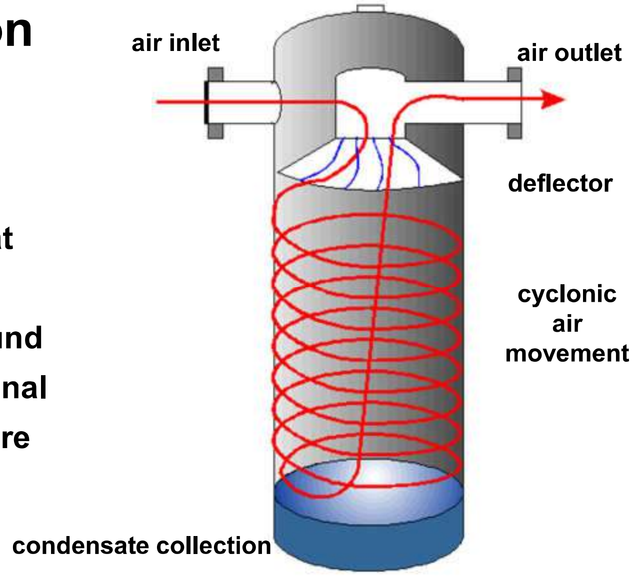
Condensate drainage



Reliable drainage must be ensured at all condensate collecting points of the air main

Condensate separation

To ensure sufficient separation, liquids and heavy particles are subjected to centrifugal forces at high rates of flow.
The degree of separation is around 95% at 6 bar, 20 °C and the nominal volumetric flow rate. The pressure drop is approximately 0.05 bar .

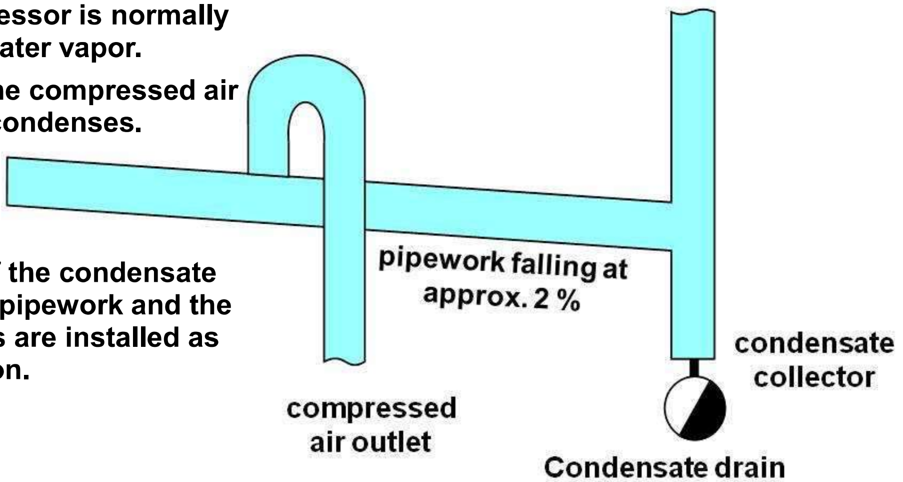


Condensate separation

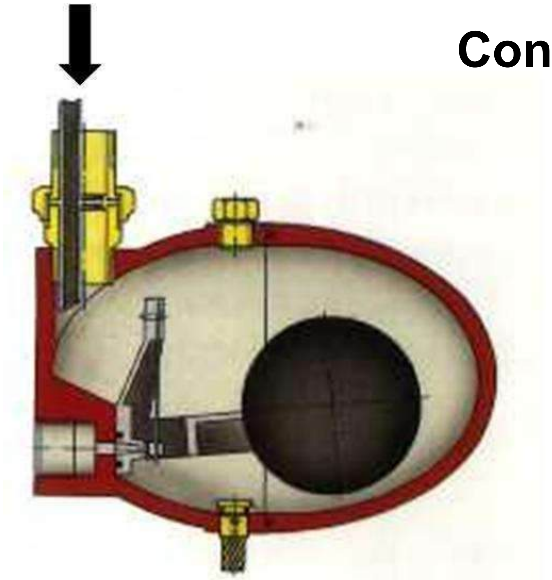
The compressed air discharged from the aftercooler of a compressor is normally 100% saturated with water vapor.

If the temperature of the compressed air falls, the water vapor condenses.

A coarse separation of the condensate can be achieved if the pipework and the compressed air outlets are installed as shown in the illustration.



Condensate drains: float type



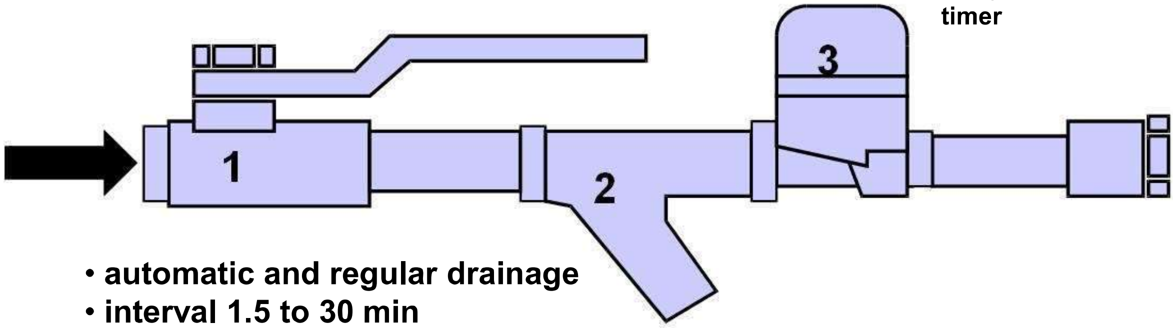
Drainage occurs only when sufficient condensate has collected

No compressed air blowoff

Regular maintenance required

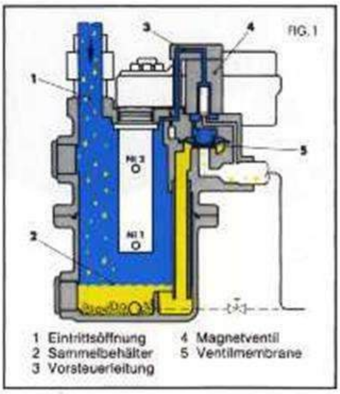
Condensate drains: solenoid valve, timer controlled

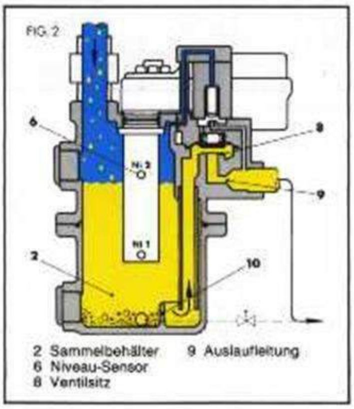
1 ball valve
2 dirt trap
3 solenoid valve with integrated or external timer



- automatic and regular drainage
- interval 1.5 to 30 min
- opening period 0.4 to 10 sec
- condensate can be directed into a disposal canister

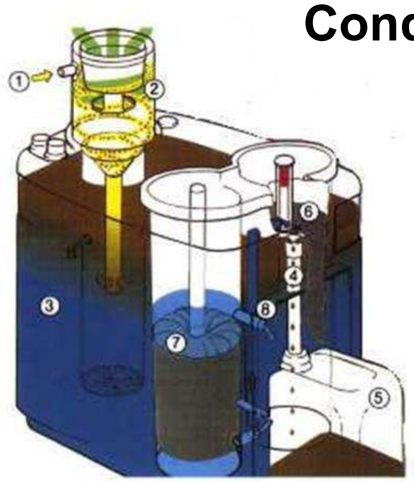
Condensate drains: Electronic level-sensing type





Capacitive level sensing
Automatic pressure matching
Self-monitoring
Volt-free alarm contact

Condensate: Oil-Water separator



1 condensate inlet
2 expansion chamber
3 separating tank: gravitational separation
4 oil overflow drain
5 oil collector tank
6 prefilter: retention of solids
7 adsorption filter: retention of oil particles
8 water drain (clean water)

Used to separate condensate components

Receivers

Purposes:

- Reduce compressor cycling
- Store air for periods of high demand
- Facilitate air/liquid separation
- Prevent oil and water migration downstream
- Dampen pulsations from piston compressors

Locations:

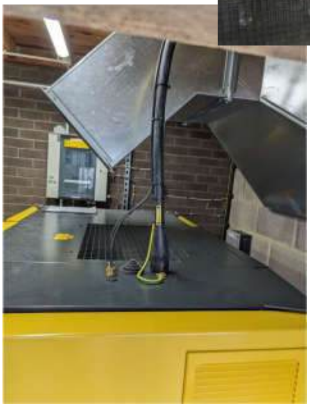
- After compressor and before dryer ("wet tank")
- After all air treatment ("dry tank")
- At points of use with high volume intermittent demand
- Not in the path of cooler exhaust

Receivers

- Sizing receivers- total storage should be at least 0.5-1 m^3 per m^3/min of trim compressor capacity
- Storage can be shared with multiple tanks and piping
- Pressure rating must exceed highest system pressure
- Must have safety relief valves sized for pressure and total flow
- Recommend large faced, liquid-filled pressure gauge
- Pipe in low and out high to prevent liquid carry-over
- Use best quality automatic drains on wet tanks

Compressor Installation

- Compressor location affects performance
- Air quality and compressor reliability are directly impacted by the environment
- Avoid high dirt/dust areas
- Avoid areas with fumes that may react with or degrade compressor fluid or filters
- Allow space around the compressor for service access
- Maintain adequate lighting for service



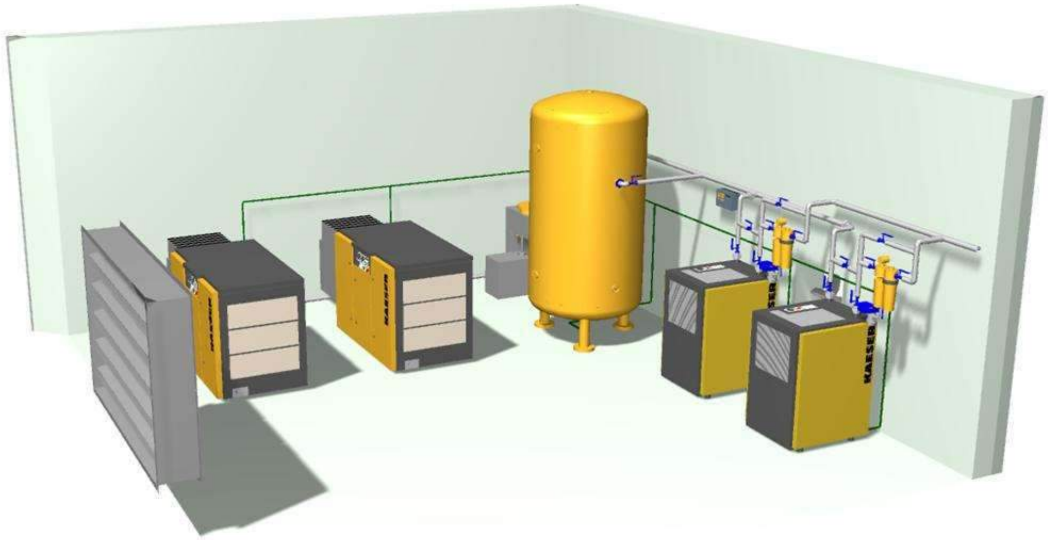
Compressor room

- Compressor rooms with ambient temperatures above 40°C:
  - Increase internal operating temperature
  - Reduce fluid life
  - Require more frequent fluid and filter changes
  - Result in more liquid moisture downstream
- High temperatures also affect equipment sizing, consult manufacturer

Ventilation for Screw Compressors

- Natural ventilation for smaller compressors
- Forced ventilation with an exhaust ventilator for larger compressors
- Ventilation to the outside through ducting without air re-circulation at air inlet temperatures above 3°C
- Ventilation through ducting with air re-circulation for winter operation to prevent freeze-up. Hot air can be mixed with the inlet air at temperatures below 3°C.
- Exhaust air ducting for heating and/or to the outside in summer (using thermostatically controlled dampers)

Ventilation Example



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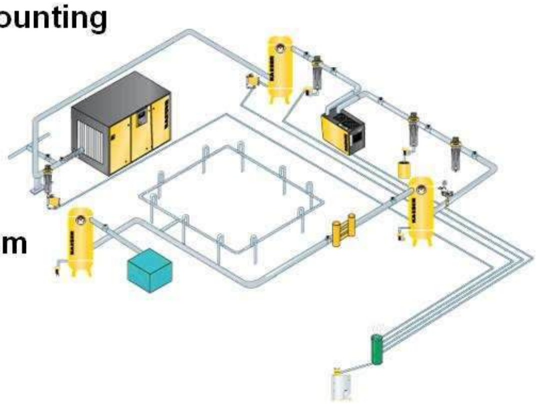
Compressed Air Distribution

Rule of thumb:

A well designed piping system will have less than a 0.15 bar pressure drop in the entire system, not counting clean air treatment equipment.

Compressed air velocity should be kept to:

- 5 meters per second in the compressor room
- 6 meters per second in the main header
- 15 meters per second in the air drops



Compressed Air Distribution

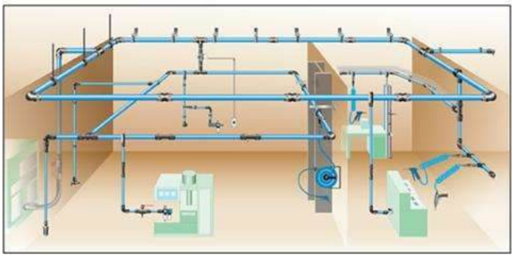
Black Iron (Mild Steel) (Carbon Steel)

- Moderate material costs with many sizes available
- Rusts, heavy, rough interior, leaks at joints, difficult to install and modify

Galvanized

- Moderate material costs with many sizes available, corrosion resistant
- Heavy, rough interior, rusts and leaks at joints, difficult to install and modify

Compressed Air Distribution



Copper

- Low installation costs, common materials, no rust, smooth, light weight
- High material cost

Aluminum

- No rust, smooth, light weight, low installation cost
- Expensive, special fittings

Compressed Air Distribution

Applying Piping

<u>Stainless Steel</u>

- No rust, smooth
- Expensive

<u>Plastics</u>

- Must be rated for compressed air use
  Do Not use PVC or ABS

Compressed Air Distribution

Applying Piping

Piping Key Points

<u>Choice of Material</u>

- Ambient conditions
- Compressed air quality requirement
- Electrostatic charge
- Applicable regulations
- Costs
- Anticipated operational life

Summary of session

Areas covered:

- Overall costs for compressed air and savings potential
- Examples of problems and good practice
- Compressor types
- Dryer types
- Filters
- Receivers
- Condensate
- Installation
- Distribution

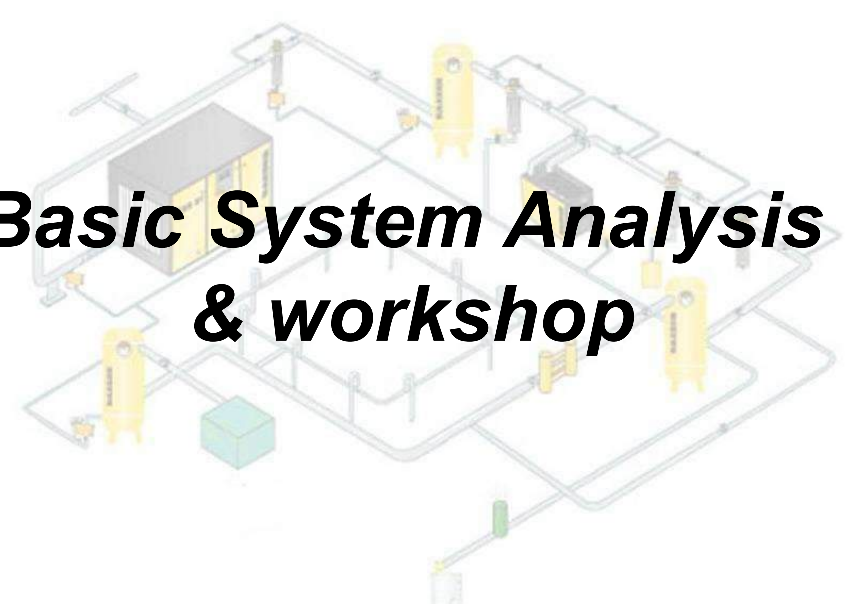
END OF SESSION
ANY QUESTIONS?

Compressed Air Systems

Ian Moore CEng FIMechE
UNIDO Compressed Air System Expert

Part 2 – Analyzing and auditing compressed air systems

Compressed Air Systems

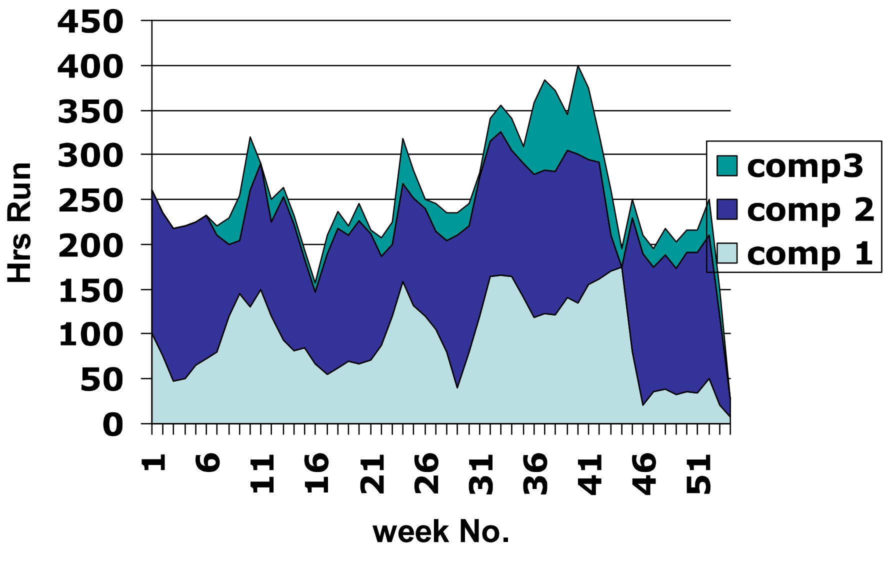


Basic System Analysis & workshop

No meters – How do you analyse a system?

- Use what you have
  - Hours run meters
  - Stopwatch
  - Installed gauges
  - Manufacturers data

Analysis of hours run



Even the most basic data can give useful results

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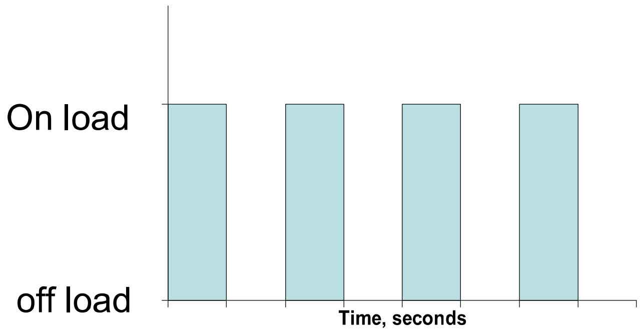
No meters? - Calculating the demand



Average load = <u>Time on load</u>
Total cycle time

Repeat during non production time to estimate leakage
Isolate areas to split up base demand

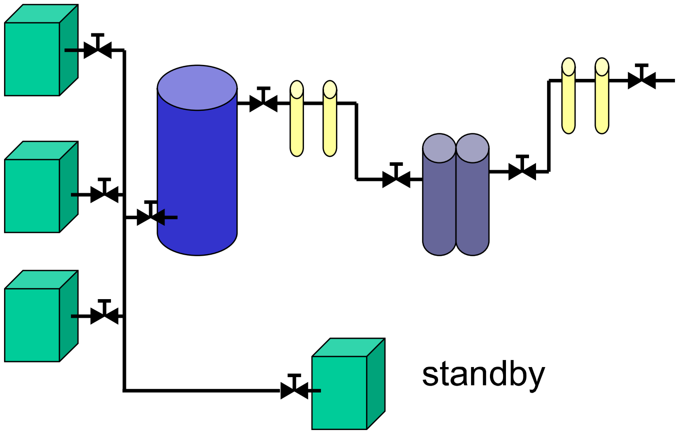
May not allow you to size a new compressor but will help you understand the system

Calculating the demand

450 cfm, 75 kW base load

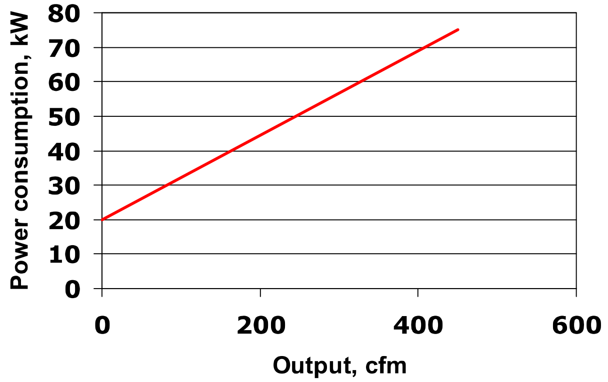
450 cfm, 75 kW base load

450 cfm, 75 kW on/off load



Calculating running costs

Typical screw compressor control characteristic



Full load = 75 kW, 450 cfm

No load = 20 kW =26.66% of power but 0cfm

System Demand (Timing calculation)

Average time on load = 30 seconds
Average time off load = 40 seconds
Average loading = 30/70 = 43%

Demand = 450+450+(450*43%)
= 1094 cfm

Power consumption

3 off 75kW compressors

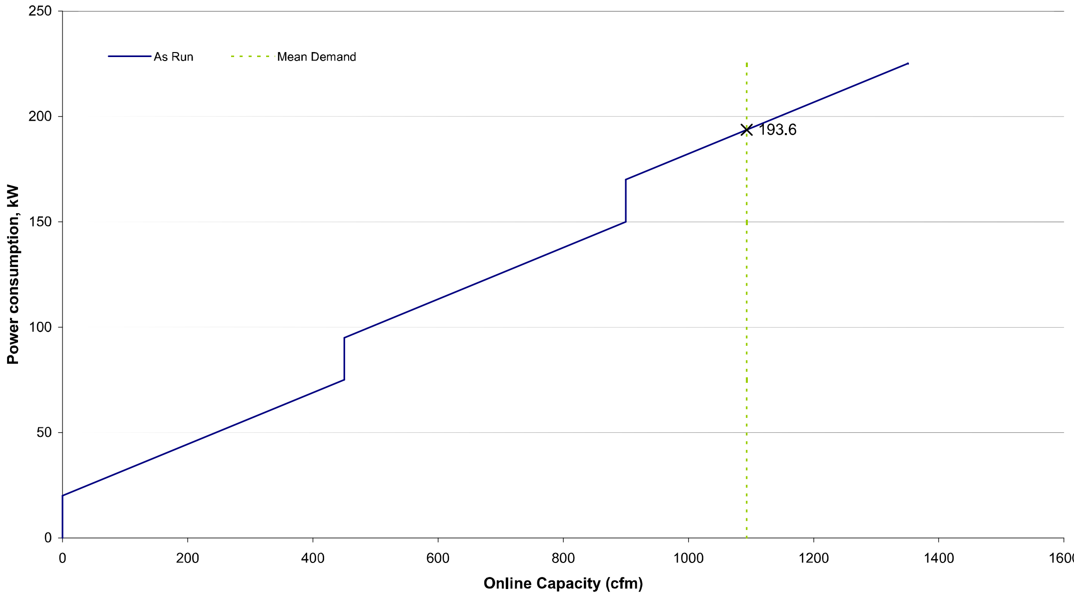
2 base load = 900 cfm, 150 kW
1 on/off load = 193 cfm, 43.6 kW

Output	450 cfm
Full load Power	75 kW
No load power	20 kW

Power = full load power + no load power
= 75*0.43 + 20*0.57
= 32.1 +11.4
= **43.6 kW**

Total power consumption 193.6 kW

Calculating generating costs

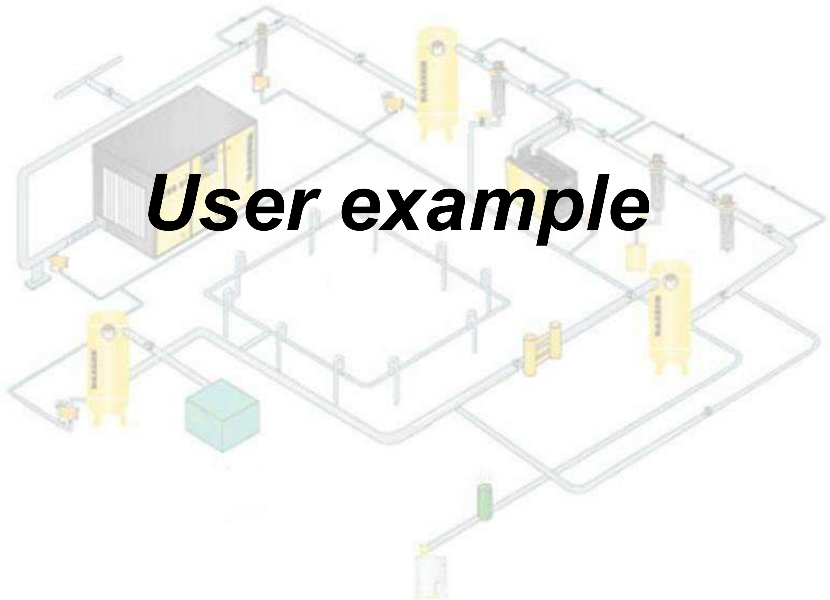


Total annual running cost

Production hours = 80 hours/week, 52 weeks/year

@ VND3000/kWh
Production cost = 193.6*80*52*3000 = VND2,416,128,000

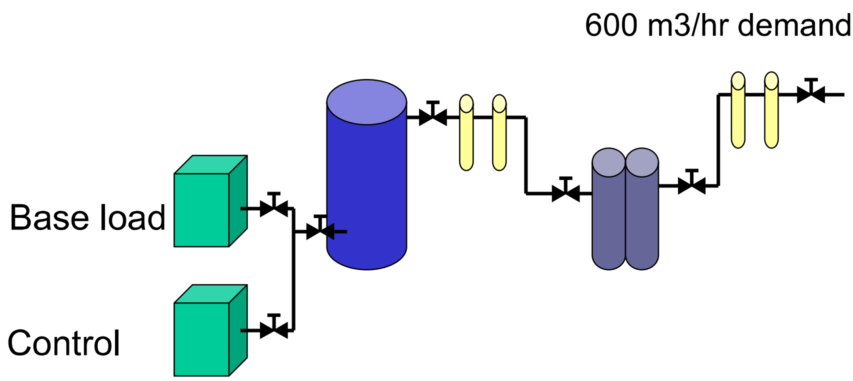
Compressed Air Systems



User example

Calculating the demand

Compressors:
400 m3/hr
50 kW on load
20% no load power



16 hours a day
5 days a week
50 weeks a year
Electricity cost – VND3000kWh

What is the annual operating cost?

Total annual running cost

Hours = 16 x 5 x 50 = 4000 hours/year

Base load = 400 m3/hr so, 50 kW x 4000hrs = 200,000kWh
= 200,000kWh x 3000 = **VND600,000,000**

Control = (600-400)/400 = 50% load, 50% no load
Full load = 50 x 4000hrs x 50% =100,000kWh
No load = 10 x 4000hrs x 50% =20,000kWh

Total control = (100,000 x 3000) + (20,000 x 3000)
300,000,000 + 600,000 = **VND360,000,000**

Total compressor house = 600,000,000+ 360,000,000 = **VND960,000,000**

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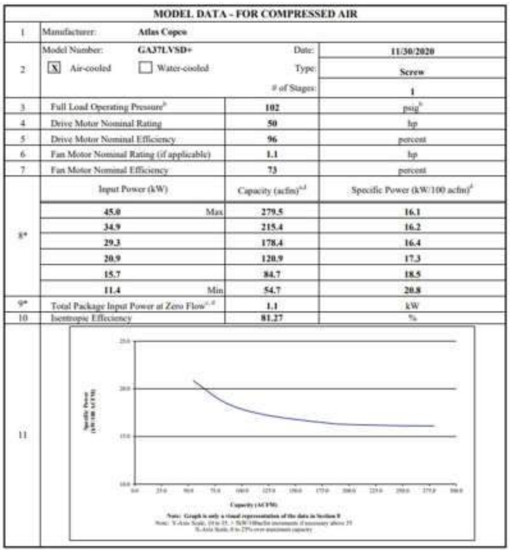
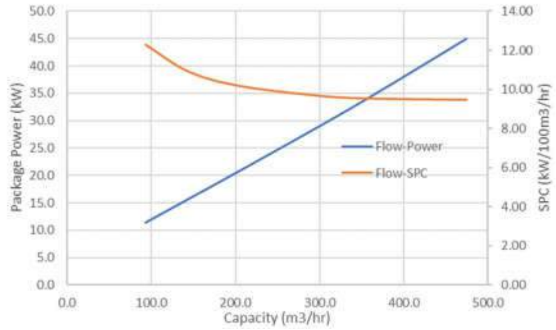
What about VSD Machines?

You need the Performance Data – See CAGI datasheets



MODEL DATA - FOR COMPRESSED AIR				
1	Manufacturer:	Atlas Copco		
2	Model Number:	GA37LVSD+	Date:	11/30/2020
	[X] Air-cooled	[ ] Water-cooled	Type:	Screw
			# of Stages:	1
3	Full Load Operating Pressure[b]	102	psig[b]	
4	Drive Motor Nominal Rating	50	hp	
5	Drive Motor Nominal Efficiency	96	percent	
6	Fan Motor Nominal Rating (if applicable)	1.1	hp	
7	Fan Motor Nominal Efficiency	73	percent	
8*	Input Power (kW)	Capacity (acfm)[a,d]	Specific Power (kW/100 acfm)[d]	
	45.0 Max	279.5	16.1	
	34.9	215.4	16.2	
	29.3	178.4	16.4	
	20.9	120.9	17.3	
	15.7	84.7	18.5	
	11.4 Min	54.7	20.8	
9*	Total Package Input Power at Zero Flow[c,d]	1.1	kW	
10	Isentropic Efficiency	81.27	%	
11				



Can select power manually from data
or use linear interpolation in excel
(can provide template for modification)

What about VSD Machines?

Demand is 600m3/hr using 2 equally sized machines

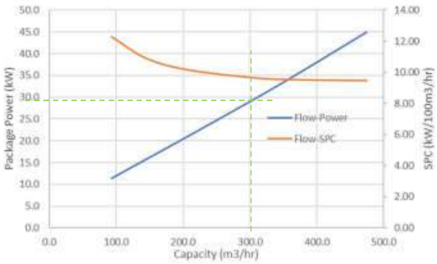
Each machine delivers 600/2 = 300m3/hr

Power required at 300m3/hr = ~29kW

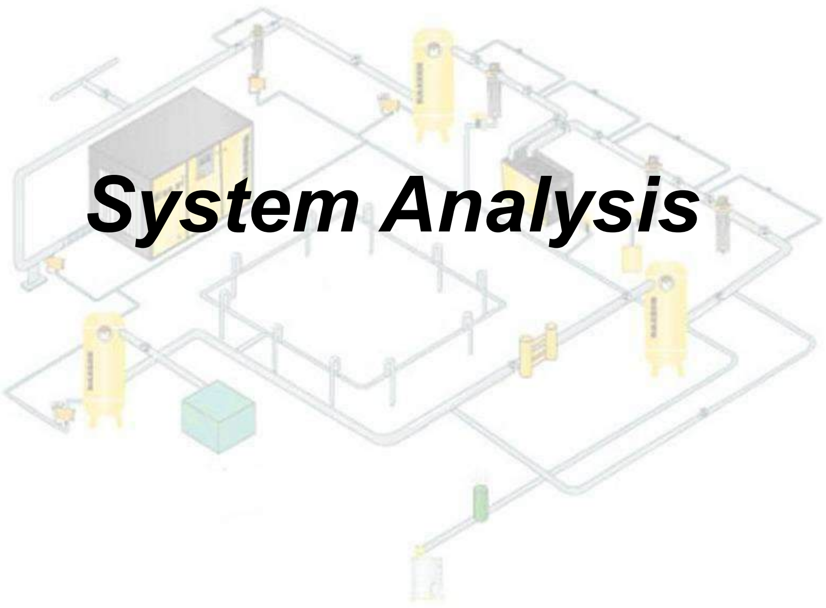
Total Power = 2 x 29kW = 58kW

58kW x 4,000hrs = 232,000kWh

232,000kWh x 3,000VND = **696,000,000VND**



Compressed Air Systems



System Analysis

Optimizing compressed air systems includes:

- **Evaluating energy requirements in factory.**
- **Matching system supply to these requirements**
- **Eliminating or reconfiguring inefficient uses and practices (sparging, open blowing, etc)**
- **Changing out or supplementing existing equipment to better match work requirements and increase operating efficiency**

Compressed Air Systems

- Most compressed air systems are initially designed with:
  - The assumption that “more” is better, where supply is concerned
  - Little or no thought given to system efficiency
  - No plan for increases or decreases in system demand
  - A “lowest first cost” goal

Compressed Air Systems

- Energy awareness must start at the corporate management level for large corporations
- Energy awareness must start with the owners of SME’s
- Operating culture must change and that change must be from the top down
- Changing company culture involves all employees

Compressed Air Systems

Where do you start?

- Ask questions
- Take notes
- Walk around
- Take notes
- Take pictures

Compressed Air Systems

FLOW

PRESSURE

QUALITY

Compressed air audits – Initial Questions

- How many hours each week is the system pressurised?
- What is the minimum pressure allowed in the plant?
- What air quality is needed?
- What is the base demand?

What to look out for in the compressor room

- Type, make, capacity, hours run and control of each compressor
- Type make and configuration of treatment package
- Room ventilation, inlets in or outside
- Is waste heat recovered?
- Generation pressure & pressure drop over treatment system
- Is there a group controller?
- What is running and estimated demand?
- Are the feeding mains OK are there any other bottlenecks?
- Are there electronic zero loss condensate traps?

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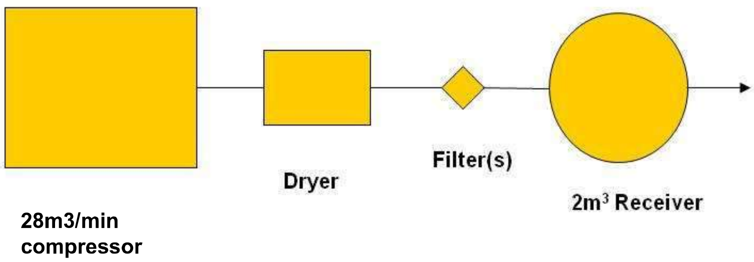
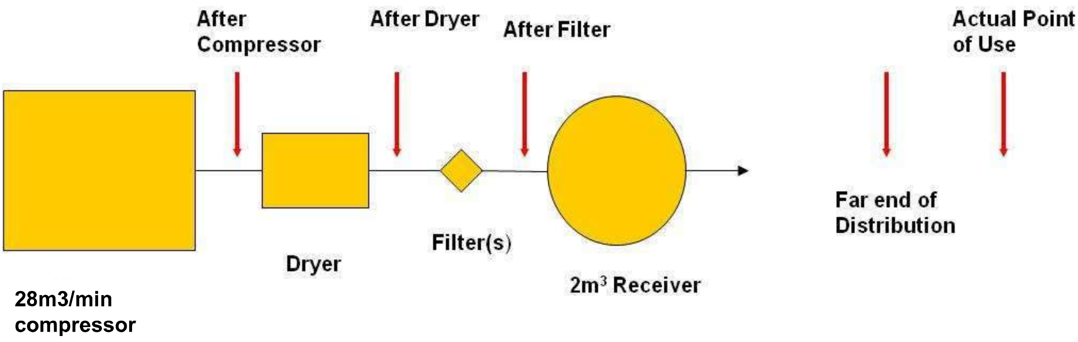
What to look out for in the factory

- Air leaks
- Main uses of air such as tools, painting, instrumentation or process
- Misuses such as open ended lances, full pressure blow guns, product ejection and vacuum venturis
- End of line pressure
- Ring or spur mains?

Start with a block diagram



Identify possible measurement points



Compressed Air Systems

Remote pressure monitor.

Pipe rope instead of pipe dope.

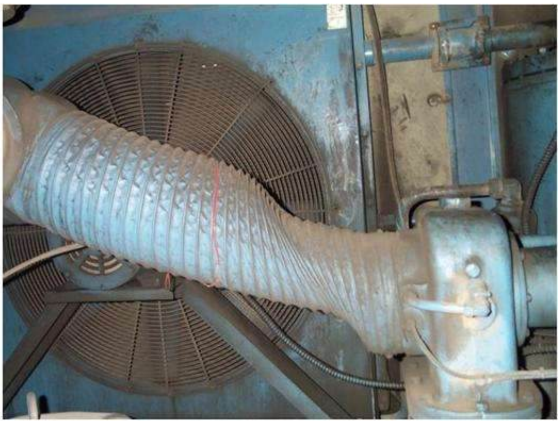
If you see something unusual, ask about it.

Compressed Air Systems

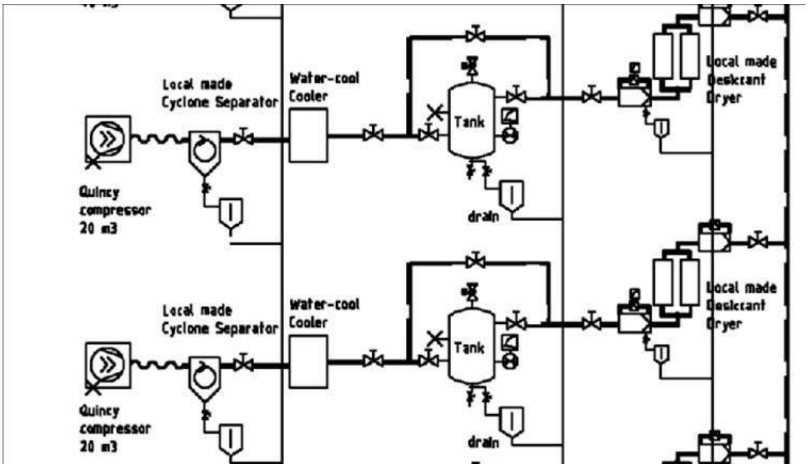
Note bad connection practices. Take pictures.

Compressed Air Systems

If a gauge reading does not look right, find out why. Instead of inlet valve modulation, you may find inlet hose modulation.



Use drawings to check installation



1) Compressor
2) Liquid separator
3) Trim cooler
4) Receiver w/drain
5) Pre-filter w/drain
6) Desiccant dryer
7) Post-filter

- The walk-through is complete.
- Interviews have been conducted.
- Notes taken.
- Pictures taken.
- Drawings corrected.
- What next?

- Sit down and think!
- Work from the point of use back to the compressor.
- Determine the true demand requirements.
- Develop information goals needed to analyze the system.
- Develop a measurement plan required to acquire that information.

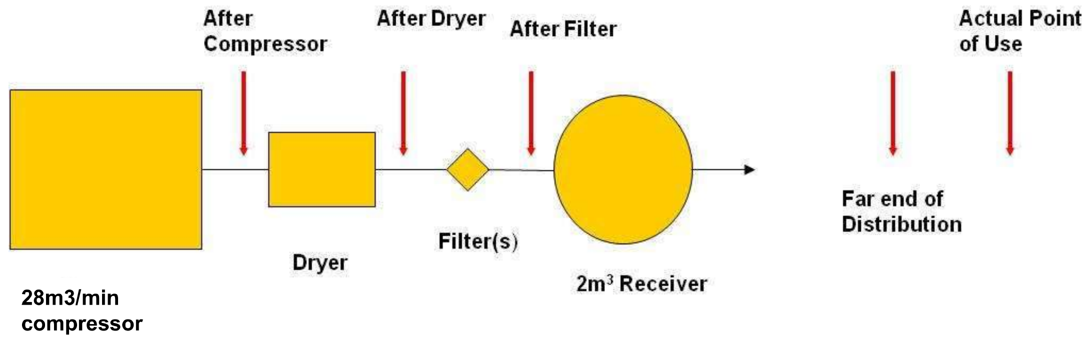
Compressed Air Systems

- Pressure profile
- Demand profile
- High volume intermittent demand events
- Perceived high pressure demands
- Power consumption
- Production levels

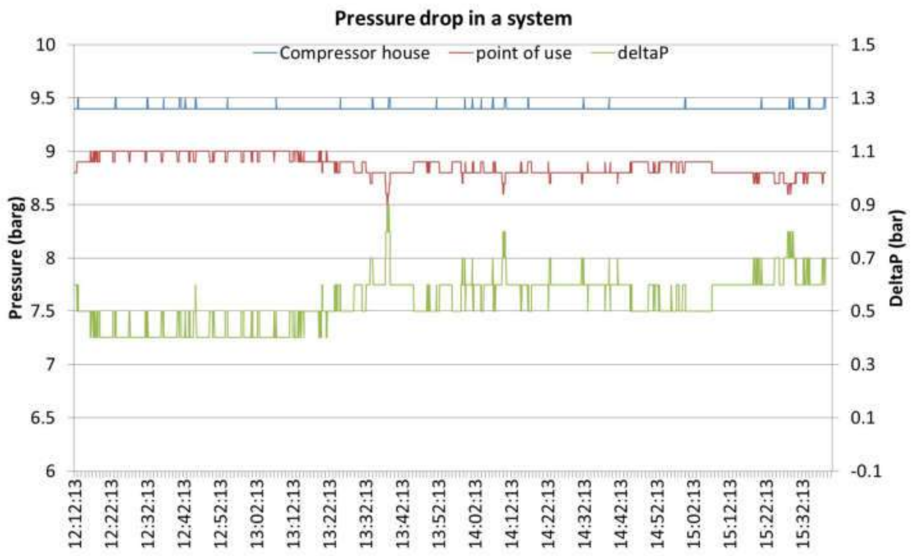
Compressed Air Systems

Remember this?

Draw a block diagram and determine where to measure.

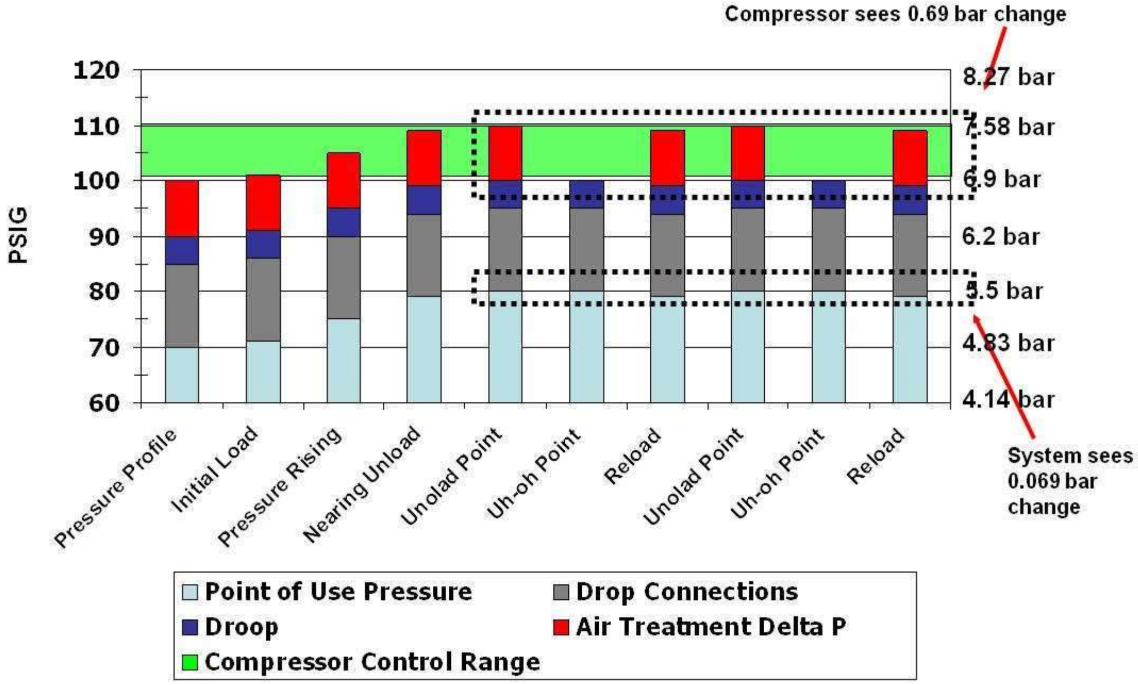


System pressure drop



- High differential pressure
- Undersized mains

Compressed Air Systems



Compressed Air Systems

- Pressure profile
- <u>Demand profile</u>
- High volume intermittent demand events
- Perceived high pressure demands
- Power consumption
- Production levels

Compressed Air Systems

What do you measure to determine a demand profile?

- •Flow in the pipe
- •Inlet vacuum on modulating machines
- •Load cycles on load/unload machines
- •Airend speed on variable speed machines
- •Inlet air flow
- •Power

Compressed Air Systems

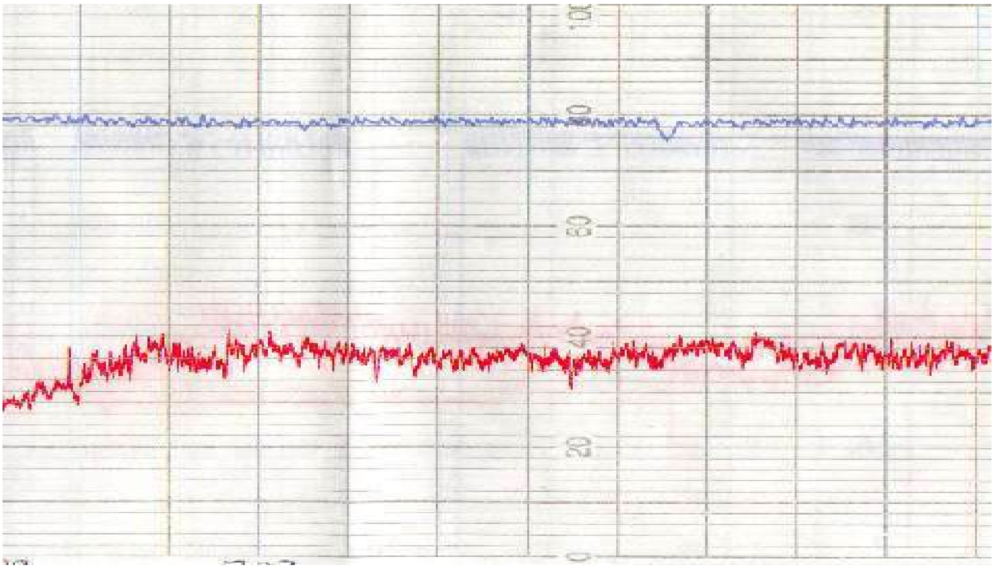
What do you measure to determine a demand profile?

- •Flow in the pipe

Flowmetering

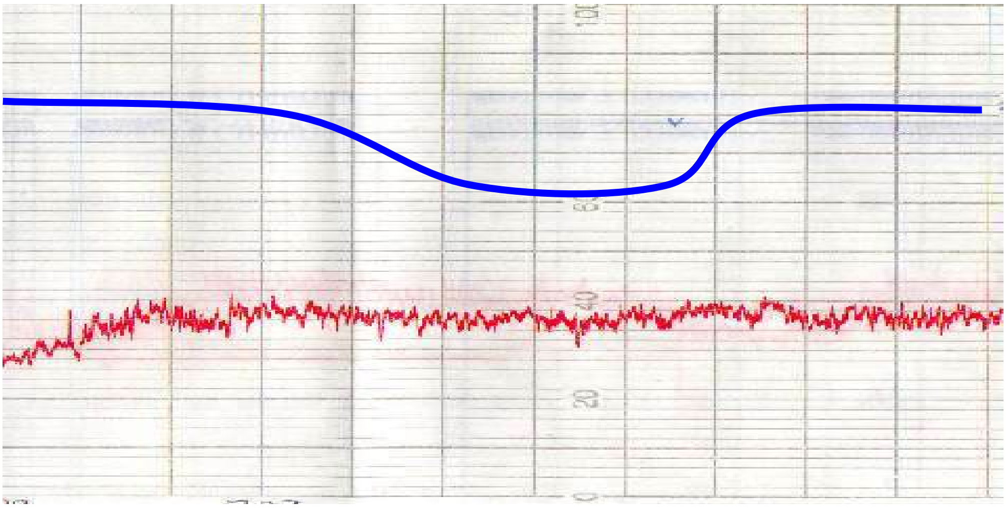
- Important to measure pressure
- Demand or flow?
- Flowmeters don’t always give a correct compressor capacity

Flowmetering – demand or flow?



Pressure held well therefore measured flow = demand

Flowmetering – demand or flow?



Pressure

Flow

Pressure drops
Flow stays steady – compressors running flat out
Measured flow is less than site demand

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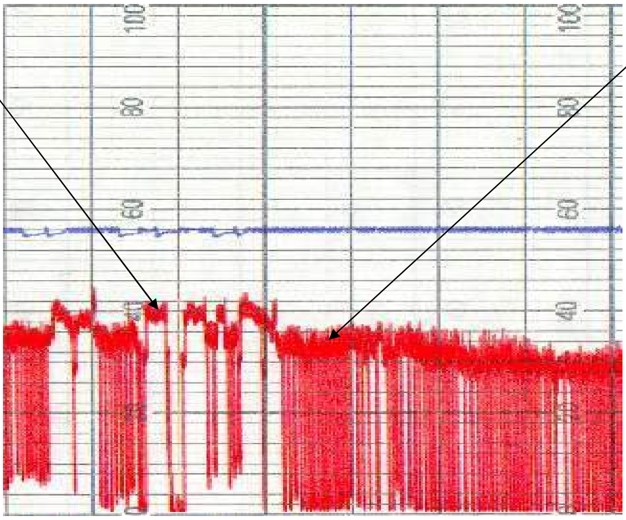
Flowmetering – compressor capacity

Compressor fully loaded for longer periods flowmeter reads over 40

Compressor cycling on and off load flowmeter reads up to 36

Pressure

Flow



Receiver damping flow changes

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Metering – inlet conditions & flowreadings

- Flow meter readings normally given at set conditions eg scfm, Nm^3/hr:
  - Standard – 1013 mbarA, 15C, 0%RH
  - Normal – 1013 mbarA, 0C, 0%RH
- Compressor outputs usually free air delivered at 1000 mbarA, 20C, 0%RH for screw compressors, different for centrifugal
- Corrections required between the two sets of data (can be over 15% difference)

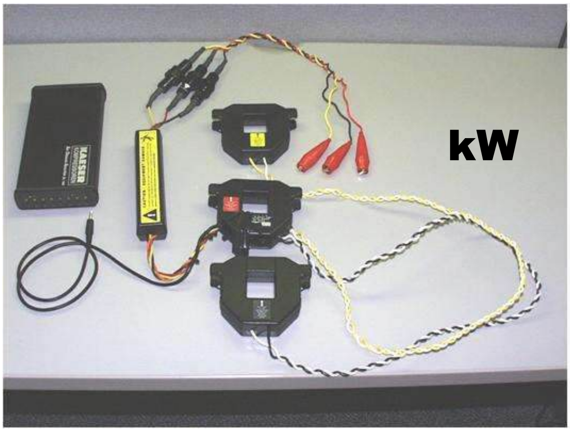
The effect of inlet conditions

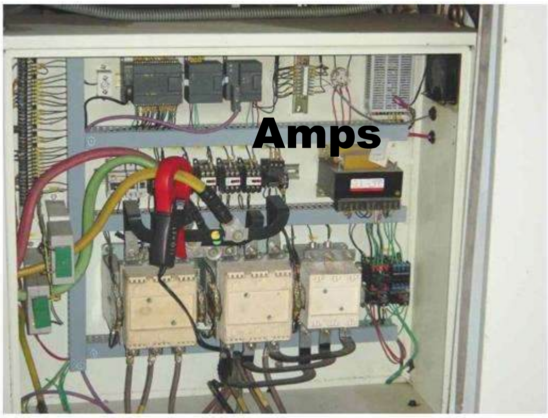
Inlet conditions	FAD	Nm^3/hr	Scfm	Comments
1000 mbarA, 20C, 60%RH	1000 m^3/hr 589 cfm	915 Nm^3/hr 91.5%	568 scfm 96.4%	Cool Vietnam
980 mbarA, 35C, 70%RH	**1000** m^3/hr 589 cfm	**845** Nm^3/hr **84.5%**	525 scfm 89.1%	Warm Vietnam
780 mbarA, 35C, 80%RH	1000 m^3/hr 589 cfm	670 Nm^3/hr 67%	416 scfm 70.6%	Mexico City

A 1000 m^3/hr compressor will only deliver 845 Nm^3/hr at certain conditions
You need to know the inlet conditions to know if the compressor is performing correctly

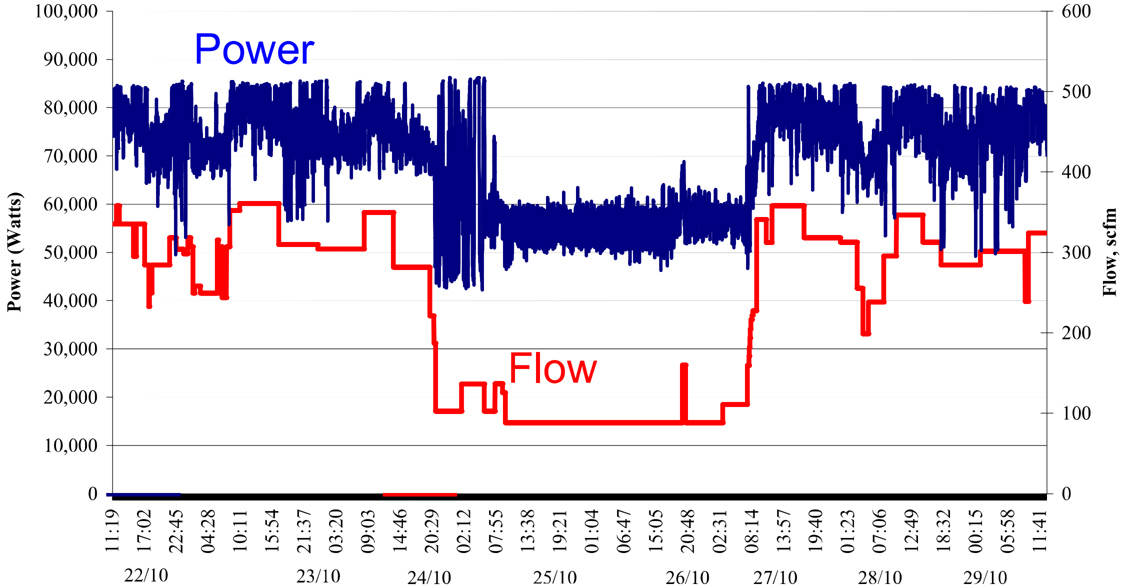
Power metering

- kW is the preferred measurement for power
- Amps can provide valuable information but power factor can be very low when off load (0.3-0.5)

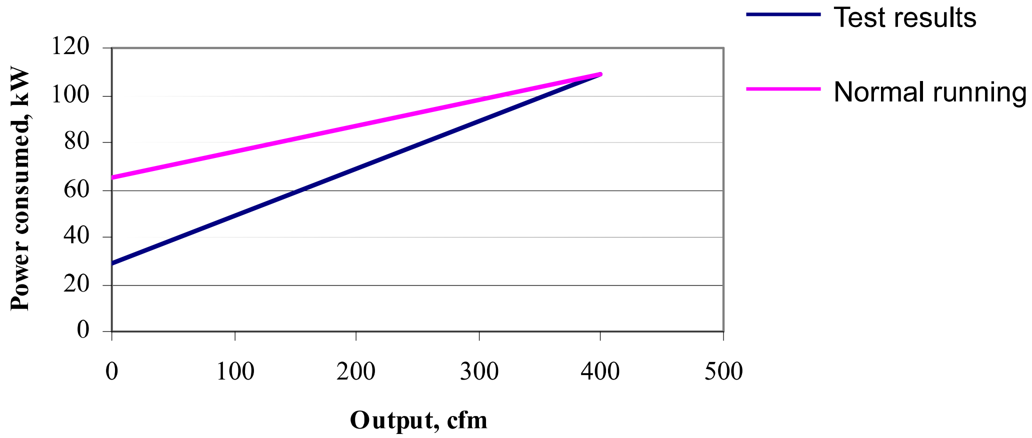




Power metering



Rapid cycling – The effect on power metering

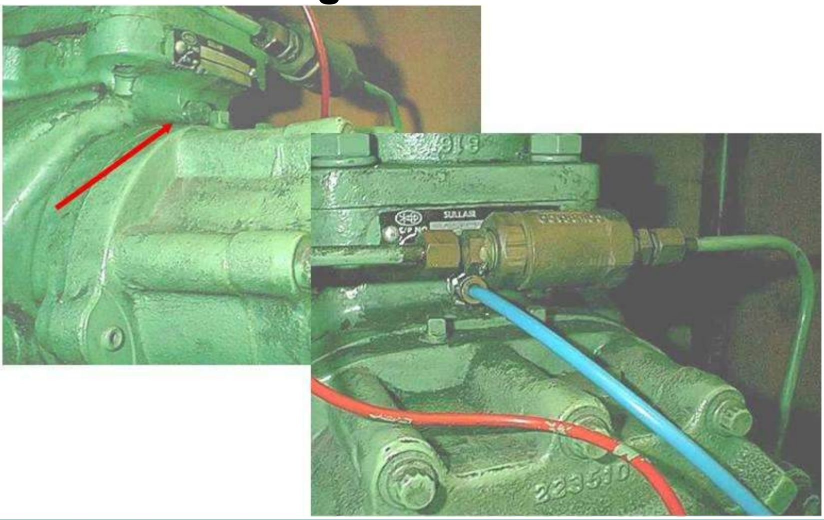


- 80 kW = 255 cfm - high base demand?
- 80 kW = 140 cfm – low base demand
- Power monitoring results can be inaccurate for flowmetering

Compressed Air Systems

What do you measure to determine a demand profile?

- **Inlet vacuum on modulating machines**



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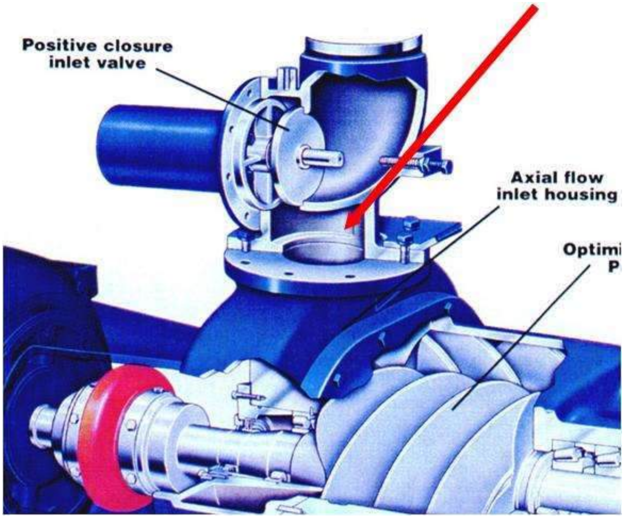
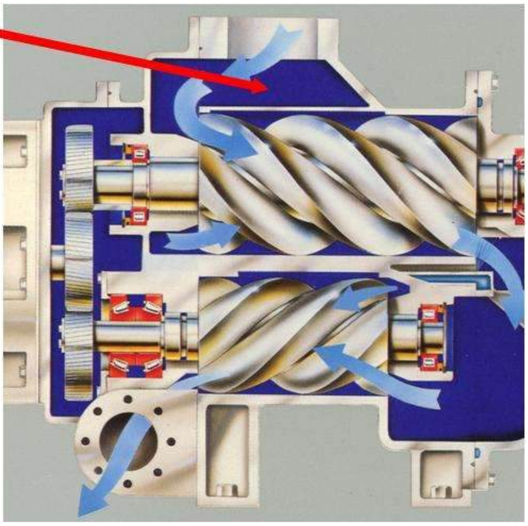
With the inlet valve modulating, absolute pressure below the valve plate will be reduced in direct proportion to the reduced flow.

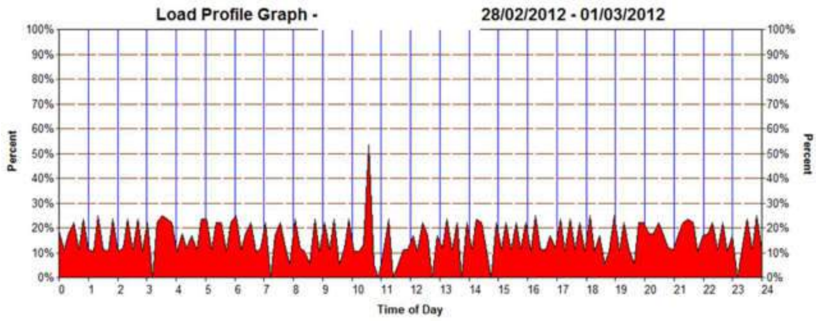




Compressed Air Systems

What do you measure to determine a demand profile?

- Load cycles on load/unload machines



Compressed Air Systems

- Pressure profile
- Demand profile
- <u>High volume intermittent demand events</u>
- Perceived high pressure demands
- Power consumption
- Production levels

Compressed Air Systems

High Volume Intermittent Demand Events:

•Define short-lived peak airflow rate, valley pressure, and rate of system pressure decay. Gather information necessary to calculate compressed air storage solutions.

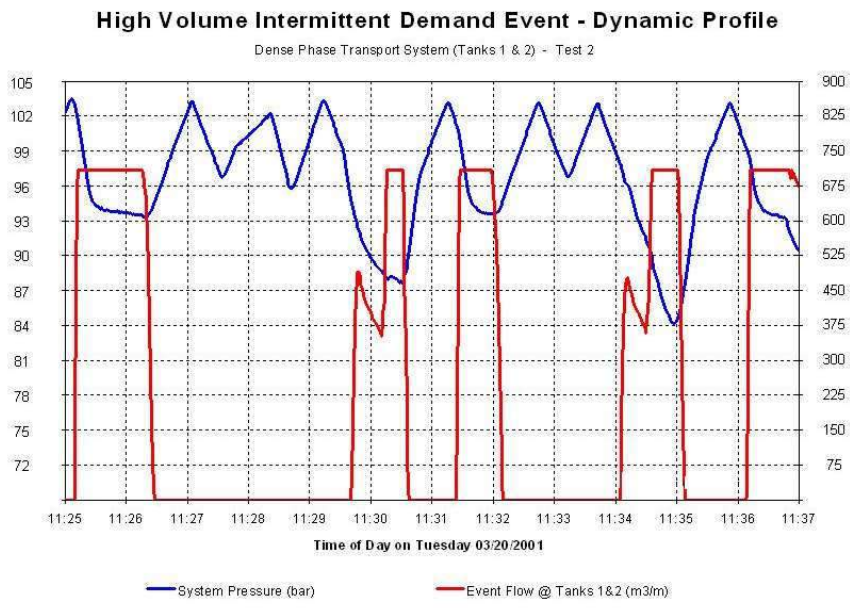
•Measure the duration of demand events and total air consumed.

•Measure the delay time between demand events and the ability to refill storage during the available delay time.

•Evaluate compressor control response and determine if compressors are running unnecessarily.

•Consider that excessive system pressure may currently be an operational solution to inadequate air storage.

Compressed Air Systems



Compressed Air Systems

- Pressure profile
- Demand profile
- High volume intermittent demand events
- <u>Perceived high pressure demands</u>
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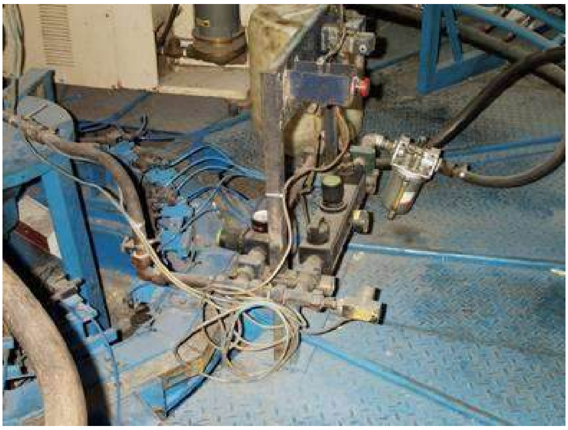
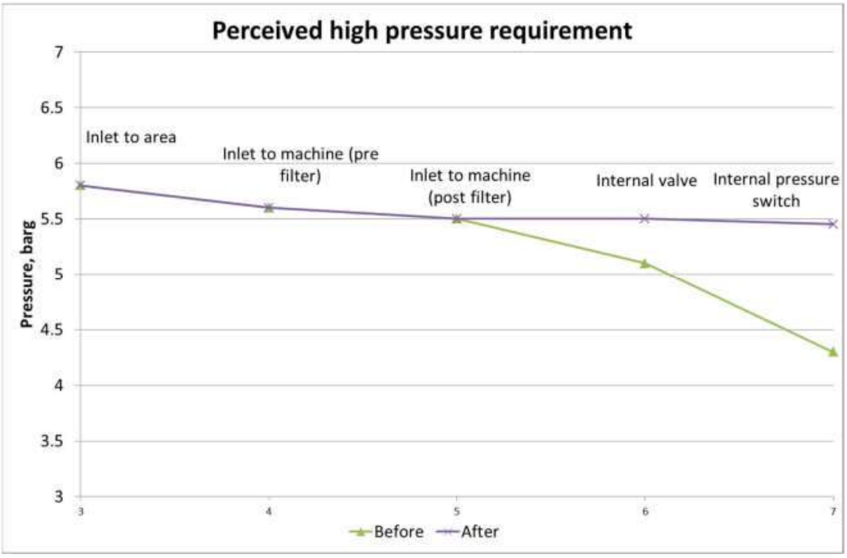
Compressed Air Systems

Are poor point of use connection practices causing the system to run at higher than required pressures?



Perceived high pressure demands

Upgrading internal lines prevented pressure increase across the site



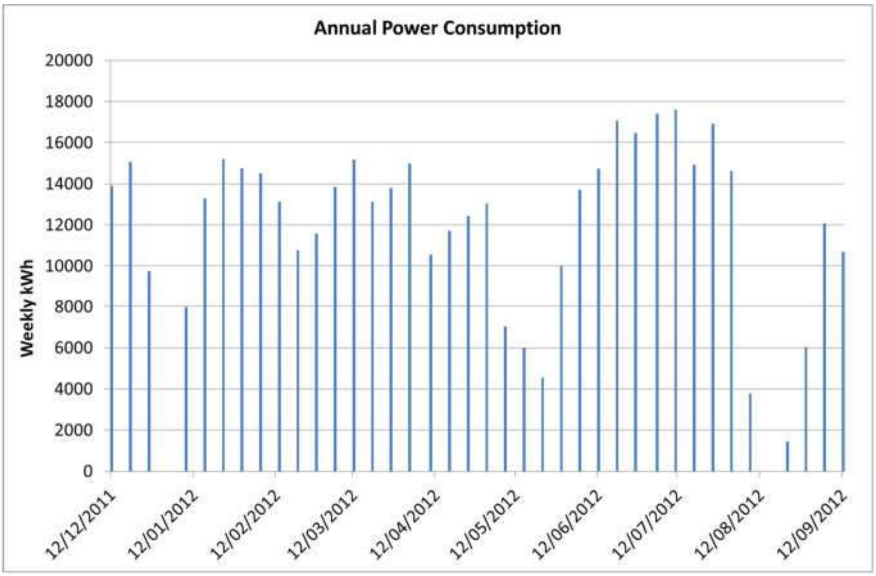
Compressed Air Systems

- Pressure profile
- Demand profile
- High volume intermittent demand events
- Perceived high pressure demands
- <u>Power consumption</u>
- <u>Production levels</u>

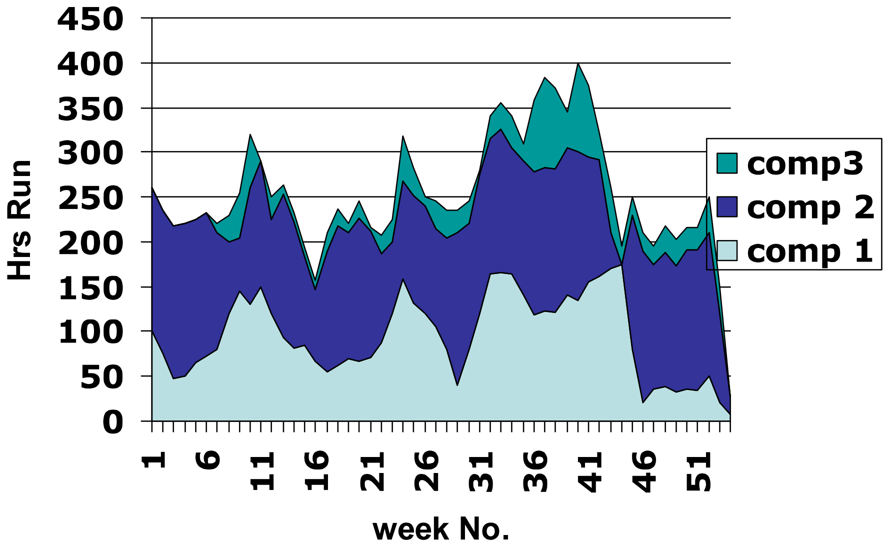
Profiling

- Compare figures over time:
  - kWh
  - Hrs run
  - m3

Is it high or low production?



Analysis of hours run



Even the most basic data can give useful results

Productivity monitoring

- Calculate air used per unit of product
  - Cfm per tonne
  - Cfm per car
  - Cfm per daily rate of production
- Set limits and rectify
- Compressor stations
  - Use total power input versus air demand - ideal for an energy management system
  - Put in acceptable limits for base use and normal production
  - Rectify when limits exceeded

Benchmarking

- Compare your air consumption per unit of production with:
  - Other group plants
    - Eg: an aluminium products plant in UK taking twice the air per tonne as a sister plant in France
  - Other similar plants
    - Eg: European car plants taking three times the air per unit as Japanese plants

Summary of session

Areas covered:

- How to carry out a survey
- Measurement options
- Pressure profile
- Demand profile
- Short duration peak demands
- Perceived high pressure demands
- Profiling and benchmarking
- Analysis with little or no metering
- Calculating running costs

Summary of the day

- Brief introduction to optimisation opportunities
- The basics of compressed air
- How to analyse and survey systems
- How to calculate running costs

Tomorrow

- Optimisation opportunities and case studies
- Analysis of compressed air projects
- New developments

END OF SESSION
ANY QUESTIONS?

Compressed Air Systems

UNIDO Compressed Air System Expert

Part 3 – Optimization opportunities

Summary of the day - yesterday

- Brief introduction to optimisation opportunities
- The basics of compressed air
- How to analyse and survey systems
- How to calculate running costs

Summary of session 1

Areas covered:

- Overall costs for compressed air and savings potential
- Examples of problems and good practice
- Compressor types
- Dryer types
- Filters
- Receivers
- Condensate
- Installation
- Distribution

Summary of session 2

Areas covered:

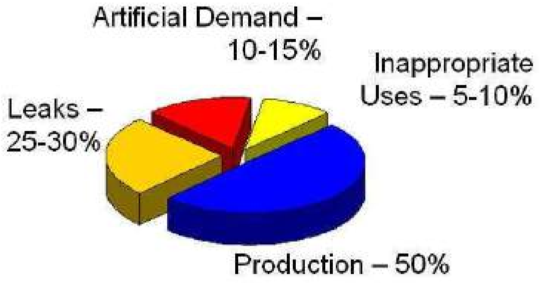
- How to carry out a survey
- Measurement options
- Pressure profile
- Demand profile
- Short duration peak demands
- Perceived high pressure demands
- Profiling and benchmarking
- Analysis with little or no metering
- Calculating running costs

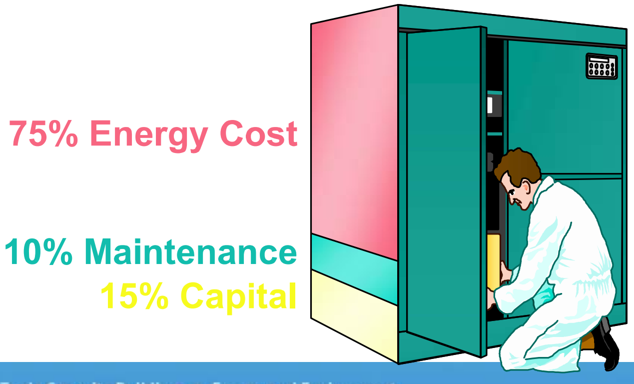
Today

- Optimisation opportunities and case studies
- Analysis of compressed air projects
- New developments

Optimisation and Waste Minimisation

- Typically 10% of industrial electricity is used to produce compressed air
- Average saving = 30%
- 75% of lifetime cost of a compressor is energy usage
- Leaks, artificial demand and inappropriate uses can use as much as 50% of the air supply.
- Compressed air driven equipment costs around 10 times more to run than electric drive.





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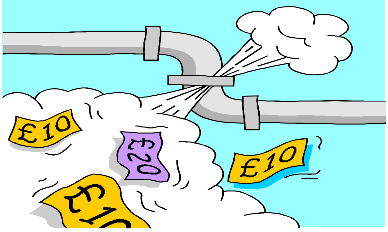
Main causes of waste

- Inefficient Generation & Treatment
  - Poor compressor control
  - Poor efficiency
  - Incorrect sizing
- Pressure drops in treatment and distribution systems
- Leaks
- Misuse of air - cooling, product ejection & ventilation
- Waste heat not recovered



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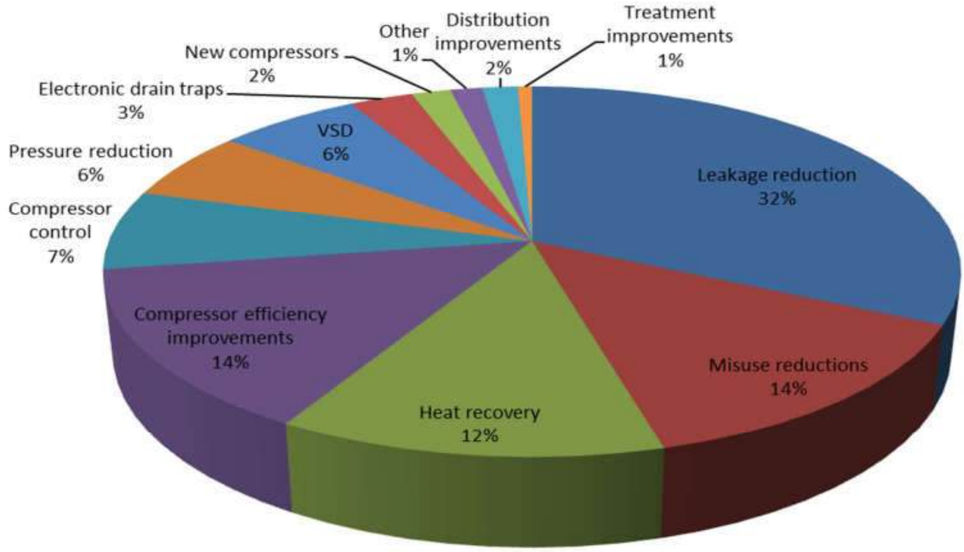
Compressed Air Key Savings Areas



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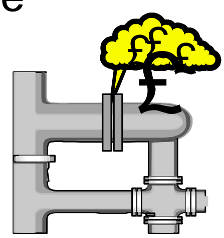
Compressed air leaks

- Carry out a no load leak test
- Should not be more than 10% of the mean production demand in a normal factory
- Can be up to 20% for large sites, over 80% measured on occasion
- Leaks come back but seldom in the same place
- Regular ongoing leakage campaigns must be conducted



Leakage losses

Hole diameter	Air consumption at 6 bar (g) m^3/min	Loss kW
1 mm	0.065	0.3
2 mm	0.240	1.7
4 mm	0.980	6.5
6 mm	2.120	12.0

At VND3000/kWh, a 4mm leak costs over VND170,820,000/year in power plus additional service on the compressed air equipment.

Leak Detection

Many leaks can be heard, felt or seen.

Other techniques:

- Using soapy water:
  - Tried and trusted, time consuming but sometimes the only way
  - Only suitable for small leaks
- Ultrasound
  - Very effective even in high background noise areas

Common sources of leaks

- Filter, Regulator, Lubricator
- Manual Drain Valves
- Quick Disconnect (QD) fittings
- Hose clamps
- Push-on Hose fittings
- Cut or Punctured Hose
- Pipe fittings
- Pipe Unions
- Flange Gaskets
- Old Rusted Piping
- Pneumatic Cylinder Rod Packing
- Pneumatic Cylinder Body
- Directional Control Valves
- Valve Pilot Lines and Ports
- Valve Stems and Packing

Rubber hose with hose clamps make poor connections that often leak.

An open valve to drain water can cost more each month than the cost of an automatic drain that prevents air loss.

Ultrasonic leak detection

Example Leak Detection results.xls

Leak Repair

– 1st priority - Leaks to repair as soon as possible
  - Leaks that represent a safety problem due to blowing air, noise, etc.
  - Leaks that have the potential to interrupt production equipment failure.
  - Large leaks with air loss that could cause local or total system drawdown.

– 2nd priority - Leaks to schedule first, repair within 1-2 weeks
  - Leaks that are in the top 20% for air volume being lost from the system. The technician will gain a sense of relative leak size, noticeably large leaks fall into this category. Hopefully over time the top 20% of leaks are getting smaller in size

Leak Repair

- 3rd priority - Leaks that should be repaired within 3-4 months
  - Leaks that account for significant air loss but are not in the top 20%.
  - Small leaks that are a direct result of poor piping practice. For example poorly constructed hose, plastic tubing, or any other leak that is small at the present time but is sure to get bigger unless corrective action is taken.
- 4th priority - Leaks to Repair Only if They Move Up in Priority
  - Leaks that are small and located in otherwise sound piping. A leak that is not likely to get larger as time goes on.

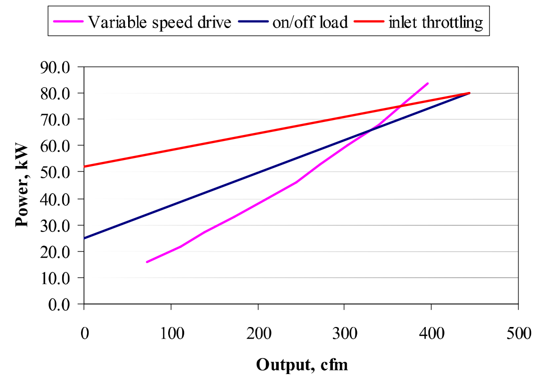
- Causes of Air Leaks
  - Physical damage, excessive heat, and vibration can cause compressed air leaks, which would otherwise not occur.
  - The largest cause of compressed air leaks is poor connection practice.

- **Prevention of Compressed Air Leaks**
  - **Isolate compressed air lines and pneumatic equipment from sources of physical damage, heat, and vibration.**
  - **Establish piping practice and equipment connection standards, which provide for strong and durable connection to the compressed air system.**
  - **Avoid over use of plastic tubing, and push-on connectors.**

- **Key Points**
  - **Understand common leak locations and start looking for leaks where you are most likely to find them.**
  - **Ultra-sonic leak detectors allow you for quickly and efficiently locate and prioritize leaks.**
  - **Prevention of compressed air leaks should focus on adopting and complying with sound piping practice standards.**

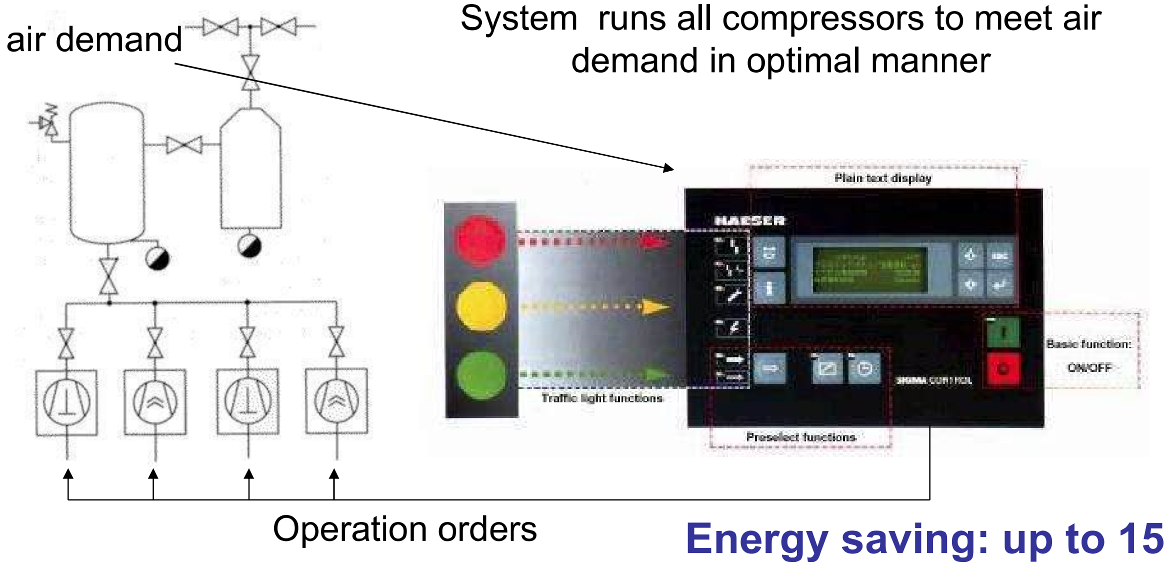
Control of compressors

- Only minimum required compressors should be on line
- How do your compressors control? – on/off, modulate, blow off
- Understand how they will interact with each other
- Consider a group control system
  - Minimise pressure band
- Auto shut down should be working to minimise long periods of no load running
- Can a variable speed drive machine be used?



Group control system

System runs all compressors to meet air demand in optimal manner

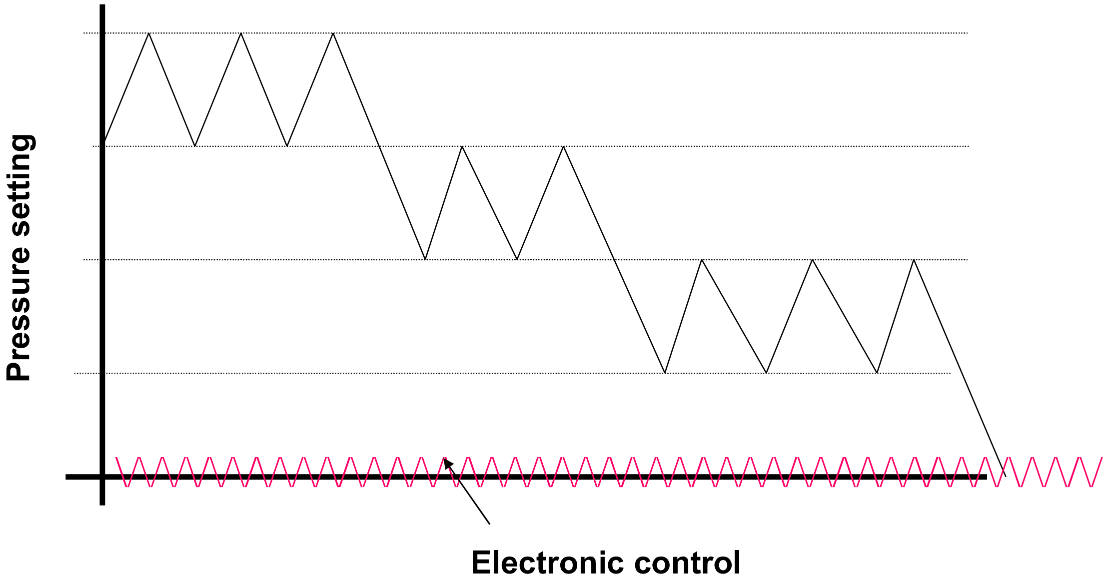


Energy saving: up to 15%

Group Control

- To provide simple control of groups of compressors
  - Sequential switching and duty rotation
  - Turning off machines when not needed
- To provide targeting and monitoring information
  - SPC of compressor installations
  - Base leakage figures
- To control zone isolation valves
- To reduce generation pressure during non-production hours
- To provide maintenance information

Normal sequential control versus electronic control
Pressure versus demand



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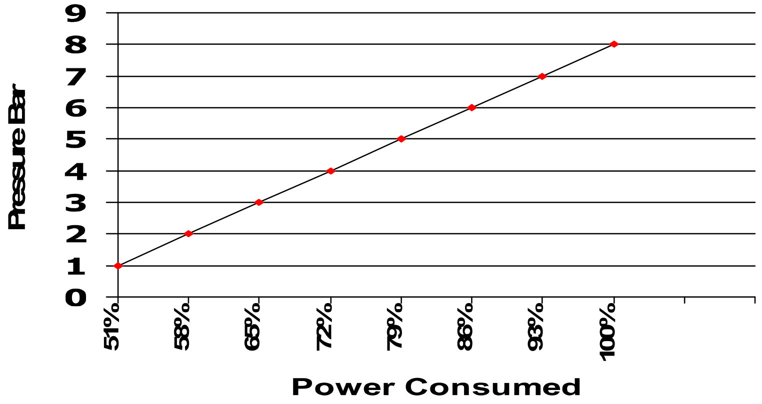
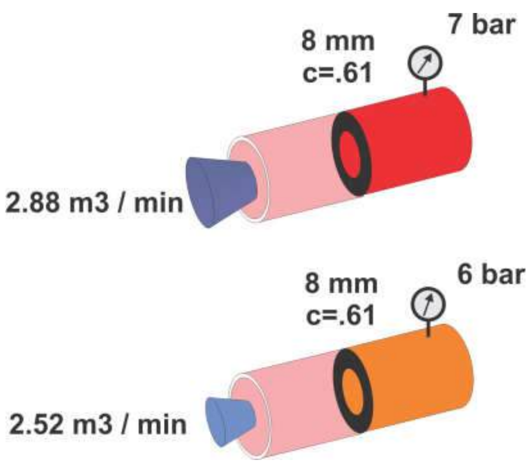
Reducing pressure - Reducing cost



1 bar = reduction of 6-7% of full load power
1 bar = reduction of around 15% in artificial demand and other unregulated usage

Artificial demand

- Increasing pressure applied to a hole in the air system, increases the airflow through the air system.
- Leaks and unregulated air demands all have a potential component of artificial demand.
- Leak repair without pressure control is not fully effective.



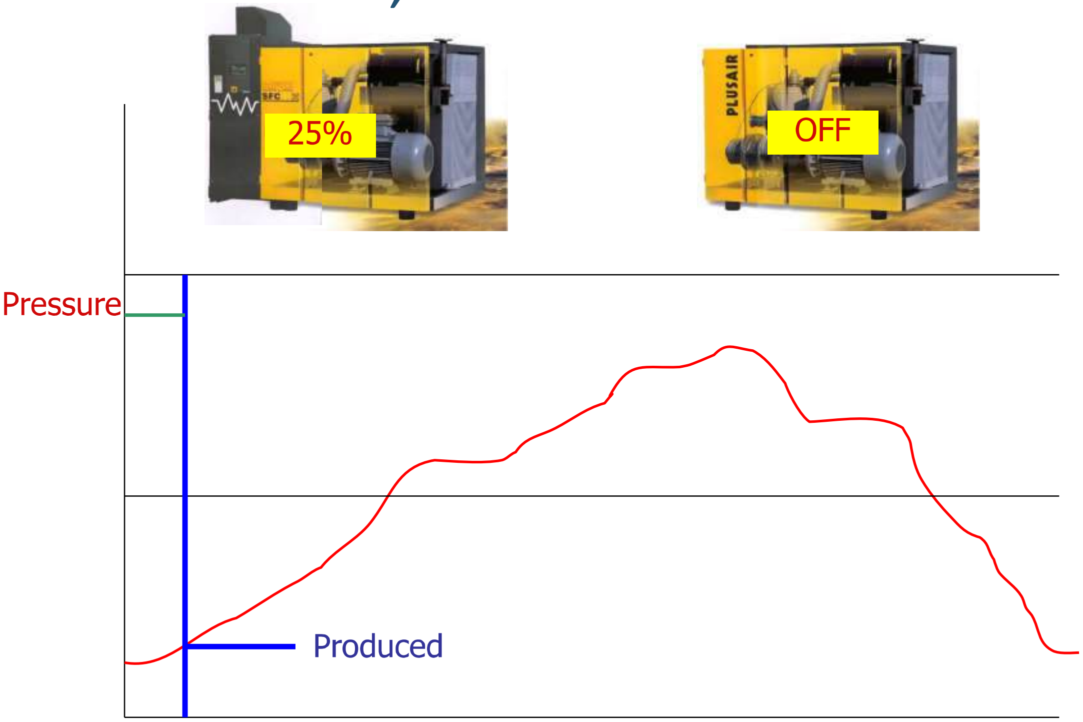
Application of a single variable speed/frequency compressor

How does it work?

VSD compressors

- Size compressor to cover demand range
- Avoid control gaps
- Maximise running at mid range speeds
- Remember not all VSDs offer the same performance range

Control, Same Sized Machines



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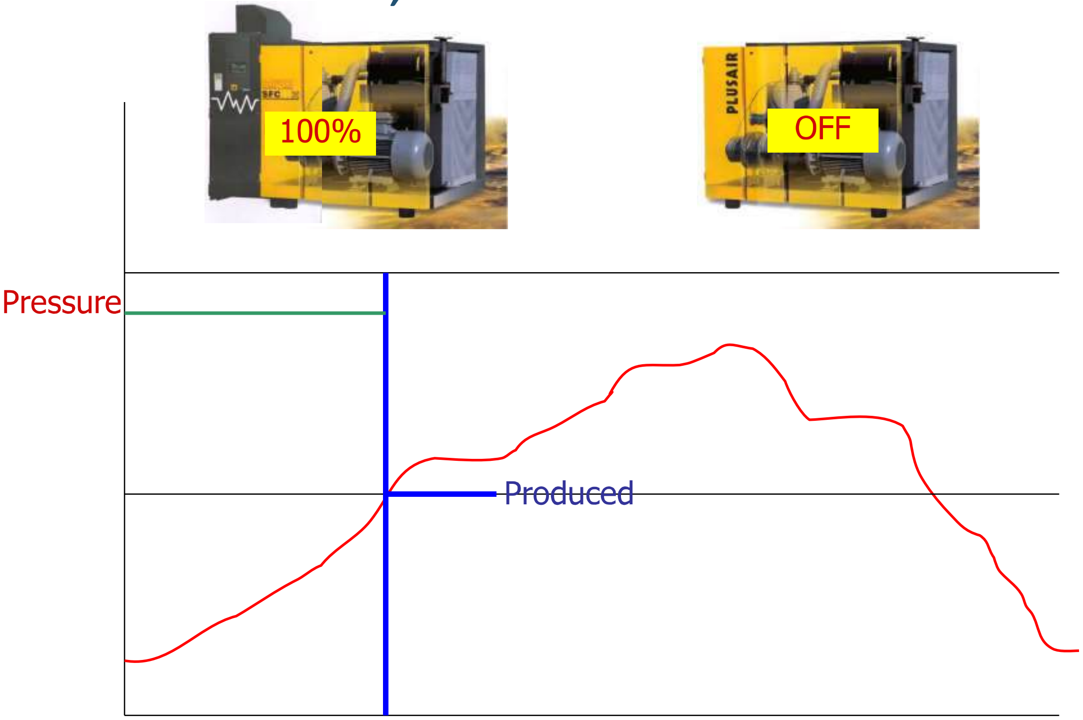

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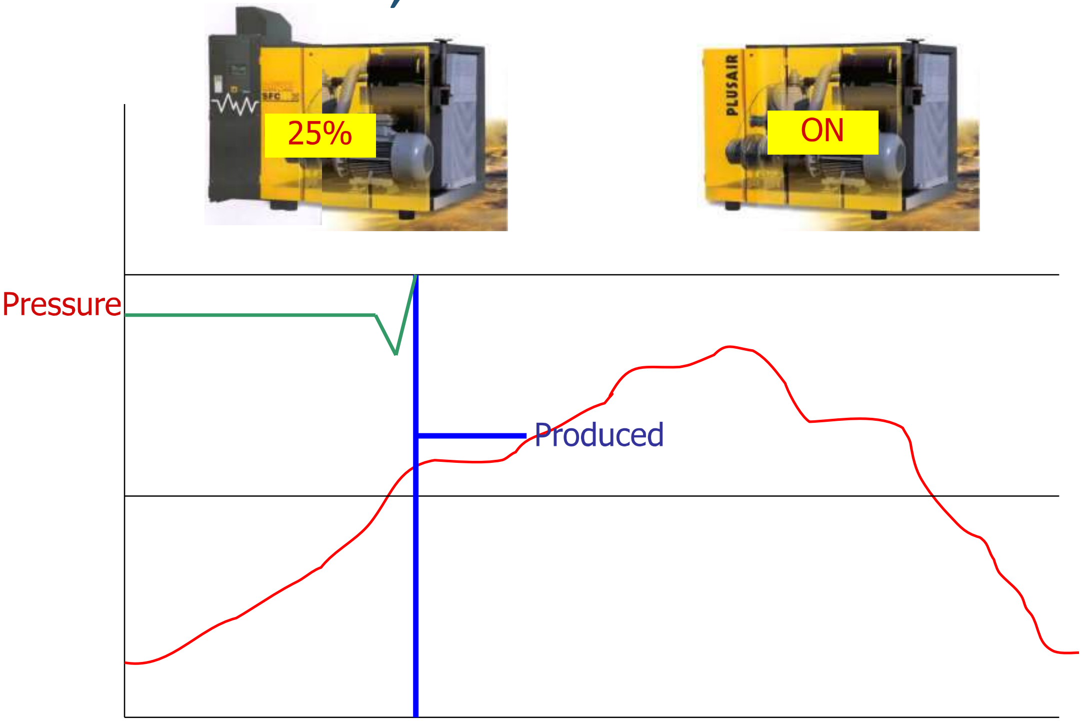

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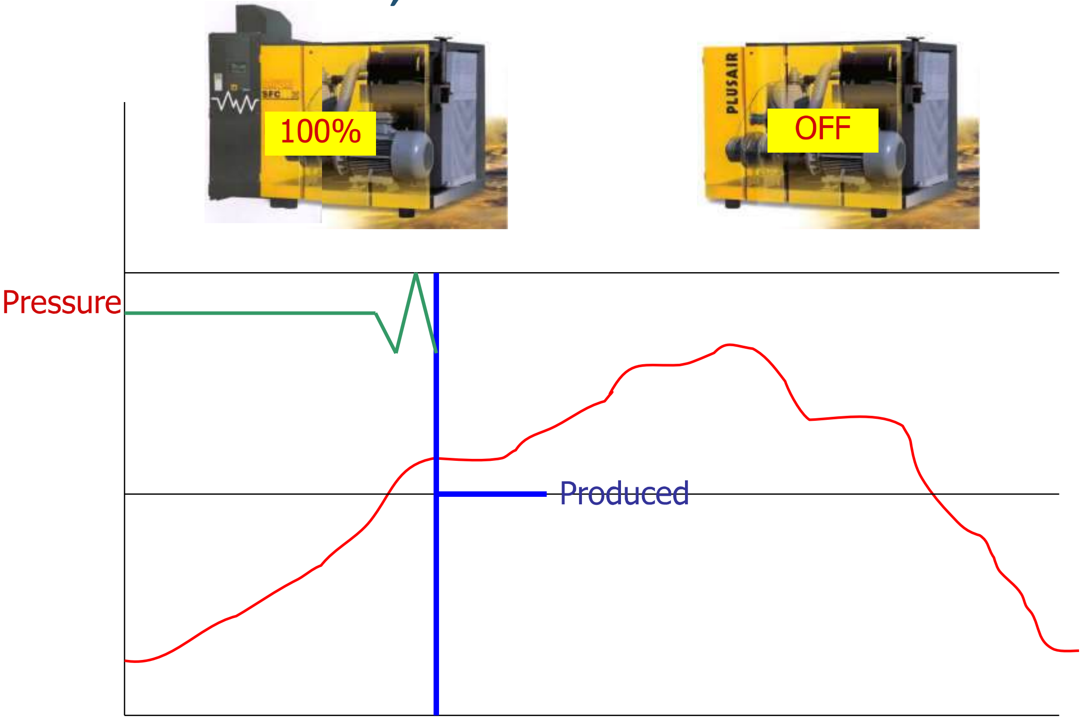

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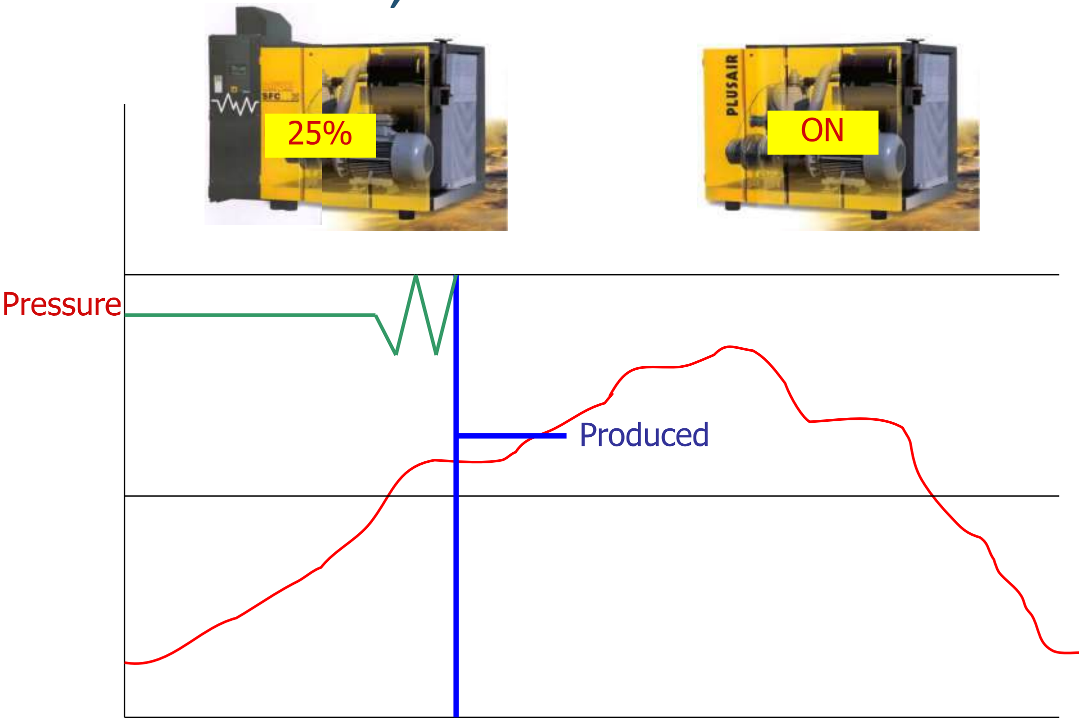

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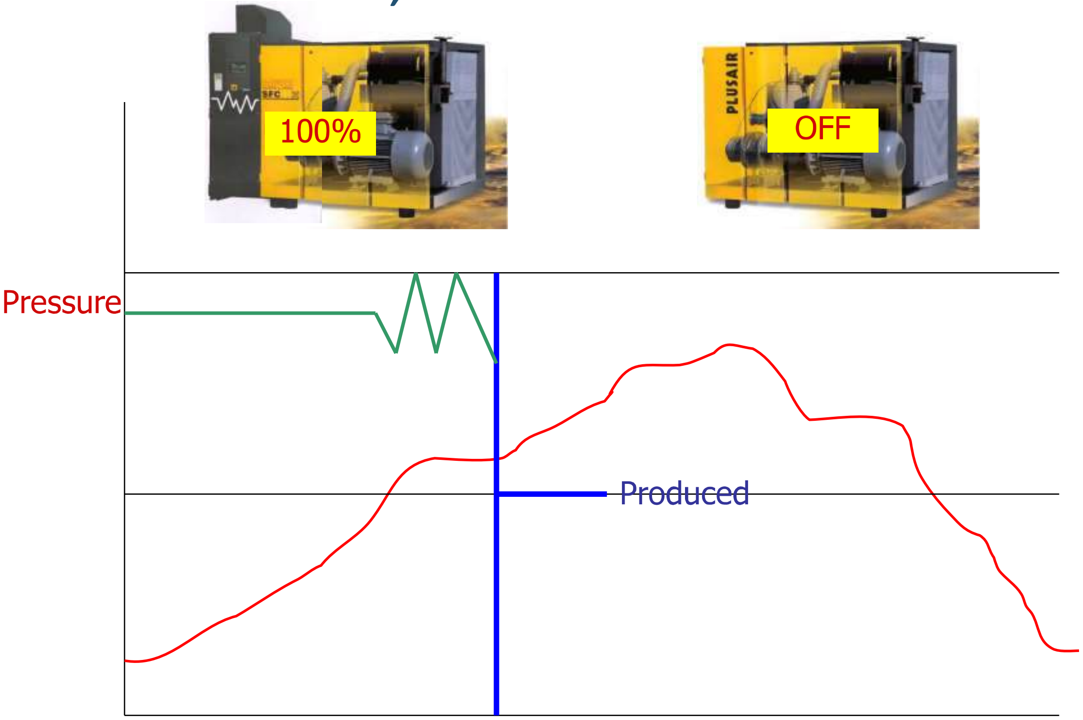

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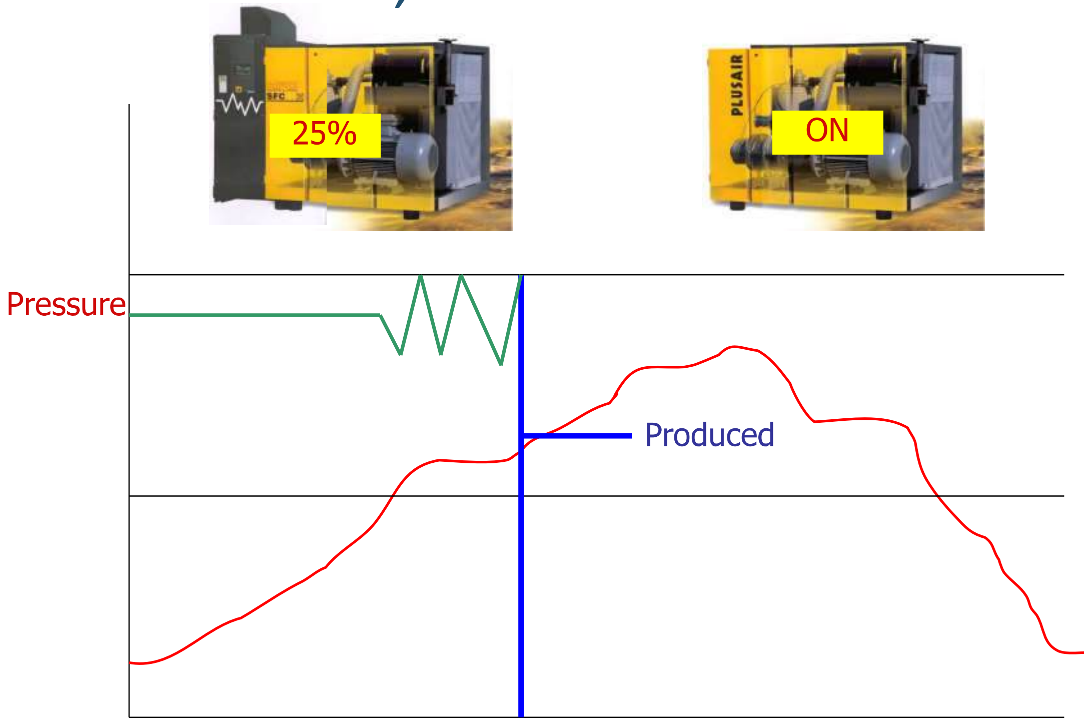

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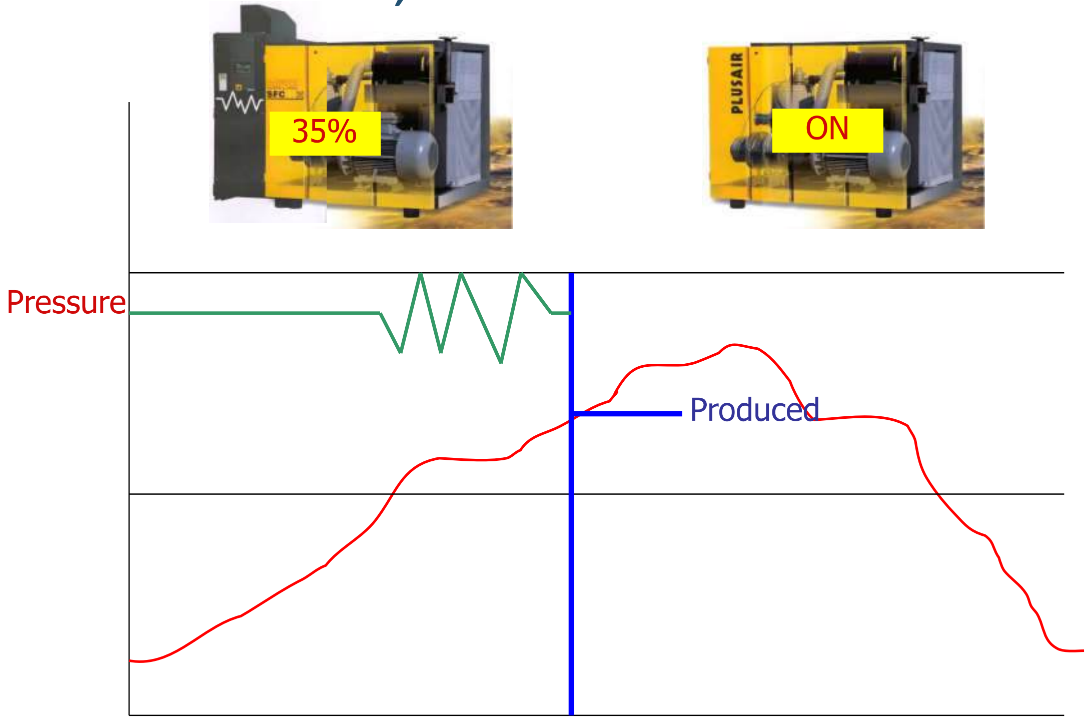
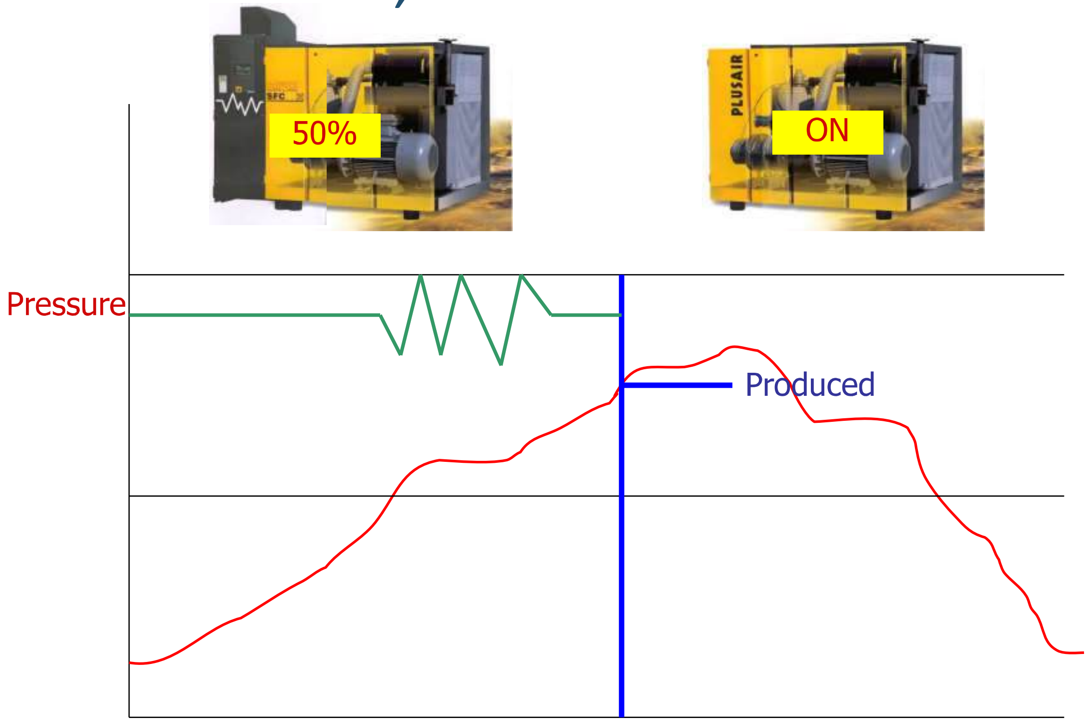
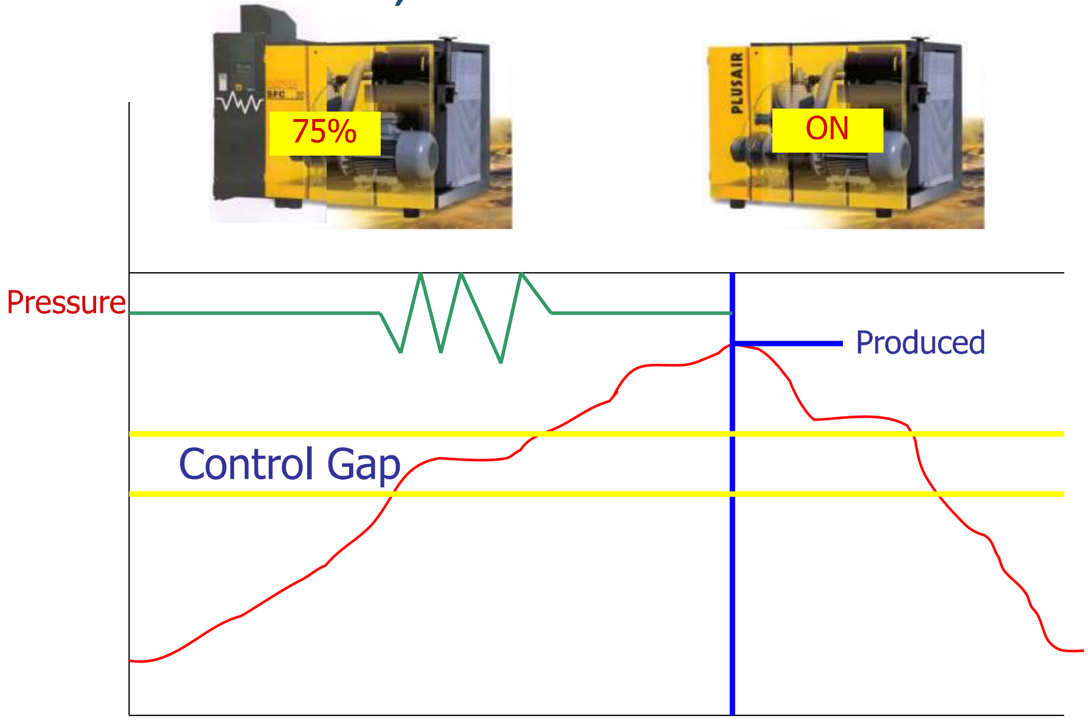


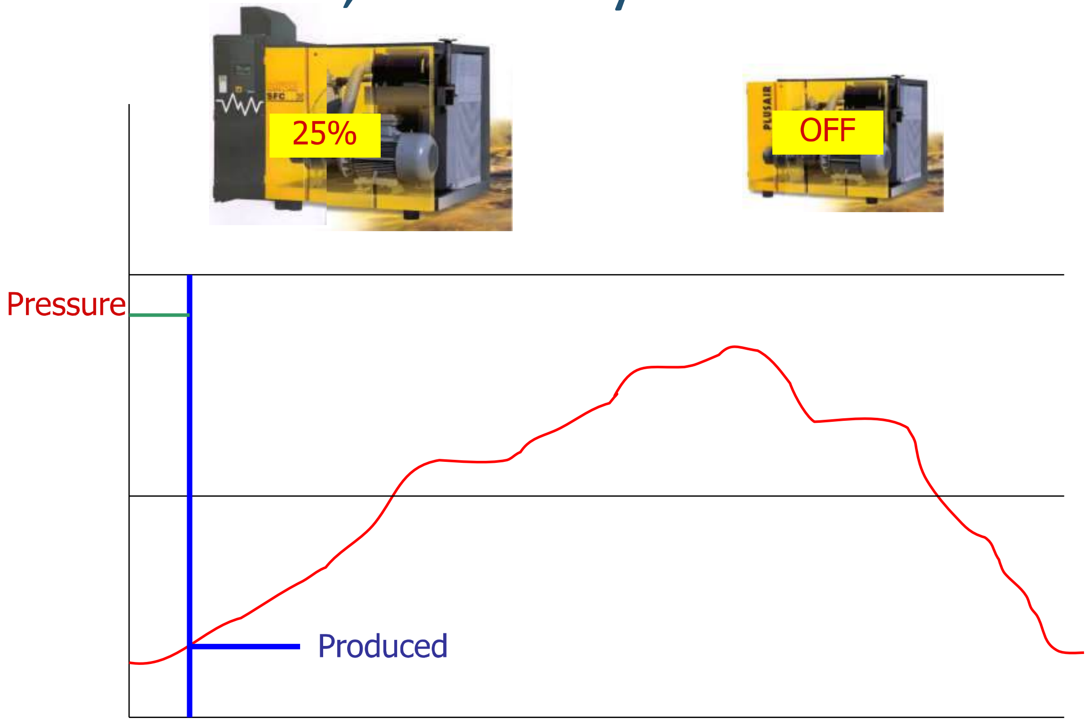
Control, Same Sized Machines



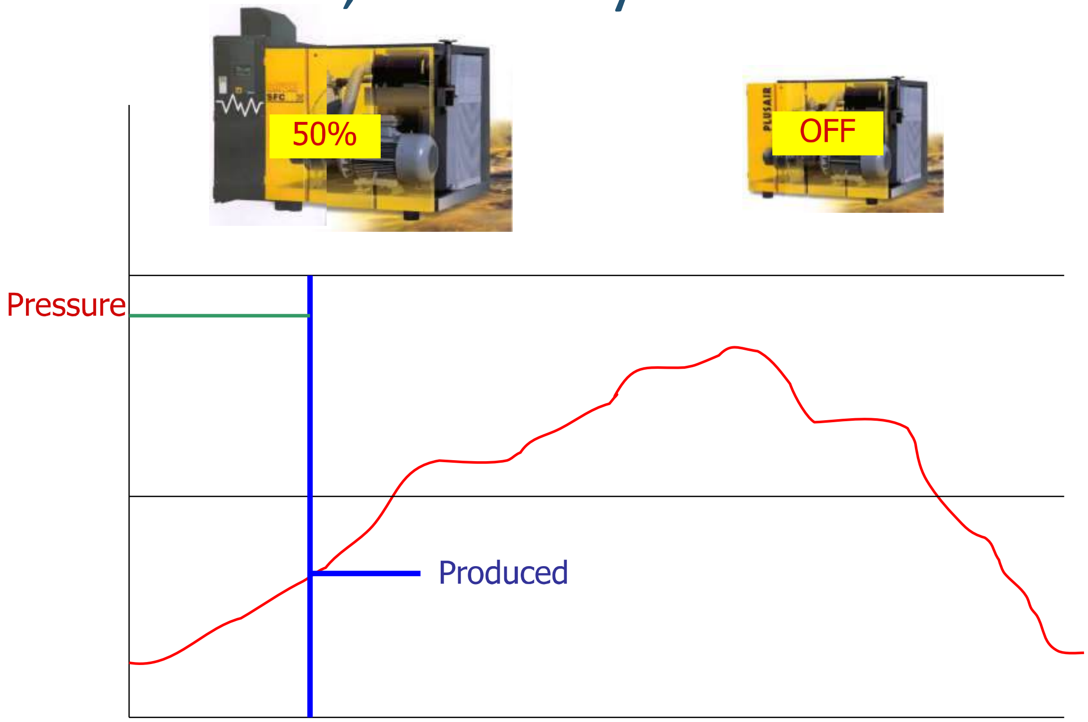
Control, Same Sized Machines



Control, Correctly Sized Machines



Control, Correctly Sized Machines



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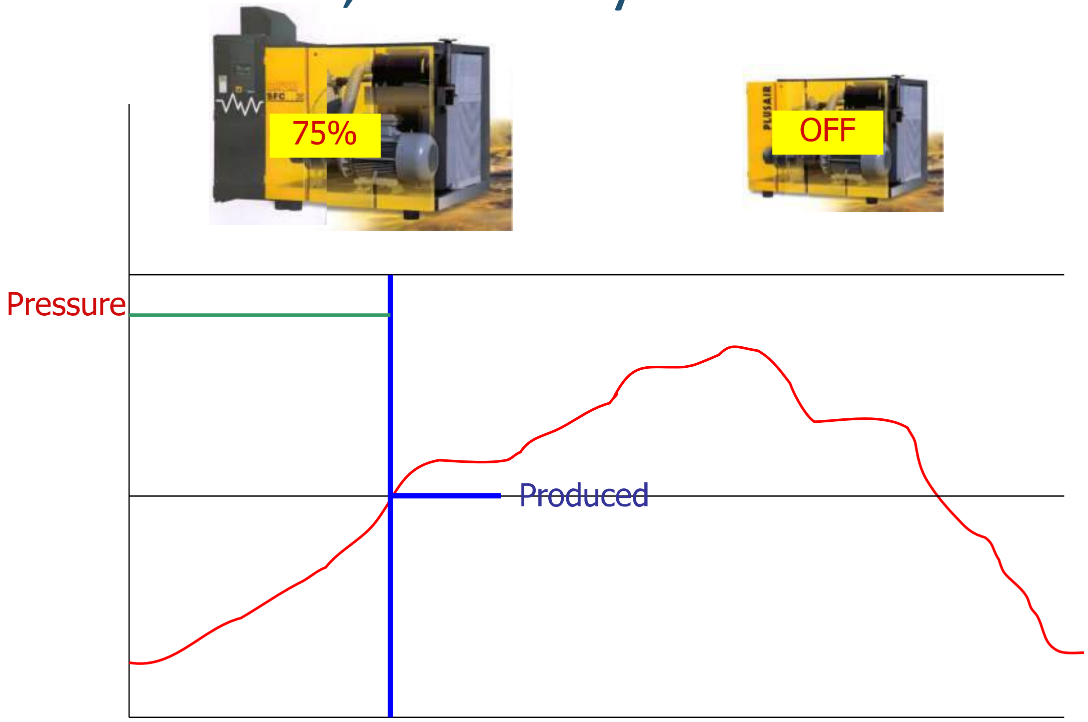

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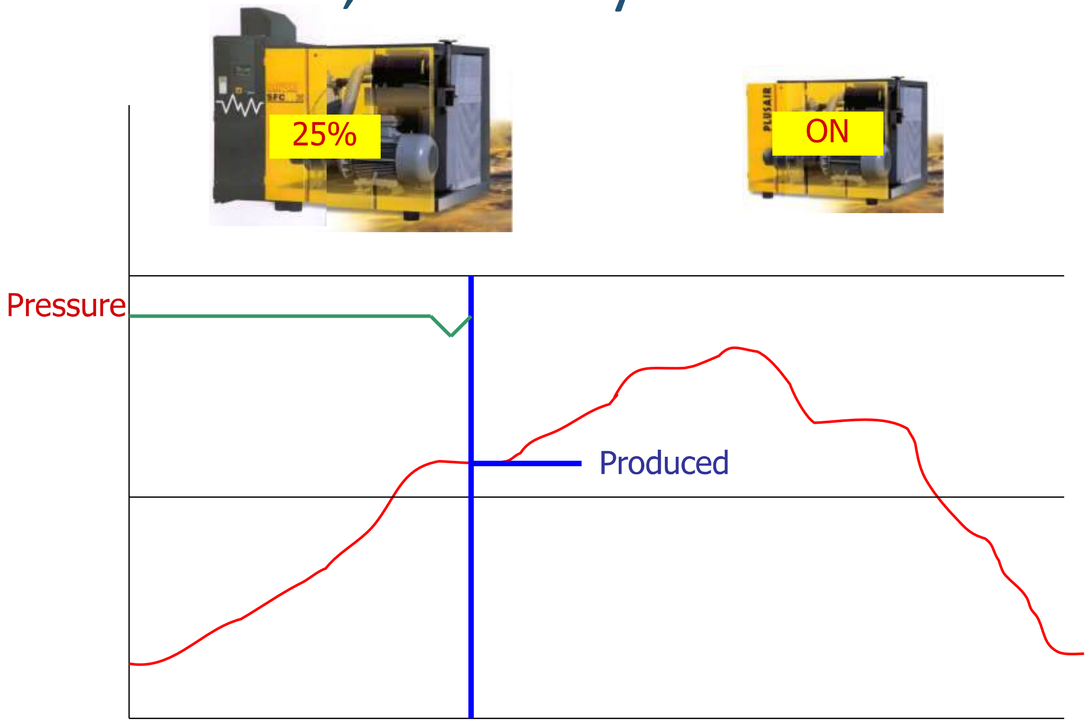

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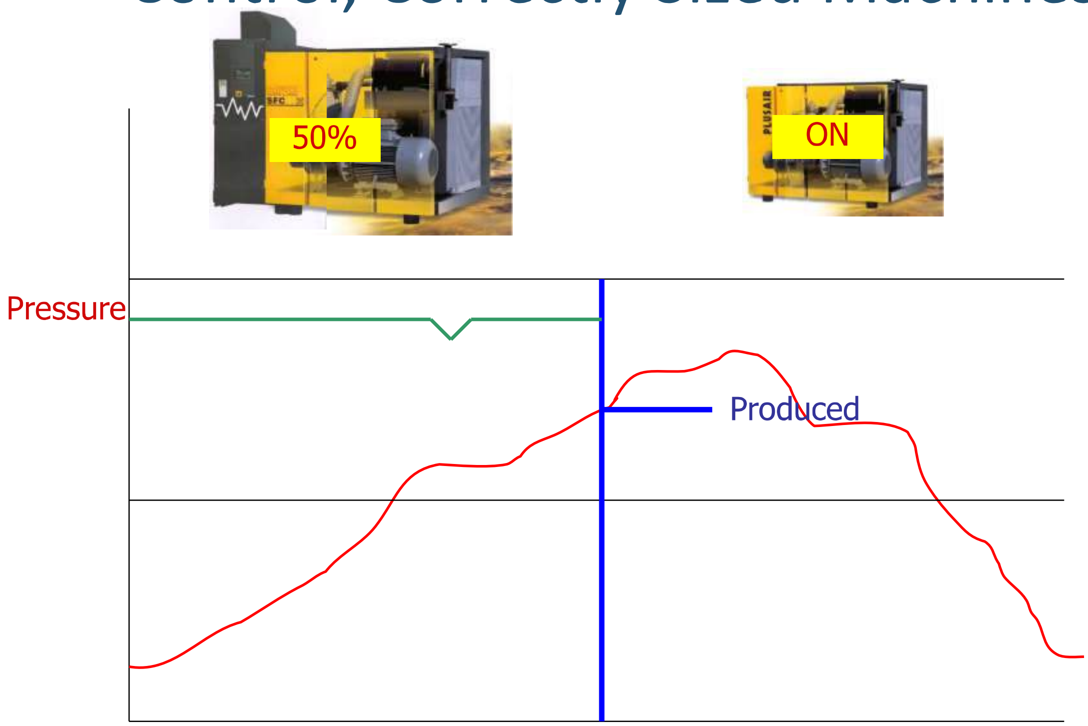

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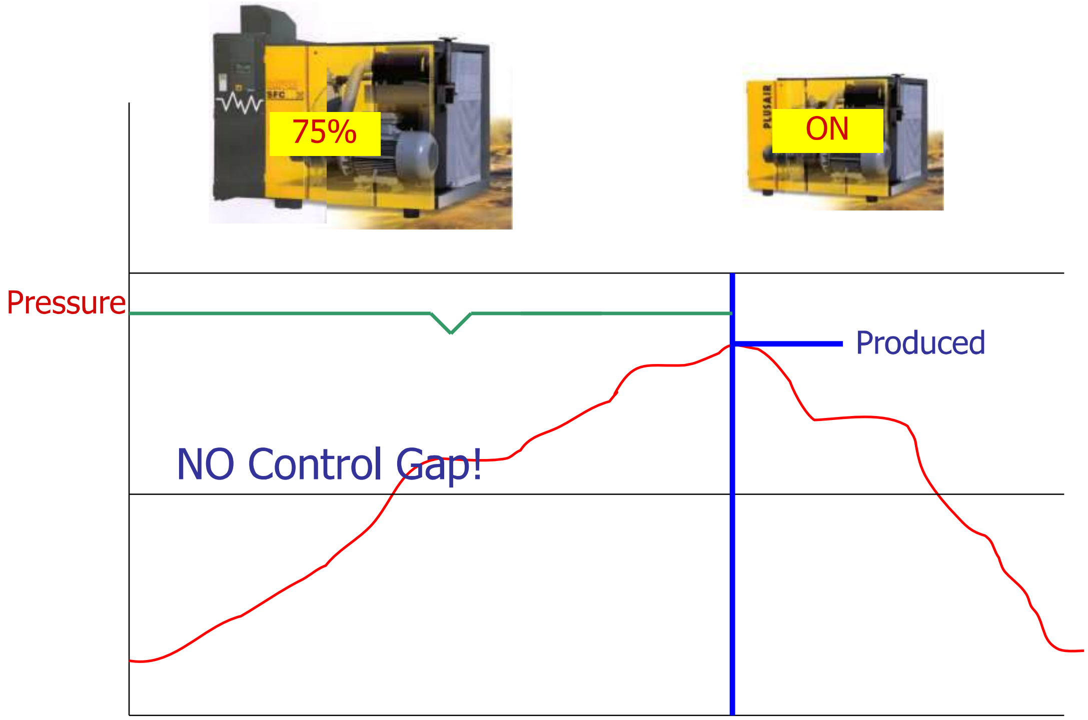
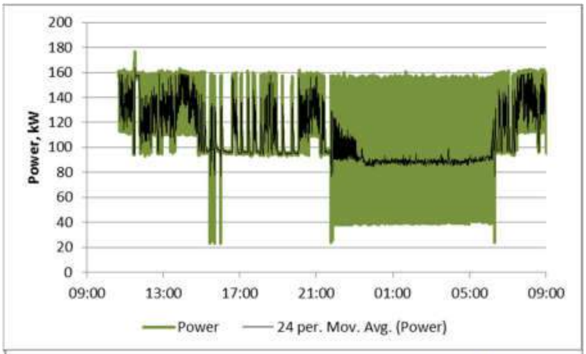
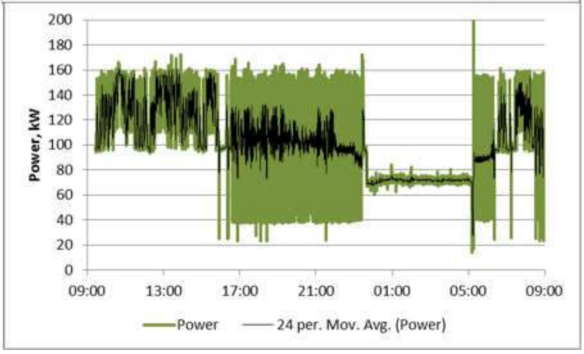


VSD misapplication

Graph 1 – VSD and on/off cycling together



Graph 2 – VSD alone

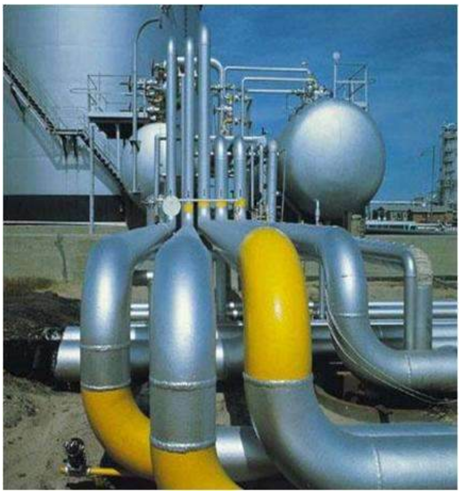


Change in control setting reduces night load by 20 kW

Compressed Air Systems

Piping

- **Size and layout have major impact on flow and pressure drop**
- **Material choice impacts air quality, pressure drop, installation costs and long term performance.**
- **Install a closed-loop piping system**
  - **Provides a two-way flow to any point in the system**
  - **Maximum length of flow for 1,000 meters of pipe is 500 meters**
- **Size pipe for minimal pressure drop taking future growth (5 to 10 years) into account!**



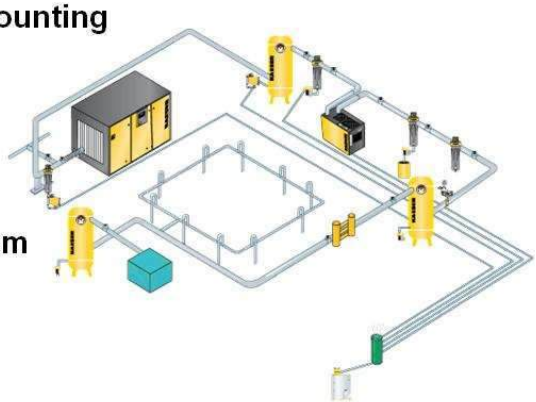
Compressed Air Distribution

Rule of thumb:

A well designed piping system will have less than a 0.15 bar pressure drop in the entire system, not counting clean air treatment equipment.

Compressed air velocity should be kept to:

- 5 meters per second in the compressor room
- 6 meters per second in the main header
- 15 meters per second in the air drops



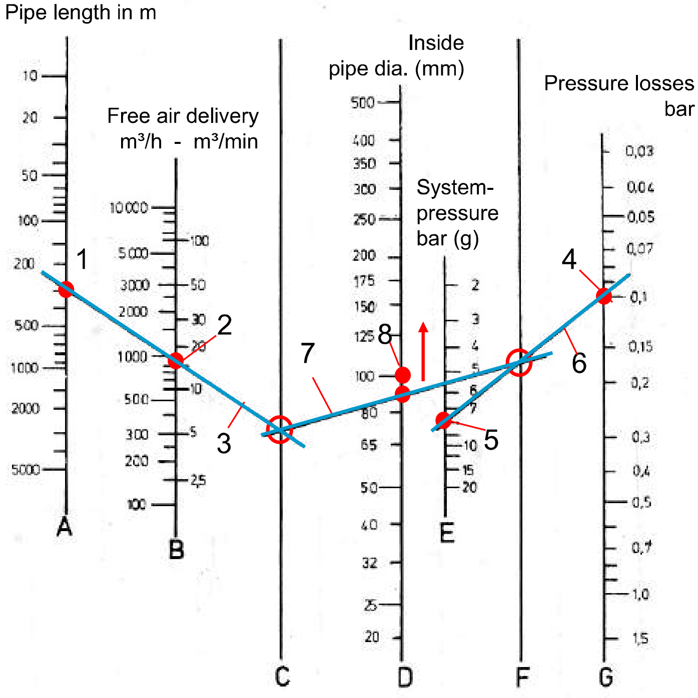
Compressed Air Distribution

Minimum diameters of pipes

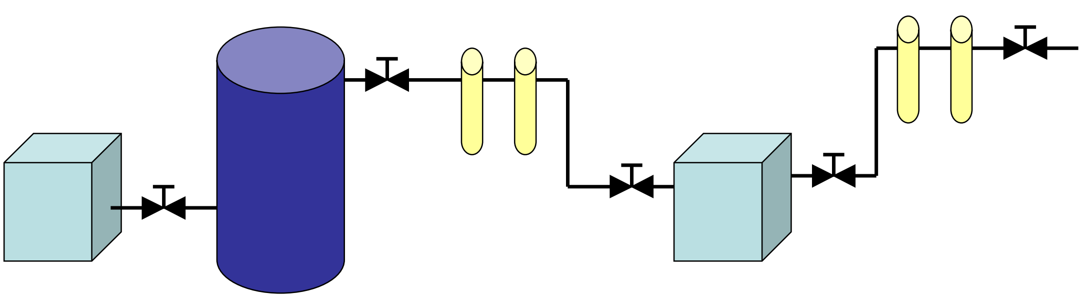
FAD m³/min	working pressure 7.5 bar (g)			
	length of pipeline up to 50 m	up to 100 m	up to 200 m	over 200 m
up to 12.5	2 1/2"	2 1/2"	3"	see straight-line graph
up to 15,0	2 1/2"	2 1/2"	3"	
up to 17.5	2 1/2"	3"	DN100	
up to 20.0	3"	3"	DN100	
up to 25.0	3"	DN100	DN100	
up to 30.0	3"	DN100	DN100	
up to 40.0	DN100	DN100	DN 125	

Straight-line graph

for determining inside pipe diameter (steps 1 to 8)



Pressure Drops in a Compressor House



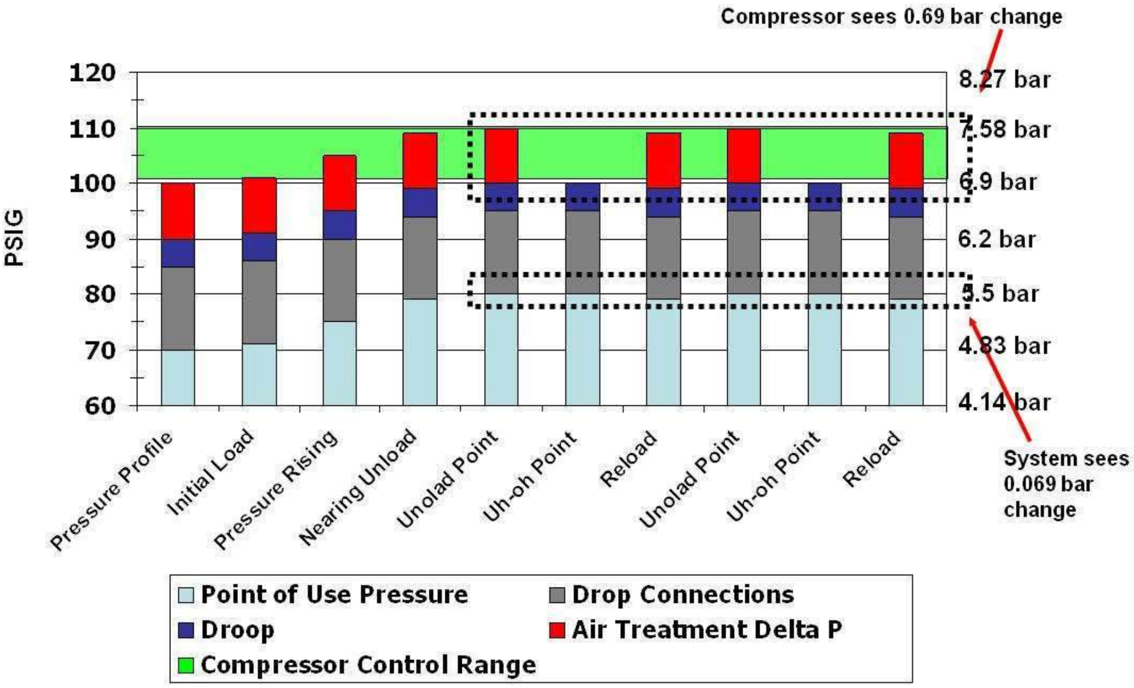
Undersized pipework
Restrictive valves
Dryer

Water separator
Prefilter
Afterfilters

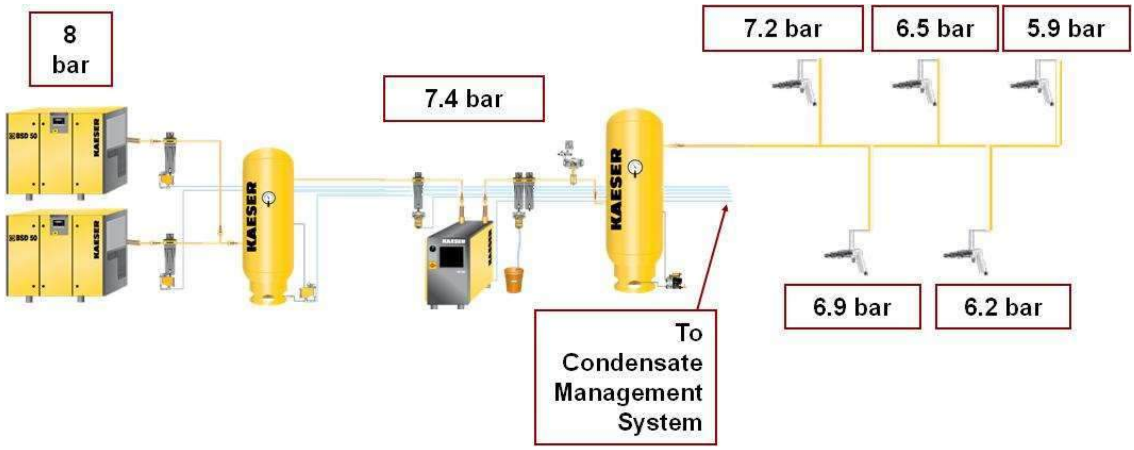
Poor design

- Filter on compressor exit
- Restrictive valves
- 1 bar pressure drop on load
- Pressure equalises when off load so compressor reloads immediately

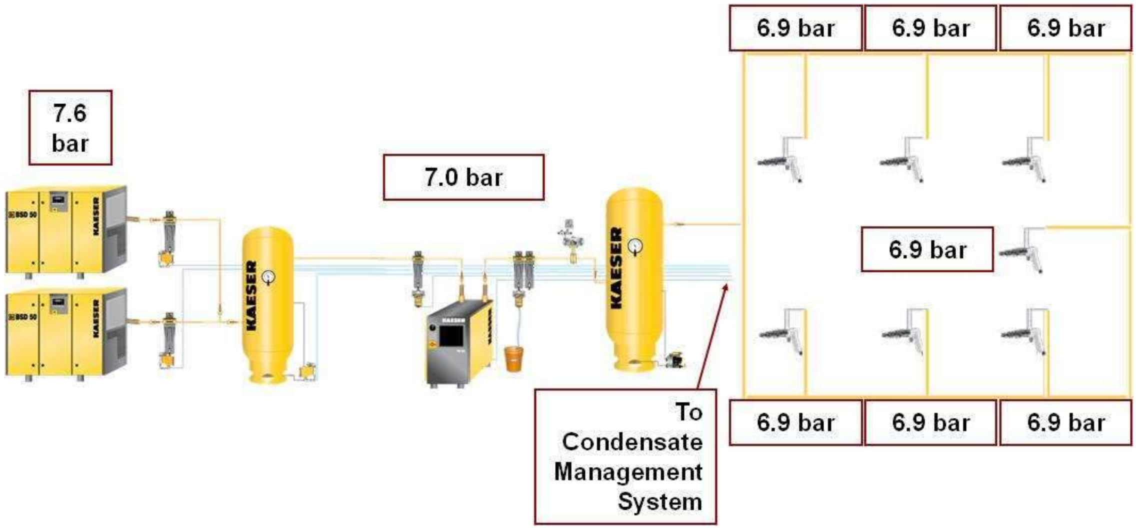
Compressed Air Systems



Pressure Drop in a Dead-End System

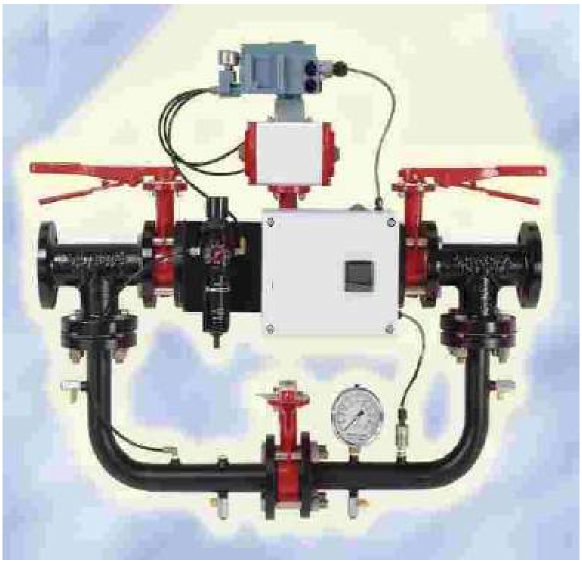


Pressure Drop in a Ring System



Flow controllers

- Used to separate supply from demand
- Allows system pressure to be maintained at a very steady level – set to minimum
- Reduces/removes artificial demand



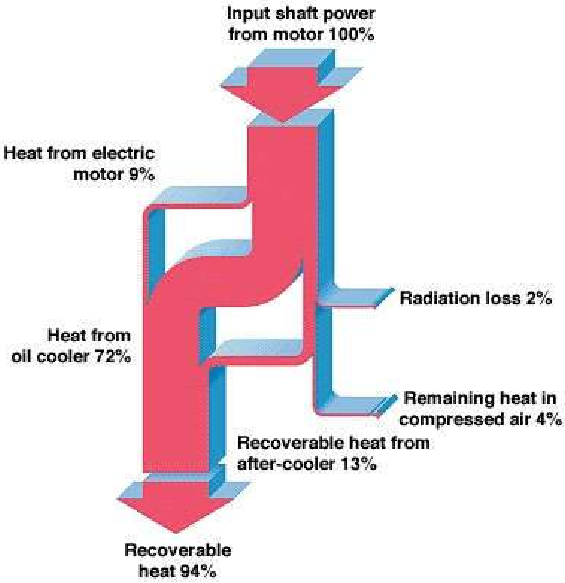
Distribution

- Remove all redundant piping
- Plug all high level valves in ring mains
- Isolate all areas that are not being used for production purposes
- Consider using light weight smooth bore tubing for new connections
  - Less prone to leaks and lower pressure losses

Distribution

- Remove the bottlenecks – don't just increase generation pressure
- Use local receivers & ring mains
- Increase feeding main sizes
- Don't develop a tubing jungle
- Consider zone isolations

Heat recovery



On average 85% of input energy can be recovered for heating applications.

The possibility for heat recovery depends on:

- Heating demand of the factory
- Matching of compressor operation and heat demand
- Proximity of compressor station to heating distribution lines/consumers
- Temperatures

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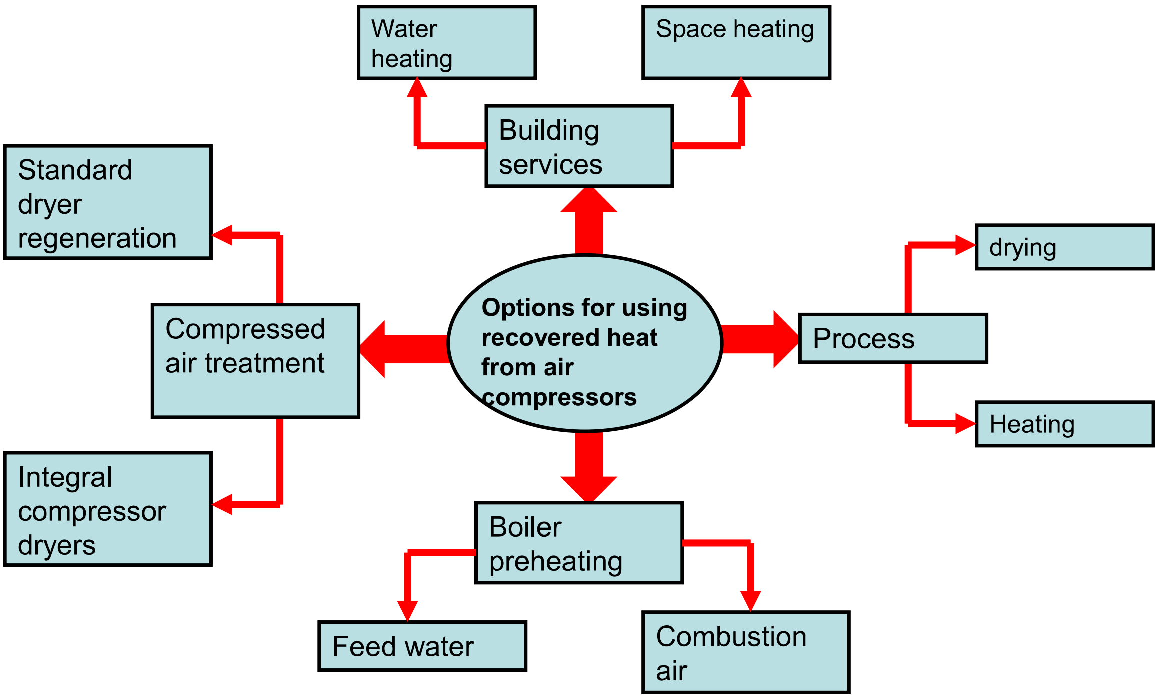
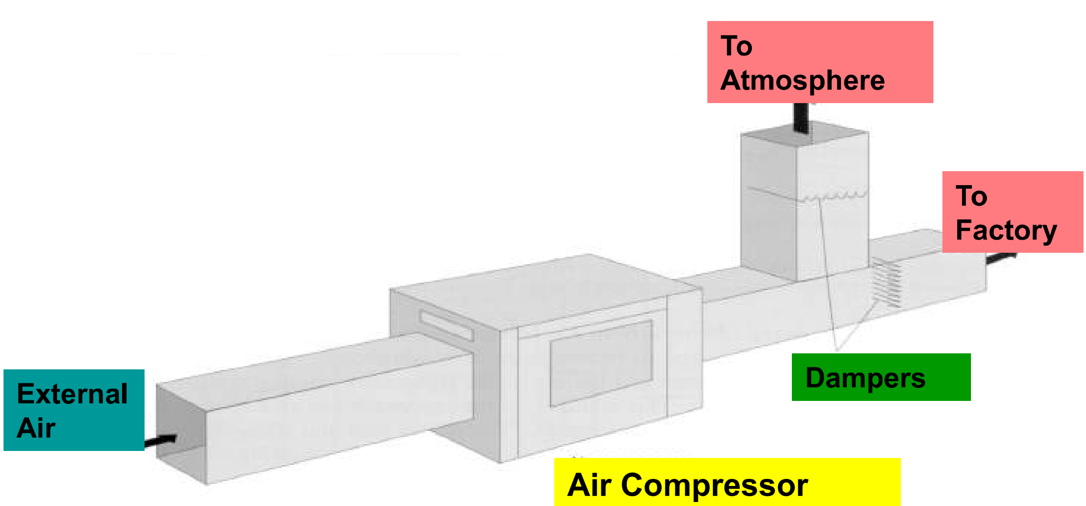
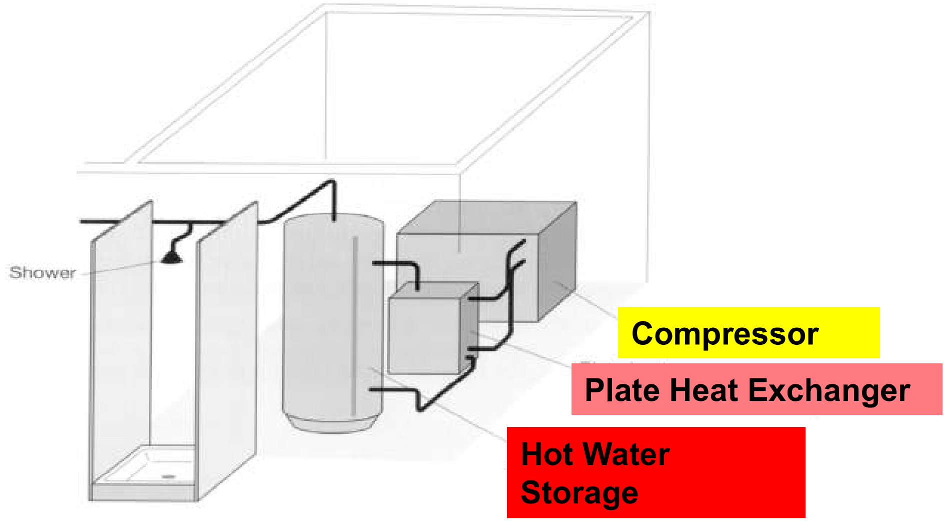
Heat recovery



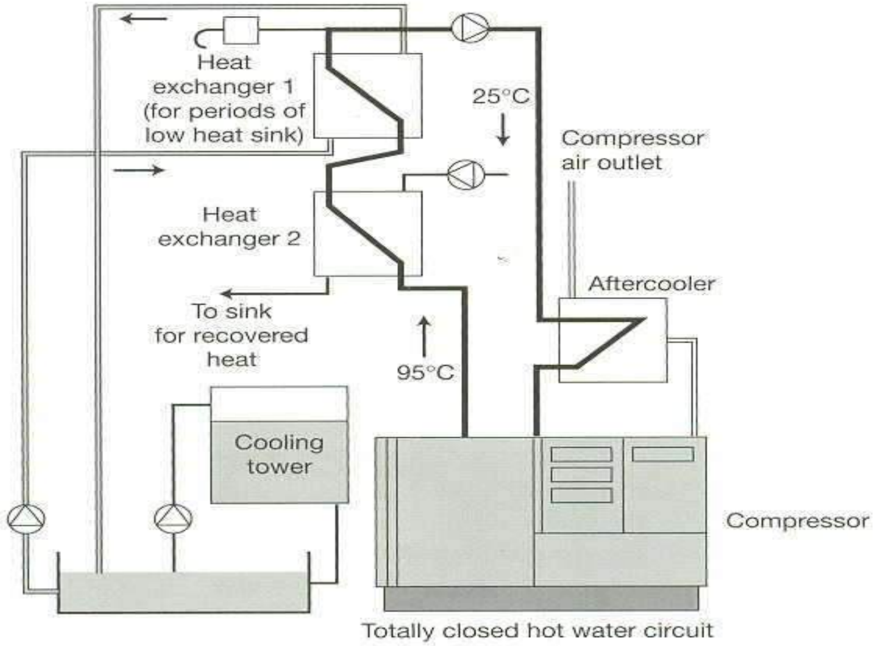
Collecting heat from air cooled packages



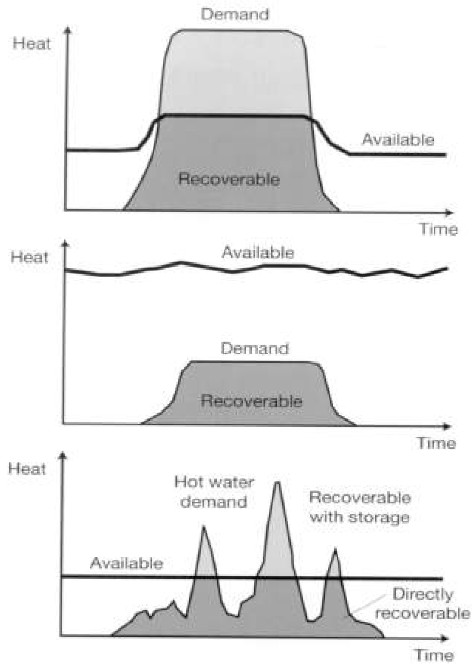
Collecting hot water from an air-cooled package



Water cooled oil free screws and centrifugals



Matching heat requirements with air demand



Recovered heat alone is insufficient to meet the demand

- All the heat available can be used during production hours
- Will need additional heat source to meet demand

Recovered heat meets the entire demand

- Demand entirely met available heat
- Potential for further use of heat
- Avoids purchase of additional heat source to meet demand

Peaks in demand and the effect of storage

- Some demands have peaks, e.g. hot water, but can be smoothed out using storage
- Some or all of the demand may be met by available heat depending on the amount of storage

Maintenance

What causes loss of compressor efficiency?

- Internal leakage paths
- Poor cooling
- High internal friction
- Internal pressure losses
- Poor lubrication
- Poor or lack of maintenance

Cooling checks

- Air cooled compressors
  - make sure compressor inlets are coolest possible
  - Don't create back pressure with ducting
  - keep oil coolers and aftercoolers clean
  - Ventilate the compressors house
  - Rule of thumb - Discharge pipe temperature should be within 15deg C on inlet air

Cooling checks

- Water cooled compressors
  - Check tower efficiency ambient versus on and off temperatures
  - Check compressor intercoolers and aftercoolers on versus off water temperatures
  - Rule of thumb discharge pipe should be within 10 degC of water on temperature

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Other vital signs of efficient running

- Total hours run
- Oil leaks and air leaks from within package
- Bearing noise when running off loaded
- Separator pressure drop (oil injected)
- Intercooler pressure and temperatures
- Temperature balance all heads (recips)
- Unloading system working correctly

Compressor Maintenance

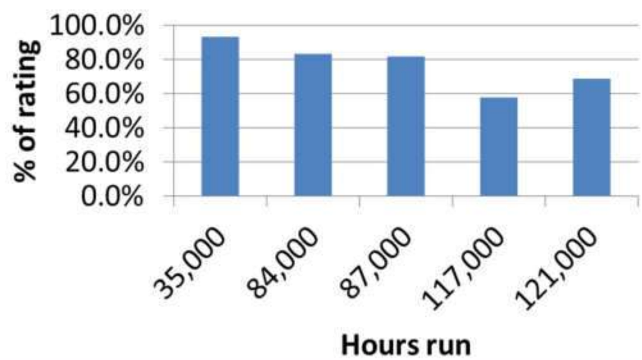
- Main Drive Motor
- Gearbox
- Main Block
- LP Compression Element
- HP Compression Element
- Intercooler
- Aftercooler

- Oil Cooler
- Inverter
- Controller
- Electrical Components
- Oil Pump
- Drive Coupling
- Control System

- Compressor Oil
- Oil Filters
- Air Filters
- Regulation System
- Bearings
- Breather System
- Load Assembly

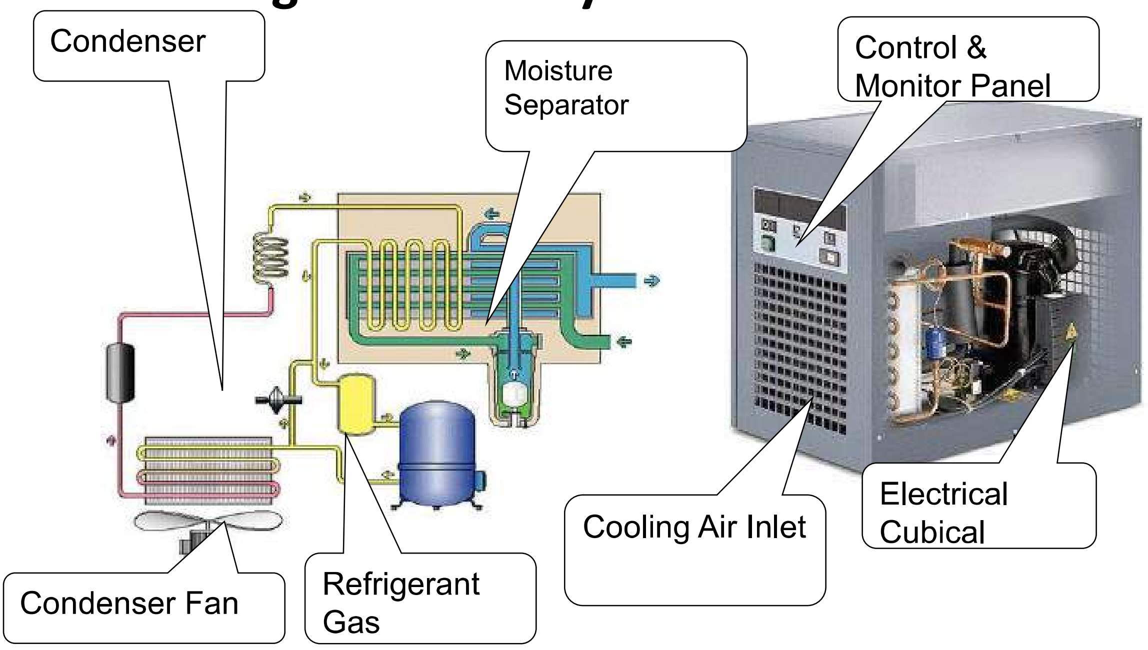
- They all work together
- Remove one and we have failure
- Fail to maintain and it will fail to operate
- 90% of failures due to lack or incorrect maintenance undertaken on products have resulted in a failure effect on more than one component.

The effect of time and maintenance

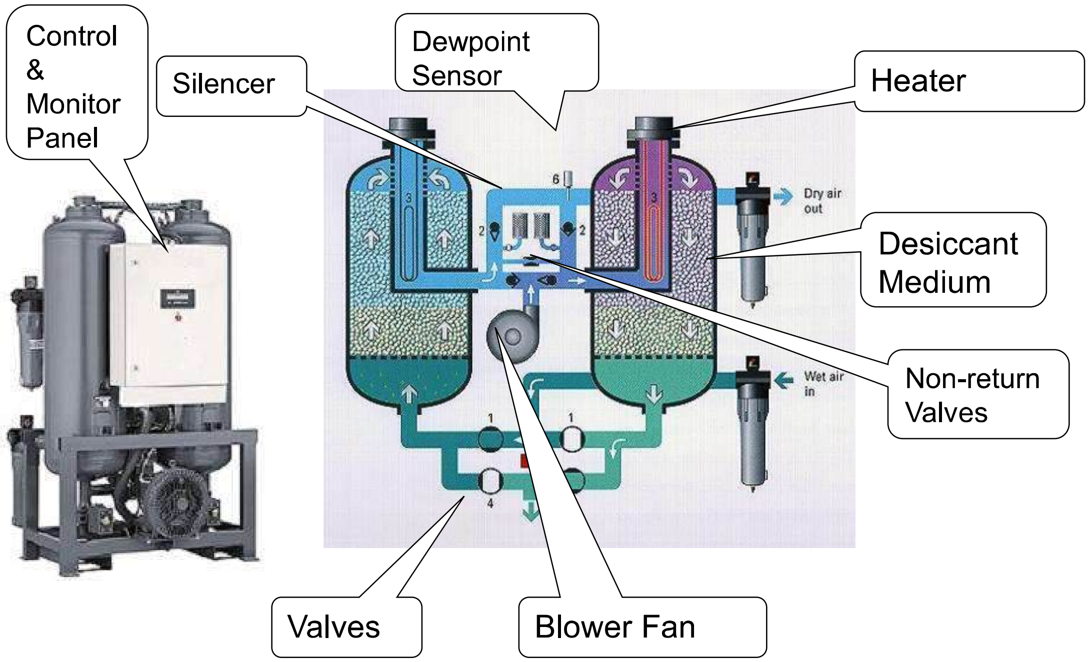


Compressor	Pressure barg	Temp °C	Hours run	Output Nm3/min	Rated Nm3/min	Result as % rated	SPC (kW/Nm3/min)
1	5.7	46.2	84,000	16.6	20	83.0%	7.15
2	5.7	65.0	117,000	11.5	20	57.5%	9.55
3	3.87	46.2	87,000	61.4	75	81.8%	6.01
4	3.8	45.8	121,000	51.4	75	68.5%	9.70
5	3.8	50.0	35,000	70.0	75	93.3%	5.29

Refrigerant Air Dryers - maintenance



Desiccant Air Dryers - maintenance



Filter maintenance

- Maximum filter life as recommended by manufacturers based on standard conditions i.e. 21°C inlet temperature.

  Standard elements : **6000hrs or 12 Months**

  Activated carbon elements: **1000hrs**

- When the standard conditions are exceeded, element life is drastically reduced. Pressure drops are induced and energy consumption is increased

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Air Receiver Maintenance

- Statutory inspection and test routine
- Main Vessel / Annual Testing & Certification
- Pressure Gauge / Annual Testing & Certification
- Pressure Relief Valve / Annual Testing & Certification
- Inspection Plugs / Manholes / Seals
- Inlet / Outlet Connections / Gaskets
- Automatic Condensate Drain / Daily Operator Testing

Summary of session

Areas covered:

- Areas of waste and potential for optimisation
- Leakage
- Control
- VSD compressors
- Distribution & Pressure drops
- Heat recovery
- Maintenance

END OF SESSION
ANY QUESTIONS?

Compressed Air Systems

UNIDO Compressed Air System Expert

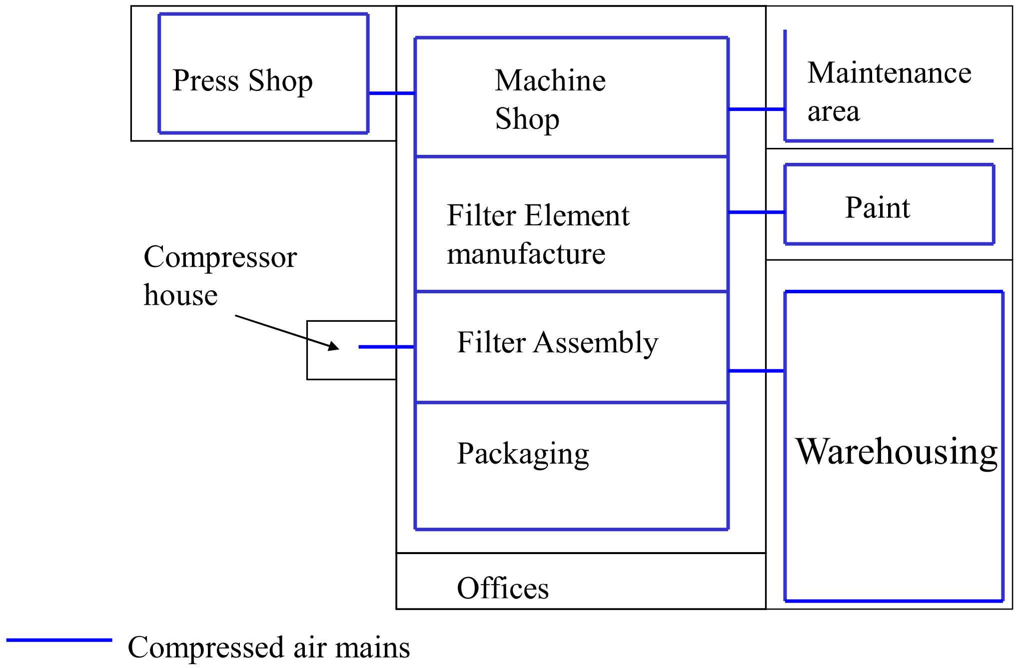
Part 4 – economic analysis

The scenario

- Oil filter manufacturer
- Compressed air costs >£250,000 pa (VND8,200,000,000)
- Mainly 2 shift, some 24 hr production
- Initial audit required
  - Where are the savings opportunities?
  - Is any more investigation required and if so what do you suggest?

The Product

The Distribution system



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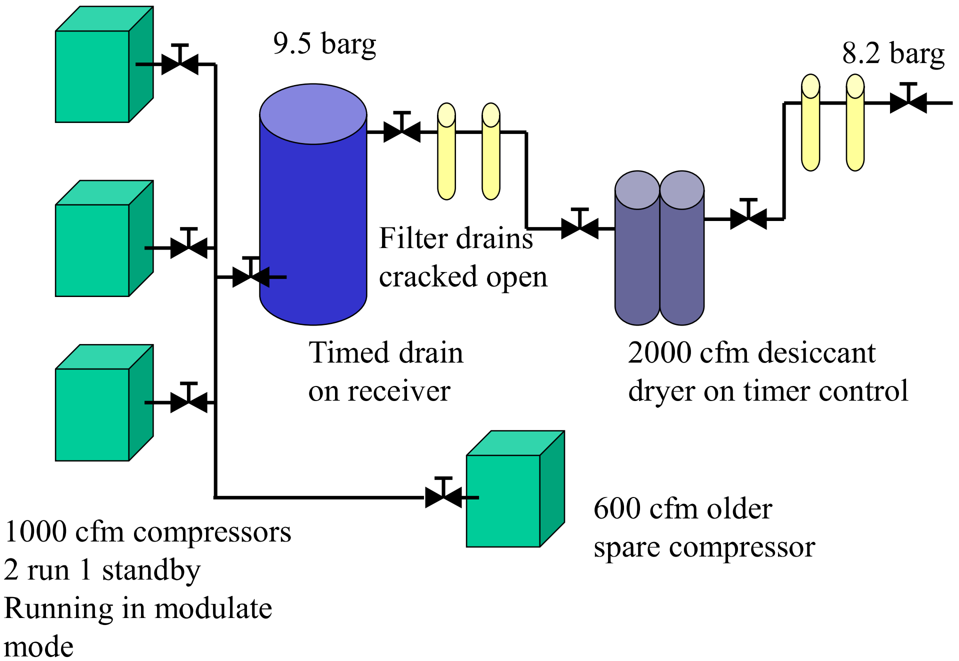
The compressor house



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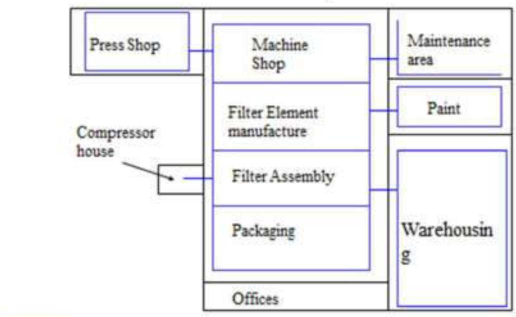
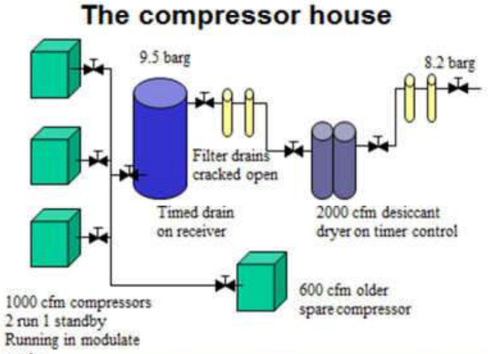


PARTNER FOR PROSPERITY

The compressor house



Compressed Air System Investigation - Fibre Board Manufacturer - RoI

Introduction

- The facility is a large MDF manufacturing plant. Production began in 1982 and since that time the plant has expanded to the state we see it in today. The facility currently has two production lines along with ancillary plant.
- Compressed air (CA) is vital to production and there are currently concerns about the systems ability to meet the site demand.

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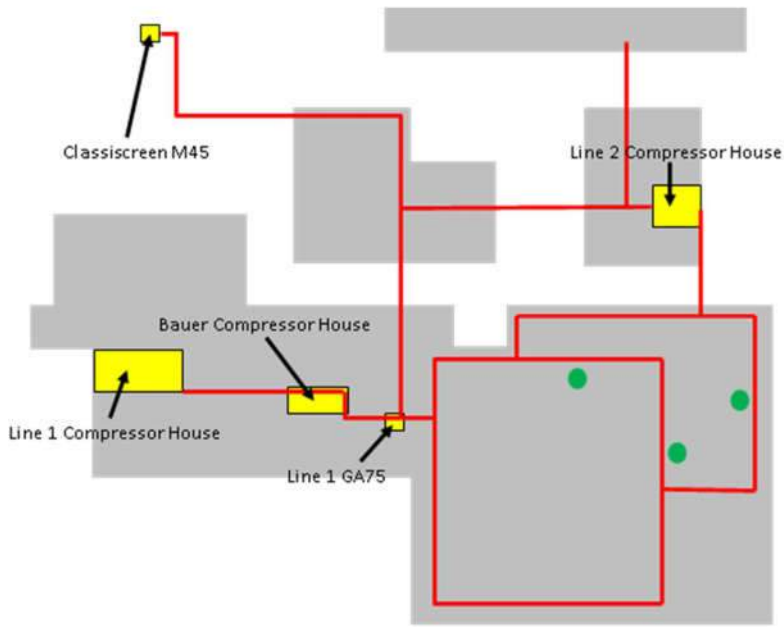
The Current CA Situation

- 5 Compressor Locations
- 8 Compressors
- 1 Main system + local Instrument Air systems



Initial visit & Proposal

- Initial visit to view site and identify job parameters and savings potential
- Prepare proposal

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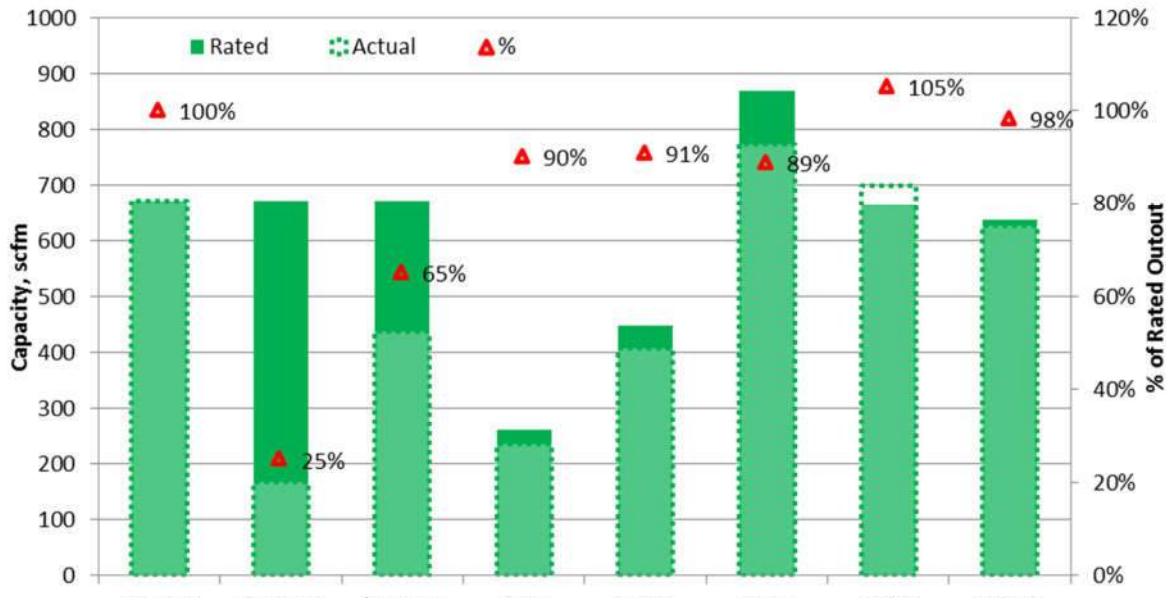
The Investigation

We focused on measurement of:

- Compressor Performance (ISO1217 annex C)
- The Site Compressed Air Demand (flowmetering)
- The Air Quality (Dewpoint & Oil)

Compressors Performance

- After testing to ISO1217 annex C we found:



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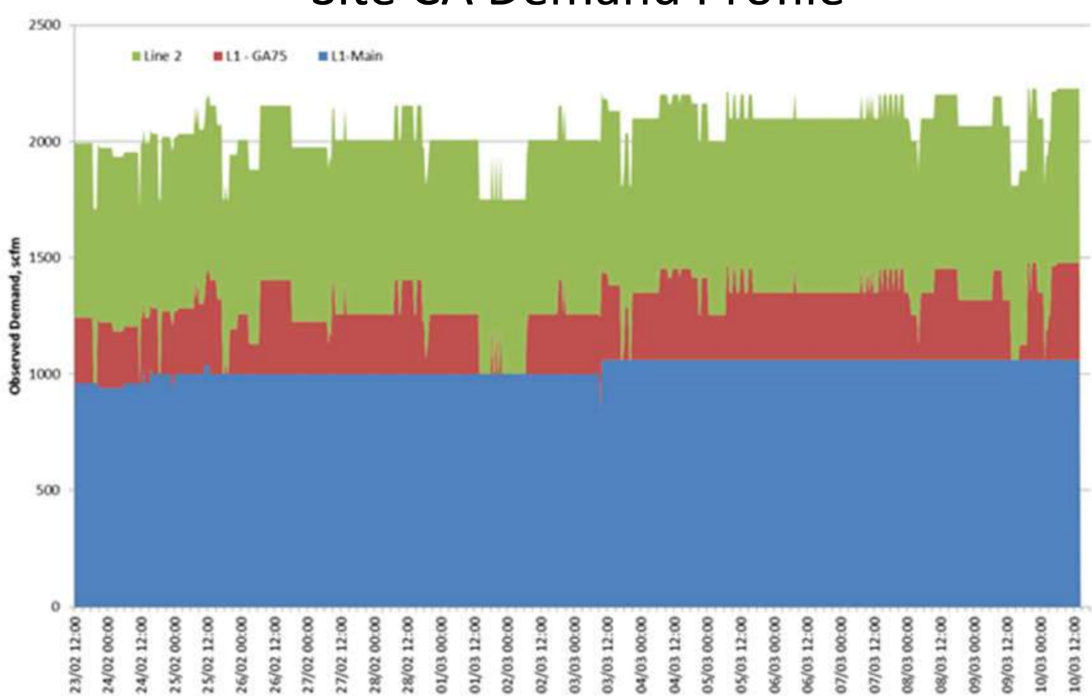
Compressors Performance

	Bauer 1	Bauer 2	Bauer 3	M45	GA75	M160	M110	GA110
Rated (scfm)	671	671	671	261	449	869	665	637
Actual (scfm)	670.6	167.5	437.2	235.1	408.1	772.1	699.7	626.3
% of rated	100%	25%	65%	90%	91%	89%	105%	98%
SPC (kW/100cfm)	18.8	59.7	24.2	21.2	21.5	24.2	21.7	20.5

Conclusions:

Bauer #2 is performing extremely poorly
Bauer #3 is performing very poorly
GA75 was exhibiting problems unloading properly
M160 machine is poor for its age

Site CA Demand Profile



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Site CA Demand Profile

- Mean demand = 2,100scfm

- Base load M160 + M110 + a Bauer m/c
- GA75 running unloaded 95%
- GA110 running unloaded 99%
- M45 running @ ~80% load

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CA Air Quality

- Dewpoint: +11.7°C PDP
- Hydrocarbons: No Oil detected at class 2 limit
- (Measured at point on feed Line 2 Sander in cold end of factory where most problems occur)

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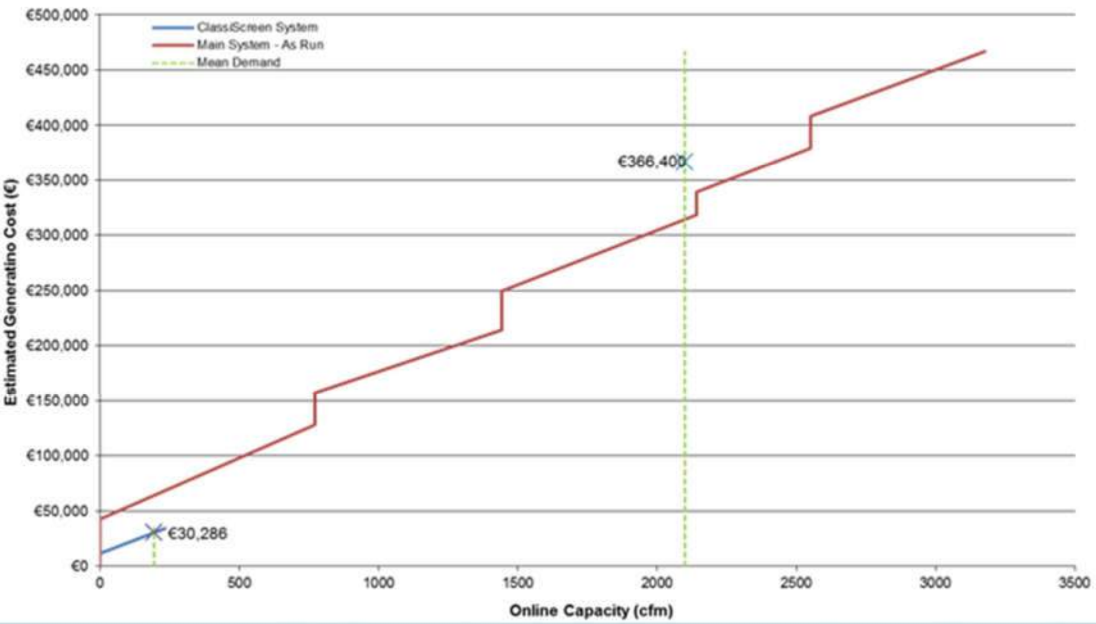
Annual Generation Costs

CALCULATION OF ESTIMATED ANNUAL PRODUCTION GENERATION COSTS FOR:



Annual Generation Costs

- Main System: ~€366,400 4,310,600kWh
- ClassiScreen: ~€30,300 356,300kWh
- **Total: ~€396,700 4,666,900kWh**
- Based on 8.5c/kWh, 8064, 24/7/48 (92% production utilisation), 2,100scfm mean demand

Recommendations

- **Using existing equipment**
- Experiment with switching off GA75 & GA110
- Run Bauer #2 as last backup
- Run Bauer #3 as penultimate backup
- Bring M160 back up to rated capacity

- If GA75 & GA110 not needed, savings of €52,000 p.a
- If GA75 required on very light load, savings of €31,850p.a

Recommendations

Using New Machinery

Install: 2 x 132kW fixed speed machines
+ 1 x 132W VSD machine

Option for heat recovery (80-90°C water) on certain machines

Benefits: Increased compressed air capacity
Increased generation efficiency
More modern machinery
Potential for heat recovery
Improved process benefits

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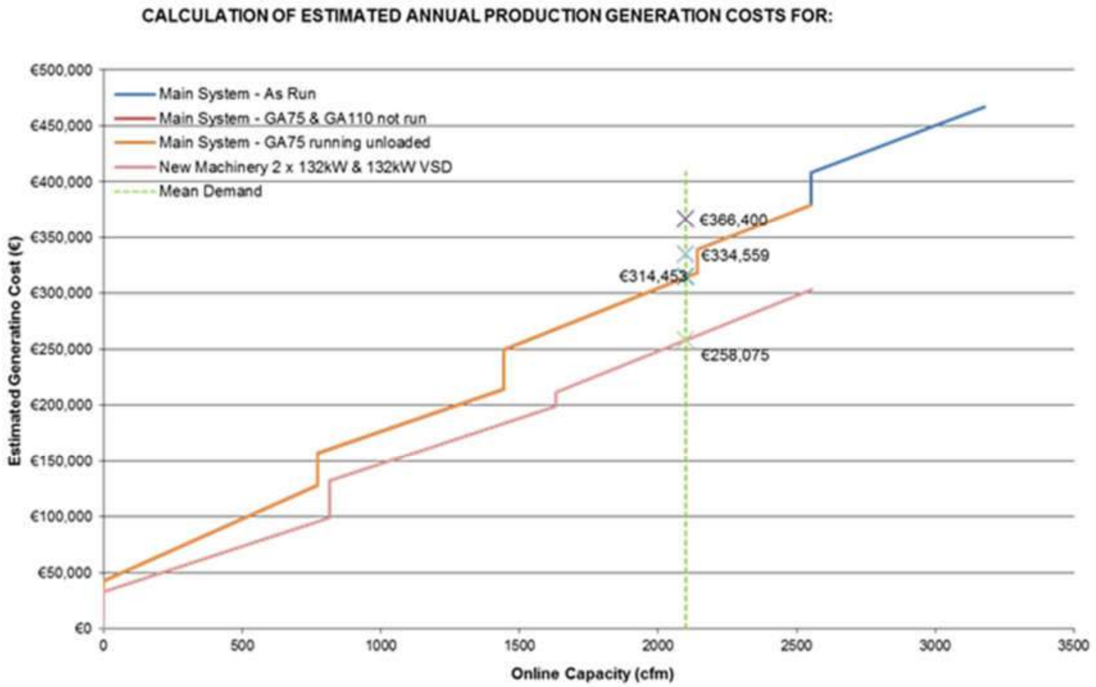
Recommendations



After the report

- Implementation assistance requested
- Specification drawn up
- Bid analysis carried out
- Customer selected most suitable package

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Customer feedback after installation

Air system is great – on average saving €9K per month
No more air issues on site and our saw has increased its production rate by 10%

So overall money very well spent

Thanks again

Pat

Engineering Manager

Examples of optimization and energy saving

Misuses of compressed air

- Cleaning
- Component ejection
- Ventilation - cooling of people & products
- Agitation of paint or cleaning baths
- Moving product around bends or on conveyors
- Keeping product in line
- Using air at higher pressures than necessary
- Vacuum generation on large scale

Misuses of Air

- Energy saving improvements can lead to process improvements
- Can a dedicated small compressor be used in non- production hours and turnoff the main compressors?
- Can a lower pressure compressor be used for some duties such as powder conveying?

Blowing

- Use air intensifying jets can save around 40% of the air at lower pressure
  - Quieter can overcome area noise issues
- Use air knives at reduced pressure
- Use fans
- Use low pressure blow guns
  - Safer and quieter

Nozzles

- Nozzles left on continually, no product flow
- Use sensors, weighing areas etc to switch on

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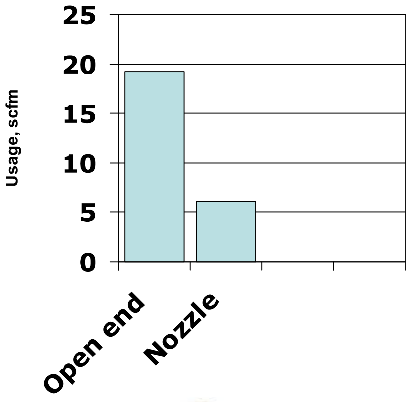
Air efficient nozzles

Copper pipe	19.2 scfm
Air efficient nozzle	6.1 scfm
Reduction	13.1 scfm



Specific energy = 0.122 kW/cfm
Energy saved = 1.6 kW/nozzle
Saving/nozzle = VND9,600,000per year
(based on 2000 hours/year)

Cost VND350,000-700,000 per nozzle
Payback < 2 months

Vacuum generation

- Use of air to create vacuum for processes:
  - Rule of thumb this should not exceed 10% of the mean air demand
  - Create local vacuum systems a vacuum pump typically uses 8% of a compressor motor input power
- Use efficient vacuum ejectors and shut off when not required
  - Multi stage
  - Check valves

Reducing system pressure

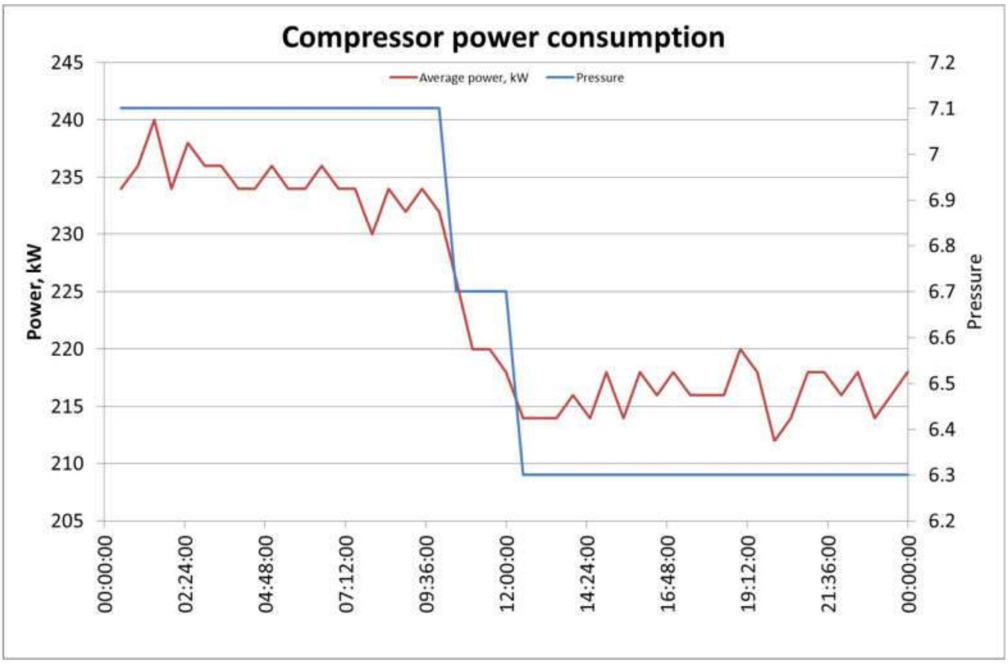
Situation
Current system pressure = 8 barg
Only usage at 8 barg are small cylinders, rest needs 6 barg

Solution
Replace cylinders with larger bore or double power type
Install a booster and receiver for several users

Benefits
Pressure reduced from 8 – 6 barg
Full load compressor power reduced by around 12%
Leakage and unregulated usage reduced by up to 22%

Costs
Air driven booster & small receiver: VND12-35,000,000
New cylinder: VND8,500,000

Reducing pressure



Pressure reduction

- Do not use air at full line pressure if it is not needed
  - Use local pressure regulation
    - Rapid payback on outlay
  - Reducing the pressure from 7 bar(g) to 5 bar(g) will save around 25% of the air
    - Will also reduce local leakage

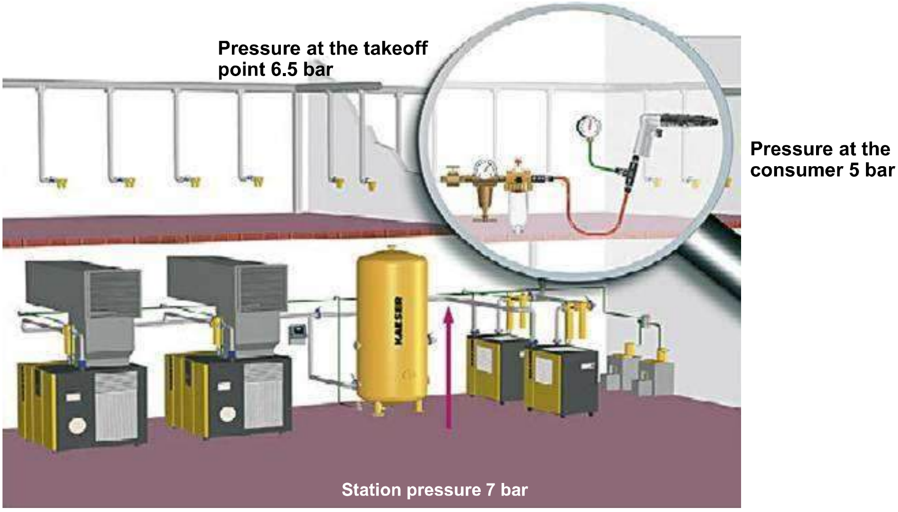
Reducing pressure at the end user

- 4mm orifice Blow gun operating at 7 barg with safety nozzle
- Consumption: 40 cfm
- Reduce pressure to 2 barg
- Consumption = 40*3/8 (absolute pressure ratio)
- = 15 cfm
- Saving = 25 cfm*0.122 = 3 kW/gun
- 25 guns used for 2 minutes/hr = 25*3*2/60 = 2.5 kW average saving

Total saving = VND30,000,000 per year (4000 hrs/yr)
Cost for preset regulator <VND700,000
Payback 1.8years (30,000,000/(25*700,000))

FIT REGULATORS!!

Air Distribution



In 80% of cases, the air distribution network is the weakest link in the chain and responsible for the most leaks and highest costs.

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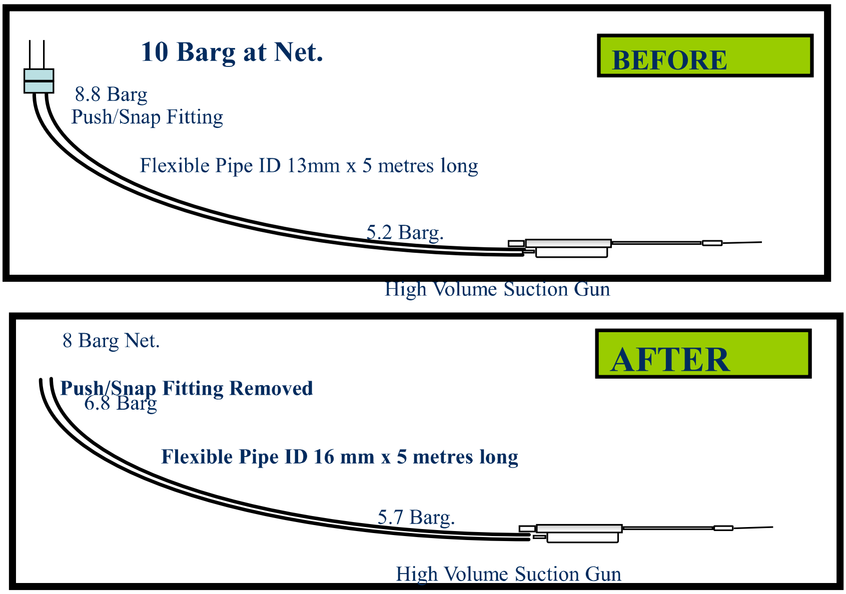
Pressure losses

- Pressure loss due to:
  - Excessive filtration
  - Small bore tubing or kinks
  - Small fittings causing local restrictions
- Use of high pressure to overcome local restrictions or:
  - Need for local higher pressure at a number of usage points

Pressure reduction at the end user

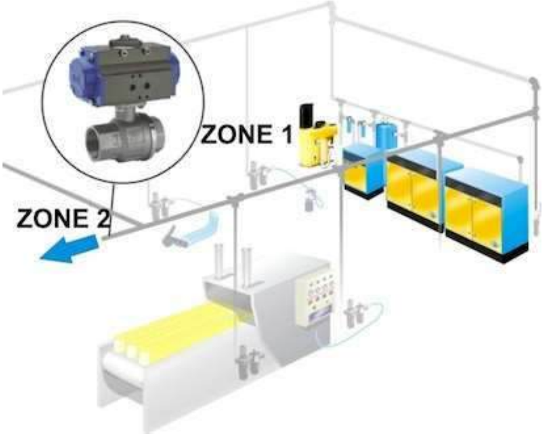


Zone & machine isolation

Isolate air using production machinery when not being used

Use local solenoid valves operated by:

- No product flow sensing
- Isolation switches
- No operator (burglar alarm mats)
- Turning off the air with the lights when everyone goes home



Machine isolation

A machine operates 8 hours a day with the air on 24 hours for users elsewhere on site

Air consumption in use: 20 scfm
Air consumption when stopped: 8 scfm
Power consumed when stopped: 0.976 kW

Annual cost = 0.976*16*3000*365
= VND17,099,520 per year

Typical cost of ½” solenoid valve
VND1,700,000

Area 1 stops production and is isolated

Plant vibrators

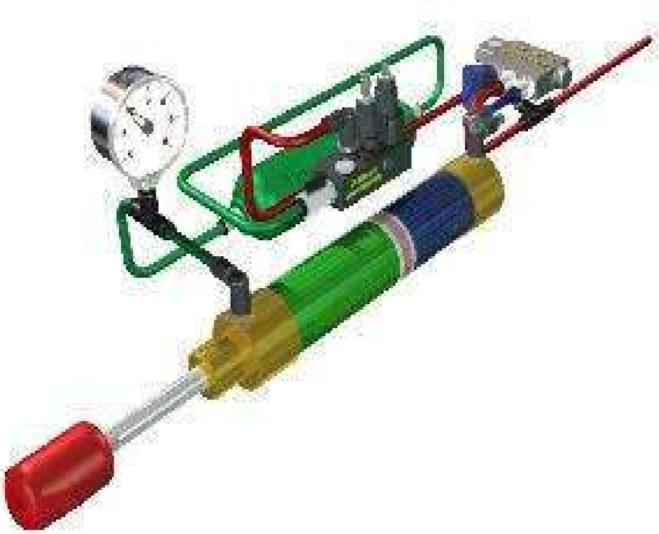
Air consumption approximately 5 cfm = 1 kW for a 50cm unit at 4 barg

Power consumption less than 100W

Quick release couplings

- Can be a major pressure loss component
- Ensure they are adequately sized
- Use low air loss quick release couplings
  - Two stage action prevents loss from pressurised side
  - Safer - no hose whip or sudden air release
  - Lower pressure loss so tools work better


Cylinder air recovery



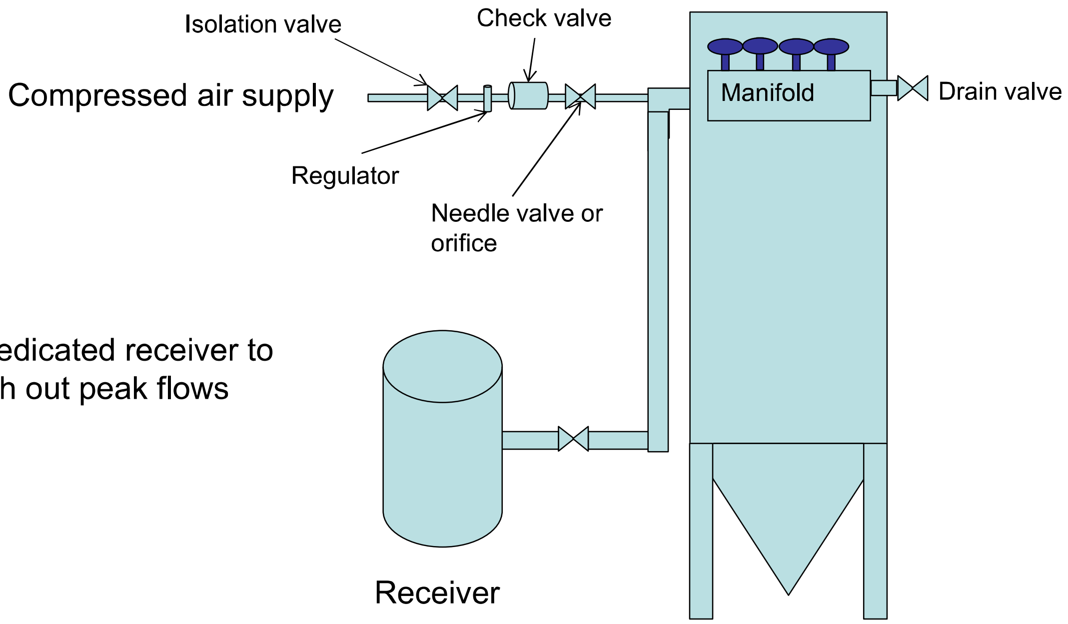
Store and reuse air normally discharged to atmosphere

Poverty Reduction through Productive Activities • Trade Capacity Building • Energy and Environment

Dust extraction plants

- Use local receiver to smooth out peaks
- Use differential pressure control not timed
- Isolate out of hours

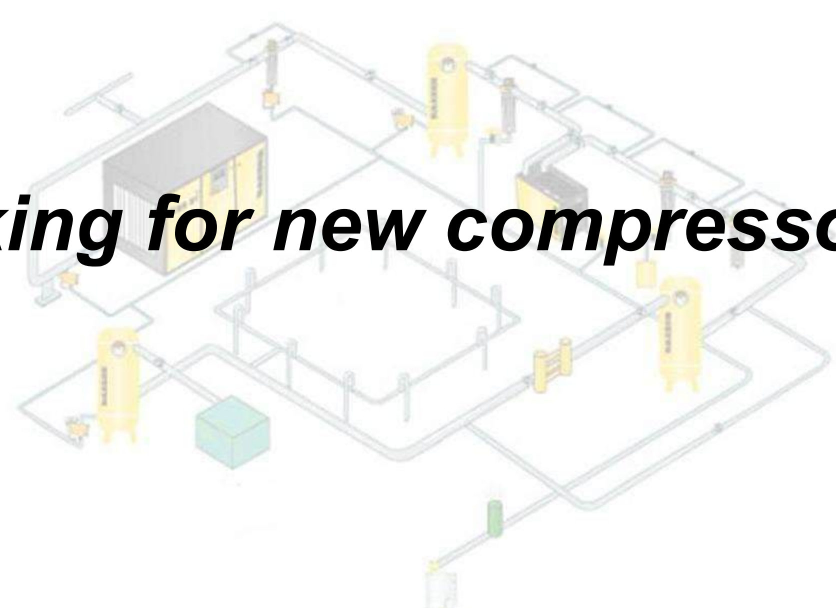
Dust Extraction plants



Use dedicated receiver to smooth out peak flows

Analysing air saving projects

- Determine the demand or pressure reduction
- Recalculate running costs based on new data
- Consider the effect of projects together
  - Two projects may each save VND150,000,000 per year alone but the two together will not save VND300,000,000
- Are there any other benefits eg increased production, reduced maintenance?
- A small demand reduction can make big savings if it means a compressor can be shut down.



Looking for new compressors?

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Compressor selection

- Capacity required?
- Oil free or oil lubricated?
  - If you need oil free air use oil free compressors
  - Reduces risk of contamination & lower pressure drop through reduced filtration requirements
- Air or water cooled?
- VSD or standard control?
- Screw, piston, vane, centrifugal?

Compressor Type: Oil-Injected vs Oil-Free

Oil-Injected
Typically Single-Stage machines
Food grade lubricant available
Require oil-removal filters

Oil-Free
Normally Two-Stage Machines
No Lubricant Required in air end
Oil-Removal filters not required
Water injected oil free now also available

Key benefit with oil free – no risk of oil contamination

Compressor Type: air or water cooled

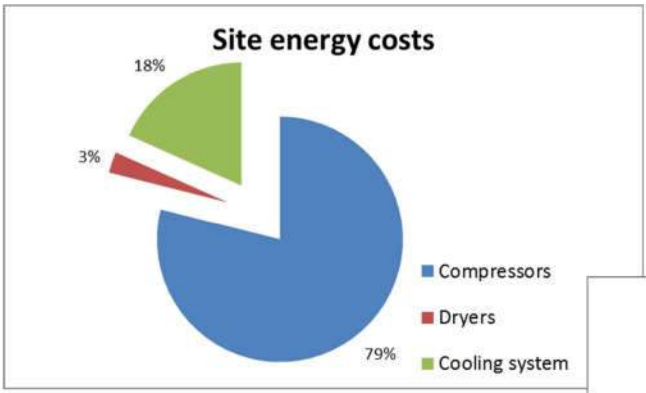
Air cooled

- Available up to 250kW
- Compressor draws more power than water cooled due to cooling fan
- Often easier to install
- Not well suited to high ambient temperatures
- Leads to higher temperature onto filters and dryers

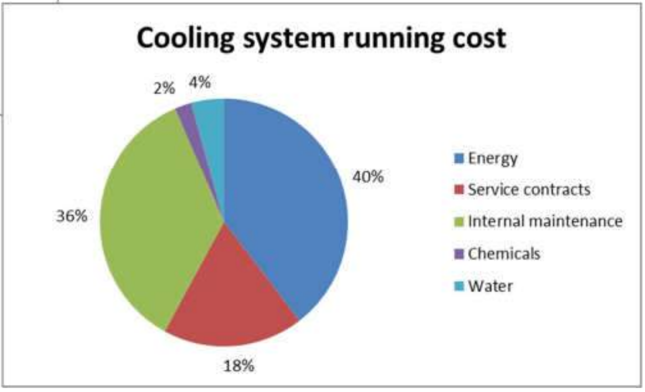
Water cooled

- Available from 30 kW
- Lower kW for compressor
- Can give up to 90C water for heat recovery
- Needs cooling system
  - Expensive to run and maintain
  - Potential for leaks and scaling

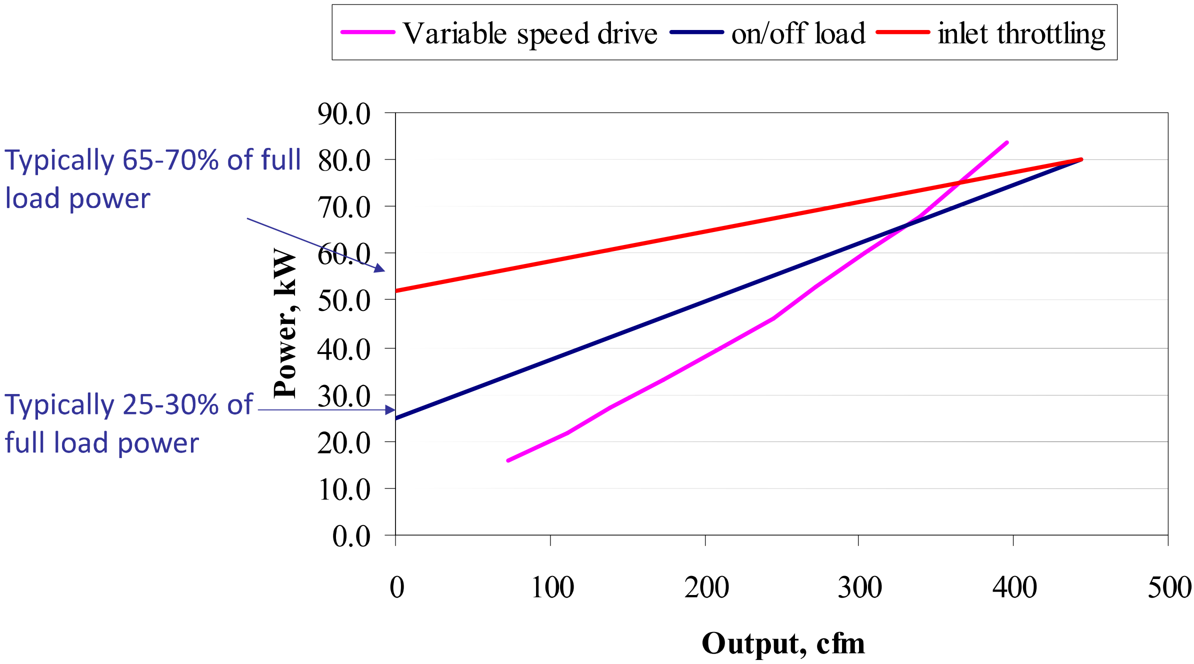
Cooling water costs



- Costs can be high
- This site switched to chilled water
- Energy costs up 17%
- Overall costs down 53%



Compressor control – positive displacement



Compressor sizing

- Need to be sized to cover the range of demands not just peak flows
- Generally several compressors improve flexibility and overall efficiency compared to one large one
- Allow for some expansion, manufacturers tolerances, adverse inlet conditions etc but do not oversize
- VSD machines should not be fully loaded and are not a universal solution
- Standby capacity for the largest compressor
- Consider out of hours demands

Writing a specification – capacity

- If you know them include maximum, mean and minimum demands with typical durations
- What allowance is needed for future expansion?
- Required capacity = peak + expansion factor
- Ensure units are quoted correctly ie m^3/hr or Nm^3/hr, cfm or scfm?
- Remember acceptance tolerances for new compressors:

	Flow	Specific power consumption
• 15-50 cfm	+/- 6%	+/- 7%
• 50-500 cfm	+/- 5%	+/- 6%
• Over 500 cfm	+/- 4%	+/- 5%

ISO1217 & PN2CPTC2

Treatment of compressed air

- Specify the minimum level you need at the compressor house
- Use point of use treatment for high quality, low demand areas
- Base the specification on ISO8573.1:2010
- Specify:
  - Particulate
  - Water (Pressure dewpoint)
  - Oil carry over
- Class 0 – 7 for each contaminant
- The higher the quality the higher the costs (capital & running costs)

Compressed air quality classes ISO8573.1:2010

Technology: **Filtration** (Particulate) — **Drying** (Dewpoint) — **Filtration** (Oil carry over)

Summary of ISO8573.1-2010						
Class	Particulate - Maximum number of particles per m³				Dewpoint	Oil carry over
	Particle size					
	≤0.1	0.1<d≤0.5µm	0.5<d≤1.0µm	1.0<d≤5.0µm	°C	Mg/m³
0	As specified by the equipment user or supplier and more stringent than class 1					
1	Not specified	20,000	400	10	≤-70	≤0.01
2	Not specified	400,000	6,000	100	≤-40	≤0.1
3	Not specified	Not specified	90,000	1,000	≤-20	≤1
4	Not specified	Not specified	Not specified	10,000	≤+3	≤5
5	Not specified	Not specified	Not specified	100,000	≤+7	
6	≤5 Mg/m³				≤+10	
7	5>Cp≤10 Mg/m³				Cw≤0.5g/m³	
8					0.5<Cw≤5	
9					5<Cw≤0.5	
X	Cp>10				Cw>10	>5

Sizing treatment systems

- Dryer capacities normally based on 7 barg 35C max
- Low pressure or high temperature reduces capacity
- Filters are tested at 21C and lose efficiency above this.
- Make sure vendors quote at your conditions

Sizing dryers

Typical correction factors

Air inlet temp, C	25	30	32	35	40	45	50
Factor	1.6	1.22	1.12	1	0.82	0.67	0.57
Inlet pressure, barg	3.5	5	7	8	10.5	14	
Factor	0.7	0.85	1	1.05	1.12	1.2	
Ambient temp, C	25	30	35	40	43		
Factor	1	0.95	0.88	0.78	0.7		

- Factors vary between manufacturers
- Choose factor for worst case condition
- Multiply factors where several vary from design

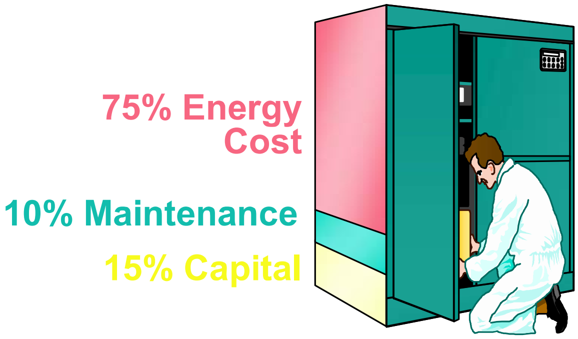
Calc

Analysing Vendors Proposals for new compressors and plant

- Check each proposal conforms to specification
  - Do the proposals offer sufficient capacity to meet peak demands?
  - Are the air quality and pressure requirements met?
  - Are all items included?
  - Is all the requested information included?
  - Is installation quoted as per spec?
  - Etc
- If not request more information from vendor

Making Comparisons

- Produce spreadsheet with all important parameters
- Calculate running cost at mean demand
- Include maintenance costs for several years, 5 or 10 is normal – allow for inflation
- Analyse total cost over 5-10 years not just capital cost



Making comparisons – initial impressions

Actual example:
3 Vendors - 3 compressors plus dryers, filters etc:

Capital cost:
- 1 VND4,158,509,991
- 2 VND4,828,180,599
- 3 VND4,305,850,966

Maintenance:
- 1 VND285,609,642 pa
- 2 VND337,019,378 pa
- 3 VND346,091,684 pa

Initial impressions:
- No.1 VND670,000,000 less than No.2, No.1 same ball park as No.3
- No.1 maintenance VND50,400,000 pa less than others
- No.1 definite top contender

Making comparisons – life cycle costs

Annual running cost:

1	2	3
VND1,763,723,543	VND1,525,155,489	VND1,682,812,012

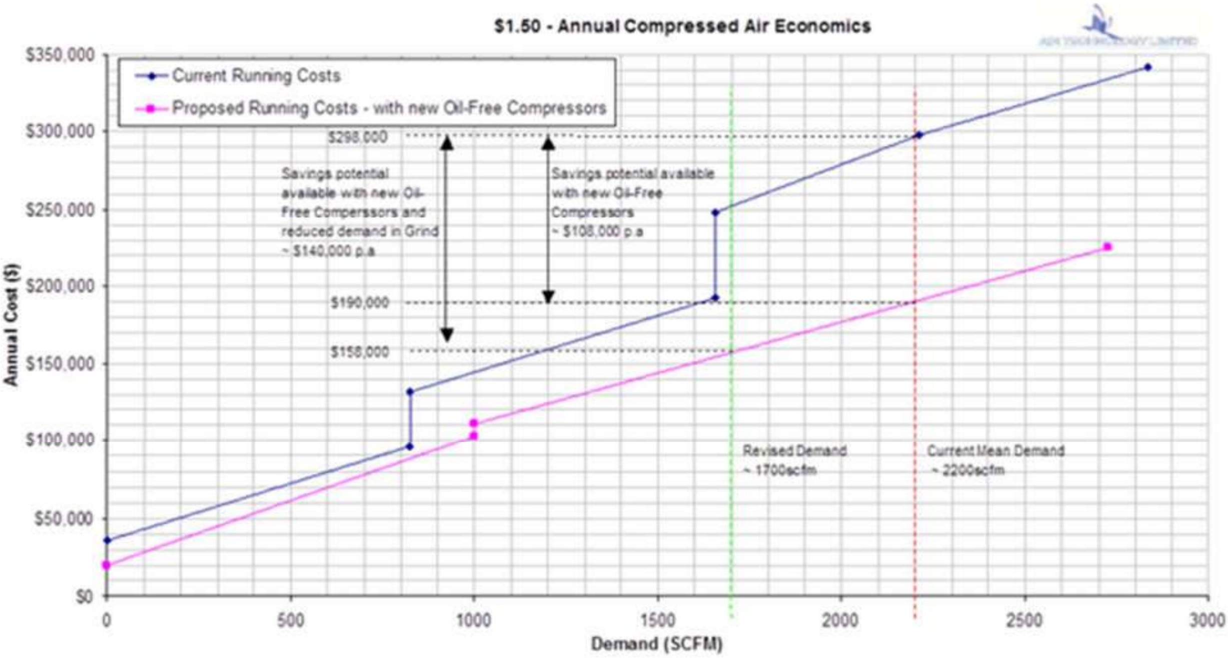
Life cycle costs	1	2	3
3yr cost	6,147,999,555	5,586,524,601	6,086,711,088
5 yr cost	10,246,665,925	9,310,874,335	10,144,518,480
10 yr cost	20,493,331,850	18,621,748,670	20,289,036,960

Over lifetime:

- No.2 VND561,474,954 cheaper than No.1 over 3 years
- No.2 VND1,871,583,180 cheaper than No.1 over 10 years
- No.2 VND1,667,288,290 cheaper than No.3 over 10 years

- Over 5-10 years No.2 is the definite winner

New compressor analysis



New developments

Vertical shaft
Single stage blower
Magnetic bearings
Variable speed drive

New developments

- VSD centrifugal compressor
- 2 stage
- Single high speed magnetic bearing drive motor
- Impellers mounted directly on drive motor shaft: no gearbox, no oil
- Both impellers on one drive shaft
- Water-cooled only

New developments

- Water injected compressors
- Screw and rotor technology available
- Integrated dryers and VSD

Summary of session

Areas covered:

- Examples of energy saving and optimisation
- Compressor selection and sizing
- System specifications
- Analysing projects and vendor bids
- New developments

Summary of the course

- Brief introduction to optimisation opportunities
- The basics of compressed air
- How to analyse and survey systems
- How to calculate running costs
- Optimisation opportunities and case studies
- Analysis of compressed air projects
- New developments

END OF SESSION
ANY QUESTIONS?

Total annual running cost

Hours = 16 x 5 x 50 = 4000 hours/year

Base load = 400 m3/hr (=50 kW) x 4000hrs = 200,000kWh
= 200,000kWh x 3000 = VND600,000,000

Control = (600-400)/400 = 50% load, 50% no load
Full load = 50 x 4000hrs x 50% =100,000kWh
No load = 10 x 4000hrs x 50% =20,000kWh

Total control = (100,000 x 3000) + (20,000 x 3000)
300,000,000 + 60,000,000 = VND360,000,000

Total compressor house = 600,000,000+ 360,000,000 = VND960,000,000

What about VSD Machines?

Demand is 600m3/hr using 2 equally sized machines

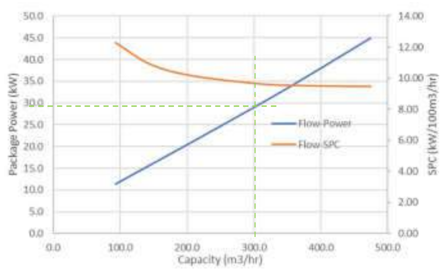
Each machine delivers 600/2 = 300m^3/hr

Power required at 300m^3/hr = ~29kW

Total Power = 2 x 29kW = 58kW

58kW x 4,000hrs = 232,000kWh

232,000kWh x 3,000VND = **696,000,000VND**



Overall demands

Timing, seconds	Weekdays	Weeknights	Weekend
On load	25	10	60
Off load	12	101	16
Total cycle time	37	111	76
Compressors running	1 full load 1 load/unload	1 full load 1 load/unload	1 load/unload
% on load	67.5%	9%	79%
% off load	32.5%	91%	21%

Generating costs

Compressors on modulate:
1000 cfm output 200 kW full load 130 kW no load

Weekday:
1 base load compressor (200kW) + 1 controlling 67.5% load, 32.5% off load
Total kW = 200 + (200*0.675) + (130*0.325)
= 377.25kW = 200 + 135 + 42.25
= 377.25kW x 16 x 5 x 52 x VND3000 = **VND 4,708,080,000**

VND3000/kWh, 16 hrs, 5 days, 52 weeks/yr

Baseload:	200 x 3000 x (16x5x52) x 100%	= VND2,496,000,000
Control (Loaded):	200 x 3000 x (16x5x52) x 67.5%	= VND1,684,800,000
Control (unloaded):	130 x 3000 x (16x5x52) x 32.5%	= VND527,280,000
		= VND4,708,080,000

Generating costs

Compressors on modulate:
1000 cfm output 200 kW full load 130 kW no load

Weeknight:
1 base load compressor (200kW) + 1 controlling 9% load, 91% off load
Total kW = 200 + (200*0.09) + (130*0.91)
= 336.3kW = 200 + 18 + 118.3
= 336.3kW x 8 x 5 x 52 x VND3000 = **VND2,098,512,000**

VND3000/kWh, 8 hrs, 5 days, 52 weeks/yr

Baseload:	200 x 3000 x (8x5x52) x 100%	= VND1,248,000,000
Control (Loaded):	200 x 3000 x (8x5x52) x 9%	= VND112,320,000
Control (unloaded):	130 x 3000 x (8x5x52) x 91%	= VND738,192,000
		= VND2,098,512,000

Generating costs

Compressors on modulate:
1000 cfm output 200 kW full load 130 kW no load

Weekend:
1 compressor controlling 79% load, 21% off load
Total kW = (200*0.79) + (130*0.21)
= 158 + 27.3 = 185.3kW
= 185.3kW x 24 x 2 x 52 x VND3000 = **VND1,387,526,400**

VND3000/kWh, 24hrs, 2days, 52weeks/yr

Control (Loaded):	200 x 3000 x (24x2x52) x 79%	= VND1,183,104,000
Control (unloaded):	130 x 3000 x (24x2x52) x 21%	= VND204,422,400
		= VND1,387,526,400

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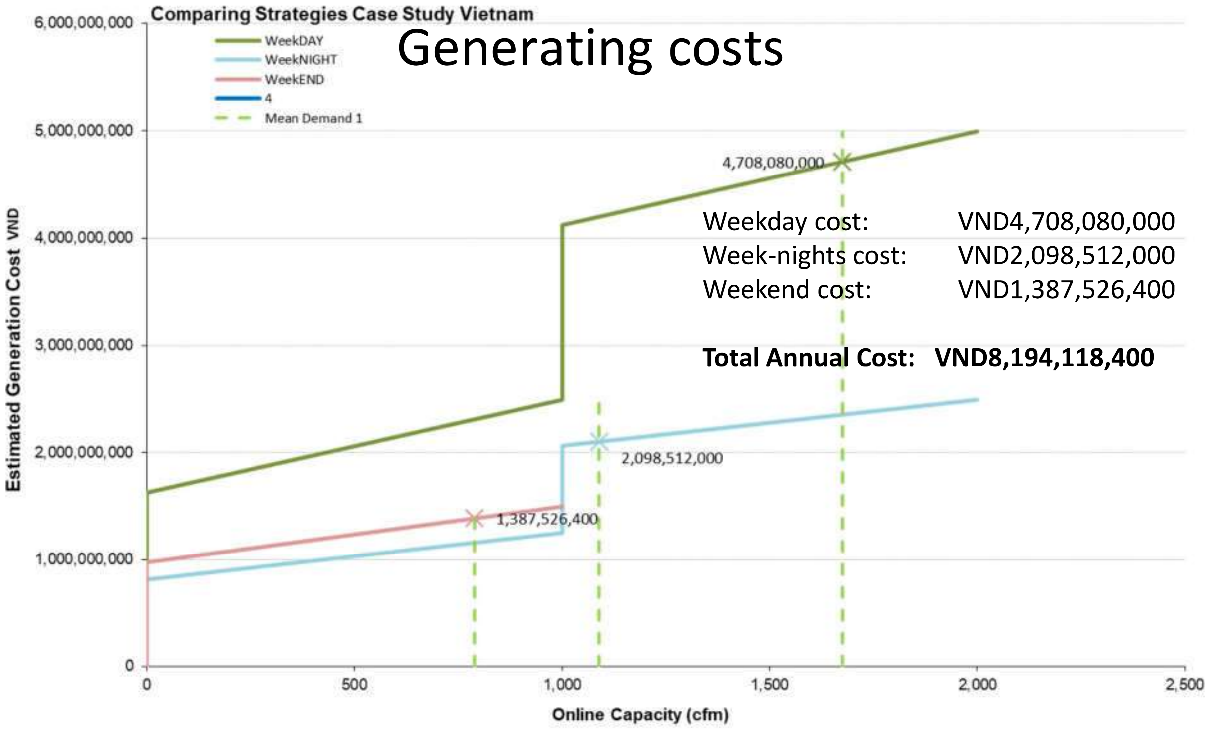
Generating costs



Weekday cost: VND4,708,080,000
Week-nights cost: VND2,098,512,000
Weekend cost: VND1,387,526,400

Total Annual Cost: VND8,194,118,400

Departmental demands

Area	Demand, cfm		
	Weekdays	Weeknights	Weekend
Press Shop	550	550	250
Paint Shop	350	65	65
Machine Shop	125	50	50
Element manufacture	150	50	50
Assembly	75	20	20
Packaging	100	45	45
Ancillaries	25	10	10
Desiccant dryer	300	300	300
Total	**1675**	**1090**	**790**

Improvements

1. Switch dryer to dewpoint control:

   Dryer demand reduces from 15% (300 cfm) at all demands to become proportional to the demand:

   Weekday: 243 cfm

   Week night: 139 cfm

   Weekend: 86 cfm

What if I don't have a dewpoint control switch?

Retrofit cost: 400,000,000
Payback: ~4 months

New cost: 7,150,628,160VND
Saving: 1,043,490,240VND
Cost: 0

Improvements

2. Switch compressors to on/off load control:

   Off load power consumption reduces from 130 kW to 40 kW

New cost: 6,395,950,080VND
Saving: 754,678,080VND
Cost: 0

Improvements

3. Run small compressor at weekend:

   Loading ratio increases from 57.6% to 96%

New cost: **6,364,200,960VND**
Saving: **31,749,120VND**
Cost: **0**

Improvements

4. Reduce leakage and misuse by 30%

   Based on Leakage survey & observations on site

   Use of nozzles, regulated blowguns etc

   Demand reduces by 172 cfm

New cost: **5,629,822,848VND**
Saving: **734,378,112VND**
Cost: **<70,000,000VND** **Payback <3months**

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Improvements

5. Install small compressor for paint agitation

   Reduces weekend demand from 404 cfm to 25 cfm

New cost: **4,951,908,000VND**
Saving: **677,914,848VND**
Cost: **167,500,000VND** **Payback <8months**

Improvements

6. Replace desiccant dryer with a refrigerant dryer and install small desiccant dryer for paint shop.

   Reduces demand by up to 190 cfm

   Reduces filtration levels required hence lower pressure drop in the compressor house (save 12kW on full load)

   Reduced demand allows small compressor to control

New cost: **4,117,470,240VND**
Saving: **834,437,760VND**
Cost: **1,600,000,000** **Payback 1.9years**

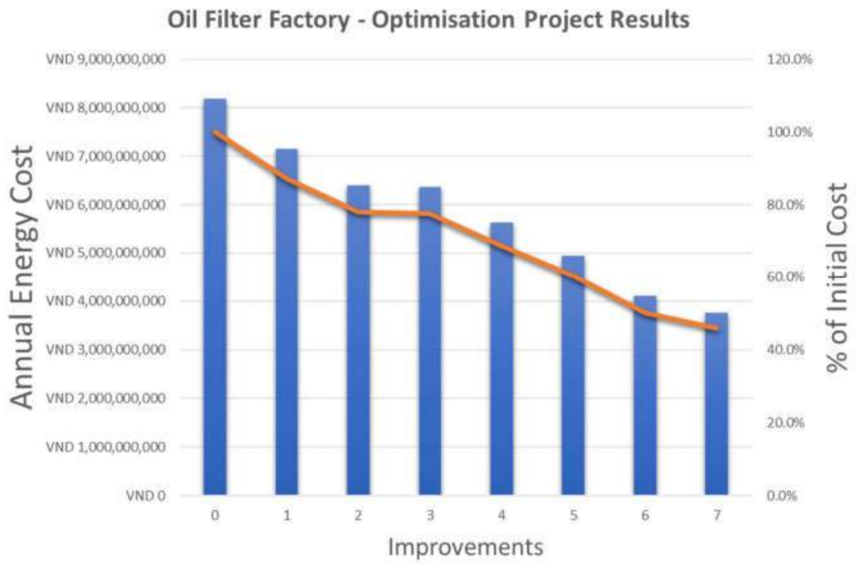
Improvements

7. Move a large compressor and the small one to the Paint Shop

   Allows main system to run at 6.5 barg, not 8.5 barg

   Full load kW reduces from 188 to 165

New cost: **3,766,650,000**
Saving: **350,820,240VND**
Cost: **~950,000,000** **Payback likely <3years**



- Cost reduced from 8,194,118,400VND to 3,766,650,000VND
- 54% of original cost saved
- Over 4,400,000,000VND saved for less than 3,000,000,000VND expenditure
- Payback <9months

DISCLAIMER

This document was developed within the framework of the project “Accelerating energy efficiency in large industries through energy management systems, system optimization and the promotion and adoption of energy efficiency in small and medium-sized enterprises (IEEP)”, funded by the European Union (EU), managed by the Ministry of Industry and Trade (MOIT), and implemented by the United Nations Industrial Development Organization (UNIDO). The content of this document is the sole responsibility of the Project and does not necessarily reflect the views of any individual or organization.