tree™

Total Resource Efficiency Education

# Compressed Air Energy Management

Training solutions brought to you by ecos

## Meet Your Panelists

Mike Carter

Mark Farrel

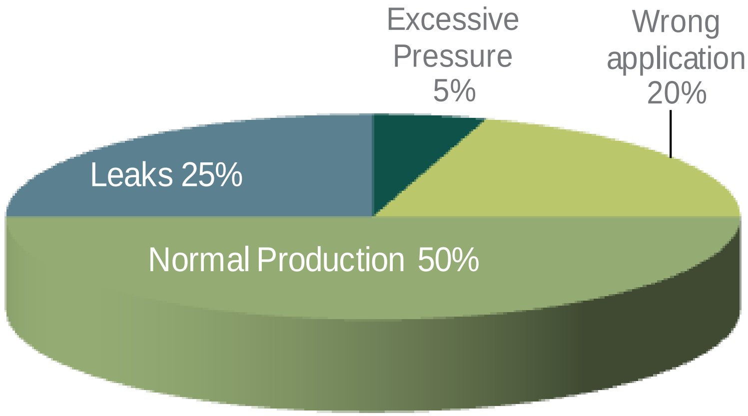
## Bottom line cost savings today!

Compressed air is the most expensive utility

Compare annual energy cost for 1 hp air motor at $1,358 versus 1 hp electric motor at $194

Easily averages $100 per cfm per year (3-shifts)!

**Typical Demand Components**



## Applications

Expanding an object

- Inflation of tires, air mattresses, other inflatables, scuba diving (buoyancy devices), and air intrusion (foam, sparging)

Moving an object

- Starting a diesel engine
(an alternative to electric starting)
- Removing scaling or contamination from a surface
(paint removal, air blasting)
- Rotating a shaft
(pneumatic screw driver, drills, motors, other tools)
- Launching a device
(air soft, paintball, air gun)

Image Credit: OSHA

## Applications

Resisting the movement of an object

- Air braking (road vehicles, rail systems)

Cooling/Heating

- Vortex enclosure cooling, vortex tubes, spot cooling, spot heating (hot air gun), and machining process cooling

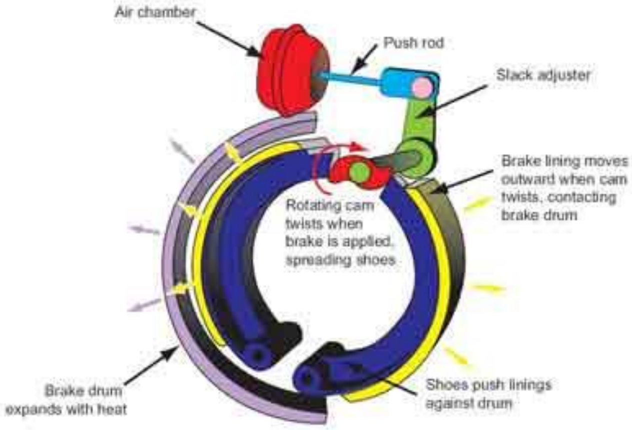



Image Credit: NTSB

## Basics

- Supply Side
  - Compressors
  - Prime Movers
  - Controls
  - Air Treatment
- Demand Side
  - Distribution
  - Storage
- Energy-Savings Ideas

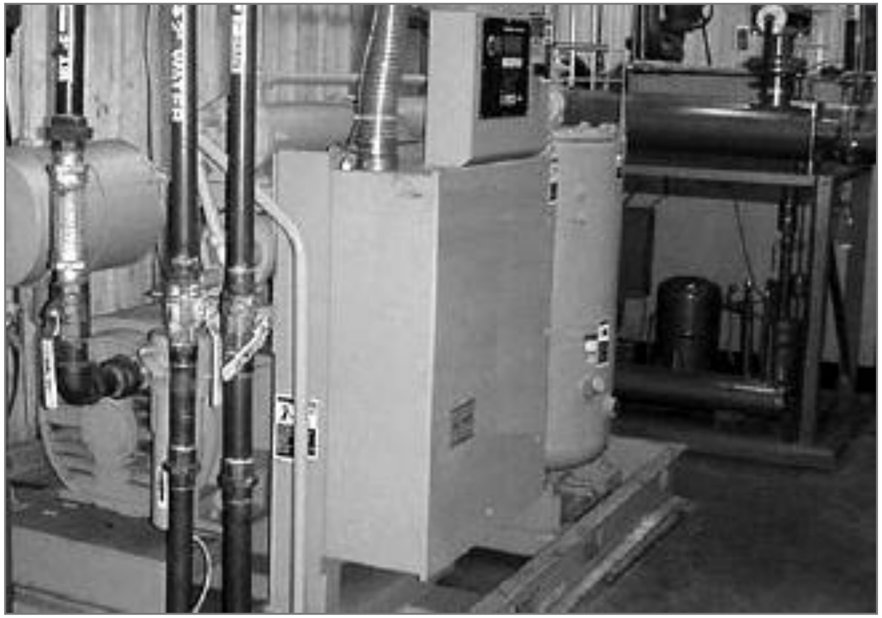


Image Credit: Compressed Air Challenge

## Heat of Compression

Roughly 80% to 90% of the electrical energy going to a compressor becomes available heat

Waste heat temperature rises

- Air delta 30°F to 40°F
- Water discharge at 130°F max

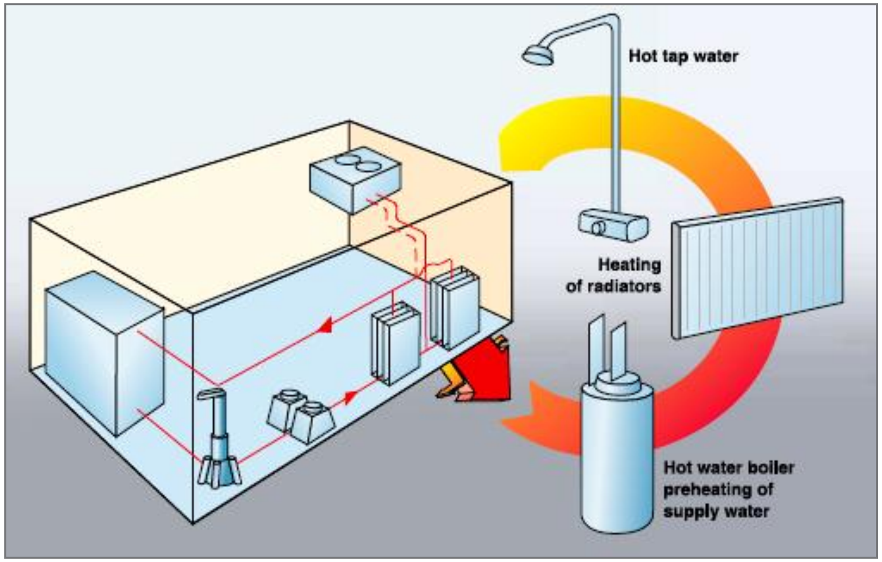
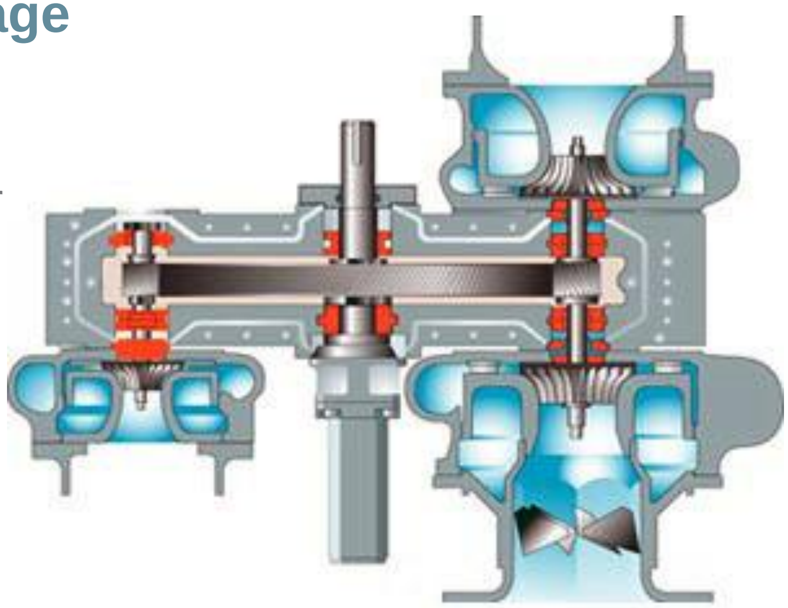



Image Credit: Atlas Copco

## Single-stage versus Multi-stage

- Multi-stage more efficient
  - Intercooling, load reduction, lower leakage potential
- Higher pressures with multi-stage



Three stage centrifugal compressor

Image Credit: Atlas Copco

## Power versus Energy

Kilowatt (kW) is a measure of power, like the speedometer of your car that records the rate at which miles are traveled

A bigger engine is required to travel at a faster rate.


Image Credit: Stock.xchng

Kilowatt-hour (kWh) is a measure of energy consumption, like the odometer on your car (miles)

Image Credit: Commonwealth of Kentucky

Energy cost = energy consumption x unit cost
= kWh x $/kWh

A 100-kW compressor motor operating 16 hours per day costs $58,400 per year

Energy cost = 100 kW x 5,840 hr x $0.10/kWh
= $58,400

## Power versus Energy

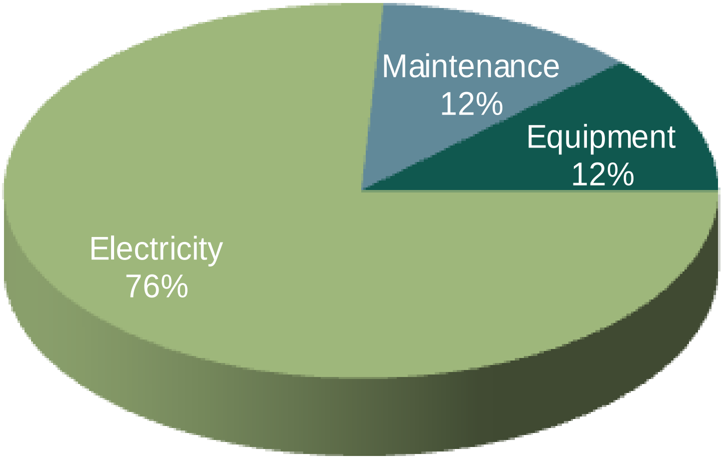
**Motor power** (kW) = Horsepower x 0.746/motor efficiency

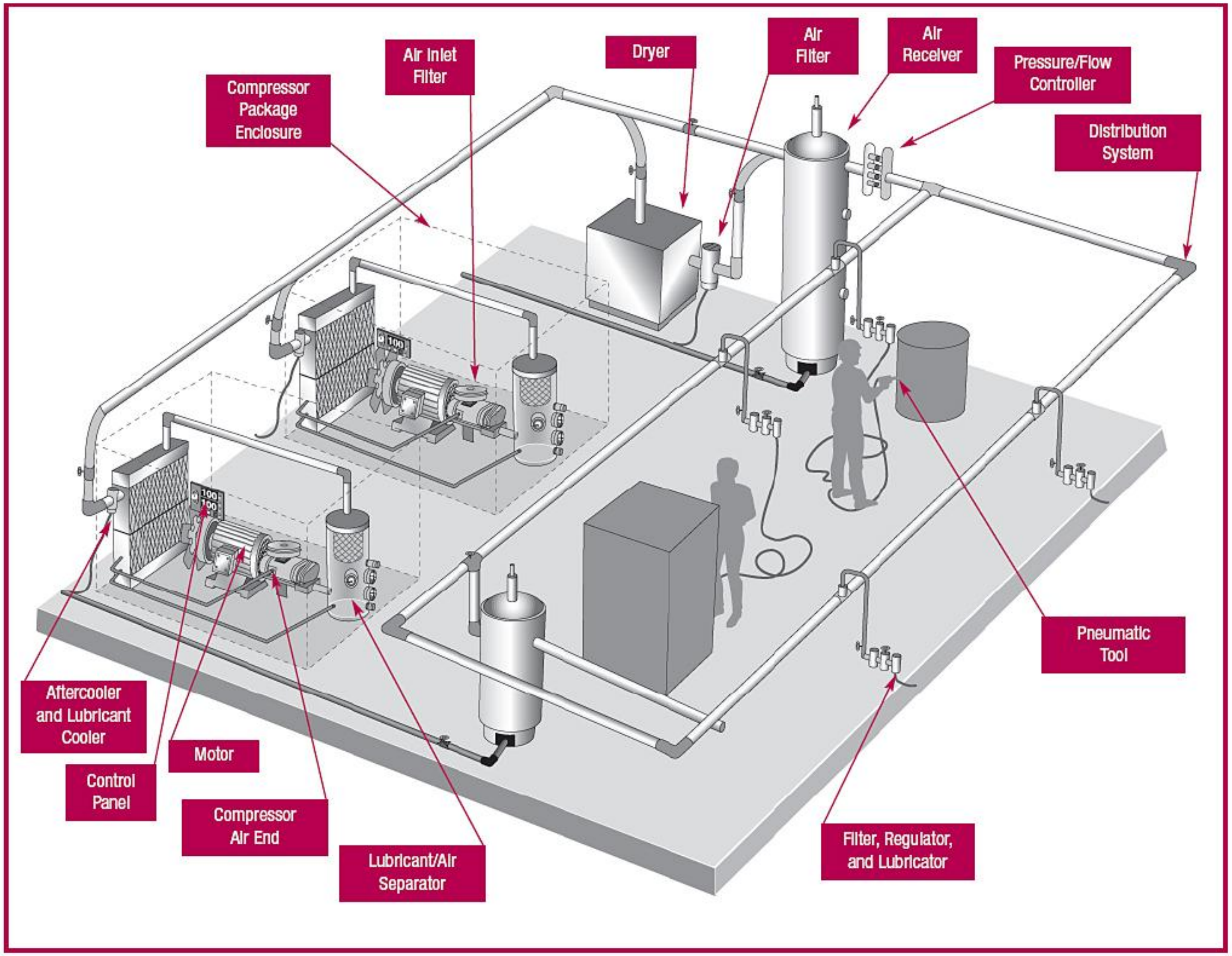
A 100 hp motor = 100 hp x 0.746/0.90 ME= 83 kW

Pay the price for improved energy efficiency!

The operating cost over the lifetime of a compressed air system can far exceed the original purchase price

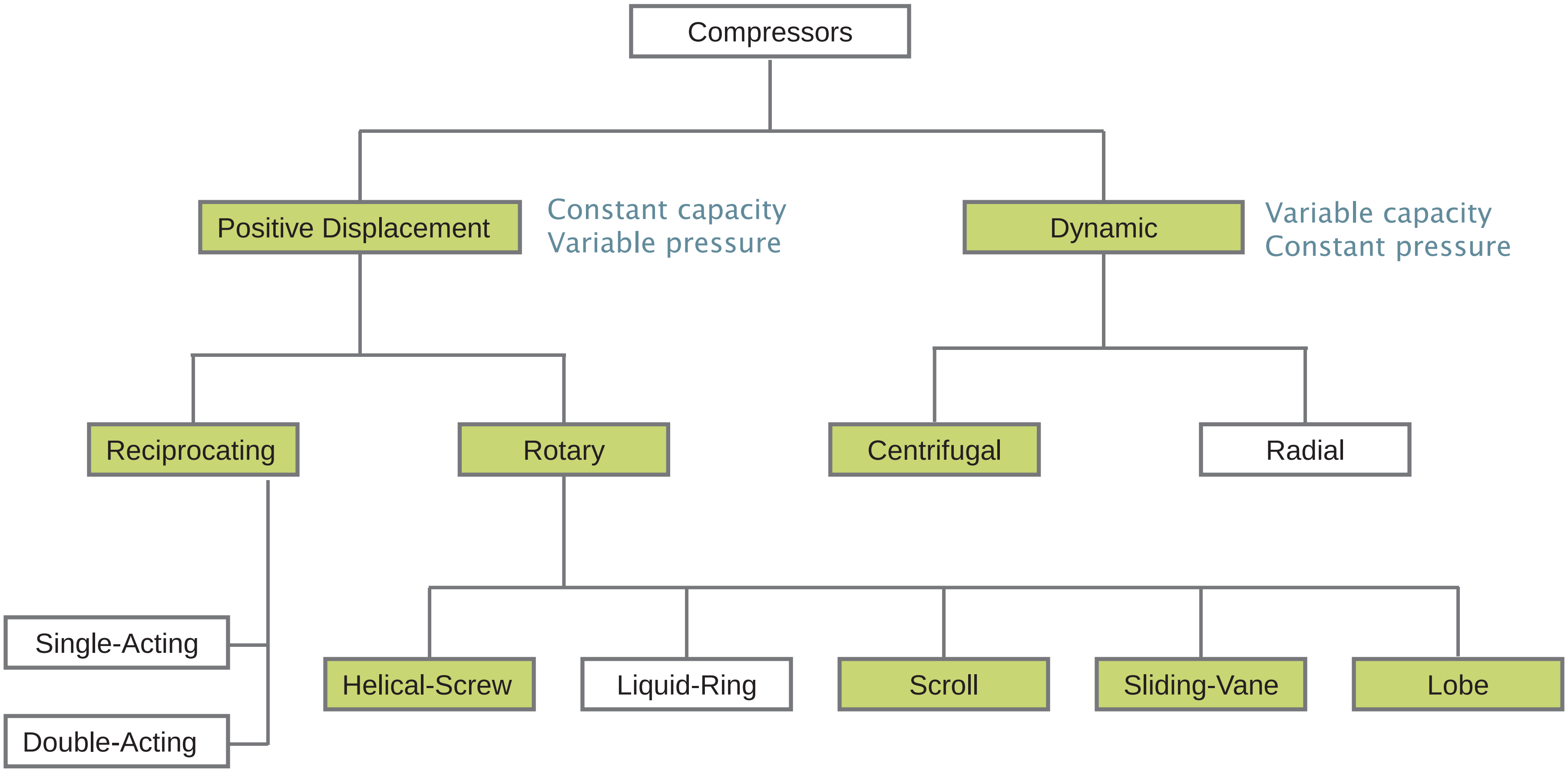
**Compressed Air Costs**






Source: DOE Compressed Air Challenge

# COMPRESSORS



## Compressors

Reciprocating single-acting air cooled compressor

- Lowest first cost, but least efficient

Higher flow capacities require dynamic compressors

- Centrifugal
- Axial

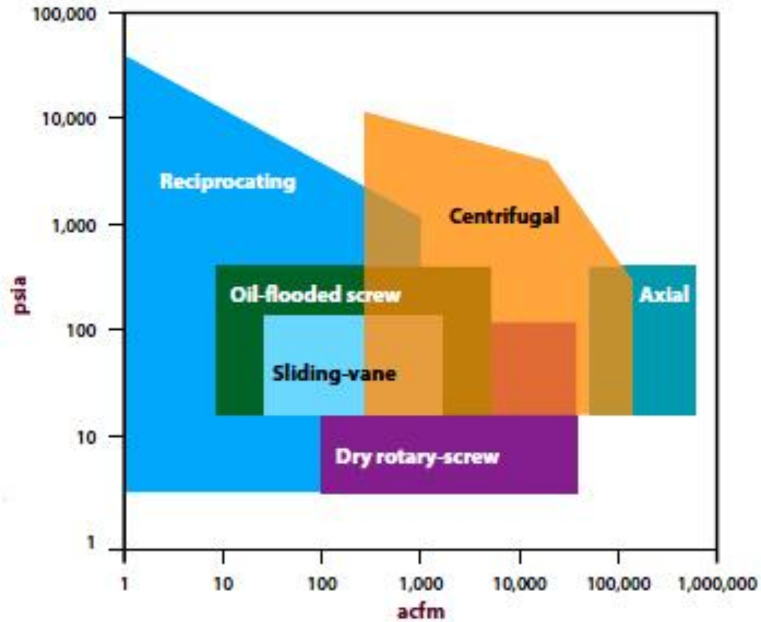



Image Credit: Research Associates

## Compressors

Spend a little more for a double-acting two-stage unit and achieve better efficiency

Lubricated compressors are often more efficient than a similar non-lubricated unit

- They contribute oil content to the system
- May impact the compressor air quality

| Air Compressor Efficiency Benchmarks | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Reciprocal | | | Rotary Screw | | Centrifugal | |
| | Air cooled | Water cooled | Water cooled | Lubricated | Lubricated | Non-lube | <250 hp |
| Energy Consumption | Single-Stage | Single-Stage | Two-Stage | Single-Stage | Two-Stage | Two-Stage | |
| bhp per 100 cfm | 26-32 | 25 | 19-22 | 23-26 | 20-22 | 20-26 | 22-27 |
| kW per 100 cfm | 22-27 | 21 | 16-18 | 19-22 | 17-18 | 17-22 | 18-22 |

- **Compressors**
- Electric Motors
- Diesel or Gasoline Engine
- Steam or Natural Gas Turbine

## Movers

The objective is to keep compressors off when they are not needed, thereby reducing energy use

- Use the appropriate controls (unloading, modulating, variable speed)
  - Reduce air usage
  - Lower input energy
- For multiple units use a modern electronic central air management system
  - Keeps all the baseline units on at full-load
  - Only one trim unit operates at part-load

# Evolution of lubricant-cooled rotary screw compressed air controls

**Load/Unload** (Blowdown)—low input kW is not reached until air/oil separator tank pressure is blown down

It can take several seconds to several minutes for the pressure in a lubricant sump/separator to be fully relieved (blue line #2)

**Inlet Valve Modulation**—features a gradually closing inlet valve at the compressor inlet controlled by a regulator (red line #1)

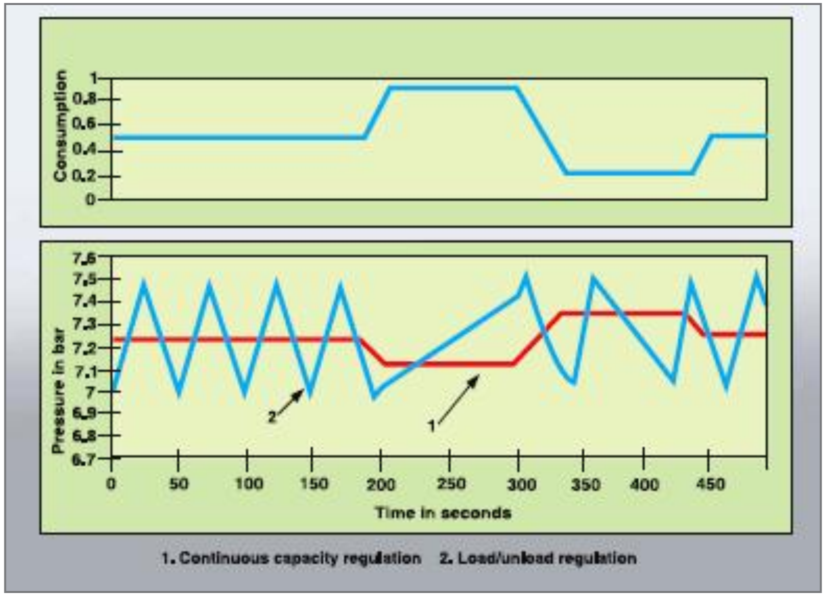



Image Credit: Atlas Copco Airpower

## Evolution of lubricant-cooled rotary screw compressed air controls

**Variable Displacement**—the sealing point of the compression chamber is moved effectively reducing the rotor length and inlet air displacement

- Controlled by slide/ turn/spiral/poppet valve

**Variable Speed Drive**— best applied to compressors that operate primarily as trim units, or as single units with loads below 75% to 80% demand

- Motor drive speed controlled to modify air supply

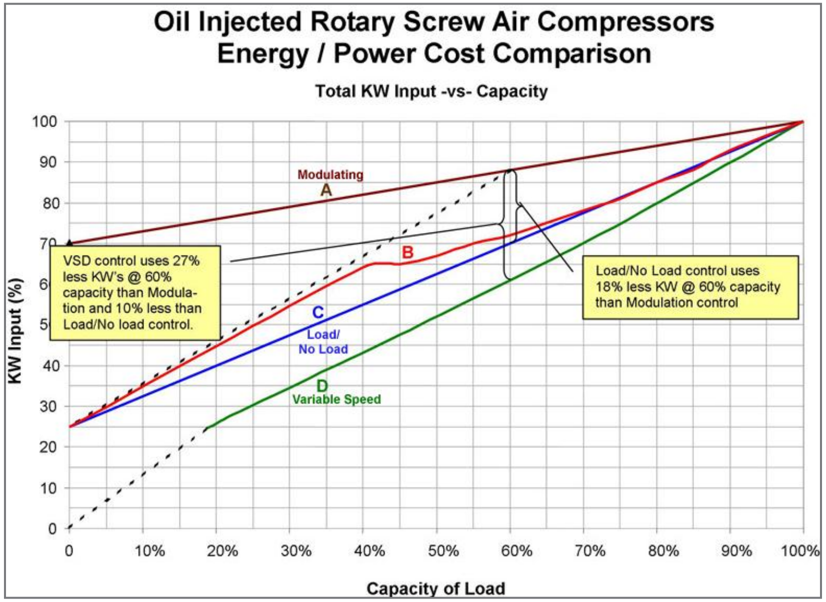



Image Credit: Air Technologies

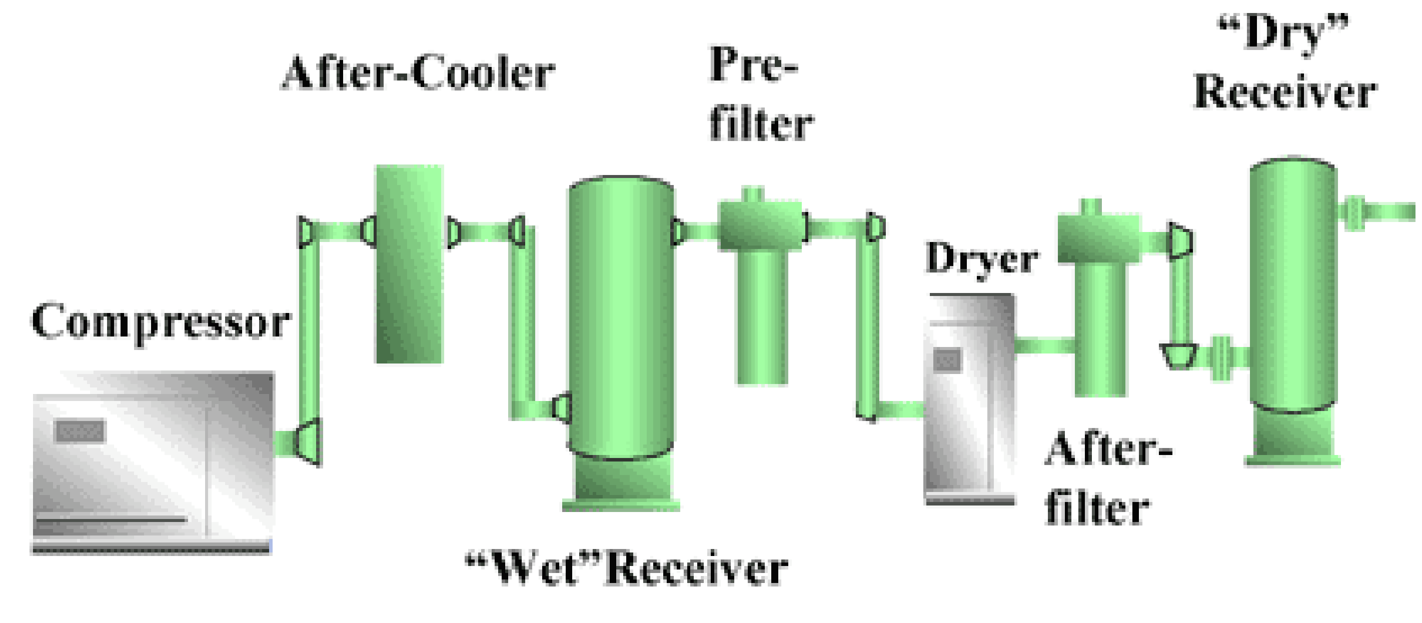
## Compressors operate at highest efficiency at full load or off

Optimum controls result in big savings

For example, at 50% full-load flow, kW input varies from 51% to 83%

| Percent kW Input at Operating Capacity for Lubricant-Injected Rotary Screw | | | | | |
|---|---|---|---|---|---|
| % Full-Load Flow | Load/No-load (5 gal/cfm) | Modulation | Variable Displace | Variable Speed | Constant Speed |
| 90% | 95% | 97% | 92% | 91% | 96% |
| 80% | 92% | 95% | 83% | 81% | 84% |
| 70% | 85% | 90% | 78% | 71% | 78% |
| 60% | 78% | 85% | 68% | 61% | -- |
| 50% | 72% | 83% | 63% | 51% | -- |
| 40% | 63% | 80% | 60% | 42% | -- |

Source: Improving Compressed Air System Performance: A Sourcebook for Industry, DOE

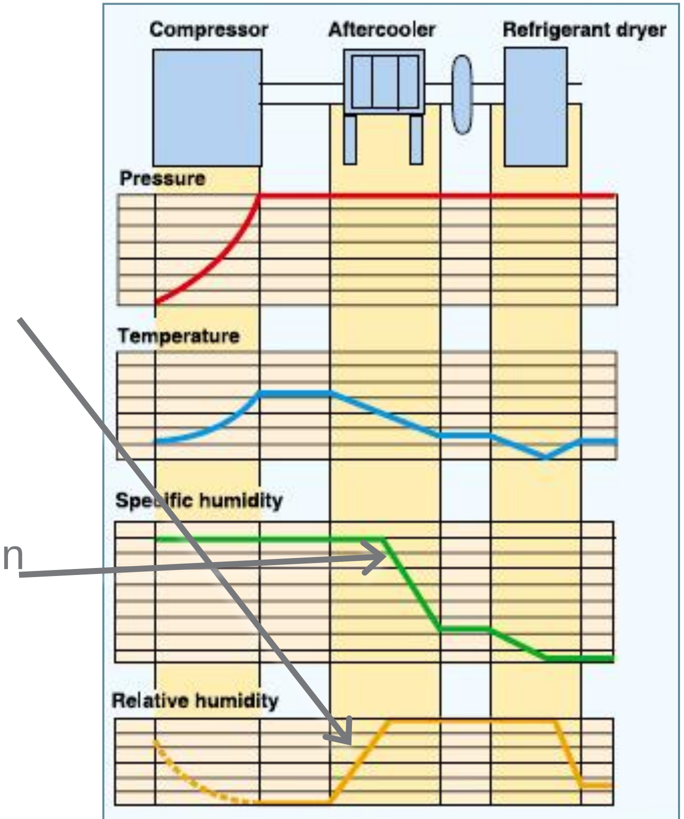



Source: Ingersoll-Rand Company

## Dryers

Refrigerated dryer water reduction process

- Temperature reduction results in higher relative humidity
- Relative humidity stays at 100% due to constantly decreasing temperatures
- Water reduction only occurs when temperature decreases below dew point



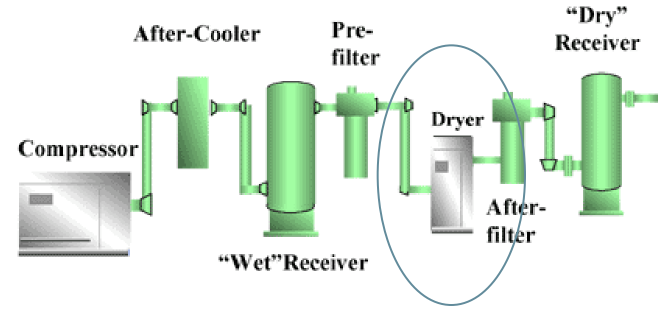

*Examples of how different parameters change with compression, aftercooling and refrigerant drying.*

Image Source: Atlas Copco

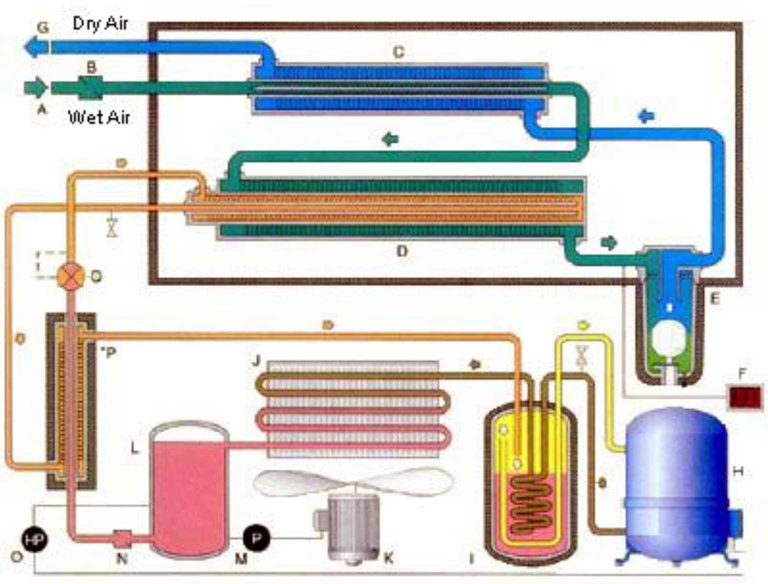
# Dryers

Refrigerated air dryer (non-cycling)

- Nominal pressure dew point of 35°F to 50°F
- Power requirement is 0.8 kW/100 cfm
- Lower inlet pressures and higher inlet air temperatures decrease the dryer flow rating
- Given a 100 psig and 100°F inlet dryer rating:
  - 125 psig, 80°F = 143% flow rating
  - 80 psig, 130°F = 40% flow rating




Source: Ingersoll-Rand Company




Non-cycling refrigerated dryer

## Desiccant Air Dryers

Desiccant adsorbs water vapor

Provides a pressure dew point of -40°F to -100°F

Requires some purge air (3% to 7% heater type or 12% to 15% heaterless)

Power requirement is 2 to 3 kW/100 cfm

Image Source: Atlas Copco

Image Source: Atlas Copco

## Membrane dryers

10% to 20% of full load rating sweep air required

Sweep air actual use is directly proportional to amount of flow through the dryer

Power requirement is 3 to 4 kW/100 cfm
40°F  to -40°F Dew Point

Image Source: Atlas Copco

Image Source: Gardner Denver

# Heat of Compression/Regeneration Dryers

Takes hot discharge air prior to aftercooler and routes it through the drying tower (50% RH) and removes water vapor from desiccant beads

Saturated air then goes to aftercooler

No purge air required

Power requirement is 0.8 kW/100 cfm

Recommended on oil-free systems only (to prevent a fire hazard)

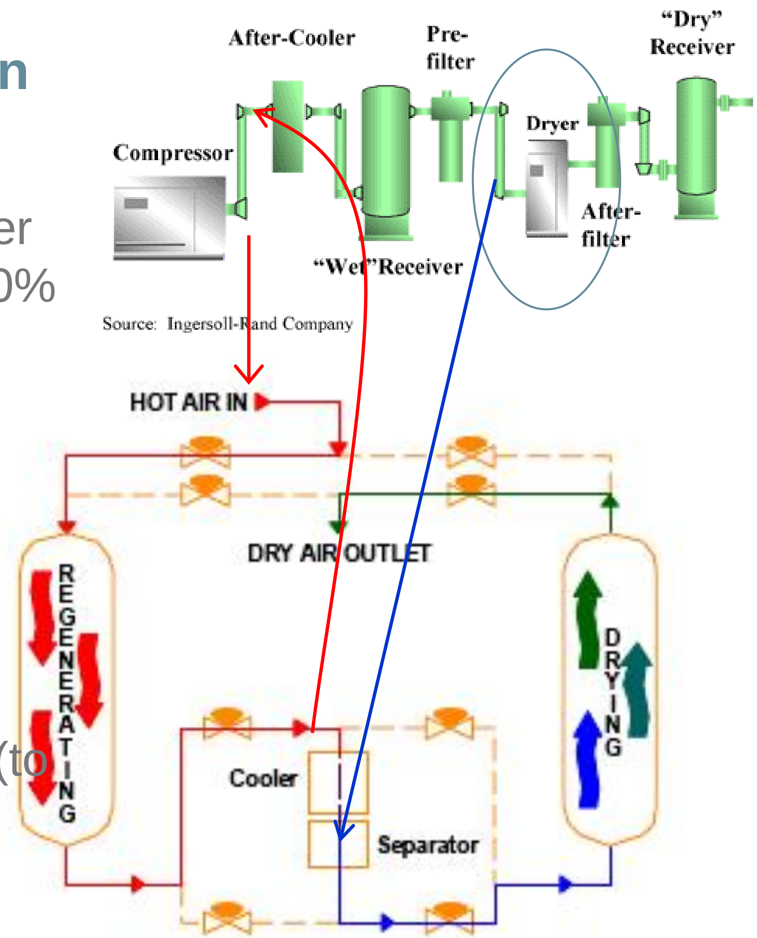



Image Source: Henderson Engineering Company, Inc

# Air Treatment

| Dryer Type | Dew Point | Air Capacity Reduction | Power Consumption | Comments |
|---|---|---|---|---|
| **Refrigerant** | 35F to 50F | None | 0.8 kW/100 cfm | - - |
| **Desiccant** | -40F to -100F | 10% to 18% | 2 to 3 kW/100 cfm | Coalescing prefilter |
| **Membrane** | 40F to -40F | 15% to 20% | 3 to 4 kW/100 cfm | Low capacity |
| **Heat of Compression** | 10F to -40F | None | 0.8 kW/100 cfm | Centrifugal, Oil-free rotary screw |

## Distribution

Required pressure levels must take into account system losses from dryers, separators, filters, and piping. Nominal pressure dew point of 35°F to 50°F

- A properly designed system should have a pressure loss of much less than 10% of the compressor's discharge pressure, measured from the receiver tank output to the point-of-use

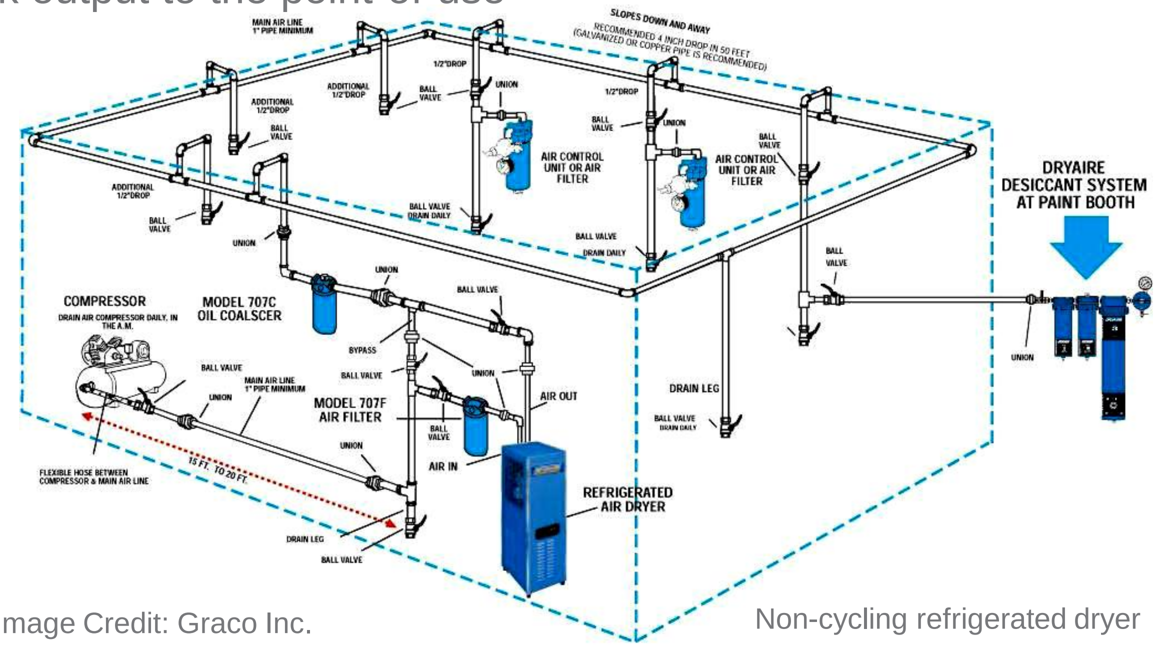



Image Credit: Graco Inc.

Non-cycling refrigerated dryer

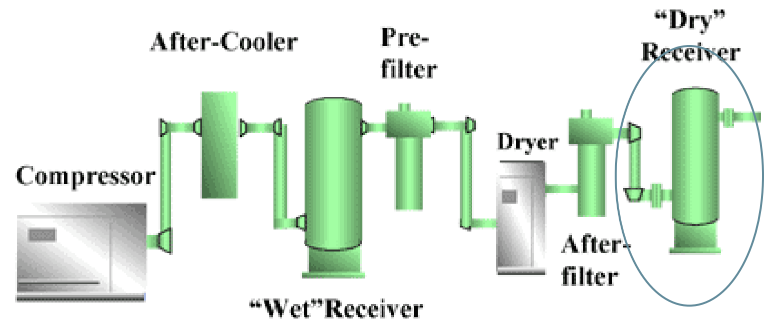
## Air Receivers

Can provide dampening of pressure pulsations, radiant cooling, and collecting of condensate

Stabilizes system header pressure and “flattens” the load peaks

Provides the time needed to start or avoid starting standby air

Storage buys time, not capacity




Source: Ingersoll-Rand Company

Image Credit: KAESER KOMPRESSOREN GmbH

## Air Receivers

Select optimum size for a short duration peak load converting a high rate of flow into a low rate of flow in the main system

Pump up decay formula

$$V = \frac{T \times C \times P_a}{(P_1 - P_2)}$$

V = Receiver Capacity ($ft^3$)
T = Time (minutes) for pressure drop
$P_1$ = Initial Receiver Pressure (psig)
$P_2$ = Final Receiver Pressure (psig)
C = Air Demand (acfm)
$P_a$ = Atmospheric Pressure (psia)

## Know your real costs!

Compare annual energy cost for 1 hp air motor at $1,358 versus 1 hp electric motor at $194

- 30 scfm at 90 psi required by air motor
- 6 to 7 bhp at compressor shaft required for 30 scfm
- 7 to 8 hp input electric power required for 6 to 7 bhp
- 5-day per week, 2 shift, $0.05/kWh

Energy cost for 6,000 hrs at $0.10/kWh = $125/cfm

- At 4 cfm/hp, a 250 hp compressor

## Only use compressed air when it is absolutely necessary!

Examples of potentially **inappropriate** uses of compressed air:

- Open blowing
- Sparging
- Aspirating
- Atomizing
- Padding
- Dilute-phase transport
- Dense-phase transport
- Vacuum generation
- Personnel cooling
- Open hand-held blowguns or lances
- Diaphragm pumps
- Cabinet cooling
- Vacuum venturis

If possible, switch to motors, mechanical actuators, and other means to accomplish the same function

## Energy-Saving Ideas

Use ¾" diameter hose for >3 hp tools or >50' lengths

Leaks often account for 20% to 30% of compressor output

- A 1/32" leak in a 90 psi compressed air system would cost approximately $185 annually

Image Credit: Ingersoll-Rand

## Produce only the pressure you really need

Reducing system pressure by 10 psi saves 8% to 10%

For every 1 pound per square inch (1 psi) increase in discharge pressure, energy consumption will increase by approximately 0.8% to 1% for a system in the 100 psig range with 30% to 50% unregulated usage *

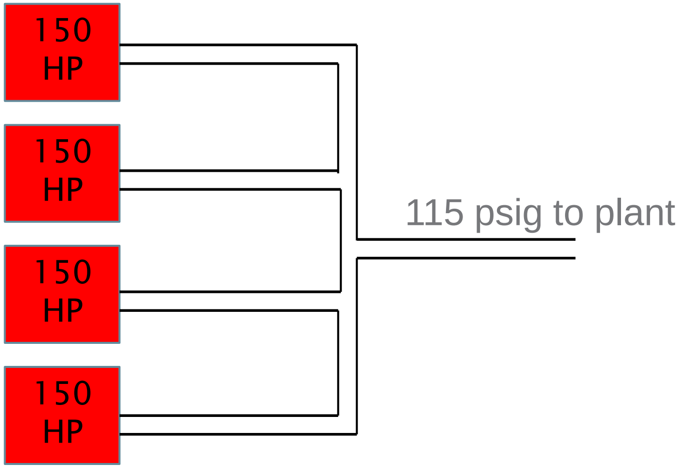
*Except for centrifugal compressors

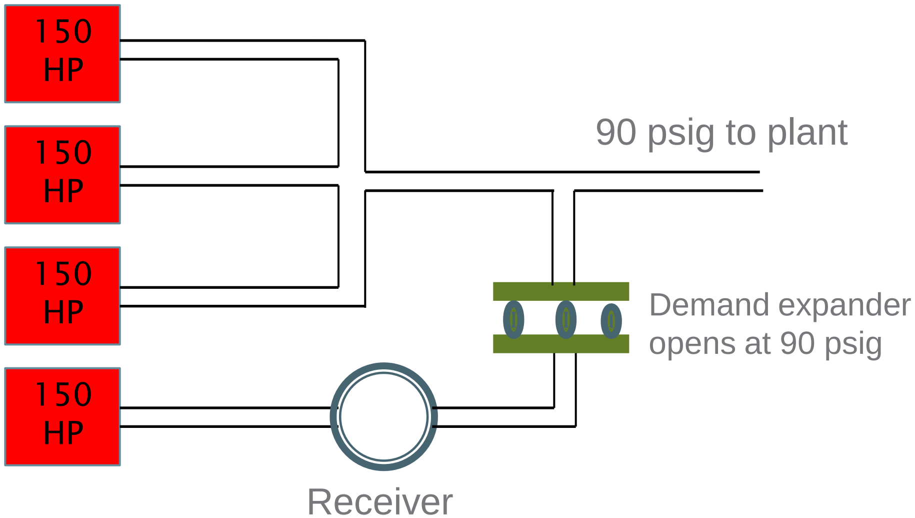
# Produce only the pressure you really need

## Demand expander valve

- Separates the supply side (compressors) from the demand side (users)
- Maintains a higher pressure on the supply side
- Claims of 10% to 15% energy savings

Image Credit: Gardner Denver

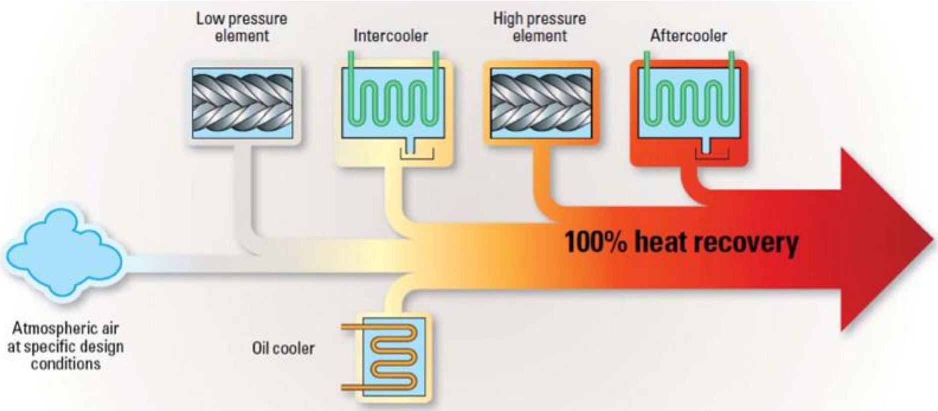


## Heat Recovery

Air-cooled compressors offer recovery efficiencies of 80% to 90%.

- Ambient atmospheric air is heated by passing it across the system's aftercooler and lubricant cooler
- As a rule, approximately 5,000 British thermal units per hour (Btuh) of energy are available for each 100 cfm of capacity (at full-load).
- Air temperatures of 30°F to 40°F above the cooling air inlet temperature can be obtained.
  - Space heating or water heating.




Water-cooled compressors offer recovery efficiencies of 50% to 60% for space heating only.

- Limited to 130°F

## When designing a compressed air system, what parameters should be included?

Average air demand (flow measurement, air survey, flow/pressure relationship)

Peak air demand (flow measurement, air survey, flow/pressure relationship)

Facility expansion plans

Maintenance requirements

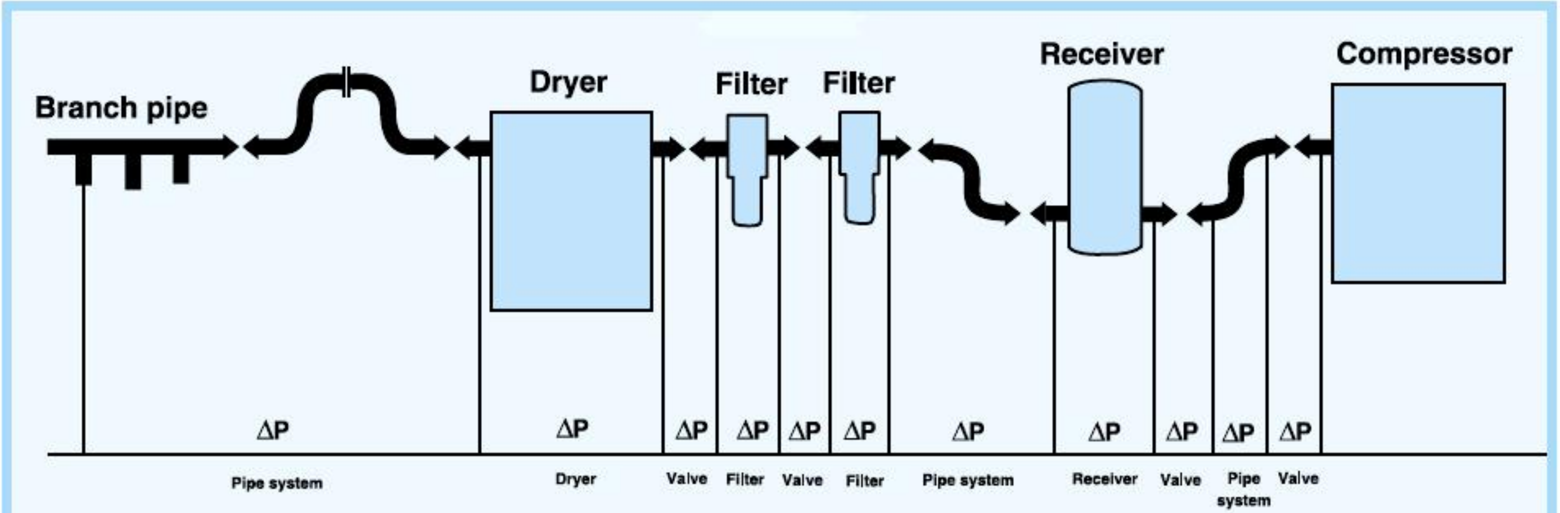
Ventilation needed

Air quality required by application

Minimum required air pressure

## Working pressure directly affects the power requirement

Minimize pressure drops!




*This is how the pressure drop across different components in the network affects the requisite working pressure.*

Image Credit: Atlas Copco

$$\Delta p = 450 \times \frac{Q_v^{1.85} \times L}{d^5 \times p_i}$$

$\Delta p$ = pressure drop (bar)
$Q_v$ = Air flow, free air (l/s)
d = Internal pipe diameter (mm)
L = Length of the pipe
$p_i$ = Absolute initial pressure (bar)

## John H. Harland Corporation printing plant in Atlanta, Georgia

Fifteen new presses used compressed air in three components: batching modules (20 scfm at 130 psig), collators (1.1 scfm at 100 psig), and print engines (also 1.1 scfm at 100 psig)

**Problems:**

- Air demand doubled to over 600 scfm
- Open-blowing air bars accounted for the greatest demand
- Joggers and lift cylinders were unable to work properly at the manufacturer's recommended pressure levels
- Hoses supplying the batching modules from the airdrops were too small
- Many push-to-connect tube fittings tended to leak on start-up
- Condensation was collecting on the metal components of the print engines, causing engine shut down

**Solutions:**

- Compressed air bars were converted to blowers
- Hoses were replaced with shorter and larger diameter hoses
- Each module was provided with a dedicated storage tank to reduce source pressure
- Onboard compressors were converted to operate manually

**Results:**

- Each machine's air demand declined from 27 scfm to only 4.5 scfm
- Site's total air demand reduced to approximately 300 scfm at 81 psig
- Facility took 70 hp of compressor capacity offline
- Avoided having to purchase between 500 and 600 hp of compressor capacity ($500,000 + $200,000 O&M)

## Southeastern Container blow molding plant in Enka, NC

The blow molders require clean, dry compressed air at an operating pressure of 600 psig in order to produce a high quality Coca-Cola bottle

**Problems:**

- Blow off rate setting of 87% vented compressed air unnecessarily
- Three booster compressors had severe internal and external leakage rates around the valve cover plates and unloader valves
- Discovered 367 scfm of low-pressure leaks and 505 scfm of high-pressure leaks in the distribution system
- Vortex coolers used for cooling and hardening the bottlenecks was wasteful

**Solutions:**

- Blow off point set below 75% without any risk of surge
- Vortex coolers replaced by cabinet cooler
- Electromechanical vibrator replaced compressed air to prevent jamming of pre-form feed lines
- Central vacuum system replaced venturi vacuum producers for pick-and-place operation
- Replaced the unloader valves and cover plates around the booster compressors with newer, more advanced models

**Results:**

- Lowering of the blow-off set points saved $100,000
- Other actions saved $80,000

## Next Steps

Facility air system audits?

On-site training/seminar?

Air system design consultation?

Workshops

- State Level, DOE EERE Industrial Tech Program sponsored
- Fundamentals of Compressed Air Systems, also web-edition (OH, UT, MN, CO, NV, IN,CA)
- Advanced Management of Compressed Air Systems (CA, IL)

Improving Compressed Air System Performance sourcebook

- http://www.compressedairchallenge.org

## NEEA Northwest Industrial Training

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# Upcoming Webinars and Trainings

Go to the NEEA calendar at www.neea.org/industrial-events for other trainings and events scheduled around the Northwest region.

## Webinars:

**October 25, 2011**: **Understanding the Pros and Cons of Variable Frequency Drives**
http://www.neea.org/participate/calendar.aspx?eventID=3096

**November 17, 2011: Advances in Lamps and Ballasts**
http://www.neea.org/participate/calendar.aspx?eventID=3097

## In-Class Trainings:

**October 5-6, 2011: Field Measurements for Industrial Pump Systems (Jerome, ID)**
http://www.neea.org/participate/calendar.aspx?eventID=3055

**October 17, 2011: Energy Efficiency of Chilled Water and Cooling Towers (Boise, ID)**
http://www.neea.org/participate/calendar.aspx?eventID=3134

**October 18, 2011: Adjustable Speed Drive Applications and Energy Efficiency (Tacoma, WA)**
http://www.neea.org/participate/calendar.aspx?eventID=2997

**October 20, 2011: Energy Data Analysis: Introduction to KPIs (Eugene, OR)**
http://www.neea.org/participate/calendar.aspx?eventID=2969

**November 9, 2011: Pumping System Optimization (Twin Falls, ID)**
http://www.neea.org/participate/calendar.aspx?eventID=3156

**November 10, 2011: Adjustable Speed Drive Applications and Energy Efficiency (Hermiston, OR)**
http://www.neea.org/participate/calendar.aspx?eventID=2990

**November 10, 2011: Energy Data Analysis: Introduction to KPIs (Helena, MT)**
http://www.neea.org/participate/calendar.aspx?eventID=3132

**November 16, 2011: Compressed Air Challenge - Level 1 (Yakima, WA)**
http://www.neea.org/participate/calendar.aspx?eventID=3133

**November 30, 2011: Energy Management: Introduction to Best Practices (Vancouver, WA)**
http://www.neea.org/participate/calendar.aspx?eventID=2974

**Thank you**