# UNIFIED FACILITIES CRITERIA (UFC)

# COMPRESSED AIR

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**UNIFIED FACILITIES CRITERIA (UFC)**

# COMPRESSED AIR



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| Change No. | Date | Location |
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**This UFC supersedes UFC 3-420-02FA, dated MAY 2003.**

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## FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

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# CHAPTER 1 INTRODUCTION

## 1-1 REISSUES AND CANCELS

This UFC reissues and cancels UFC 3-420-02FA, 15 May 2003.

## 1-2 PURPOSE AND SCOPE.

The intention of this UFC is to provide criteria to achieve economical, durable, efficient, and dependable compressed air systems to support Tri-Service facilities. Utilize industry standard practices for sizing and selecting equipment, components, fittings, piping, etc. except as otherwise noted in this UFC. Non-Government standards form the foundation of criteria requirements as represented in MIL-STD-3007G (General Requirements, figure 1). Refer to MIL-STD-3007G as DoD policy authority to adopt non-government standards (NGS).

## 1-3 APPLICABILITY.

This UFC provides criteria for the provision and design of low pressure compressed air systems with a maximum design operating pressure of 125 psig (8.62 barg), including piping, compressors, aftercoolers, separators, air receivers, and air dryers. For medium and high pressure compressed air systems, refer to CAGI and the ASME Piping Series (B31.1 and B31.3) for further guidance.

This UFC is applicable to all service elements and contractors involved in the planning, design, and construction of DoD facilities worldwide. Where conflicts in requirements appear between sections of any mechanical UFC or applicable codes or laws, the most restrictive requirement will govern.

## 1-4 GENERAL BUILDING REQUIREMENTS.

Comply with UFC 1-200-01. UFC 1-200-01 provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, high performance and sustainability requirements, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

### 1-4.1 Additional Requirements.

Use this UFC in conjunction with UFC 3-401-01 and the UFCs and government criteria referenced therein. This includes, but is not limited to, taking the following into consideration: maintainability; site location (weather, elevation, air cleanliness, etc.); conflicts in design criteria; and control system integration. Please refer to UFC 4-510-01 for Medical Gas Systems, including Dental Compressed Air and Medical Compressed Air.

### 1-4.2 Environmental Severity and Humid Locations.

In corrosive and humid environments, provide design detailing, and use materials, systems, components, and coatings that are durable and minimize the need for preventative and corrective maintenance over the expected service life of the component or system. UFC 1-200-01, section titled “Corrosion Prone Locations” identifies corrosive environments and humid locations requiring special attention. UFC 1-200-01, section titled “Requirements for Corrosion Prone Locations” provides examples of necessary actions. To determine Environmental Severity Classifications (ESC) for specific project locations refer to UFC 1-200-01 Appendix titled “Environmental Severity Classifications (ESC) for DoD Locations”.

## 1-5 CYBERSECURITY.

All control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

Cybersecurity is implemented to mitigate vulnerabilities to all DoD real property facility-related control systems to a level that is acceptable to the System Owner and Authorizing Official. UFC 4-010-06 provides requirements for integrating cybersecurity into the design and construction of control systems.

## 1-6 DESIGN GUIDANCE.

The leading compressed air standards organization in the USA is the Compressed Air and Gas Institute (CAGI). Utilize CAGI's Compressed Air and Gas Handbook for design guidance, best practices, and calculation procedures in conjunction with this UFC. Figure 4-1 illustrates the arrangement of a typical compressed air system. As an additional resource of technical information on compressed air systems, please refer to the Army Technical Manual TM-5-810-4/Airforce Manual 88-8, Chapter 3 which can be found on the Whole Building Design Guide (https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-3-420-02).

## 1-7 BEST PRACTICES.

APPENDIX A contains information that is considered best practice based on experience and lessons learned.

## 1-8 GLOSSARY.

APPENDIX B contains acronyms and abbreviations.

## 1-9 REFERENCES.

APPENDIX C contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

# CHAPTER 2 TECHNICAL REQUIREMENTS

## 2-1 BASIC PRINCIPLES.

### 2-1.1 Life Cycle Consideration.

Energy and water-efficient and sustainable design attributes for military construction must be based on the cost-benefit analysis, return on investment, total ownership costs, and demonstrated payback. Provide mechanical systems based on achieving the lowest life cycle cost of the approved alternatives. Ensure that all operation and maintenance costs are included in any life cycle cost analysis.

Follow procedures for Life Cycle Cost Analysis (LCCA) stated in UFC 1-200-02. In selecting alternatives for analysis, give preference to features and systems with lower complexity and maintenance burden. Do not include alternatives for which it is clear, prior to LCCA that the cost exceeds the potential savings based on historic information or engineering judgment. Where such alternatives were considered, but not analyzed, identify those alternatives and provide an explanation.

### 2-1.2 Energy Conservation.

Utilize Life Cycle Cost Effective (LCCE) strategies in design and operation of compressed air systems. Energy Conservation Best Practices are discussed further in APPENDIX A.

### 2-1.3 HVAC Considerations.

Provide heating, ventilating, and air conditioning systems to maintain space temperatures within acceptable ranges for the compressed air systems. Refer to APPENDIX A for design considerations.

### 2-1.4 Electrical Considerations.

Provide electrical systems for compressed air systems and components thereof in accordance with UFC 3-501-01 & UFC 3-520-01.

### 2-1.5 Noise and Sound Considerations.

Determine the sound power levels for each piece of equipment used for compressed air systems. Use this information to predict the acoustic characteristics and the resulting ambient noise level. Refer to UFC 3-101-01 and appropriate facility-type UFCs for sound transmission requirements (STCs) into adjacent building spaces.

For additional information on noise control refer to UFC 3-450-01.

### 2-1.6 Breathing Air Systems

Breathing Air systems must deliver Grade D breathable air in accordance with CGA G-7.1-2018. Table 2-1 is derived from OSHA Standard 29 CFR 1910.134(i)(1) which lists minimum criteria of Grade D air. Coordinate Breathing Air System design with the stakeholders to ensure equipment, materials, design, and configuration comply with local regulations and requirements (for example, Tinker Air Force Base INSTRUCTION 48-103 “RESPIRATORY PROTECTION PROGRAM”).

**Table 2-1 Minimum Grade D Breathing Air Characteristics**

| **Component** | **Criteria** |
|---|---|
| Oxygen Content (volume/volume) | 19.5% - 23.5% |
| Hydrocarbon (condensed) | <= 2-gr/ft$^3$ (5 mg/m$^3$) |
| Carbon Monoxide (CO) | <= 10 parts per million (ppm) |
| Carbon Dioxide (CO2) | <= 1,000 ppm |
| Odor | Lack of a noticeable odor |

# CHAPTER 3 COMPRESSED AIR SYSTEM COMPONENTS

## 3-1 INTRODUCTION.

Compressed air systems are comprised of multiple components, including but not limited to air intakes, intake filters, compressors, aftercoolers, wet receivers, dry receivers, valves, air dryers, condensate removal, regulators, oil separators, and lubricators.

### 3-1.1 Redundant Systems.

When a system failure would result in unusually high repair costs, or replacement of process equipment, or when activities are disrupted that are mission critical, the designer must provide redundancy requirement analysis to support the justification of redundancy.

### 3-1.2 Air Intakes.

The intake for a compressor will be located either outdoors or indoors, whichever provides better air quality. All air compressors are sensitive to dust and airborne vapors which can form adhesive, abrasive, and corrosive mixtures within the compressor. These contaminants build up in rotating parts and can induce excessive wear and mechanical unbalance, thereby damaging the compressor.

- Locate air intakes outside of the building where practicable (save for breathing air systems which must always be located outside of the building). Locate the air intake at least 6-feet (2 m) above the ground or roof level. Position intake pipes to prevent entrance of snow or rainwater. If the intake would be subject to adverse weather conditions, provide a hood or louver for protection therefrom. Locate intakes far enough away from steam, gas, or oil engine exhaust pipes to ensure that the intake air is free of moisture or pollution.
- Locate intakes for reciprocating compressors at least 3-feet (1 m) away from any wall to minimize the pulsating effect on the structure. Provide an intake filter silencer or a pulsation damper.
- Do not locate compressor air intakes within an enclosed courtyard.

#### 3-1.2.2 Intake Pipe Materials.

Provide plastic, copper, stainless steel, aluminum, or galvanized steel for air intake pipes. Utilize mechanical couplings for metallic pipe. Welded joints are prohibited.

#### 3-1.2.3 Intake Air Filter.

Select air filters based on manufacturer’s recommendations for the type of compressor (for example, lubricated or non-lubricated) and based on the ambient air quality. Provide the necessary stages of filtration required to ensure the air entering the compressor is within the compressor manufacturer's recommendations, accounting also for the purpose of the compressor (for example, breathing air versus shop air).

#### 3-1.2.4 Pressure Drop.

Provide a means to monitor the pressure drop across the inlet air filters. Coordinate with end user as to the level of detail required (for example, a binary input dirty filter switch versus directly measuring the pressure drop).

## 3-2 COMPRESSORS.

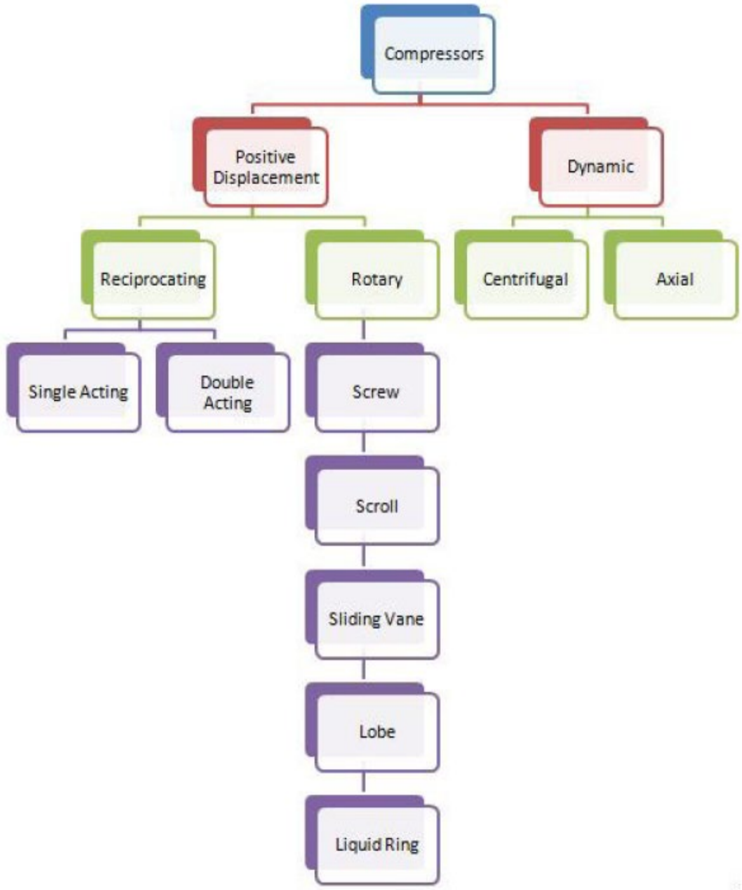
Utilize a central compressed air system whenever it is economically feasible as determined via a Life Cycle Cost Analysis. Compressors and all accessories must conform to ANSI/CAGI B19.1 and ASME B19.3, ASME BPVC Section VIII, PTC-9 & PTC-10, and ISA 7.0.01-1996, as applicable.

Where lubricating oils cannot be tolerated at the point of use, oil-free air compressors must be used. Oil-free air is required for such end uses as food handling, medical and dental application, chemical processing, and instrument air for pneumatic controls. Breathing air must be oil-free unless otherwise permitted by the end-user (for example, Contingency Operations).

### 3-2.1 Compressor Types.

Perform an analysis for each compressor to ensure that the best value is obtained by comparing such items as brake horsepower (bhp) per 100 cubic feet per minute (cfm) (kilowatt (kW) per cubic meter per minute ($m^3$/min)), unloaded horsepower (kilowatt), expected compressor life, and expected operation and maintenance costs. See Figure 3-1 for type of compressors. Typical applications for each type of compressor can be found in TM 5-810-4.

**Figure 3-1 Types of Compressors**




*Courtesy of the Compressed Air and Gas Institute (CAGI)*

### 3-2.2 Capacity.

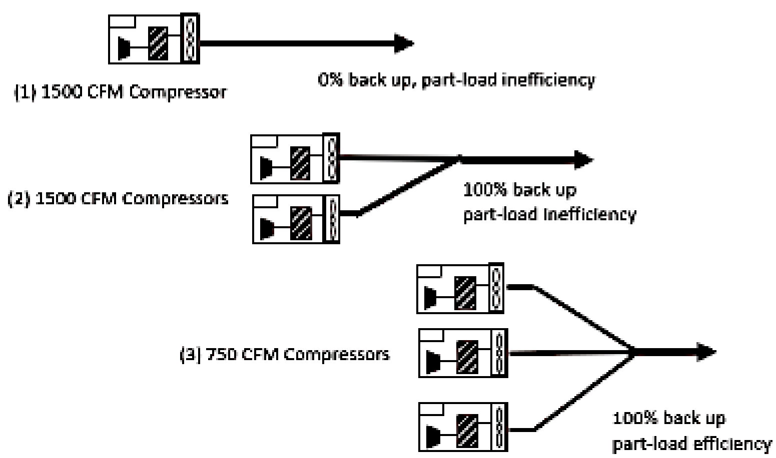
Size compressor based on the sum of the average air consumption of the end use devices, not the sum of the maximum air consumption (that is to say, utilize a load factor in determining compressor capacity). Utilize the CAGI Handbook, along with user input, to determine load factors.

Add an additional 10% to the estimated consumption to account for system leakage.

### 3-2.3 Multi-staging.

Multistage compressors may be used; however, only if LCCE. If multistage compressors are used, intercoolers must be used. An economic evaluation is necessary to determine whether a central compressed air distribution system or a system of separate compressors located near the point of usage is most cost-effective. Selection of the number of compressors for either situation must be based upon economics and other factors such as system reliability. Seasonal or operational load variations must also be considered. The efficiency of larger compressors is generally higher than that of smaller units but use of smaller air-cooled units permits savings on water, water piping, and system losses. Multiple units with interconnecting piping give flexibility for maintenance shutdown of one compressor. A smaller air compressor to handle requirements for weekends, holidays and other low usage times may also be economical (see Figure 3-2).

**Figure 3-2 Multiple Compressor Installation**




*Courtesy of the Compressed Air and Gas Institute (CAGI)*

### 3-2.4 Location.

Locate compressor(s) in a clean, well-lit, and ventilated area of sufficient size to permit easy access for cleaning, inspection, and any necessary dismantling (for example, removal of pistons, wheels, crankshafts, intercoolers, motors, and drivers). Provide aisle space between equipment for normal maintenance as well as for equipment removal and replacement as recommended by the manufacturer and code.

The temperature of the room in which air-cooled compressors are located must not exceed 100°F (38°C) or the maximum inlet air temperature specified by the compressor manufacturer, whichever is lower.

### 3-2.5 Automatic Warning and Shutdown.

Protect air compressor systems against high temperature, high pressure, and low oil pressure. In the case of centrifugal compressors, provide protection against excessive vibration. Protective controls will include a fault indicator and a manual reset device.

### 3-2.6 Vibration Limits.

To obtain guidance for establishing centrifugal compressor vibration levels, please contact manufacturers.

Flexible connectors, such as flexible metal hose, must be used to connect the discharge piping system to the air compressors.

### 3-2.7 Lubrication System.

System design will be in accordance with the manufacturer’s recommendations. Lubricant type will depend on the compressor application:

- Gravity, splash, or pressure petroleum oil must be used where oil contamination of the compressed air at the point of use is not a problem.
- Synthetic liquid lubricants must be used where there is a danger of fire, where the carbonaceous deposits must be reduced, or where lubricant is provided for extended maintenance periods
- Solid lubricants, such as carbon or Teflon piston rings, must be used for oil-free reciprocating compressed air applications.

## 3-3 AIR DISCHARGE PIPE.

### 3-3.1 Critical Pipe Length.

Determine critical pipe lengths of the air discharge pipe by coordinating with air compressor manufacturers. Critical pipe lengths must be avoided to prevent resonance.

### 3-3.2 Surge Volume.

Provide pulsation dampers or surge bottles at the discharge of reciprocating compressors if LCCE.

### 3-3.3 Safety Provision.

Provide a safety valve between a positive displacement compressor discharge and any isolation valve or other flow restricting device, as well as between the compressor and an internally finned tube aftercooler. The safety valve or valves will have a total capacity sufficient to handle the entire output of the compressor. Connect safety valves directly into the piping without unnecessary additional piping or tubing. Direct safety valve discharge away from personnel areas and traffic lanes.

## 3-4 AFTERCOOLER AND SEPARATOR.

### 3-4.1 Circulating Water.

When water-cooling is provided or required, provide the required waterflow through the intercooler, cylinder jacket, and aftercooler for cooling the compressor, cooling the compressed air, and for moisture removal. Provide controls and components to prove waterflow (for example, flow switch or differential pressure sensor) to ensure that sufficient cooling water is flowing before the compressor is allowed to start. Water for the aftercooler for liquid seal rotary compressors must be piped in series with the compressor. Waterflow for rotary screw compressors and rotary lobe compressors is not required prior to startup. Design the pipes to conform to the manufacturer's recommendations. Use a strainer or filter in the piping system to reduce fouling of the cooler system components.

Ensure cooling water temperature entering compressor cylinder jackets is at least 15°F (8.3°C) above the inlet air dew point to prevent condensation from forming in the cylinder inlet ports. Consult with a compressor manufacturer to verify the cooling water requirements for cooling compressor cylinder jackets.

## 3-5 AIR DRYER.

Provide air dryers where required. Coordinate the required air dew point temperature with customer and as required by the application (for example, very low dew point air for piping exposed to freezing where heat tracing is not practicable.).

### 3-5.1 Dryer Types.

In determining the type of dryer to be used for a given application, drying requirements, flow pressure, inlet temperatures, and the pressure dew point must be accurately determined. Select the dryer that meets these requirements most economically and efficiently. The various drying methods are as follows:

a. Refrigeration. Refrigeration dryers remove moisture from compressed air by cooling the air in a heat exchanger. This condenses and removes the moisture from the airstream and produces an operating pressure dew point at the dryer outlet in the range of 35°F to 39°F (2°C to 4°C). By adjusting the refrigeration unit operating parameters, these units can produce pressure dew points of 50°F (10°C). Higher dew points are available in either direct refrigeration or chiller-type design. The temperature of the room in which an air-cooled refrigerated dryer is located must not exceed 100°F (38°C) or the maximum inlet air temperature specified by the compressor manufacturer, whichever is lower.

b. Twin-tower regenerative. Regenerative dryers utilize non-consumable desiccants to remove moisture form the inlet air while the other is being regenerated (typical dew point ranges from -150°F up to 33°F (-101°C up to 1°C)). This method of regeneration includes the following dryer classifications:

    (1) Heatless desiccant regeneration passes a quantity of dried (purge) air through the off-stream bed. No external heat is applied. This type, with a field-adjustable purge control must be selected so that purge rate (and therefore pressure dew point) can be adjusted to accommodate seasonal variation in ambient temperatures, thereby reducing operating costs. Provide prefiltering to remove oil from the air stream to minimize future desiccant replacement.

(2) Heat regenerative dryers utilize heat from an external source (either electric or steam) in conjunction with purge air to regenerate the off-stream tower.

c. Deliquescent. Deliquescent (salt pellet) dryers and ethylene glycol stills are mentioned here for general information purposes only and must not be used.

A summary of typical applications for the above dryers are illustrated in Figure 3-3.

**Figure 3-3 Air Dryer Types**

| Type of Dryer | Pressure Dew Point Range | Typical Applications | Initial Cost | Operating Cost | Remarks |
|---|---|---|---|---|---|
| **DELIQUESCENT** | | | | | |
| | 12-20°F below inlet temperature | Protection against condensation in indoor air lines. | Lowest | Low to moderate | Causes high maintenance of downstream equipment due to salt solution in air lines. |
| **REFRIGERATED** | | | | | |
| | Above 33°F | General plant air, air-operated tools, instruments; materials conveying. | Low | Lowest | Most widely used type of air dryer because of its inherent reliability and low cost factor. |
| **TWIN-TOWER REGENERATIVE** | | | | | |
| Heatless Desiccant | Below 33°F (down to minus 150°F) | Outside air lines; chlorine padding; manufacturing processes requiring very dry air such as assembling electronic components and making urethane foam. | Low to moderate | Highest | Inefficient operation due to high purge rate. |
| Heat Regenerative | | | Moderate to high | Moderate to high | Minimum air waste for high flow, low dew point applications. |

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## 3-5.2 Prefilters and After-Filters.

Consideration must be given to providing a prefilter upstream of the air dryer. A prefilter may be required to remove compressor carry-over oil and other undesirable particles from the air prior to the air entering the air dryer. This filter can extend the life of the air dryer and reduce air dryer maintenance costs. An air filter must be considered to protect the downstream piping system and equipment from impurities and undesirable particles added to the air as a result of passing through the air dryer. Consult the air dryer manufacturers for recommendations and selection of prefilters and after filters for specific air quality requirements.

## 3-6 AIR RECEIVER.

Air receivers must be constructed in accordance with ASME BPVC Section VIII. Provide both a wet receiver and a dry receiver for applications that require dry air. Tank mounted compressors do not require wet and dry storage.

### 3-6.1 Determining Receiver Size.

Determine the appropriate receiver size after establishing the air compressor capacity. Size the receiver in accordance with the recommendations of the CAGI Handbook or the compressor manufacturer's recommendations. If the compressor manufacturer's literature recommends a larger air receiver, then provide the larger receiver.

### 3-6.2 Installation.

Install each receiver on a dry equipment pad. Provide space around each unit to facilitate draining, inspection, and maintenance. When a receiver is located outside, install the safety valve and pressure gauge indoors to prevent freezing. Heat trace the associated outdoor piping and arrange piping to drain back to the receiver. Where an automatic condensate trap is used with a receiver located outdoors, locate the trap indoors and heat trace the outdoor piping, or provide the outdoor trap and piping with electric heat tape to protect them from freezing.

## 3-7 PIPING.

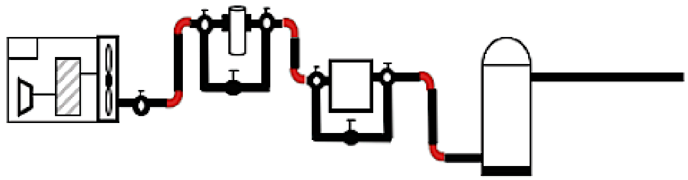
### 3-7.1 Materials.

- Steel compressed air piping must be a minimum of Schedule 40 and be galvanized, black, or stainless steel. Pipe fittings will be galvanized, black, or stainless steel, to match piping used. Fittings must be threaded, flanged, or welded type. Grooved fittings may only be used if permission is received by the Authority Having Jurisdiction.
- Copper compressed air piping or tubing will be Type K or Type L with brazed joints. Brazing filler metals with melting temperatures between 1,000°F (537.8°C) and 1,600°F (871.1°C) will be used.
- Thermoplastic piping system for transport or storage of compressed air will not be allowed. Safety records show that leaks in this type of pipe (when used for compressed air service) have caused the pipe to rupture, causing serious injury to personnel and/or property damage.

### 3-7.2 Loss of Air Pressure Due to Friction.

The maximum allowable pressure drop from the compressor to the most distant point of use must not exceed 5 percent. Utilize equivalent lengths of pipe to account for fittings, valves, and other minor losses.

**Figure 3-4 Piping Loss Calculation**



Pipe length calculation

| | Piping and Equivalent Length Fitting Adjustment | |
|---|---|---|
| | 2" piping and components | 3" piping and components |
| Piping | 500' | 500' |
| 5 Gate Valves | 6.05 equivalent feet<br>1.21 x 5 | 8.95 equivalent feet<br>1.79 x 5 |
| 6 Long Radius Elbows | 12.42 equivalent feet<br>2.07 x 6 | 18.42 equivalent feet<br>3.07 x 6 |
| **Total Piping** | **518.47 feet** | **527.37 feet** |

Pressure drop calculation

| | pressure drop @ 500 cfm with 2" piping and components | pressure drop @ 500 cfm with 3" piping and components |
|---|---|---|
| Piping | 9.95 psid<br>518.47/1000 x 19.2 psid | 1.23 psid<br>527.37/1000 x 2.34 psid |
| Filter | 2 psid | 2 psid |
| Dryer | 3 psid | 3 psid |
| **System Total** | **14.95 psid** | **6.23 psid** |

System conditions and assumptions

- 500 cfm compressor, fully loaded
- 50' of pipe in compressor room
- 450' of pipe in distribution header
- 5 open gate valves
- 6 long radius elbows
- Pipe is schedule 40 steel
- Filter pressure drop is 2 psid
- Dryer pressure drop is 3 psid

*Courtesy of the Compressed Air and Gas Institute (CAGI)*

### 3-7.3 Piping Layout.

Arrange piping system in a closed loop or "ring main" where possible. Provide dedicated main air lines to services requiring heavy air consumption and that are long distances from the compressor unit. Install piping parallel with the lines of the building, with main and branch headers sloping down toward a dead end. Install traps in airlines at all low points and dead ends to remove condensed moisture.

- Branch headers from compressed air mains, and all other takeoffs, must be taken off at the top to avoid picking up moisture.
- A strainer or filter and a lubricator must be provided in piping that serves tools.
- Provide all end points with a filter/strainer, pressure regulator, and dryer/lubricator (depending on end use application). Provide pressure gauges upstream and downstream of pressure regulator if a pressure gauge is not integral to the regulator. Provide filters and dryers with automatic drains.

- Provide service drops with isolation ball valves.
- Provide end point quick connect couplings compatible with end user equipment.
- Coordinate service drop locations and configurations with end user.

## 3-8 CONTROL SYSTEM.

Compressed air system controllers must be integrated into the building automation system (BAS) where a BAS is available; to the extent of which the compressor controls are capable; and to the extent of the user's needs. For example, a rotary screw compressor may be provided with web-based controls from the manufacturer that can display operating conditions and permit remote modification and control; however, manufacturers might only offer auxiliary contacts and relays to facilitate remote monitoring for tank mounted reciprocating compressors. Integrate air dryers into the BAS to monitor operating status, faults, alarms, and leaving compressed air dry bulb temperature and dew point.

- Align the control features and needs provided with a compressed air system with the end-user and Installation during design development.
- If a BAS is not available, provide the compressor with the means to facilitate future integration. Compressor controller must natively communicate using open protocols (BACnet, LON, or MODBUS) using standard objects and services, or provide a gateway to facilitate the aforementioned communication.
- Refer to UFC 3-410-02 and UFC 4-010-06 for additional control requirements.
- These requirements do not apply to portable air compressor units.

## 3-9 SOUND TESTS.

After installation, perform a sound test on all compressors and accessories in accordance with UFGS 22 05 48.00 20. Sound reading test results must not exceed limitations set by OSHA Standard 1910.95.

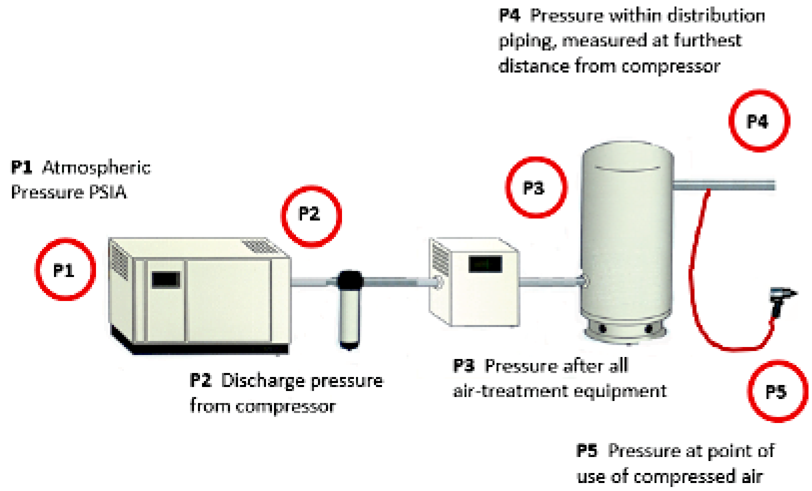
# CHAPTER 4 GENERAL DESIGN AND EQUIPMENT SCHEDULES

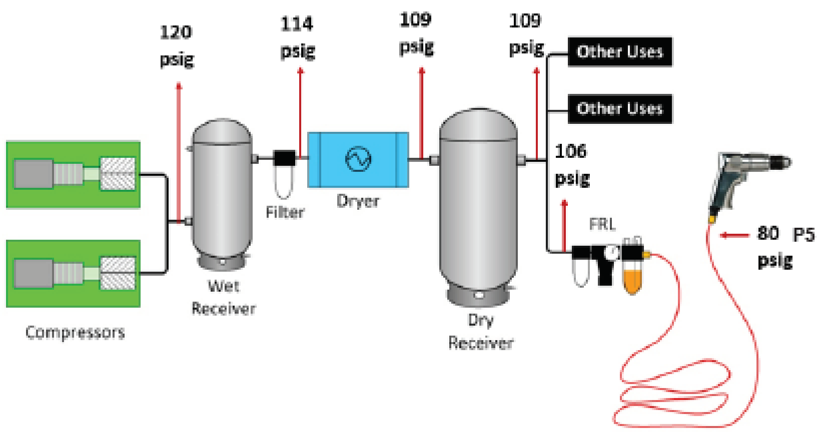
## 4-1 DESIGN ANALYSIS.

The following items must be included in the design analysis:

- Equipment redundancy requirements for critical system operation.
- Application (hospital, industrial, etc.)
- Maximum operating pressure required
- Location of air requirement in buildings
- Total compressed air flow and compressor sizing calculation including, but not limited to adjustments for altitude, moisture, temperature, and additional environmental factors that impact the compressed air system design.
- Heat Rejection Rates and rejection methods (for example, heat rejected to space, remote radiator, or other)
- Makeup/intake air system(s) design, including calculations.
- Air usage continuous or intermittent demand
- Operating pressure dew point requirement
- Dryer type selection and justification
- Air filtration needs at points of use
- Need for oil-free air
- Life Cycle Cost Analyses performed in accordance with UFC 1-200-02.
- Pressure drop calculations due to components, fittings, and piping from compressor outlet to end point devices (see Figure 4-1).
- List end point air consumption rates with corresponding minimum operating pressure requirements. If used, provide diversity factors for each corresponding end point load.
- Consider the Best Practices enumerated in APPENDIX A and document in the design narrative/analysis the best practices incorporated into the design. Include justification/rationale in the design narrative when a best practice is not incorporated into the design.

**Figure 4-1 Design with the End in Mind**




*Courtesy of the Compressed Air and Gas Institute (CAGI)*

## 4-2 EQUIPMENT SCHEDULES.

Equipment schedules will be shown on the drawings, including the following:

### 4-2.1 Air Compressor.

a. Capacity in standard cubic feet of air per minute (SCFM) (standard cubic meters per minute (Standard $m^3$/min))

b. Inlet air pressure in psia (bar)

c. Discharge pressure in psia (bar)

d. Ambient air temperature range with coincident humidity in gr/lb (g/kg)

e. Heat rejection type (water/oil/air cooled)

f. Heat Rejection characteristics (for example, for air-cooled: btu/h (kW), CFM ($m^3$/min), and temperature difference).

g. Minimum motor power in horsepower (kW)

h. Volts, phase, frequency

i. Minimum Circuit Ampacity

j. Maximum Overcurrent Protection Device in Amps

k. Type of Compressor

l. Number of Compressors

m. Oil-free or not oil-free

n. Accessory list

o. Spare parts list

**4-2.2 Air Receiver.**

a. Type (wet or dry)

b. Capacity in $ft^3$ ($m^3$)

c. Design Pressure in psia (bar)

d. Orientation: horizonal or vertical

e. Diameter in feet and inches (mm)

f. Length in feet and inches (mm)

g. Accessory list

h. Spare parts list

i. Drain type

j. Accessories

**4-2.3 After Cooler-Separator.**

a. Water-cooled

    i. Capacity in cfm ($m^3$/min) and psig (barg)

    ii. Dew point temperature entering and leaving in °F (°C)

    iii. Length in inches (mm)

    iv. Diameter in inches (mm)

    v. Cooling water

        1. Flow rate in gpm (L/s)

        2. Inlet Temperature in °F (°C)

        3. Outlet Temperature in °F (°C)

4. Fluid Type (for example, water, glycol, etc.)
5. Percentage of Glycol or level of freeze protection required

vi. Accessory list

vii. Spare parts list

b. Air-cooled

i. Capacity in cfm (m$^3$/min) and psig (barg)

ii. Compressed air inlet temperature entering after cooler in °F (°C)

iii. Approach temperature in °F (°C)

iv. Ambient air temperature in °F (°C)

v. Minimum fan motor power in horsepower (kW)

vi. Volts, phase, hertz,

vii. Minimum Circuit Ampacity

viii. Maximum Overcurrent Protection Device in Amps

ix. Accessory list

x. Spare parts list

**4-2.4 Air Dryer.**

a. Type (for example, refrigerated)

b. Capacity (cfm (m$^3$/min)) and operating pressure in psig (barg)

c. Dew point temperature entering and leaving in °F (°C)

d. Ambient temperature in °F (°C)

e. Volts, phase hertz (if applicable)

f. Refrigerant Type (if applicable)

g. Approx. Refrigerant Charge (if applicable)

h. Regeneration air flow in cfm (m$^3$/min)

i. Regeneration air temperature in °F (°C)

j. Regeneration Heater Input in btu/h (W) (if applicable)

k. Accessory list

l. Spare parts list

m. Drain type

# APPENDIX A BEST PRACTICES

The Best Practices Appendix is considered to be guidance and not requirements. Its main purpose is to communicate proven facility solutions, systems, and lessons learned, but may not be the only solution to meet the requirement.

## A-1 ENERGY CONSERVATION MEASURES.

To the extent practicable and LCCE, consider the following energy conservation measures:

### A-1.1 Compressors.

a. Variable speed compressor(s).

b. Multiple compressors versus a single compressor (for example, if demand differs significantly on nights and weekends versus during weekday daytime demand, then multiple small compressors may be a LCCE solution than a single large single speed compressor).

c. Shut down idling compressors.

d. Utilize heat from compressors to provide compressor room heating in winter.

e. Select an air compressor with a pneumatic load- unload feature that, when fully unloaded, consumes approximately 15 percent of the base load horsepower.

f. Use waste heat from the oil cooler to heat makeup air or for building space heating during the heating season.

g. When economically justifiable, use multistage compression with intercoolers.

h. Integral size motors must be the premium efficiency type in accordance with NEMA MG 1.

i. Provide a dedicated room for air compressors.

### A-1.2 Aftercooler with Separator.

a. Aftercooler selection must be based on degree of drying required downstream of the aftercooler. Final discharge air temperature of the aftercooler will affect dryer sizing and can reduce both the initial and operating costs of compressed air dryers.

b. Duct air from air cooled aftercoolers to provide space heating in winter and to remove heat form the plant in summer. Pipe coolant water to recycle waste heat.

### A-1.3 Filters and Dryers.

a. Improve air quality only to the degree required at the point of use. If air quality requirements differ at various points of use, specify appropriate filters or dryers in applicable branch lines.

b. Accurately determine the dew point required at each point of use since that affects the selected type(s) and size(s) of dryer(s).

c. Room air temperatures will affect drying efficiency. If practicable, locate dryers where ambient temperature will not exceed 100°F (38°C).

d. Select dryer in conjunction with aftercooler so inlet air temperature to the dryer can be as low as feasible. Keep inlet pressure as high as possible. Accurately determine operating temperature and pressure, since even minor changes in either can result in substantial operating costs.

### A-1.4 Air Leakage.

a. Maximum acceptable air leakage rate for a compressed air system must not exceed 10 percent of the installed system flow rate. Air leaks occur most often at pipe joints. Hose connections, and equipment connections; and are usually a result of poor maintenance practices and/or inadequately trained maintenance personnel.

b. Specification of quality materials and workmanship are a major contribution the designer of a compressed air system can provide for a safe and relatively leak-free air system. In addition, designing the compressed air system with minimum piping and pipe joints, will reduce potential leakage sources.

## A-2 AIR INTAKES.

It is desired that the intake air filter be located on the compressor and piped from the enclosed filter hood to the outside. This method prevents ingestion of foreign material to the internals of the compressor should the piping have a poor joint or other leak upstream of the intake filter.

## A-3 AIR COMPRESSORS.

Oil-free air can be obtained by using a centrifugal compressor, which is not lubricated due to its configuration; a water-sealed rotary compressor: or a reciprocating nonlubricated air compressor using carbon or Teflon for piston and packing rings. For isolated cases where oil-free air is required on a compressed air system coalescing filters may be used to remove solids, moisture, and oil from the air stream.

## A-4 AIR PRESSURE ADJUSTMENTS.

Converting between actual cubic feet per minute (ACFM) and standard cubic feet per minute (SCFM) can be accomplished using the following equation which is illustrated in Figure A-1 utilizing I-P units of measure.

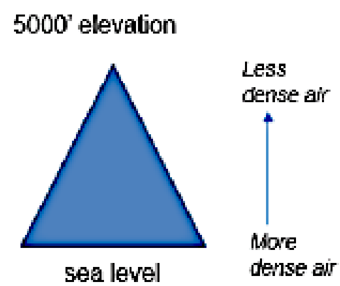
$$Flow_{act} = (Flow_{std})\left(\frac{P_{std,abs}}{P_{act,abs} - (P_v RH)}\right)\left(\frac{T_{act,abs}}{T_{std,abs}}\right)$$

Where:
*$Flow_{act}$ = Actual Flow Rate in CFM ($m^3$/minute)*
*$Flow_{std}$ = Standard Flow Rate in CFM ($m^3$/minute)*
*$P_{std,abs}$ = Standard Pressure (Absolute) in PSIA (bar)*
*$P_{act,abs}$ = Actual Pressure (Absolute) in PSIA (bar)*
*$P_v$ = Partial Pressure of Moisture in Air at Actual Temperature in PSIA (bar)*
*RH = Actual Relative Humidity*
*$T_{act,abs}$ = Actual Temperature (Absolute) in Rankine (Kelvin)*
*$T_{std,abs}$ = Standard Temperature (Absolute) in Rankine (Kelvin)*

**Figure A-1 Flow Rate Adjustments**

## Site Conditions

Example: Determine acfm




Requirement:

- 1000 scfm
- Altitude 5000 ft above sea level
- Maximum ambient temperature 100°F
- Maximum Relative Humidity 50%

- Atmospheric pressure at 5000 ft. = 12.2 psia
- Partial pressure of moisture at 100°F from vapor pressure chart = 0.95 psia
- Partial pressure at 50% RH = 0.95 x 0.50

**Use CAGI standard conditions: 14.5 psia, 0% RH, 68°F**

$$1000scfm\ x\ \underbrace{\frac{14.5}{[12.2-(0.95\ x\ 0.50)]}}_{\text{pressure adjustment}}\ x\ \underbrace{\frac{(460+100)}{(460+68)}}_{\text{temperature adjustment}} = 1000\ x\ \frac{14.5}{11.725}\ x\ \frac{560}{528} = 1311\ acfm$$

*Courtesy of the Compressed Air and Gas Institute (CAGI)*

## A-5 AIR RECEIVER SIZING.

Oversizing dry receivers by at least 10% may reduce the risk of running out of dry air if an unusual period of high demand exceeds the amount of usable storage.

## A-6 AUTOMATIC BLOW DOWNS & DRAINS.

Blow downs and drains must be the automatic type to conserve energy. Typical locations include, but are not limited to, air receivers, filters, and dryers.

# APPENDIX B GLOSSARY

## B-1 ACRONYMS.

| | |
|---|---|
| ACFM | Actual Cubic Feet per Minute |
| AFCEC | Air Force Civil Engineer Center |
| ASME | American Society of Mechanical Engineers |
| BACnet | Building Automation and Control network |
| BARG | Bar (Gauge) |
| BAS | Building System Automation |
| BIA | Bilateral Infrastructure Agreement |
| CAGI | Compressed Air and Gas Institute |
| CFM | Cubic Feet per Minute |
| DoD | Department of Defense |
| DN | Diametre Nominal (Nominal Diameter) |
| ER | Engineering Regulation |
| ESC | Environmental Severity Classifications |
| HNFA | Host Nation Funded Construction Agreements |
| HQUSACE | Headquarters, U.S. Army Corps of Engineers |
| HVAC | Heating, Ventilation, and Air Conditioning |
| ISA | Instrument Society of America |
| LCCA | Life Cycle Cost Analysis |
| LCCE | Life Cycle Cost Effective |
| LON | Lonmark® LONtalk |
| m | Meter |
| mm | Millimeter |
| NEMA | National Electrical Manufacturers Association |
| OSHA | Occupational Safety and Health Administration |

| | |
|---|---|
| PSIA | Pounds per Square Inch, Absolute |
| PSIG | Pounds per Square Inch, Gauge |
| RH | Relative Humidity |
| SCFM | Standard Cubic Feet per Minute |
| SOFA | Status of Forces Agreements |
| UFC | Unified Facilities Criteria |
| U.S. | United States |

## B-2 DEFINITION OF TERMS.

**Actual Cubic Feet Per Minute (Actual Cubic Meters Per Minute):** The flow rate of air expressed in terms of actual conditions, that is at non-standard conditions.

**Standard Conditions:** For the purposes of this UFC, standard conditions are taken to be those of CAGI: Standard Pressure of 14.5 psia (1 bar); Standard Dry Bulb Temperature of 68°F (20°C); Standard Humidity of 0% Relative Humidity.

**Standard Cubic Feet Per Minute (Standard Cubic Meters Per Minute):** The flow rate of air expressed in terms of standard conditions.

# APPENDIX C REFERENCES


## AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

ASME B19.3, *Safety Standard for Compressors for Process Industries*

ASME *Boiler and Pressure Vessel Code Section VIII*, 2021

ASME PTC-9, *Performance Test Code on Displacement Compressors, Vacuum Pumps, and Blowers*, 1997

ASME PTC-10, Performance Test Code on Compressors and Exhausters, 1997

## COMPRESSED AIR AND GAS INSTITUTE (CAGI)

CAGI *Compressed Air and Gas Handbook*, 7th Ed., 2016

ANSI/CAGI B19.1, *Safety Standard for Compressor Systems*

## COMPRESSED GAS ASSOCIATION (CGA)

CGA G-7.1-2018, *Commodity Specification for Air - Seventh Edition*

## INSTRUMENT SOCIETY OF AMERICA

ANSI/ISA-7.0.01-1996, *Quality Standard for Instrument Air*

## INTERNATIONAL STANDARDS ORGANIZATION

ISO 2151-2004, *Acoustics - Noise Test Code for Compressors and Vacuum Pumps-Engineering Method (Grade 2)*

## OCCUPATIONAL SAFETY AND HEALTH AGENCY (OSHA)

OSHA (29 CFR) 1910.95, *Occupational Noise Exposure*

OSHA (29 CFR) 1910.134(i), *Breathing Air Quality and Use*

## UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

UFC 1-200-01, *DoD Building Code*

UFC 1-200-02, *High Performance and Sustainable Building Requirements*

UFC 3-101-01, *Architecture*

UFC 3-401-01, *Mechanical Engineering*

UFC 3-410-01, *Heating, Ventilating, and Air Conditioning Systems*

UFC 3-410-02, *Direct Digital Control for HVAC and Other Building Control Systems*

UFC 3-450-01, *Noise and Vibration Control*

UFC 3-501-01, *Electrical Engineering*

UFC 3-520-01, *Interior Electrical Systems*

UFC 4-010-01, *DoD Minimum Antiterrorism Standards for Buildings*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

UFC 4-510-01, *Design: Military Medical Facilities*

**UNIFIED FACILITIES GUIDE SPECIFICATIONS**

UFGS 22 05 48.00 20, *Mechanical Sound, Vibration, and Seismic Control*

**US ARMY CORPS OF ENGINEERS**

Engineering Regulation No. 1110-1-8173, *Energy Modeling and Life Cycle Cost Analysis*