Compressed Air System Audit Specification
Minimum Elements for Compressed Air System Audits

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1 Introduction

Energy efficiency program administrators often work with commercial and industrial customers to achieve energy savings in compressed air systems. Because compressed air systems are complex and uniquely designed for a particular facility, savings opportunities are typically identified through compressed air system audits.

Program administrators have observed that the current marketplace for audits does not always meet their needs for a credible, comprehensive audit to support consistent savings recommendations. Some audits concentrate on supply-side recommendations, without considering demand-side opportunities to eliminate inappropriate uses, eliminate waste and artificial demand, and optimize pressure. To be effective, compressed air system audits need to strike a balance. While audits must address system energy performance holistically, the rigor of the audit must be appropriate for the size and complexity of the system for the audit to be economically justified.

To better understand the current marketplace for compressed air audits, CEE staff worked with program administrators to assess a set of 23 off-the-shelf compressed air system audits to see how thorough the audit process was, how market performance compares with best audit practices. To screen this dataset, the 23 audits were assessed using a checklist designed to allow a comparison with industry best practices and the audit behaviors included in the CEE Audit Specification. To understand the potential benefit of adopting the CEE Audit Specification, the recommended audit actions were paired with energy savings projections from the 2010 United Nations Industrial Development Organization (UNIDO) Motor Systems Efficiency Supply Curves. Using the savings projections in the UNIDO report, the audits analyzed left an average of 43 percent of potential savings on the table by failing to evaluate some energy conservation opportunities.

In 2015, 34 CEE members had specific compressed air offerings beyond support for custom projects. However, member compressed air programs represent a patchwork of different offerings across the United States and Canada. CEE staff interviewed 16 program administrators with compressed air offerings and found that only four had clear guidelines on what actions and data collection, specific to a

compressed air system, should occur during a compressed air system audit. In many cases, programs either relied on their general custom data collection policies as the only guidance, or left it entirely up to customers and third parties to determine what would occur during the audit. This lack of consistency mirrors the marketplace for compressed air audits, resulting in market confusion and lost savings opportunities.

Program administrators identified a role for CEE to define program expectations around compressed air system audits by creating a set of minimum audit practices consisting of data collection and reporting requirements paired with guidance on best practices for collecting the required data. The objectives of promoting program administrator-defined audit practices in the market are:

- Enabling program administrators and customers to specify a holistic compressed air audit based on the size and complexity of the system under consideration
- Creating demand in the marketplace for compressed air system audits that better meet customer and program needs, thereby increasing the availability of auditors who provide holistic audits and driving down the cost of these services

The CEE Industrial Compressed Air System Initiative provides additional detail on the binational market strategy behind the Program Priorities for Compressed Air System Audits.

1.1 Resource Objective
The goal of the CEE Compressed Air Audit Specification (hereafter “Audit Specification”) is to improve awareness and increase availability of core audit practices in the marketplace, increasing the energy savings opportunities for customers and programs alike by establishing a set of audit practices recommended by energy efficiency program administrators. This will help transform the market for compressed air audits by:

- Increasing demand for compressed air system optimization, including leak management, improved operations and management practices, compressed air storage where appropriate, and evaluation of demand reduction opportunities
- Encouraging holistic examination of compressed air systems of all sizes, including consideration of both the supply and demand sides of each system, to enable more accurate assessments of energy efficiency opportunities
- Improving consistency in the measurement and reporting of compressed air system baseline performance data, increasing the accuracy and comparability of baseline data, and increasing confidence in the results of audits
- Improving trust of auditors and the audit process in both programs and customers

1.2 How to Use this Resource
The CEE Audit Specification is not a new audit standard and is not intended to replace standards such as ISO 11011. Rather, the CEE Audit Specification is guidance
for energy efficiency program administrators and their vendors, implementers, and contracted auditors, created by program administrators, to define a minimum level of data collection program administrators need in order to support compressed air energy efficiency improvement projects. This includes the following minimum requirements:

- Measuring or estimating system power, flow, and leak load
- Characterizing pressure drop across the system
- Holistic system consideration (audit of the supply and demand side)
- Establishing documented baseline energy performance
- Using direct measurement techniques, where possible, over adequate time periods
- Providing adequate justification for alternative measurement methods when adherence to recommended best practices for data collection is not possible

The CEE Audit Specification is designed to be flexible enough to be adopted in a variety of jurisdictional environments, considering regulatory and market variances, while also establishing a firm floor to achieve a greater degree of consistency in the marketplace. To that end, the CEE Audit Specification is not prescriptive but performance-based, designed to be adapted by program administrators to fit their local conditions and needs.

The Audit Specification includes a Walkthrough Assessment designed to help program administrators, or a designated third party, scope the compressed air audit based on the size and complexity of the compressed air system. The Audit Specification also defines a CEE Level 1 and Level 2 audit with specific lists of minimum audit actions for each level:

- **CEE Level 1 Audit** is designed for smaller, less complex systems
- **CEE Level 2 Audit** is designed for larger, more complex systems and includes a longer baseline data collection period and a more detailed examination of the compressed air system operations, maintenance practices, and end uses

Individual program administrators have different criteria for determining which level of audit to support. The data points recommended in the Walkthrough Assessment represent the minimum amount of compressed air system information program administrators need to make individual determinations about whether to proceed with a Level 1 or Level 2 audit. In turn, the recommended data collection for Levels 1 and 2 represent the minimum amount of data program administrators need to ensure quality of data, provide consistency of data across different audits to allow comparison and verification, and support energy efficiency improvement projects.

The Audit Specification does not define small and large systems with specific horsepower ranges or other criteria because different energy efficiency program administrators in different parts of the United States and Canada will have different
interpretations of small and large systems. Program administrators with many large industrial facilities in their service territory may routinely deal with systems that have multiple 1000 horsepower compressors. In other locations, a system with a single 100 hp compressor may be considered large. The CEE Audit Specification provides the flexibility for individual program administrators to adapt the requirements for minimum data collection to their individual needs. Since the CEE Audit Levels are voluntary, program administrators may select the Audit Level that is most appropriate for their local market conditions, regulatory environment, and program policies.

2 Scope of Guidance
This resource applies to three-phase electrically-driven compressed air systems in commercial and industrial facilities. An air compressor has operating pressures between 36 and 250 psig with pressure-increase ratios exceeding 1.3. A compressed air system is comprised of integrated sets of components, including air compressors, treatment equipment, controls, piping, condensate traps, pneumatic tools, pneumatically powered machinery, and process applications using compressed air. Compressed air systems are typically subdivided between their supply side and their demand side. Some facilities have multiple compressed air systems.

2.1 Definition of a Compressed Air Audit
The CEE Audit Specification defines a compressed air audit as a holistic evaluation of the performance of a compressed air system, including both the supply and demand side of the system, with the goal of identifying all available energy efficiency and performance improvement opportunities.

2.2 Supply Side Equipment
The supply side of a compressed air system typically includes air intake, air compressor(s), motor, control, air treatment equipment, and primary storage.

Air Compressor: Many air compressors are now sold “packaged,” including a compressor, motor, control, and other accessories mounted on the frame. There are many different types of air compressors. See Section 6.1.1 in the CEE Industrial Compressed Air Systems Initiative. This Audit Specification document applies to any system including a three-phase electrically-driven air compressor.

Control: Controls regulate the amount of compressed air produced to maintain a specific system pressure and manage the operation of the compressed air system. Control types are used to match compressor output to demand, which can occur in different patterns in various applications. Control types include:

- Start/stop
- Load/no load
- Modulating controls
- Variable displacement
• Variable frequency drives/variable speed drives
• Multiple compressor controls

Air Treatment: When air leaves an air compressor, it is usually not yet suitable for its intended use. This is due to a number of factors:

• Atmospheric air, particularly in an industrial environment, contains pollutants, including particulate matter, moisture and hydrocarbons.
• The air inlet filter on an air compressor may not provide sufficient filtration for the equipment using the compressed air.
• The air compressor contributes contaminants such as wear particles and compressor oil carry-over.
• The discharge temperature from the compressor may be too high for distribution and use.
• Cooling after compression results in saturated air leaving the aftercooler, which can affect pneumatic tools, spray painting, and other applications.

Air treatment can include air filters and dryers. Air filters remove oil and other contaminants from the compressed air, and air dryers remove moisture. The selection of an appropriate type of dryer depends on the demands of the end use applications in the system. The Compressed Air and Gas Institute (CAGI) provides data sheets to help assess the performance of refrigerant dryers in the marketplace. Dryers, like compressors, are rated based on their specific package power.

Compressed Air Storage: Compressed air storage can improve system efficiency and stability and provide system pressure balance between supply and demand.

Pressure/Flow Controllers (P/FC): A special type of valve called a P/FC is used together with storage and compressor system controls to deliver compressed air to the demand side at the lowest stable pressure, allowing the system to meet variable demand with stored compressed air.

2.3 Demand Side Equipment
The demand side of a compressed air system typically includes the distribution system, secondary storage, and end use equipment.

Distribution System: The distribution system conveys compressed air from the supply side to the end use equipment. It includes distribution piping, mainline and branch headers, piping drops, and pressure regulators.

Secondary Storage: Secondary, or point-of-use, storage can be used to improve pressure stability or meet a particular variable load.

End Use Equipment: Compressed air can be used to operate machinery, equipment, or processes. Applications are abundant in both industrial and commercial facilities. Specific end use equipment varies by sector, but includes pneumatic tools, hoists, air brake systems, controls and actuators, and conveyers.
2.4 Ensuring a Successful Audit

To increase the effectiveness of compressed air system audits and improve the implementation rate of optimization projects, it is essential that the customer is prepared to successfully participate in the audit process and trust the auditor and energy efficiency program administrator to deliver valid recommendations that will help improve their productivity and bottom line. The procedures outlined in the CEE Audit Specification are designed to increase the confidence of both customers and program administrators in the results and recommendations produced by auditors.

However, customers are busy, and without their full attention, the recommendations in even the best audits can fail to produce results. The Department of Energy has developed an implementation guide, “Guiding Principles for Successfully Implementing Industrial Energy Assessment Recommendations,” which identifies the conditions that must be in place at the customer level before, during, and after an audit to optimize the implementation rate.2 These include the following conditions, which the CEE Audit Specification recommends as best practices:

- Plant representatives must be engaged in the audit process and prepared to potentially implement recommendations
- Plant operators should understand the implications and potential value of conducting an audit and trust the credibility of the auditor before the audit process begins
- A customer should undertake an audit only if they demonstrate a commitment to potential implementation by providing resources to the audit process, such as personnel time or production delays to support the audit
- During an audit, plant leadership should ensure that identified opportunities overcome organizational financial hurdles, sign off on including them in the recommendations, and participate in the closeout meeting
- After the audit, the customer should work with their utility and other stakeholders to minimize financial and technical risks
- Projects should be tracked through implementation, with energy savings benefits quantified for senior management

2.4.1 Selecting an Auditor

There are several different types of auditors available in the marketplace. Vendors, in many cases representing specific compressed air manufacturers, typically provide audits as part of their sales and service outreach. Independent auditors and engineering firms also provide audits, typically at a greater expense.

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Preferably, audits should be conducted by organizations and individuals that have demonstrated experience conducting similar audits and have an understanding of compressed air equipment and control systems. In addition, auditors must understand the holistic nature of a compressed air system. It is important for auditors to maintain their competency through frequent participation in audits as well as through regular professional development. There are existing training resources and certifications that can improve an auditor’s body of knowledge and provide confidence to both the customer and the program administrator that the auditor will provide a holistic system audit. For example, the Compressed Air Challenge, in conjunction with partner utilities and the Department of Energy, regularly holds training courses across the United States and Canada.\textsuperscript{3}

DOE and Compressed Air Challenge provide additional guidance on selecting a compressed air system auditor in their \textit{Guidelines for Selecting a Compressed Air System Provider.}\textsuperscript{4}

3 CEE Audit Levels

Compressed air system audits must be comprehensive enough to identify opportunities to improve the overall performance and energy efficiency of a compressed air system, yet appropriate to the size and complexity of the system so that the rigor and costs of the audit will be economically justified. The CEE Audit Specification defines an initial walkthrough assessment and two levels of audit practices that align with program administrator objectives and provide greater value to customers. By creating common definitions of audit practice and associated audit characteristics despite jurisdictional variations, the CEE Audit Specification is intended to increase consistency in the marketplace and confidence on the part of customers and programs. The templates for audits included here identify a minimum standard of practice for compressed air audits; program administrators or third party implementers can use these resources as a basis for developing their own procedures.

The CEE Audit Specification supports two audit levels differentiated by system size and complexity. However, the requirements and guidance may be inappropriate for systems that are very large and complex. For very large systems, individual program administrators may require the installation of permanent metering equipment for long term continuous monitoring, or other more robust system audit methodologies.

3.1 CEE Walkthrough Assessment

The Walkthrough Assessment is the basic starting point for compressed air system optimization. It can be conducted by a customer, trade ally, or utility program

\footnote{For more information about upcoming courses, see “Upcoming Trainings,” Compressed Air Challenge, \url{compressedairchallenge.org/calendar/}.}

\footnote{“Guidelines for Selecting a Compressed Air Service Provider,” Compressed Air Challenge, last modified 2002, \url{energy.gov/sites/prod/files/2014/05/f16/guidelinesforweb.pdf}.}
administrator. The data collected in the Walkthrough Assessment will help the program administrator understand the size and complexity of the compressed air system and decide whether further evaluation is warranted, and if so, how to scope that effort. It involves brief interviews with plant operators, a review of the plant’s utility bills and operating data, and a walkthrough of the compressed air system. A template for conducting the Walkthrough Assessment is located in Appendix A.

3.2 CEE Level 1 Compressed Air Audit

A CEE Level 1 compressed air audit is a basic supply- and demand-side audit. Systems appropriate for a Level 1 audit are generally lower horsepower and have a single compressor and a limited number of end uses. A Level 1 audit uses the information collected in the Walkthrough Assessment as a starting point and collects additional information inside the plant, including interviewing one or more plant representatives to discuss ongoing concerns with the operation of the compressed air system.

A Level 1 audit requires a minimum of 24 hours of baseline data collection but recommends seven days, including measurement of power, flow, and pressure drop across the system. Direct measurement is recommended, but may be less cost-effective on smaller systems. Justification must be provided if direct measurements are not taken. Data must be collected during a period of typical plant operation; if a production line goes down, the data collection period should be reset. A Level 1 audit also includes a leak assessment and an evaluation of the demand side to consider opportunities to reduce compressed air demand. A complete list of the required actions for a Level 1 audit is located in Appendix B.

3.3 CEE Level 2 Compressed Air Audit

A Level 2 compressed air audit is appropriate for larger, more complex compressed air systems, such as those with multiple compressors, a large variety of end uses, or multiple header pressures. A Level 2 audit uses the information collected in the Walkthrough Assessment as a starting point and begins with the collection of additional information inside the plant. The Level 2 audit contains a more detailed examination of the compressed air system’s operations and maintenance (O&M) practices and end uses.

A Level 2 audit requires a minimum of seven days of baseline data collection but recommends 14 days, including the direct measurement of power and flow data when possible, and the development of a system pressure profile. Direct measurement is strongly recommended for Level 2 audits; justification must be provided if direct measurements are not taken. As with a Level 1 audit, data must always be collected during a period of typical plant operation; if a production line goes down the data collection period should be reset. A Level 2 audit also includes a leak assessment and an evaluation of compressed air demand and identifies potential opportunities for demand reduction and the use of waste heat. A complete list of the recommended actions for a Level 2 audit is located in Appendix B.
4 Minimum Data Collection Requirements

Accurate measurement of power, pressure, and flow provides the foundation for auditors to make recommendations for compressed air optimization strategies. It also provides critical information for both program administrators and customers to properly assess those recommendations and determine which opportunities to move forward with and potentially incentivize. Therefore, at a minimum, regardless of audit level, the following data should be collected for any compressed air system being audited as part of an energy efficiency program.

- System power
- System pressure
- System flow
- System leak load

Ideally, data will be measured directly through installed or portable meters in the field. However, common barriers to direct measurement include a lack of installed metering capability, the cost of metering equipment in relation to the system size and energy savings potential, and in some cases safety issues preventing the use of kW metering. When it is not practical to measure data directly, indirect measurements can be used. Whether data is collected directly or indirectly, auditors should give a detailed explanation about which tools were used and why others were not used in order to provide program administrators with a full understanding of the reported data.

Finally, data must be collected in the field. Desk audits that estimate measurements based on equipment nameplates and utility data do not qualify for either level of compressed air system audit.

4.1 Key Performance Indicators

In addition to power, pressure, flow and leak data, key performance indicators (KPIs) help customers and program administrators to track the performance of compressed air systems using measurements of energy consumption and how it relates to production. The KPIs below should be calculated by the auditor from the baseline data and reported to the customer and program administrator.

- **System Specific Power**: The power required to produce a volume of compressed air, measured in kW/100 SCFM
- **Annual Energy Consumption**: The power consumed by a compressed air system in a calendar year
- **Specific Energy Consumption**: The power consumed by a compressed air system per unit of production, measured in kWh (for example, 10 kWh/widget)

4.2 Audit Equipment Guidelines

Regular calibration is essential to ensuring measurement accuracy. All metering equipment used in a compressed air system audit should be maintained and
calibrated in accordance with the manufacturer’s specifications, and should have sufficient data storage and resolution capabilities to meet audit needs. Common equipment used in a compressed air audit includes the following.

- Multi-channel data logger with adequate storage capability to store a minimum of one week of high-frequency data samples of the pressure, flow and power of each compressor in a system
- Compressed air flow meter with transducer with data download capability
- At least three pressure transducers with output connections to facilitate data logging
- One or more kW transducers
- Current transformers as needed

4.3 Recommended Data Collection Frequency

In developing an accurate baseline for a compressed air system it is important to take into consideration the plant’s typical operating periods, as well as the size and complexity of the compressed air system, with the goal of capturing as many typical operating periods as feasible during the audit.

Power consumption, air pressure, and air flow are an audit’s three fundamental measurements. Temperature and humidity measurements can also provide valuable information about the performance of compressors and other system equipment. The length and frequency of data collection will vary based on the plant’s typical operating periods, the size of the compressed air system, and desired data resolution. However, all data should be recorded consistently over the same baseline period to ensure that it can be related in the proper context.

In addition, it is important to consider requirements for post-project evaluation. Data collected during the compressed air audit should be normalized for flow, production, and other possible confounding factors.

For Level 1 audits, a baseline period of seven days is recommended, but the baseline period may be reduced to as little as 24 hours if this period is representative of typical operations. For Level 2 audits, a baseline period of 14 days is recommended, but the period may be reduced to as little as seven days if this period is representative of typical operations.

The CEE Audit Specification recommends that data frequency across all measurements be the expected event duration divided by three. For example, if an event is expected to last 30 seconds, data would be collected at ten-second intervals. However, the intention of the CEE Audit Specification is to capture dynamic response in the compressed air system. While the Specification recommends the "rule of three," individual program administrators can choose to accept alternative data collection frequencies that capture dynamic response as long as the frequency is adequately justified to the program administrator.
5 Recommended Data Measurement Practices

5.1 Measuring Power

Power consumption is one of the most important variables in a compressed air system, as it directly drives the biggest cost, electricity. Power consumption coupled with compressed air flow data determines the compressed air system’s Specific Power, the metric commonly used to define system efficiency.

Power can be measured in one of two ways: directly using a kW meter, or indirectly using a voltmeter or ammeter and converting to kW. Direct measurement is more accurate than indirect measurement and is recommended when possible, especially during Level 2 audits.

There are several obstacles to measuring kW directly that may lead auditors to measure power indirectly. First, measuring true kW requires built-in metering capabilities or kW meters, which are more expensive than portable voltmeters or ammeters. Additionally, auditors are not always certified to perform kW readings safely. Finally, and most commonly, customers can be reluctant to shut down their compressed air systems to allow for the installation of kW meters. However, measuring amps and converting to kW is less accurate because Power Factor (PF) with electric motor loads is nonlinear across different loads.\(^5\) The Compressed Air Challenge writes in Best Practices for Compressed Air Systems that “the best electrical measurements provide kW” and that indirect measurement “is not a recommended best practice.”\(^6\)

CEE recommends that true kW should be recorded during compressed air system audits whenever feasible. Additionally, programs and customers should consider installing built-in metering capabilities while conducting a system audit, as built in meters provide the ability to monitor and evaluate system operating trends moving forward and should be considered a potential investment.

If measuring true kW is not feasible, CEE recommends that voltage and amps be measured for all three phases and averaged.\(^7\) Amps should be recorded at full-load output and for all common loading conditions. The PF of the motor is a critical variable when converting to kW and should be measured under all common loading conditions if possible.\(^8\)

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\(^5\) PF drops significantly at low loads, which must be accounted for to get quality kW. Generally, the larger the electrical load, the more important direct measurement becomes. CAC recommends the use of kW meters when the operating load is greater than 150 kW for at least two shifts.


\(^7\) If it is measured that all three phases are relatively well balanced, it is typically sufficient to log the current of only one of the legs.

\(^8\) Assumed PF can be determined as a function of the fraction full load amperage of the motor, using information from CAGI data sheets or generic motor curves. However, PF and motor efficiency drop
The following formula can be used to calculate kW:

\[
kw = \frac{\text{amps} \times \text{volts} \times 1.732 \times \text{PF}}{1000}
\]

Regardless of the method used, auditors should provide program administrators with a clear explanation of which method was used and why. If power was not measured directly, auditors need to provide a justification, such as cost, safety, or customer concerns.

### 5.2 Measuring Pressure

A compressed air system’s pressure readings are the key measurement for understanding overall system operation. In order to evaluate system support for end use applications and pressure reduction opportunities, it is helpful to understand a system’s minimum, target, and actual operating pressures. The best way to accomplish this is to develop a pressure profile for the entire system which shows pressure gradients from the compressor discharge to points of use. A pressure profile is developed from a series of pressure measurements across the compressed air system at a particular moment during system operation.

At a minimum, for a Level 1 audit, CEE recommends that pressure be recorded at the compressor discharge, with pressure drops recorded on available installed gauges or pipe openings using a transducer. The Compressed Air Challenge recommends in *Best Practices for Compressed Air Systems* that gauges should monitor pressure at the midpoint of the gauge range and have an accuracy and repeatability of +/- 1%, while transducers should have an accuracy and repeatability of +/- .5%.

For Level 2 audits, CEE recommends that pressure drops be recorded across dryers, filters, and other auxiliary equipment; across air receivers; across the header of the distribution system; and across filters, regulators, and lubricators (FRLs) for high-pressure applications as appropriate.\(^9\) Again, the requirement of the CEE Audit Specification is to develop a pressure profile across the system; auditors should use their discretion to determine the number and location of the taps necessary to develop the pressure profile and should provide justification in their report.

### 5.3 Measuring Flow

System flow is an important metric because it allows the audit to evaluate the air demand characteristics of the plant, which is critical for evaluating storage, controls, and staging opportunities. Flow can be measured directly using flow meters or estimated using direct kW measurement data.

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The preferred method of flow measurement is through permanently installed flow meters. If permanently installed meters are not available, portable flow meters are an option. In either case it is important to follow the manufacturer’s requirements to ensure accurate readings and to ensure proper calibration on an ongoing basis. Flow meters often prescribe specific placement with sufficient upstream and downstream pipe length to reduce turbulence, since turbulence can lead to inaccurate results. In addition, without flow meters downstream from all air treatment, measurements do not capture demand, but supply-side response to changes in demand.

Calculating flow from measured power is a less reliable way to determine flow than direct measurement. However, if an auditor and customer decide that estimating flow using kW measurement data is the best option in a specific situation, it is important to take the compressor type or types into consideration.

- **Rotary Compressors (Variable Speed):** CAGI data sheets provide performance data across a range of loads that can be used to build a flow curve and calculate flow at applicable loading points.

- **Rotary Compressors (Fixed Speed):** For these types of compressors it is important to take into consideration the compressor’s capacity control mode and obtain its capacity power vs. fraction capacity curve. The auditor can use this information, along with performance data from a CAGI data sheet, to calculate flow.

- **Centrifugal Compressors:** Most centrifugal compressors operate efficiently between 60 or 70 and 100 percent load depending on the inlet control, but below 60-70 percent release excess air through their blow-off valve. The auditor needs to account for blow-off, as well as the air intake temperature, when calculating flow using performance information from manufacturer performance curves. CAGI data sheets are not available for centrifugal compressors.

- **Reciprocating Compressors:** These compressors cycle on and off relatively quickly and may be equipped with an additional ability to unload compression cylinders. Most reciprocating compressors have good part load efficiency, maintaining a relatively constant power draw per flow output across varying loads. Auditors must typically rely on manufacturer data to determine expected performance curves.

If CAGI data sheets are not available, auditors should check for manufacturer performance curves and use them if possible. If manufacturer performance curves are not available, generic performance curves can be used.\(^\text{10}\) However, generic curves should be used with caution because they will not necessarily align with the load of the specific application in question. Auditors should report which type of performance curve was used.

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\(^{10}\) Generic performance curves for many motors are provided by CAGI and CAC and can be found in the DOE Pumping System Assessment Tool, available at [energy.gov/eere/amo/articles/pumping-system-assessment-tool](http://energy.gov/eere/amo/articles/pumping-system-assessment-tool).
If no kW measurement data is available, flow can be estimated using the compressor operating status and the aforementioned performance curves, but this method is less accurate and is not recommended as a standard practice. Whether flow is measured or estimated, it is always a good idea to cross-check flow and power to make sure that the readings and estimates make sense.

5.4 Determining the Leak Load

Air leaks are one of the most significant sources of compressed air waste; the Compressed Air Challenge estimates that leaks can account for 20 to 30 percent of a compressor’s output, but that proactive leak detection and repair can reduce leaks to less than 10 percent of output.\(^{11}\) Leak load, along with artificial demand, should be estimated during an audit to develop a holistic understanding of optimization opportunities. Additionally, if the customer does not have a regular leak detection and repair practice, the auditor should make a recommendation to develop one.

While it may not be appropriate for very large, complex systems and may not be necessary in facilities that do their own regular leak auditing, in most cases the most accurate methodology for conducting a leak survey is to use ultrasonic leak detection equipment capable of estimating the volume of leakage. A concise methodology is included in the DOE Uniform Methods Project.\(^{12}\) To get an estimate of the total system leak load and understand whether ultrasonic leak detection is warranted, auditors should perform a system bleed-down test, or, if that is not possible, measure supply flow during a non-production period. The following formula can be used to calculate leak load:

\[
\text{Leak Volume ACFM} = \frac{[V(P1 - P2)/(\text{Time} \times 14.7)]}{1.25}
\]

- \(V\) = Total storage volume
- \((P1-P2)\) = Drop in pressure in psig
- \(\text{Time}\) = Minutes it takes for pressure to drop 50 percent from normal operating pressure
- \(14.7\) = Atmospheric pressure (psia)
- \(1.25\) = Multiplier that corrects leakage to normal system pressure

When estimating leak load, it is important that nonproductive air demand, such as HVAC pneumatic controls, be quantified and isolated from the estimate. If the leak estimate indicates a significant leak load, auditors should use an ultrasonic leak detector to identify, tag, and record on a map the location of each leak identified. They should then record the decibel level (dBA) and size of the leak and the observed system pressure nearest the leak. Finally, they should calculate the annual leak load for each leak and for the whole system, comparing it to the estimate from the bleed-down test to make sure it is reasonable.

---

\(^{11}\) Compressed Air Challenge, “Best Practices for Compressed Air Systems,” p. 75

Bleed-down Procedure and Limitations

To perform a bleed-down test, estimate the total storage volume of the compressed air system in cubic feet. During nonproduction hours, start the system and allow it to reach normal operating pressure. Turn off production loads, and then shut down the compressor(s). Allow the system to bleed down to 50 percent of its normal pressure, and record the time it takes to get to that point.

Estimating leak load by using a bleed-down test or by measuring supply flow during nonproductive periods can underestimate the actual leak rate. Leaks inside production equipment can be a substantial portion (sometimes 50 percent) of the total leakage and may not be present when equipment is not running. In addition, CEE recognizes these methods may not be appropriate for systems that operate 24/7. Auditors may need to work with program administrators to determine an appropriate and acceptable method for measuring system leaks.

While there is no hard-and-fast rule, a leak estimate greater than 10 percent can easily justify an ultrasonic leak detection effort, keeping in mind that estimating leak load by using a bleed-down test or by measuring supply flow during nonproductive periods can underestimate leak load by as much as 50 percent.

6 Data Presentation and Documentation

A compressed air audit can require a significant financial investment. It is important that any data collected, and any analysis performed, be transparent to both the customer and to the program manager. Transparency helps the program administrator to assess the recommendations included in the audit report.

Below are some guidelines to ensure that the data collected is useful and that the recommendations included in an audit report are properly assessed and presented.

- The auditor should provide graphs and tables of all baseline data collected, including summaries of power, pressure, and flow, as well as a breakdown for each compressor during each operating period. The graphs should show power, pressure, and flow synchronized with time for each compressor and for the system as a whole.
- Data should also be provided in spreadsheet format for review by the program administrator, or by a designated third party upon request.
- Based on the logged data, the auditor should present a description of how the compressors in the system are staged and the capacity control mode operations of each.
- The auditor should provide information on the meters used to monitor the system, as well as the data capture rate, and indicate monitoring points on the block diagram. Figure 1 demonstrates a block diagram.
- Finally, the methodology and results from any data analysis, including estimated energy savings should be documented. Any software used to evaluate data, such as Airmaster+, should be disclosed. If private or proprietary software or spreadsheets are used to analyze data, they should be documented with a brief
summary of the methods applied. If nonstandard formulas or calculations are used, they should be disclosed where applicable. Assumptions and other pertinent information, such as manufacturer’s data, ambient conditions, or energy costs, should be provided where applicable.

Figure 1. A Compressed Air System Block Diagram
Appendix A  Walkthrough Assessment Template

The Walkthrough Assessment can be conducted by the customer, a trade ally, or a utility program administrator. The Walkthrough Assessment is NOT a rigid decision tree; individual program administrators can use the data collected in this assessment to help inform whether a Level 1 or Level 2 audit is an appropriate next step, using individual program criteria. The Walkthrough Assessment is the basic starting point for a compressed air energy efficiency project. It involves brief interviews with site operating personnel, a review of the facility’s utility bills and other operating data, and an abbreviated walkthrough of the compressor system. The Walkthrough Assessment will help the program administrator understand the type and nature of the compressed air system and decide whether further evaluation is warranted, and, if so, where and how to focus that effort. At a minimum, the following information in the following tables should be collected in a Walkthrough Assessment.

Compressed Air System Operational Schedule

<table>
<thead>
<tr>
<th>Annual operating hours of compressed air system, including operating hours by shift and weekends</th>
<th>M</th>
<th>T</th>
<th>W</th>
<th>R</th>
<th>F</th>
<th>S</th>
<th>S</th>
<th>Weekly Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shift One: xx a.m.–xx p.m.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shift Two: xx p.m.–xx p.m.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shift Three: xx p.m.–xx a.m.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Total</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Describe any significant seasonal variation in production.
# Equipment Specifications

<table>
<thead>
<tr>
<th></th>
<th>Size (hp)</th>
<th>Operational or Backup?</th>
<th>Design/Control Type</th>
<th>Pressure Rating/Operational Set Point</th>
<th>Cooling (Air or Water)</th>
<th>CAGI Sheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressor 1: Make</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressor 2: Make</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressor 3: Make</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressor 4: Make</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Size (hp)</th>
<th>Design Type</th>
<th>Capacity (ACFM)</th>
<th>CAGI Sheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dryer 1: Make</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dryer 2: Make</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dryer 3: Make</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Size</th>
<th>Location</th>
<th>Connection to System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Tank 1:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage Tank 2:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage Tank 3:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Does your system have a demand expander valve, operational flow valve, or pressure flow control?

Please describe the type(s) of filters and drains currently in your system.
System Performance

Use the cost per unit of energy to compute the estimated annual energy expenditure of your compressed air system.

Are your compressors located in multiple locations? If so, do they share the same distribution piping?

What is the diameter and length of the primary header, beyond the receiver tank?

What is the pressure drop from receiver to far end of plant piping?

Do you see performance issues that indicate a pressure performance problem? If so, please describe.

Are there any production quality or reliability issues due to quality of compressed air? If so, please describe.
Block Diagram

Include a block diagram showing major components of compressed air system and piping diagram to plant air header.
Compressed Air Demands

What are the largest frequent compressed air end uses in your system?

<table>
<thead>
<tr>
<th>End Use 1</th>
<th>Rated Consumption</th>
<th>Nature of Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>End Use 2</td>
<td>Rated Consumption</td>
<td>Nature of Use</td>
</tr>
<tr>
<td>End Use 3</td>
<td>Rated Consumption</td>
<td>Nature of Use</td>
</tr>
<tr>
<td>End Use 4</td>
<td>Rated Consumption</td>
<td>Nature of Use</td>
</tr>
<tr>
<td>End Use 5</td>
<td>Rated Consumption</td>
<td>Nature of Use</td>
</tr>
</tbody>
</table>

Are there any high-volume, intermittent-demand applications in the system?

<table>
<thead>
<tr>
<th>End Use 1</th>
<th>Rated Consumption</th>
<th>Nature of Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>End Use 2</td>
<td>Rated Consumption</td>
<td>Nature of Use</td>
</tr>
<tr>
<td>End Use 3</td>
<td>Rated Consumption</td>
<td>Nature of Use</td>
</tr>
</tbody>
</table>

What is the required minimum pressure of the system, and which end use requires it?

Have you ever conducted a leak assessment? If so, when was your last leak assessment? Do you regularly work to minimize leaks? Do you have a systematic program to continuously address compressed air leaks?
Additional System Context

Note any system reliability and operational concerns.

Note any known inappropriate uses of compressed air.

Is there any other information about this system that will help determine an appropriate audit level?
Appendix B  CEE Levels 1 and 2 Compressed Air System Audit Specification – Templates for Program Administrators

The following tables serve as a short form template for program administrators who support compressed air system programs. The tables describe the data collection requirements and guidance for Level 1 and Level 2 compressed air system audits, as defined by the CEE Compressed Air Audit Specification. The tables are not intended to serve as turnkey checklists or training materials, or otherwise serve as standalone requirements for individual energy efficiency programs. Rather, CEE intends for member program administrators to build on the compressed air audit specification tables to create locally appropriate checklists, training materials, and program requirements documents for local vendors, customers, and other compressed air service providers and end users.
# Level 1 Audit Template

<table>
<thead>
<tr>
<th></th>
<th>Plant and System Description – Vendors describe the system to Program Administrators</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Provide an overview of the manufacturing processes, including typical hours of operation as well as any production or seasonal variations. Use the information provided through the Walkthrough Assessment as a starting point.</td>
</tr>
<tr>
<td>b.</td>
<td>Provide a description of the facility, including environmental conditions in the compressor room.</td>
</tr>
<tr>
<td>c.</td>
<td>Provide a block diagram of the compressed air system, including the location of major compressed air system components, production areas, and end uses served by the system, noting high energy end uses in particular. Use the information provided through the Walkthrough Assessment as a starting point.</td>
</tr>
<tr>
<td>d.</td>
<td>Document compressed air system equipment, including compressor(s), control(s), air treatment equipment, drains, and storage. Collect CAGI data sheets and part load performance charts where appropriate and document equipment serial numbers. Note if compressors are air or water cooled. Use the information provided through the Walkthrough Assessment as a starting point.</td>
</tr>
<tr>
<td>e.</td>
<td>Review existing compressed air management practices and procedures and interview a plant representative to learn about standard plant O&amp;M practices and to identify major outstanding issues or concerns.</td>
</tr>
<tr>
<td>f.</td>
<td>Document major end uses and interview a facility representative, such as the plant manager, to identify any areas of concern affecting plant operations, such as problems supplying air to a specific end use.</td>
</tr>
<tr>
<td>Compressed Air System Data Monitoring</td>
<td>Vendors provide Program Administrators with specific data</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>---------------------------------------------------------</td>
</tr>
<tr>
<td><strong>a.</strong></td>
<td>Develop baseline period, considering the facility’s production schedule and associated compressed air demands as well as the size and complexity of the system, with the goal of capturing as many typical operating periods as feasible. The Level 1 baseline period should be 7 days but can be 24 hours if representative of typical operations. The Level 2 baseline period should be 14 days but can be 7 days if representative of typical operations. Typical operating periods may need to be estimated from historical data.</td>
</tr>
<tr>
<td><strong>b.</strong></td>
<td>Measure the power consumption of the compressor package during the baseline period, including a breakdown for each compressor during each typical operating period. Power (kW) should be measured directly using a power meter or built-in meters, but can be estimated if necessary by measuring amps and converting using an estimated power factor based on % load. If amps are logged, provide assumptions used for voltage, power factor, and phase.¹³</td>
</tr>
<tr>
<td><strong>c.</strong></td>
<td>Determine annual compressed air energy use, considering typical operating periods identified and measured power consumption. Determine Total Energy Consumption or annual energy cost using the cost per unit for energy powering the compressor(s).¹⁴ Calculate Specific Energy Consumption, energy per unit of production, if KPI is available.</td>
</tr>
<tr>
<td><strong>d.</strong></td>
<td>Determine flow for individual compressors and total system during the baseline period. Determine annual compressed air usage, taking into consideration typical operating periods identified. When feasible, flow should be measured directly. If power (kW) is measured directly, flow can be estimated using performance curves from CAGI data sheets or manufacturer documentation. If power is not measured directly, flow should be measured directly if possible. Flow meters should be calibrated and installed per manufacturer specifications; validation of readings with a secondary source is recommended.</td>
</tr>
<tr>
<td><strong>e.</strong></td>
<td>Find circumference of major system headers and manifolds to ensure they are sized for maximum flow per cycle.</td>
</tr>
<tr>
<td><strong>f.</strong></td>
<td>Determine system pressure drop by logging compressor discharge pressure as well as pressure at one other location and using available gauges to capture additional pressure drops where appropriate.</td>
</tr>
<tr>
<td><strong>g.</strong></td>
<td>Determine volume of storage tanks in system.</td>
</tr>
</tbody>
</table>

¹³ In some cases it can be useful to conduct a performance test of individual compressed air performance, measuring power, flow, and pressure to build a unit-specific performance curve.  
¹⁴ If the compressed air system is a large portion of peak load consumption, be sure to consider peak load energy costs when calculating annual energy usage.
### Leaks

**J.** Estimate leak load and calculate annual compressed air loss through leaks. Unless the estimated leak load is less than 10%, conduct leak survey using ultrasonic leak detector and tag and record leaks.

### Demand Side

**k.** Using the baseline measurements and information collected on plant operating shifts as well as major compressed air end uses, document compressed air demand profile. Identify minimum and maximum pressure and flow requirements, including shift schedules and production variations.

**l.** Evaluate existing compressor control strategy and determine if it is appropriate for the system size and demand profile. Identify opportunities to optimize compressor control strategy.

### Data Presentation

**o.** Using baseline power measurements and flow (estimated or measured), calculate full load compressed air supply efficiency and specific power (kW/100 SCFM). If data is collected in ACFM, it should be converted to SCFM for reporting purposes to allow program to compare audit results across projects in different locations and conditions.

**p.** Provide graphs and tables of all baseline data collected, including summaries of power, pressure, and flow, as well as a breakdown for each compressor during each operating period. Show pressure, flow, and power synchronized with time. Show all information for each compressor and then for system as a whole.

**q.** Provide information about meters used to monitor the system and data capture rate. Indicate monitoring points on block diagram. Describe how compressors are staged and the actual capacity control mode operations of each.
<table>
<thead>
<tr>
<th></th>
<th>Developing Recommendations – Program Administrator guidance for determining project action</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Determine the system’s true minimum pressure requirements and evaluate opportunities to eliminate artificial demand with pressure optimization, control, or storage.</td>
</tr>
<tr>
<td>b.</td>
<td>Evaluate opportunities to reduce demand by assessing leak load and developing recommendations for regular leak detection and repair if necessary.</td>
</tr>
<tr>
<td>c.</td>
<td>Evaluate existing compressor control strategy and compressor staging for optimization opportunities.</td>
</tr>
<tr>
<td>d.</td>
<td>Include recommendations for improving system operations and maintenance practices, including the development or improvement of standard operating practices (SOP), where appropriate. Recommend the development of KPIs to benchmark compressed air usage if needed.</td>
</tr>
<tr>
<td>e.</td>
<td>Include data to back up recommendations. Include CAGI data sheets and applicable cut sheets, cost estimates, and projected energy and cost savings with all holistic recommendations.</td>
</tr>
<tr>
<td>f.</td>
<td>Evaluate opportunities to improve system performance and efficiency with the following potential upgrades:</td>
</tr>
<tr>
<td></td>
<td>Adding storage to isolate intermittent high pressure or high volume uses</td>
</tr>
<tr>
<td></td>
<td>Replacing condensate drains with zero-loss type</td>
</tr>
<tr>
<td></td>
<td>Adding engineered nozzles to improve end use efficiency</td>
</tr>
<tr>
<td></td>
<td>Adding dryers, such as cycling, VSD refrigerated, or thermal mass types</td>
</tr>
<tr>
<td></td>
<td>Adding low pressure drop filters (compressor room filtration)</td>
</tr>
<tr>
<td></td>
<td>Adding trim or VSD compressor to meet variable loads more efficiently</td>
</tr>
<tr>
<td></td>
<td>Other, such as sequencing, low pressure blowoff, pressure-driven vacuum generators, vortex electrical cabinet coolers, better-quality quick disconnects</td>
</tr>
</tbody>
</table>
## Level 2 Audit Template

<table>
<thead>
<tr>
<th></th>
<th>Plant and System Description Template – Vendors describe the system to Program Administrators</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Provide an overview of the manufacturing processes, including typical hours of operation as well as any production or seasonal variations. Use the information provided through the Walkthrough Assessment as a starting point.</td>
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<td>Provide a description of the facility, including environmental conditions in the compressor room.</td>
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<tr>
<td>c.</td>
<td>Provide a block diagram of the compressed air system, including the location of major compressed air system components, production areas, and end uses served by the system, noting high energy end uses in particular. Use the information provided through the Walkthrough Assessment as a starting point.</td>
</tr>
<tr>
<td>d.</td>
<td>Document compressed air system equipment, including compressor(s), control(s), air treatment equipment, drains, and storage. Collect CAGI data sheets and part load performance charts where appropriate and document equipment serial numbers. Note if compressors are air or water cooled. Use the information provided through the Walkthrough Assessment as a starting point.</td>
</tr>
<tr>
<td>e.</td>
<td>Review existing compressed air management practices and procedures and interview a plant representative to learn about standard plant O&amp;M practices and to identify major outstanding issues or concerns.</td>
</tr>
<tr>
<td>g.</td>
<td>Document all compressed air end uses, noting those that use large amounts of compressed air, those that require high or low pressure, and those with intermittent demand.</td>
</tr>
<tr>
<td>h.</td>
<td>Describe the finished product(s) and document applicable NAICS codes. Identify any Key Performance Indicators (KPIs) that could be used to benchmark compressed air system efficiency, such as energy usage per unit of production.</td>
</tr>
<tr>
<td>i.</td>
<td>Identify plant applications with potential to use waste heat generated from the compressor. Consider opportunity to leverage outside air for the compressor intake(s).</td>
</tr>
<tr>
<td></td>
<td>Compressed Air System Data Monitoring – Vendors provide Program Administrators with specific data</td>
</tr>
<tr>
<td>---</td>
<td>------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>a.</td>
<td>Develop baseline period, considering the facility’s production schedule and associated compressed air demands as well as the size and complexity of the system, with the goal of capturing as many typical operating periods as feasible. The Level 1 baseline period should be 7 days but can be 24 hours if representative of typical operations. The Level 2 baseline period should be 14 days but can be 7 days if representative of typical operations. Typical operating periods may need to be estimated from historical data.</td>
</tr>
<tr>
<td>b.</td>
<td>Measure the power consumption of the compressor package during the baseline period, including a breakdown for each compressor during each typical operating period. Power (kW) should be measured directly using a power meter or built-in meters, but can be estimated if necessary by measuring amps and converting using an estimated power factor based on % load. If amps are logged, provide assumptions used for voltage, power factor, and phase.(^{15})</td>
</tr>
<tr>
<td>c.</td>
<td>Determine annual compressed air energy use, considering typical operating periods identified and measured power consumption. Determine Total Energy Consumption or annual energy cost using the cost per unit for energy powering the compressor(s).(^{16}) Calculate Specific Energy Consumption, energy per unit of production, if KPI is available.</td>
</tr>
<tr>
<td>d.</td>
<td>Determine flow for individual compressors and total system during the baseline period. Determine annual compressed air usage, taking into consideration typical operating periods identified. When feasible, flow should be measured directly. If power (kW) is measured directly, flow can be estimated using performance curves from CAGI data sheets or manufacturer documentation. If power is not measured directly, flow should be measured directly if possible. Flow meters should be calibrated and installed per manufacturer specifications; validation of readings with a secondary source is recommended.</td>
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<td>Find circumference of major system headers and manifolds to ensure they are sized for maximum flow per cycle.</td>
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\(^{15}\) In some cases it can be useful to conduct a performance test of individual compressed air performance, measuring power, flow, and pressure to build a unit-specific performance curve.  
\(^{16}\) If the compressed air system is a large portion of peak load consumption, be sure to consider peak load energy costs when calculating annual energy usage.
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>h.</td>
<td>Measure system pressure profile during the baseline period. Record pressure variations and differentials between defined test points. Test points should be chosen to measure pressure drop across the system and major treatment equipment.(^\text{17})</td>
</tr>
<tr>
<td>i.</td>
<td>Determine volume of storage tanks and major headers in system.</td>
</tr>
<tr>
<td><strong>Leaks</strong></td>
<td></td>
</tr>
<tr>
<td>j.</td>
<td>Estimate leak load and calculate annual compressed air loss through leaks. Unless the estimated leak load is less than 10%, conduct leak survey using ultrasonic leak detector and tag and record leaks.</td>
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<td><strong>Demand Side</strong></td>
<td></td>
</tr>
<tr>
<td>k.</td>
<td>Using the baseline measurements and information collected on plant operating shifts as well as major compressed air end uses, document compressed air demand profile. Identify minimum and maximum pressure and flow requirements, including shift schedules and production variations.</td>
</tr>
<tr>
<td>l.</td>
<td>Evaluate existing compressor control strategy and determine if it is appropriate for the system size and demand profile. Identify opportunities to optimize compressor control strategy.</td>
</tr>
<tr>
<td>m.</td>
<td>Evaluate compressed air end uses, using nameplate information and personnel interviews, to look for opportunities to reduce pressure or to service high-pressure demand with alternative technology. Evaluate potential inappropriate uses of compressed air (see Appendix E for common examples) and identify any justification for continued use.</td>
</tr>
<tr>
<td>n.</td>
<td>Evaluate end uses’ air quality requirements to determine if existing treatment equipment is appropriate for the system and whether any opportunities exist to reduce pressure loss.</td>
</tr>
<tr>
<td><strong>Data Presentation</strong></td>
<td></td>
</tr>
<tr>
<td>o.</td>
<td>Using baseline power measurements and flow (estimated or measured), calculate full load compressed air supply efficiency and specific power (kW/100 SCFM). If data is collected in ACFM, it should be converted to SCFM for reporting purposes to allow program to compare audit results across projects in different locations and conditions.</td>
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<td>Provide graphs and tables of all baseline data collected, including summaries of power, pressure, and flow, as well as a breakdown for each compressor during each operating period. Show pressure, flow, and power synchronized with time. Show all information for each compressor and then for system as a whole.</td>
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<td>Provide information about meters used to monitor the system and data capture rate. Indicate monitoring points on block diagram. Describe how compressors are staged and the actual capacity control mode operations of each.</td>
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<td>b.</td>
<td>Evaluate opportunities to reduce demand by assessing leak load and developing recommendations for regular leak detection and repair if necessary.</td>
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<tr>
<td>c.</td>
<td>Evaluate existing compressor control strategy and compressor staging for optimization opportunities.</td>
</tr>
<tr>
<td>d.</td>
<td>Include recommendations for improving system operations and maintenance practices, including the development or improvement of standard operating practices (SOP), where appropriate. Recommend the development of KPIs to benchmark compressed air usage if needed.</td>
</tr>
<tr>
<td>e.</td>
<td>Include data to back up recommendations. Include CAGI data sheets and applicable cut sheets, cost estimates, and projected energy and cost savings with all holistic recommendations.</td>
</tr>
<tr>
<td>f.</td>
<td>Evaluate opportunities to improve system performance and efficiency with the following potential upgrades:</td>
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<td></td>
<td>Adding storage to isolate intermittent high pressure or high volume uses</td>
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<td></td>
<td>Replacing condensate drains with zero-loss type</td>
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<td></td>
<td>Adding engineered nozzles to improve end use efficiency</td>
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<td></td>
<td>Adding dryers, such as cycling, VSD refrigerated, or thermal mass types</td>
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<td></td>
<td>Adding low pressure drop filters (compressor room filtration)</td>
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<td></td>
<td>Adding trim or VSD compressor to meet variable loads more efficiently</td>
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<tr>
<td></td>
<td>Other, such as sequencing, low pressure blowoff, pressure-driven vacuum generators, vortex electrical cabinet coolers, better-quality quick disconnects</td>
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<td></td>
<td>Outside air intake for non-oil-flooded compressors</td>
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<tr>
<td>h.</td>
<td>Evaluate opportunities to reduce air demand by eliminating inappropriate uses of compressed air, such as installing blowers to accomplish the same tasks with less energy. See Appendix E for a list of typical inappropriate uses.</td>
</tr>
<tr>
<td>i.</td>
<td>Evaluate opportunities to reduce the supply side target pressure by reducing pressure drops across the system, including distribution piping, treatment equipment, and end use drops or FRLs. Note: any consideration of opportunities to reduce supply side target pressure MUST maintain system reliability.</td>
</tr>
<tr>
<td>j.</td>
<td>Evaluate end uses’ air quality requirements to determine if existing treatment equipment is appropriate for the system and whether any opportunities exist to reduce pressure loss by removing or replacing unnecessary or ineffective treatment equipment.</td>
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<tr>
<td>k.</td>
<td>In appropriate geographies with a significant heat load, evaluate potential applications to leverage compressor waste heat.</td>
</tr>
</tbody>
</table>
Appendix C  Acronyms, Terms, and Definitions

- **Artificial Demand**: Excess air volume required by a system’s unregulated uses due to those uses being operated at a pressure in excess of what is required to perform the work
- **Audit (Compressed Air)**: A holistic evaluation of the performance of a compressed air system with the goal of identifying energy efficiency and performance improvement opportunities
- **Baseline**: Set of typical operating period, work conditions, and performance parameters revealed by assessment and used as a basis for comparison of the efficiency of the measures recommended as a result of energy efficiency assessment procedures
- **Actual Cubic Feet Per Minute (ACFM)**: The volume of air at actual operating temperature and pressure; normally refers to compressor capacity and is measured at the discharge point on the compressor package and converted back to volume at ambient conditions
- **Inlet Cubic Feet Per Minute (ICFM)**: The flow rate of air ahead of equipment, such as inlet filters, under rated conditions; normally associated with dynamic compressors
- **Standard Cubic Feet per Minute (SCFM)**: The mass flow rate of air at a standard set of reference conditions, representing sea level; there are several definitions of “standard,” but the International Standards Organization and the Compressed Air and Gas Institute define it as 14.5 psia, 68°F, and zero percent relative humidity
- **Compressed Air End Use**: The applications that use compressed air by converting pneumatic energy into mechanical work such as opening or closing a valve
- **Compressed Air System**: The group of subsystems comprised of integrated sets of components utilizing compressed air, including air compressors, treatment equipment, controls, piping, pneumatic tools, pneumatically powered machinery, and process applications
- **Direct Measurement**: Identifying the value of a parameter, such as kW, with an instrument designed for the task, such as a power meter
- **Estimation**: The process of determining the value of a parameter through the use of stipulated values, assumptions, observation, calculation, and judgment
- **Energy**: Power used over period of time, usually expressed as kWh
- **End Use Application**: Where compressed air energy is converted into mechanical work or accomplishes a production-related task
- **Flow**: Air movement through the compressed air system measured in ACFM (actual cubic feet per minute)
- **Indirect Measurement**: Identifying the value of a parameter, such as kW, by measuring a group of related parameters such as amps or V
• **Investment-Grade Audit:** An audit performed in sufficient detail to ensure mostly accurate assessment of the air system, with recommendations that could be used to justify improvements to the system with confidence that they would provide good payback

• **Leak Assessment:** An inspection of a compressed air system in which leaks are identified, measured, and included in a calculation of the total leak load; leaks identified during a leak assessment should be tagged for repair and recorded in a leak log

• **Power:** Electrical load, usually expressed as kW

• **Pressure:** Force applied to a surface, expressed in pounds per square inch (psi) or newtons per square meter (Pa, kPa, or bar)

• **Storage Volume:** The volume contained within a storage vessel expressed in cubic feet or gallons

• **Typical Operating Period:** Period of time during which the plant is operating at normal levels of activity; plants may have multiple typical operating periods, such as weekdays, weekends, and peak seasons
Appendix D  List of Resources

The following is a list of resources referenced throughout the document.

Appendix E  Typical Inappropriate Uses

Compressed air is important for industrial processes. When used wisely, it can be an instrumental driver for industrial processes. However, end uses should be evaluated to determine if there is a more effective or efficient substitute energy source.

1. Low pressure applications (<20 psig) are in many cases an inefficient use of compressed air. Needs such as the following can be met by substituting a fan or blower.
   
   a. Open blowing: cooling, drying, cleanup, draining compressed air lines, clearing jams on conveyors
   
   b. Sparging: aerating agitating, oxygenating, or percolating liquid with compressed air
   
   c. Aspirating: using compressed air to induce the flow of a separate gas
   
   d. Atomizing: using compressed air to disperse a liquid as an aerosol
   
   e. Dilute phase transport: using compressed air to transport solids such as powdery material
   
   f. Personnel cooling: operators directing compressed air onto themselves for cooling

2. Air motors and air-operated double diaphragm pumps are used in hazardous environments such as chemical manufacturing as a safety measure instead of electric motors and mechanical pumps. However, outside of hazardous environments, electric motors and mechanical pumps are far more efficient.

3. Vacuum generation can be replaced with a dedicated vacuum pump or central vacuum system.

For more information, see the Department of Energy Compressed Air Tip Sheet #2.\(^{18}\)

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