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**Compressed air — Energy  
efficiency — Assessment**

*Air comprimé — Efficacité énergétique — Évaluation*

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# Contents

	Page
<b>Foreword</b> .....	<b>v</b>
<b>Introduction</b> .....	<b>vi</b>
<b>1 Scope</b> .....	<b>1</b>
<b>2 Normative references</b> .....	<b>1</b>
<b>3 Terms and definitions</b> .....	<b>1</b>
3.1 General.....	2
3.2 Flow.....	3
3.3 Pressure.....	4
3.4 Storage.....	5
3.5 Volume.....	5
<b>4 Roles and responsibilities</b> .....	<b>6</b>
4.1 Identification of assessment team members.....	6
4.2 Site management support.....	7
4.3 Communications.....	7
4.4 Access to equipment, resources, and information.....	7
4.5 Assessment objectives and scope.....	7
4.6 Identification of other assessment team members.....	7
4.7 Objective check.....	7
<b>5 Assessment methodology</b> .....	<b>8</b>
5.1 General.....	8
5.2 Systems engineering methods.....	8
5.3 Systems engineering process.....	8
5.4 System assessment process.....	9
<b>6 Parameters and their determination</b> .....	<b>10</b>
6.1 General.....	10
6.2 Measurement.....	10
6.3 Pressure.....	10
6.4 Flow rate.....	11
6.5 Power.....	12
<b>7 Initial data collection and evaluation</b> .....	<b>13</b>
7.1 General.....	13
7.2 Plant background.....	13
7.3 Plant function.....	13
7.4 Compressed air system definition.....	13
7.5 Inventory of key end-use air demands.....	13
7.6 Heat recovery.....	13
7.7 Baseline period and duration of data logging.....	14
7.8 Energy use.....	14
7.9 Compressed air system supply efficiency.....	14
7.10 System volume.....	14
7.11 Pressure.....	15
7.12 Flowrate.....	15
7.13 Critical air demands.....	15
7.14 Compressed air waste.....	15
7.15 Air treatment.....	15
7.16 Compressor control.....	16
7.17 Storage.....	16
7.18 Maintenance.....	16
7.19 Ambient intake conditions.....	16
<b>8 Analysis of data from assessment</b> .....	<b>16</b>
8.1 General.....	16

8.2	Baseline profiles .....	17
8.3	System volume .....	19
8.4	Pressure profile .....	19
8.5	Perceived high-pressure demand .....	21
8.6	Demand profile .....	22
8.7	Critical air demands .....	23
8.8	Compressed air waste .....	24
8.9	Optimized air treatment .....	25
8.10	Reduced system operating pressure .....	26
8.11	Balance of supply and demand .....	27
8.12	Maintenance opportunities .....	27
8.13	Heat recovery opportunities .....	28
<b>9</b>	<b>Reporting and documentation of assessment findings .....</b>	<b>28</b>
9.1	Assessment report .....	28
9.2	Confidentiality .....	29
9.3	Energy-saving opportunities .....	29
9.4	Data for third-party review .....	29
<b>Annex A (informative) Introduction to energy assessment .....</b>		<b>30</b>
<b>Annex B (informative) Assessment activities — General .....</b>		<b>32</b>
<b>Annex C (informative) Assessment activities — Supply .....</b>		<b>37</b>
<b>Annex D (informative) Assessment activities — Transmission .....</b>		<b>43</b>
<b>Annex E (informative) Assessment activities — Demand .....</b>		<b>47</b>
<b>Annex F (informative) Competencies .....</b>		<b>50</b>
<b>Bibliography .....</b>		<b>51</b>

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2. [www.iso.org/directives](http://www.iso.org/directives)

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received. [www.iso.org/patents](http://www.iso.org/patents)

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

The committee responsible for this document is ISO/TC 118, *Compressors and pneumatic tools, machines and equipment*, Subcommittee SC 6, *Air compressors and compressed air systems*.

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## Introduction

This International Standard has been developed with reference to available documentation<sup>1)</sup> (see Bibliography) relating to energy assessment of compressed air systems.

This International Standard is produced to support the objectives of energy management for those organisations utilizing compressed air and wishing to improve the energy efficiency of such systems. Remembering the words of Lord Kelvin who said in 1883, “If you cannot measure it, you cannot improve it”, this International Standard aims to assist with measurement and provide the knowledge to enable improvement.

The prime consideration for any compressed air system is the ability to generate air with the least amount of energy. Having done this, the next consideration is to transmit energy from the point of generation to the point of use with the least loss. The final consideration is to eliminate waste and use the least amount of air for the production process.

This International Standard uses speciality terms which relate the needs of assessment activities to those of compressed air systems. Many terms will appear new to the users of this International Standard who are familiar with general compressed air terms.

A general introduction to energy assessment is given in [Annex A](#).

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1) Extracts from ASME EA-4-2010 were used with permission from ASME. The core elements used are from Scope and Introduction, Organizing the Assessment, Analysis of Data From the Assessment, Reporting and Documentation, and Mandatory Appendices — I, Preliminary Data Collection Matrix.

# Compressed air — Energy efficiency — Assessment

**WARNING — Users of this International Standard are advised that energy-related judgements should not compromise safety issues.**

## 1 Scope

This International Standard sets requirements for conducting and reporting the results of a compressed air system assessment (hereafter referenced as an “assessment”) that considers the entire system, from energy inputs to the work performed as the result of these inputs.

This International Standard considers compressed air systems as three functional subsystems:

- supply which includes the conversion of primary energy resource to compressed air energy;
- transmission which includes movement of compressed air energy from where it is generated to where it is used;
- demand which includes the total of all compressed air consumers, including productive end-use applications and various forms of compressed air waste.

This International Standard sets requirements for

- analysing the data from the assessment,
- reporting and documentation of assessment findings, and
- identification of an estimate of energy saving resulting from the assessment process.

This International Standard identifies the roles and responsibilities of those involved in the assessment activity.

This International Standard provides indicative information in [Annexes B, C, D](#), and E of the type of data to be collected to assist in a successful assessment. The information provided is not exhaustive and therefore is not intended to restrict the inclusion of other data. The form and presentation of the information given in the annexes is also not intended to restrict the manner of presentation of the reporting to the client.

## 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1217, *Displacement compressors — Acceptance tests*

ISO 5598, *Fluid power systems and components — Vocabulary*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1217 and ISO 5598 and the following apply.

### 3.1 General

#### 3.1.1

##### **air treatment**

any process provided for the purpose of separation and purification of the compressed air

#### 3.1.2

##### **artificial demand**

excess air consumed by a system's unregulated or poorly regulated uses due to operating at a pressure in excess of actual requirements

#### 3.1.3

##### **assessment team**

authority to fulfil roles and responsibility of the assessment having appropriate functions and knowledge

#### 3.1.4

##### **baseline**

set of typical operating period, work conditions, and performance parameters revealed by assessment and used for comparison of efficiency of measures recommended as a result of energy efficiency assessment procedures

#### 3.1.5

##### **compressed air point of use**

components using the pneumatic energy for physical or chemical actions

#### 3.1.6

##### **compressed air systems**

group of subsystems comprising integrated sets of components, including air compressors, treatment equipment, controls, piping, pneumatic tools, pneumatically powered machinery, and process applications utilizing compressed air

#### 3.1.7

##### **compressed air system assessment**

activity which considers all components and functions, from energy inputs (SUPPLY SIDE) to the work performed (DEMAND SIDE) as the result of these inputs; undertaken to observe, measure, and document energy reduction and performance improvement opportunities in a compressed air system

#### 3.1.8

##### **data logging**

measurement of physical parameters while tabulating a periodic log (record) of their numerical value using time-aligned data frames for the plurality of recorded parameters

Note 1 to entry: Two types of data logging are:

- a) dynamics: data logging while creating a sufficiently high frequency periodic log (record) so as to investigate the time-based variation of measured physical parameters
- b) trending: data logging during an extended duration of time for the purpose of investigating regularities, irregularities, or both in the measured physical parameters throughout time

#### 3.1.9

##### **demand**

total of all compressed air consumers, including productive end-use applications and various forms of compressed air waste

#### 3.1.10

##### **drawdown**

circumstance observed in a compressed air system that is characterized by continual pressure decay arising from a compressed air system event whereby air demand exceeds the capacity of supply

**3.1.11****operating period**

group of typical time periods that share similar compressed air energy and compressed air demand profiles

Note 1 to entry: See [3.1.15](#).

**3.1.12****spot check measurement**

measurement of physical parameters creating a log (record) of their numerical value that is carried out at random time intervals or limited to a few instances

**3.1.13****supply**

conversion of primary energy resource to compressed air energy

**3.1.14****transmission**

movement of compressed air energy from where it is generated to where it is used

**3.1.15****typical operating period**

time period that represents a period of typical plant operation

**3.2 Flow****3.2.1****demand flow rate**

total airflow rate of demand-side consumption

Note 1 to entry: Demand-side consumption includes productive consumers, inappropriate usage, artificial demand, and demand-side waste. This takes into account supply flow plus or minus the compressed air supplied to system demand from secondary storage as system pressure decreases. This can also account for the airflow entering secondary storage as system pressure increases.

**3.2.2****flow dynamic application**

end use wherein the peak airflow rate and minimum pressure occur simultaneously

**3.2.3****flow static application**

end uses characterized when peak airflow rate and minimum pressure required do not occur simultaneously

**3.2.4****generation flow rate**

airflow rate of compressed air generated by the air compressor(s) before any air treatment equipment air use and supply-side waste

**3.2.5****peak airflow**

maximum value of the airflow during the daily or other periodic operating cycle

**3.2.6****storage flow rate**

airflow rate entering the storage volume as pressure increases or the airflow rate exiting the storage volume as pressure decreases

Note 1 to entry: The airflow can be either entering or exiting the system or the primary or secondary storage.

3.2.7

**supply flow rate**

net airflow rate leaving the supply side of the system

3.3 Pressure

3.3.1

**compressor inlet pressure**

pressure of the aspirated air at the standard inlet point of the compressor which varies with compressor design and type

Note 1 to entry: The pressure is at the inlet flange for bare compressors or ambient air entry point into the package for packaged compressors.

3.3.2

**drawdown pressure**

total pressure decay in compressed air system pressure that occurs during a particular drawdown event

3.3.3

**pressure loss**

reduction in compressed air pressure resulting from the interaction of airflow through the fixed resistance associated with a component of the air system

Note 1 to entry: See [3.3.8](#).

3.3.4

**pressure signature**

pressure profile of a repeated event that is correlated with a specific end-use or production activity

3.3.5

**minimum system pressure**

lowest possible air pressure a system can reach before adversely affecting the process

3.3.6 Operating pressure

3.3.6.1

**user operating pressure**

prescribed air pressure at the inlet point of the particular compressed air user equipment according to its specifications

3.3.6.2

**system operating pressure**

air pressure at the entry point into the network of the compressed air users

3.3.7

**pressure gradient**

rate of pressure change with respect to distance in the direction of maximum change

Note 1 to entry: In fluid mechanics, the change in pressure,  $P$ , along the length and distance,  $d$ , of a fluid conduit. It is represented by  $\Delta P/\Delta d$ .

Note 2 to entry: The air velocity in a pipeline depends on the magnitude of the gradient and resistance of the pipeline.

Note 3 to entry: Without gradient, there is no airflow. In a compressed air system, air moves from high-pressure toward low-pressure areas.

3.3.8 Pressure profile

**3.3.8.1****cyclic pressure profile**

timely function of the compressed air pressure variations in daily or other periodical operation cycles at a particular point of the compressed air system caused by combination of different air consumption cycles of several end users

**3.3.8.2****distance pressure profile**

function of pressure degradation along the compressed air transmission and distribution system at a certain typical period of operation cycle caused by pressure loss in its components

Note 1 to entry: Components such as air treatment facilities, fittings, air transmission pipes, branch pressure take-offs, etc.

**3.3.9 Pressure differential****3.3.9.1****available pressure differential**

compressed air pressure difference between the inlet and outlet of a component, which represents a variable resistance to airflow

Note 1 to entry: The available compressed air energy represented by the upstream volume and greater pressure that is available to the system.

Note 2 to entry: See [3.3.3](#).

**3.3.9.2****storage pressure differential**

difference between pressure in a storage volume and the desired target pressure of the connected system or sector

**3.3.10****target pressure**

compressed air pressure that is desired to be consistently supplied to a compressed air system or sector of a compressed air system at a specific point

EXAMPLE A specific point may include the main header downstream of supply, air treatment equipment, upstream of a system control valve, downstream of a system control valve, etc.

Note 1 to entry: See [3.3.5](#).

**3.4 Storage****3.4.1****primary storage**

compressed air storage system that is located on the generation side (supply) of a compressed air system

**3.4.2****secondary storage**

auxiliary storage vessel installed close to the end-user equipment by heavy intermittent air consumption and use of long and small transmission lines with the purpose of elimination of overloading the main air transmission line and excessive pressure losses

**3.5 Volume****3.5.1****effective volume**

internal volume of a single storage component or sector of a compressed air system reflecting its capability to store compressed air energy

### 3.5.2

#### **geometrical volume mechanical volume**

calculated by adding all of the geometric volumes in the system based on the observed sizes of those volumes

### 3.5.3

#### **system volume**

internal volume of the compressed air system reflecting its capability to store compressed air energy and to suppress air pressure pulsations

## **4 Roles and responsibilities**

### **4.1 Identification of assessment team members**

The functions and knowledge required to accomplish an assessment are listed in [4.1.1](#). The assessment team shall have members that have responsibility and authority to carry out these functions.

#### **4.1.1 Required functions and personnel**

##### **4.1.1.1 Resource allocation**

- a) Determine availability of on-site, as well as other off-site participants.
- b) Allocation of funding and resources necessary to plan and execute the assessment.
- c) Exercise final decision-making authority on resources.
- d) Oversee participation of outside personnel, including items such as contracts, scheduling, confidentiality agreements, statement of work, and/or other items.

##### **4.1.1.2 Coordination, logistics, and communications**

- a) Obtain necessary support from plant personnel and other individuals and organizations during the assessment.
- b) Participate in organizing the assessment team and coordinate access to relevant personnel, systems, and equipment.
- c) Organize and schedule assessment activities.

##### **4.1.1.3 Compressed air systems knowledge**

- a) Have background, experience, and recognized abilities to perform the assessment activities, data analysis, and report preparation.
- b) Be familiar with operating and maintenance practices for compressed air systems.
- c) Have experience applying the systems approach in assessments.

##### **4.1.1.4 Competency**

Assessment personnel shall have the knowledge and skills necessary to perform assessments. Those personnel can also require formal documentation in order to meet some national requirements.

In the absence of national requirements, those leading the assessment shall provide evidence of familiarity with and understanding of, compressed air technology basics through recognized qualifications, as well as a relevant period of experience in assessment activities. See [Annex F](#) for further information.

Information on other assessment team members is identified in [4.6](#).

## 4.2 Site management support

Site management support is essential for the successful outcome of the assessment. Site management understanding and support of the purpose of the assessment shall be secured. The site personnel shall be engaged in the assessment to the extent necessary. The support of site management shall be gained prior to conducting the assessment as follows:

- a) Commit the necessary funding, personnel, and resources to support the assessment.
- b) Communicate to site personnel the assessment's importance to the organization.

## 4.3 Communications

Lines of communication required for the assessment shall be established. Clear guidance shall be provided to facilitate communications among members of the assessment team so all necessary information and data can be communicated in a timely manner. This includes administrative data and logistics information, as well as operational and maintenance data.

## 4.4 Access to equipment, resources, and information

For the performance of a complete and comprehensive assessment of a facility's compressed air system, it is necessary to physically inspect and make selected measurements on the system components. Therefore, access shall be required to

- a) plant areas and compressed air system components required to conduct the assessment,
- b) plant personnel (engineering, operations, maintenance, etc.), their equipment vendors, contractors, and others to collect information pertinent and useful to the assessment activities and analysis of data used for the preparation of the report; and
- c) other information sources such as drawings, manuals, test reports, historical utility bill information, computer monitoring and control data, electrical equipment panels, and calibration records necessary to conduct the assessment.

## 4.5 Assessment objectives and scope

The overall goals and scope of the assessment shall be discussed and agreed upon at an early stage by the assessment team. The overall objectives of the assessment shall include identification of performance improvement opportunities in the compressed air system being assessed using a systems approach. The scope of the assessment shall define the area(s) of the facility to be assessed.

## 4.6 Identification of other assessment team members

The assessment considers the entire system from energy inputs to the work performed as a result of those inputs. As a result of facility specialists interviews, certain manufacturing equipment or processes that use compressed air may be identified for detailed study requiring the participation of individuals with specialized knowledge related to these applications.

## 4.7 Objective check

Prior to conducting the assessment, the plan of action shall be reviewed to establish that it meets the stated assessment objectives. The assessment plan of action shall be reviewed for relevance, cost effectiveness, and capacity to produce the desired results.

## 5 Assessment methodology

### 5.1 General

Assessments involve collecting and analysing system design, operation, energy inputs, energy use, and performance data and identifying energy performance improvement opportunities for system optimization. An assessment can also include additional information, such as recommendations for improving resource utilization, reducing per unit production cost, reducing lifecycle costs, and improving environmental performance related to the assessed system(s).

The methodologies to be applied in performing the assessment shall include one or more of the following techniques:

- a) observation and research;
- b) spot-check measurements;
- c) data logging, including dynamics and trend.

### 5.2 Systems engineering methods

This International Standard utilizes systems engineering methods applied to a compressed air system assessment. It is necessary to:

- a) Understand compressed air point of use as it supports critical plant production functions.
- b) Correct existing poor performing applications and those that upset system operation.
- c) Eliminate wasteful practices, leaks, artificial demand, and inappropriate use.
- d) Create and maintain an energy balance between supply and demand.
- e) Optimize compressed air energy storage and air compressor control.

Application of a systems approach to a compressed air system assessment directs the focus toward total system performance rather than individual component efficiency.

**NOTE** Systems engineering focuses on defining client needs and required system functionality early in the development cycle, documenting system requirements, and then proceeding with system design while considering the entire system.

### 5.3 Systems engineering process

The systems engineering process is described in 10 steps:

- a) Identify what needs to be accomplished.
- b) Identify what needs to be evaluated.
- c) Get organized, identify the assessment team, and get plant background information.
- d) Define the present system.
- e) State site-specific system assessment goals.
- f) Design the system assessment (what, how, when).
- g) Test the assessment's design for relevance, completeness, and cost effectiveness.
- h) Do the assessment and gather facts and data.
- i) Analyse the facts and data to develop solutions and estimate cost and savings.

j) Report and document recommendations and findings.

NOTE 1 Compressed air systems engineering is an iterative process including requirements definition, the assessment process, and evaluation of outcomes and results. It is a fluid process whereby outcomes and results can achieve defined goals or can result in new or revised requirements definition.

NOTE 2 There are many compressed air system integration factors where decisions related to one component or subsystem impact other components or subsystems. Concept alternatives should be proposed and analysed before final conclusions are reached.

## 5.4 System assessment process

### 5.4.1 General

The assessment should document issues and concerns about compressed air use, critical production functions, and poor compressed air system performance. The assessment should identify and quantify energy waste, compressed air supply-and-demand balance, energy use, and total compressed air demand. These generalizations should be used to guide the selection of objectives and action items for preliminary data collection.

### 5.4.2 Relationships in the system assessment process

The relationships of those involved in the assessment and the assessment process are shown in [Figure 1](#).

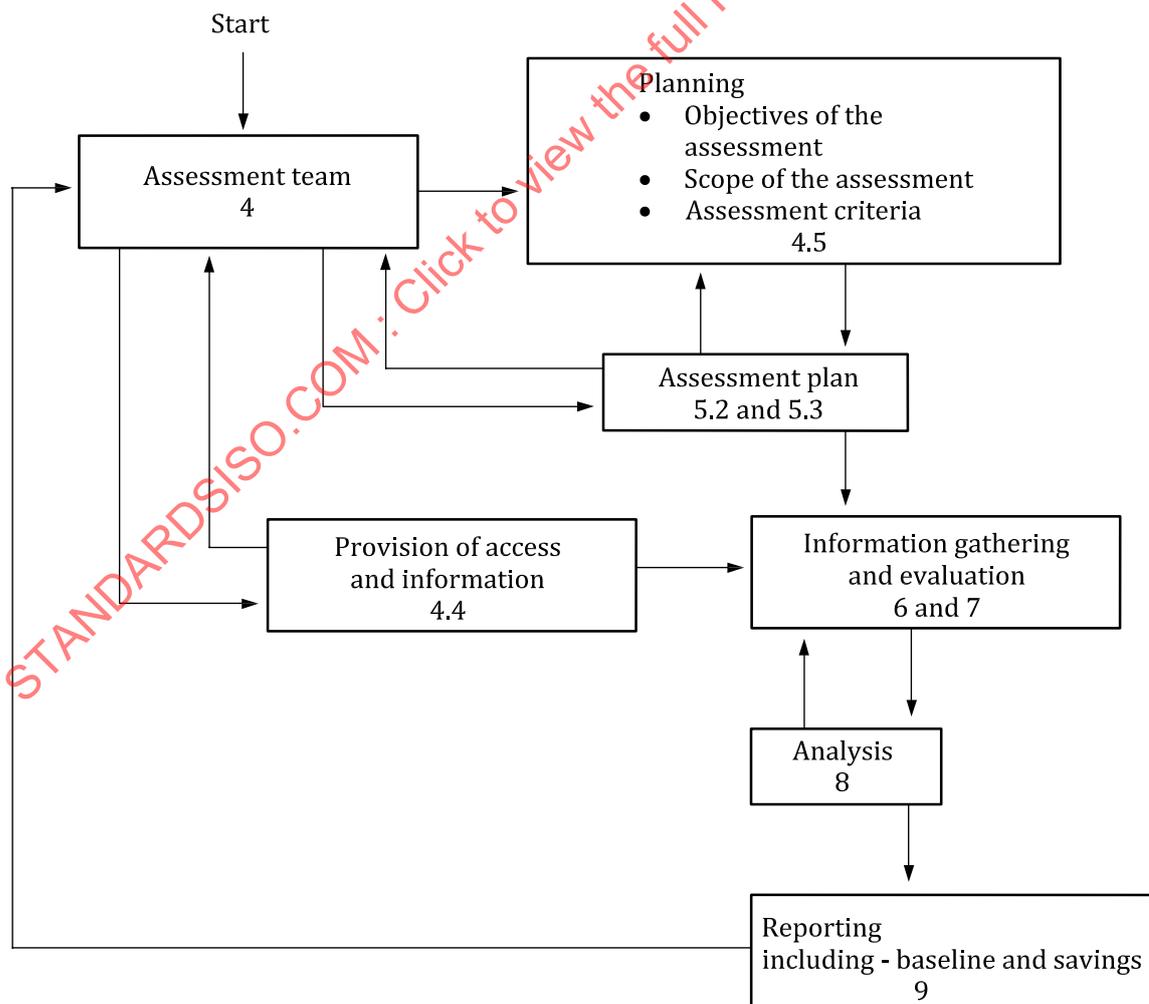


Figure 1 — Process for conducting an energy assessment of a compressed air system

## 6 Parameters and their determination

### 6.1 General

Pressure, flow rate, and power are the key parameters required to provide essential details for the determination of the energy balance in the compressed air system under review. In addition, each of these parameters is affected by the installed control system.

### 6.2 Measurement

#### 6.2.1 Units

The preferred measurement units used when applying this International Standard shall be SI units. If due to common use or understanding imperial units are applied, then the SI units should also be given. The use of units shall be agreed upon when establishing the parameters of the assessment and identified in the assessment report.

#### 6.2.2 Accuracy

Where necessary to ensure valid results, measuring equipment shall be calibrated, verified, or both at specified intervals or prior to use against measurement standards traceable to international or national measurement standards; where no such standards exist, the basis used for calibration or verification shall be recorded.

All instruments used for measurement including those permanently installed shall have a record of the most recent calibration information of which the accuracy and calibration details for all devices should be mentioned in the report.

The measurement accuracy level for a particular parameter can vary depending on the sensitivity of the assessment conclusions and recommendations to the value of the particular parameter as identified in [6.3](#), [6.4](#), and [6.5](#).

#### 6.2.3 Data interval

The data interval is the time between recorded data required to capture the dynamic nature of an event in a compressed air system. Where dynamic events are to be recorded, a data interval of at least one order of magnitude less than the duration of the event being measured shall be applied.

Dynamic events are, by nature, of short duration. Average air consumption during the day or shift is not a dynamic event.

NOTE If, for example, a dynamic event in the system has a duration of one second, the data interval would have to be no greater than one tenth of a second or less, or 10 recorded data points per second, to characterize that event.

## 6.3 Pressure

### 6.3.1 Pressure profile

A pressure profile is an important tool for assessing end-user requirements over time, allowing identification of any pressure losses and helps identify potential improvements. Transient and dynamic behaviour within the profile can also be analysed from the collected data.

### 6.3.2 Pressure test points

Pressure test points are identified in [Table C.1](#), [Table D.1](#), and [Table E.1](#) and should be included in the assessment. Not all points are valid for all systems and additional points can be required; therefore, the actual points used shall be identified in the assessment plan.

### 6.3.3 Pressure identity

Pressure is commonly considered in only one way and that is supply pressure. Other pressure variations should also be considered.

The assessment of a functional system should take into consideration the following pressure variations:

- a) minimum system pressure;
- b) actual operating pressure;
- c) target pressure;
- d) pressure gradient;
- e) drawdown pressure;
- f) pressure loss;
- g) available pressure differential;
- h) storage pressure differential;
- i) compressor inlet pressure.

NOTE Pressure in a compressed air system is seen as a key driver for end-use applications.

## 6.4 Flow rate

### 6.4.1 Flow rate profile

The system flow rate profile is important to properly support end-use requirements, allowing identification of any flow restrictions and opportunities to improve system design. Transient and dynamic behaviour of the system can also be analysed from collected data.

### 6.4.2 Flow rate test points

Flow test points are identified in [Table C.1](#), [Table D.1](#), and [Table E.1](#) and should be included in the assessment. Not all points are valid for all systems and additional points can be required; therefore, the points used shall be identified in the assessment plan.

### 6.4.3 Flow rate identity

Flow rate is commonly considered in only one way and that is generation flow rate. Other flow rate variations should also be considered.

The assessment of a functional system should take into consideration the following airflow rate variations:

- a) supply flow rate;
- b) storage flow (system, primary, or secondary);
- c) demand flow rate;
- d) peak airflow;
- e) flow dynamic;
- f) flow static;
- g) generated flow rate.

NOTE Airflow rate in a compressed air system is seen as a key driver for maintaining optimum capacity for end-use applications.

### 6.5 Power

#### 6.5.1 Power profile

The power profile is important to properly support the energy requirements of the system by the effective conversion to compressed air energy, allowing identification of any variations in energy transitions and opportunities to improve system design. Transient and dynamic behaviour of the system can also be analysed from collected data.

Power consumed is the total or individual power consumed by the compressor(s) and ancillary equipment.

#### 6.5.2 Power test points

Electrical test points are identified in [Table C.1](#), [Table D.1](#), and [Table E.1](#) and should be included in the assessment. Not all points are valid for all systems and additional points can be required; therefore, the points used shall be identified in the assessment plan.

The test points for power should all be significant electrical inputs that contribute to either generation or treatment of compressed air.

NOTE In many applications, the significance of a factor is indicated by its value being greater than 10 % of the total value of the given factor.

#### 6.5.3 Power identity

##### 6.5.3.1 Electricity

The assessment of a functional system shall take into consideration the following non-exhaustive listing of electrical inputs:

- a) compressor (stand-alone);
- b) compressor package;
- c) compressor control devices;
- d) air treatment;
- e) cooling system;
- f) electrically driven condensate systems.

The method used to determine power shall be identified. The assessment of a functional system shall also take into consideration those items that indirectly impact the efficiency of a compressed air system such as pumped cooling systems. Where open-circuit water coolant is identified, the volume of water discharged to sewer shall be quantified and recorded.

NOTE Electricity is the prime energy source used in the conversion to compressed air. Electricity is also used to power devices that either directly process the compressed air or indirectly process the unwanted by-products of compressed air, e.g. heat.

##### 6.5.3.2 Non-electric power sources

Where compressed air is generated or processed using other energy sources, then these should be taken into consideration in respect of the energy balance.

## 7 Initial data collection and evaluation

### 7.1 General

A process shall be identified for elements of assessment activity required to evaluate client needs and system assessment requirements. The process should define assessment requirements using objectives and action items including, but not limited to,

- a) initial data collection,
- b) measurement of key system operating variables,
- c) facility specialist interviews,
- d) review of previous assessments, audits, baselines, or benchmarking (see [Table B.7](#)),
- e) identification of already client-approved/initiated system projects,
- f) review of utility bills and energy costs,
- g) review of control systems,
- h) performance-monitoring equipment, and
- i) preliminary data evaluation.

### 7.2 Plant background

Document plant background information, including a brief description of current production levels and manufacturing processes and products (see [Annex B](#)).

### 7.3 Plant function

Describe the plant's location, size, and ambient/environmental conditions and the compressed air system's functional attributes (see [Annex B](#) and [Table D.2](#)).

### 7.4 Compressed air system definition

Define the plant's compressed air system(s), including the scope of the system's supply side, transmission equipment, and demand-side characteristics (see [Annex B](#)).

### 7.5 Inventory of key end-use air demands

Based on the information gathered during the investigation associated with [7.2](#), [7.3](#), and [7.4](#), tabulate end-use air demands to identify and prioritize opportunities for energy reduction (see [Table E.3](#)).

### 7.6 Heat recovery

Identify existing heating applications with the potential to use heat rejection from the compressor to offset existing energy use, as well as the potential for augmenting heat requirements in processes.

Evaluate interaction with other systems, such as heating, ventilation, and air-conditioning (HVAC) equipment performance and energy use. Investigate opportunities to improve performance and reliability while reducing total energy use. Recommend specific remedial measures, and estimate energy reduction and savings.

## 7.7 Baseline period and duration of data logging

### 7.7.1 Activity

The first step to be taken to establish a baseline is measurement. This requires the measurement of power, pressure, flow, and temperature under different operating conditions and the estimation of leak load.

The baseline period should include “typical operation” of plant functions. Typical periods are representative of the plant’s planned or unplanned changes in production. Changes can be seasonal, based on the day of the week, market conditions, availability of raw materials, or other factors. Compressed air system energy profiles exhibit both time-dependent and production-dependent variations. Depending on a particular period’s production operation, the production-dependent portion of the plant’s compressed air energy baseline exhibits different characteristics.

NOTE The purpose of baselining or benchmarking is to establish performance levels and energy consumption of a compressed air system and to correlate the results with the plant’s production levels. As improvements are made to the system from the record of expected improvements, it is possible to estimate the success by comparing the future measurements with the original baseline (see [Table B.7](#)).

### 7.7.2 Time periods

Time periods with similar compressed air energy profiles (“typical periods”) are grouped together as different “operating periods”. When considering the duration of baseline measurement, all typical periods of operation shall be measured. Some typical periods, such as holidays, can represent a small fraction of the plant’s compressed air energy base-year operation. Baseline performance for a typical period may be stipulated based on historical operating information. Stipulated baseline performance should not exceed 10 % of the plant’s base-year energy use.

## 7.8 Energy use

Quantify and document the power consumption of each air compressor included in the system. Quantify and document the power consumption of auxiliary supply-side equipment, air dryers, ventilation fans, cooling pumps, etc. Quantify and document total energy use and cost of all supply-side equipment (see [Table B.5](#)).

Using a baseline period as required in [7.7](#), annualize estimated base-year energy use and cost. Review primary energy cost used to power air compressors.

## 7.9 Compressed air system supply efficiency

Quantify and document the overall compressed air system supply efficiency, including specific power and specific energy or power and energy per unit of output.

## 7.10 System volume

Estimate the total volume of the entire compressed air system. There are two methods to determine system volume: mechanical volume and effective volume. The effective volume of the compressed air system shall be determined by calculation. If testing to determine effective volume cannot be accomplished, then an estimate of the system’s mechanical volume can be used.

NOTE System volume is the actual volume of the system which can be different from the calculated mechanical volume. This difference can be due to corrosion buildup in the pipes, actual pipe sizes that are different from what was calculated, water in the receivers that take volume out of the receiver, etc.

## 7.11 Pressure

### 7.11.1 Pressure profile

Document the system pressure profile. The pressure profile shall be established from test pressure points chosen from some or all of those indicated in [Table C.1](#) for the supply side, [Table D.1](#) for the transmission system, and [Table E.1](#) for the point of use.

### 7.11.2 Perceived high-pressure demands

Where perceived high-pressure demands are identified, assess performance of those demands.

## 7.12 Flowrate

### 7.12.1 Compressed airflow profile

Quantify and document the overall compressed air demand over time supplied to the system.

### 7.12.2 Demand profile

Quantify and document the dynamic demand profile, including airflow rate and effectiveness of existing compressed air storage.

## 7.13 Critical air demands

Assess performance of critical air demands and existing poor-performing end-use applications.

## 7.14 Compressed air waste

### 7.14.1 General

Compressed air wasted should be identified as leakage, inappropriate end-use, and artificial demand (see [Table E.2](#)).

### 7.14.2 Leakage

Identify and, where practical, record compressed air leaks within the system. An estimate of the total amount of leakage shall be established.

### 7.14.3 Inappropriate end-use

Identify and document those end-use processes which are deemed to be inappropriate.

NOTE The processes can be identified as "inappropriate" where a more energy-efficient alternative technology renders the use of compressed air as unnecessary.

### 7.14.4 Artificial demand

Identify, quantify, and document artificial demand as a function of present demand-side system or sector pressure and recommended target pressure.

## 7.15 Air treatment

Evaluate treatment in all areas with respect to the system pressure profile and energy balance and air purity requirements. The air purity specification as provided for general use within the compressed air

system should be identified. In addition, where at the point of use, there is a more stringent specific air purity requirement, this should also be identified (see [Table C.8](#), [Table D.4](#), and [Table E.4](#)).

NOTE The application of compressed air treatment within a system may be located at the supply side, within the transmission system, and at one or more air demands.

## 7.16 Compressor control

Evaluate the present compressor control strategy and performance response to the existing demand profile. For multiple compressor systems, assess the current method used to coordinate the operation of all compressors.

## 7.17 Storage

### 7.17.1 Primary storage

Quantify and document that the primary storage is maintained effectively and controls a stored potential of useable compressed air energy on the generation side (supply) of a compressed air system.

Primary storage necessarily comprises a storage volume (air receiver) providing storage pressure differential (storage pressure minus target system pressure), with appropriate control considerations (pressure/flow control).

### 7.17.2 Secondary storage

Quantify and document secondary storage as installed. Identify the use of storage such as piping.

## 7.18 Maintenance

Document maintenance practices and note whether these are part of a planned maintenance programme (see [Table B.6](#)).

## 7.19 Ambient intake conditions

Measure and record the ambient intake conditions at the compressor(s) location taking particular note of

- temperature,
- pressure,
- humidity, and
- altitude, if applicable.

Where these characteristics are influenced by seasonal variations and have an influence on compressor performance, consideration shall be given for the inclusion of such information (see [Table B.4](#)).

## 8 Analysis of data from assessment

### 8.1 General

Using data collected during the assessment, baseline profiles and annualized projections of base-year performance shall be established.

The assessment shall

- a) analyse compressed air supply-and-demand balance to identify opportunities for improved performance and increased energy efficiency,

- b) evaluate the system pressure profile and identify opportunities to eliminate pressure loss,
- c) analyse dynamic airflow changes and resultant transient pressure profile response to assess the performance impact and possible upset of end-use applications,
- d) include an analysis of end-use applications and specific energy performance opportunities as a result of potential system pressure reduction, elimination of compressed air waste, and improved performance of critical end-use applications, and
- e) perform root cause analysis for current operation methods to identify energy-efficient remedial measures, identify specific energy performance improvement opportunities, and quantify projected energy savings.

The key factor to bear in mind is that if there is a less expensive compressed air alternative for a particular process, it should be considered.

## 8.2 Baseline profiles

The assessment shall

- a) determine baseline performance for the system power profile and the associated airflow rate of demand,
- b) determine baseline performance through analysis of energy use and total air demand,
- c) baseline the system's compressed air supply efficiency, analyse baseline performance trends, and identify the profile for typical periods of operation,
- d) include annualized data for the expected number of operating periods for each typical period profile that has been identified (see 8.2.6), and
- e) include a projection of base-year energy and air demand totals.

### 8.2.1 Compressor control optimization

Identify opportunities to improve compressor control, optimize response to the system demand profile, and quantify projected energy reduction.

### 8.2.2 Power and energy profiles

An evaluation of the power response of air compressors to dynamic changes in system performance shall be undertaken.

The assessment shall

- a) identify inefficient control response through analysis of individual compressor performance and also the combined response of multiple compressors,
- b) identify days of operation that have similar energy profiles and correlate with plant functional information, and
- c) develop hourly energy and air demand totals to establish operating profiles.

### 8.2.3 Demand profile

The assessment shall

- a) analyse dynamic air demand to identify system performance requirements and the resultant air compressor power response,
- b) identify periods of inefficient operation that require more detailed analysis of the dynamic demand profile,

## ISO 11011:2013(E)

- c) integrate airflow rate measures over time to represent demand trends and establish operating profiles, and
- d) identify periods of operation that have similar air demand profiles and correlate with plant functional information.

### 8.2.4 Supply efficiency

The assessment shall

- a) relate measured power and energy data to measured airflow rate and total air demand to establish baseline compressed air supply efficiency,
- b) include an evaluation of the relationship of air demand trends to supply efficiency and identify periods of reduced supply efficiency that require more detailed investigation, and
- c) include an analysis of system operation to evaluate the supply and demand dynamic balance and compressor control response.

NOTE This is a system test and is not a test of individual components.

### 8.2.5 Operating period types

The assessment shall

- a) correlate total energy and total air demand profiles to plant functional information and establish typical operating periods, and
- b) create groupings of similar typical operating periods.

### 8.2.6 Annualized energy use and air demand

#### 8.2.6.1 General

Plant energy costs shall be applied to determine annual compressed air energy cost and cost per unit of compressed air.

Any appropriate time period may be used so long as the sum of all time periods fairly represents the total for annual operation.

#### 8.2.6.2 Plant and operating profiles

The assessment shall

- a) include annual plant profiles to establish base-year performance, total energy use, and total air demand,
- b) for each operating period identified, estimate on an annual basis the number of such periods for which the plant uses that profile, and
- c) include a calculation of base-year totals using each typical operating period profile and number of times the plant is operating at each typical period.

#### 8.2.6.3 Base-year performance

To calculate base-year performance, the assessment shall define the following:

- a) individual operational periods;
- b) measured energy use for each operational periods;
- c) total air demand for each operational periods;

- d) number of operating days per year for each operational periods;
- e) annual energy use base-year performance;
- f) annual total air demand base-year performance.

### 8.3 System volume

Evaluate the effectiveness of the total volume of the entire compressed air system.

NOTE System volume is an important parameter necessary to assess system events and compressor control response. As system pressure increases, compressed air energy is entering storage, and that energy is released from storage as system pressure decreases. This information is useful in calculating system air leakage or for correlating with compressed cycle times.

### 8.4 Pressure profile

#### 8.4.1 General

The assessment shall

- a) identify energy and performance improvement opportunities that result from elimination of pressure loss,
- b) include an analysis to determine the impact of airflow variations and interaction with the flow resistance of system components and piping and the resultant dynamic pressure profile response,
- c) include the pressure profile performance as it affects compressor control response, airflow supply-and-demand balance, and performance of end-use demands,
- d) establish specific recommendations for an improved system pressure profile, taking into account the cumulative result of all remedial measures. This includes mitigating the effect of
  - 1) pressure variations,
  - 2) drawdown events,
  - 3) dynamic pressure instability,
  - 4) pressure loss, and
  - 5) excessive end-use dynamic pressure loss, as applicable,
- e) state the recommended demand-side target pressure(s) and pressure variation tolerance(s) for each various demand sector, and
- f) provide a control strategy to align supply with demand and maintain alignment throughout normal variations in the demand profile.

#### 8.4.2 Pressure profile elements

The recommended pressure profile should account for all pressure requirements from supply to the end-use device, including the following:

- a) compressor control pressure range, including accommodation for multiple compressor control strategy;
- b) treatment equipment pressure drop considering peak airflow rate and the greatest pressure drop through filters when element change is recommended;
- c) primary storage pressure differential given the recommended storage volume and the necessary useable mass flow of compressed air to support efficient compressor control, permissive startup time for stand-by compressors, and demand events;

- d) transmission pressure loss to one or more sectors of the plant site considering peak airflow rate to each various sector. Pressure loss should be inclusive of pipeline pressure gradient, pressure drop through treatment equipment, and pressure differential for applied secondary storage within the transmission system;
- e) point-of-use pressure profile considering the flow static or flow dynamic characteristic of end use. Point-of-use pressure profiles shall be inclusive of pressure loss from the equipment connection point through point-of-use treatment equipment, piping, and controls. If secondary storage is recommended, the pressure profile shall indicate the necessary storage pressure differential.

#### 8.4.3 Average pressure and pressure variations

The assessment shall

- a) include an analysis of the system pressure profile using data collected during the assessment,
- b) determine average system pressure correlation with energy and total air demand profiles,
- c) investigate dynamic pressure variations and correlate them to supply-and-demand airflow balance, and
- d) identify characteristic signatures of system events that require more detailed investigation and opportunities to improve the supply-and-demand balance with application of storage and quantify the energy benefit resulting from pressure profile improvement.

#### 8.4.4 Peak airflow — Effect on pressure profile

The assessment shall

- a) perform root cause analysis to identify the cause-and-effect relationship associated with the pressure profile's interaction with peak airflow,
- b) investigate specific remedial measures of storage and/or reduced system resistance, and
- c) identify the anticipated performance impact and quantify the energy benefit resulting from pressure profile improvement.

NOTE Peak airflow and the resultant pressure drawdown and/or pressure instability can cause the pressure profile to fall below the plant's minimum system pressure requirement. Increasing the overall system pressure to accommodate pressure drawdown and pressure instability can be a very energy-intensive solution.

#### 8.4.5 Excessive pressure loss

The assessment shall

- a) determine pressure drop associated with various system components and correlate data from dynamic pressure and demand profiles,
- b) correlate component pressure drop with periods of low, average, and peak air demand,
- c) identify remedial measures to reduce airflow rate through elimination of waste and inappropriate use or application of secondary storage with controlled refill to reduce peak demand,
- d) recommend the size and application of system components for proper airflow capacity, taking into account projections of reduced airflow rate, and
- e) identify specific remedial measures and estimate the performance impact and energy benefit of pressure profile improvements in consideration of the entire compressed air system.

### 8.4.6 Excessive pressure gradient

The assessment shall

- a) include an analysis of pipeline pressure gradients and identify if excessive pressure loss at the current airflow rate is a function of high pipeline velocity and distance travelled or if restrictive choke points exist,
- b) identify sectors of the transmission system presenting excessive pressure loss, and
- c) include the following supplemental element action if excessive pressure gradient is identified:
  - 1) Evaluate air demand in the affected sector(s) to identify remedial measures that will decrease airflow rate to the sector through elimination of waste and inappropriate use or application of secondary storage with controlled refill.
  - 2) With projections of reduced airflow rate through the affected pipeline, calculation of the expected pressure gradient associated with the reduced air demand shall be done.
  - 3) Identify specific remedial measures for sector demand reduction, piping modifications to eliminate choke points, opportunities to create piping loop connections to existing pipelines having unused flow capacity, or complete pipeline redesign.
  - 4) Estimate the performance impact and energy benefit of pressure profile improvements.

## 8.5 Perceived high-pressure demand

### 8.5.1 General

The assessment shall validate the end-use pressure requirement for all applications identified as perceived high-pressure demand using data gathered during the assessment.

NOTE The end-use air demand performance can be the result of systemic issues that are the root cause of the perceived need for high pressure.

### 8.5.2 Rated/recommended end-use pressure

The assessment shall

- a) establish from research any recommended operating data for the end-use compressed air demand in the context of *in situ* performance requirements,
- b) verify from a checking process that general operating data do not overstate the pressure requirement for the actual production function being accomplished, and
- c) verify recommended end-use pressure in the context of the “as-installed”, end-use requirement.

### 8.5.3 Dynamic flow/pressure relationship

The assessment should

- a) include analysis of the dynamic performance of the end-use demand, using high-frequency data gathered during the assessment. This includes investigating the dynamic point-of-use pressure profile from the equipment connection point to the subject end-use device,
- b) evaluate the nature of the end-use as flow static or flow dynamic demand, and
- c) assess the appropriateness of the current end-use pressure profile and dynamic pressure signature.

#### 8.5.4 Stability of supply pressure

The assessment should

- a) ascertain the stability of pressure delivered at the equipment connection point, and
- b) rule out upstream pressure instability as a reason for perceived high-pressure requirements.

NOTE Pressure instability can be caused by the dynamic performance of the transmission system or the impact of other system events on the equipment connection pressure.

#### 8.5.5 Remedial measures and quantification of savings

##### 8.5.5.1 General

The assessment should

- a) identify specific remedial measures addressing high-pressure air demands,
- b) estimate the performance impact of pressure profile improvements, and
- c) estimate the energy benefit of pressure profile improvements.

##### 8.5.5.2 Existing pressure anomalies

If the root cause of the perceived need for high pressure is a result of systemic or point-of-use pressure anomalies, then remedial measures to address the root cause issue shall be investigated.

##### 8.5.5.3 Valid high-pressure use

The assessment shall

- a) identify if the end use is a valid high-pressure demand representing a small fraction of total air demand and is driving the system pressure profile to excessively high pressure, then alternatives shall be investigated that will reduce system energy consumption,
- b) analyse the potential to modify the end-use device to allow successful operation at lower supply pressure, and
- c) indicate if it is not feasible or cost effective to modify the end-use device, then the proposed alternative means to supply the air demand shall be identified.

#### 8.6 Demand profile

##### 8.6.1 General

The assessment shall

- a) identify energy and performance improvements that relate to the compressed air demand profile,
- b) evaluate the potential for reducing demand, improving the supply-and-demand balance, and optimizing the compressor control response to normal variations in air demand,
- c) analyse the combined performance of the supply system (generation and storage), transmission system, and point-of-use equipment to identify opportunities to better control and support the system's demand profile, and
- d) identify specific remedial measure(s) to exercise compressed air demand management and quantify estimated energy savings.

### 8.6.2 Average airflow and airflow variations

Using data gathered during the assessment, the air demand profile, including its correlation to the energy profile and average system pressure, shall be identified.

The assessment shall

- a) identify periods of high and low demand and the system's ability to maintain an optimum supply-and-demand balance,
- b) identify any specific periods of operation that warrant more detailed analysis,
- c) analyse periods of supply-and-demand imbalance and identify specific remedial measures to better align supply and demand,
- d) consider measures necessary to maintain alignment throughout normal changes in the plant's compressed air demand,
- e) include a review of airflow variations and the dynamic performance of system air demand together with the system's dynamic pressure profile,
- f) analyse demand events and system response, including pressure drawdown rate and airflow contribution of storage,
- g) include a quantification of demand events and their total airflow rate and duration, and
- h) demonstrate, as a result of investigation, the characteristic signatures of repeated events and, if possible, correlate the event to the associated production equipment and/or activity.

### 8.6.3 Transmission system performance

The assessment shall

- a) consider the performance of transmission during demand events and identify any effects on the system pressure profile,
- b) determine whether compressor controls respond in an efficient manner,
- c) analyse how demand events are reflected in control signal pressure and the resultant supply-side response,
- d) analyse how demand events are reflected in the connection pressure at end-use applications, and
- e) determine whether there is any adverse effect of pressure variation at end-use demands.

### 8.6.4 Remedial measures and quantification of savings

The assessment shall

- a) evaluate alternatives for improved compressor control, primary/secondary storage, and flow pressure control to more efficiently deal with airflow variations that occur, and
- b) identify specific remedial measures and quantify the expected energy reduction.

## 8.7 Critical air demands

### 8.7.1 Critical end-use characteristics

The assessment should

- a) determine whether compressed air system performance related to the critical end use should be considered as a process variable,

- b) document the dynamic performance and characteristic signatures for airflow and/or critical end-use pressure for critical end-use applications,
- c) include an analysis of end-use function data and performance, comparing characteristic signatures for periods of normal operation with periods of unsatisfactory operation, and
- d) include an analysis of the end-use function to quantify the value and allowable tolerance for end-use pressure and/or airflow rate necessary to properly support the end-use application.

A root cause analysis shall be performed to identify issues impacting critical compressed air performance. Analysis should also consider and, if possible, rule out other causes, such as mechanical vibration or reactionary force acting on the end-use pneumatic device.

NOTE 1 In some instances, the result of analysis can be to rule out compressed air-related performance as a causative effect.

NOTE 2 Analysis of a critical air demand benefits from defining the flow and pressure characteristics of this demand.

### 8.7.2 Analysis of process limits

The need to provide monitoring and control of compressed air as a process variable shall be determined. If necessary, process constraints with appropriate methods of process monitoring, alarm indicators, and documentation of performance shall be established.

### 8.7.3 Remedial measures and quantification of savings

Specific remedial measures for critical air demands and an indication of the expected cost savings shall be identified. Measures needed to implement process monitoring may be identified, if required. A financial analysis shall include the cost of control and monitoring. The net savings shall include the productivity impact and net energy change from implementing the remedial measures.

NOTE Critical air demands are those end uses of compressed air that have the potential to impact product quality, production rate, scrap rate, rework cost, customer satisfaction, etc. As such, improving performance of critical air demand is most relevant in terms of non-energy benefits to production operations. However, there are often energy-related benefits associated with improving performance of critical air demands.

## 8.8 Compressed air waste

### 8.8.1 General

Using data collected during the assessment, the various components of compressed air waste shall be identified. Specific remedial measures necessary to eliminate waste shall be provided, and energy savings estimates for each remedial measure shall be calculated.

### 8.8.2 Leakage

The total amount of leakage present in the system shall be estimated. Observations shall be made with respect to the existing piping and maintenance practice as it relates to the relative number and size of leakages. Specific recommendations shall be developed to address any existing poor piping practice.

Short-term leak reduction targets and recommendations of specific remedial actions to achieve the targeted leak reduction shall be established. For the leak reduction target, estimated energy savings shall be provided.

NOTE It can be expected that greater leak reduction is achievable when there are relatively fewer large leaks as compared with numerous small leaks. Poor piping practice is generally considered the precursor to numerous small leaks.

### 8.8.3 Inappropriate use

Using data gathered during the assessment, inappropriate uses shall be identified and alternatives shall be provided. Calculation of the projected energy use of alternative methods and an estimate of the total net energy savings from the implementation of the identified alternative methods shall be provided.

It can also be the case that where compressed air is deemed to be essential that an alternative compressed air solution can be identified, e.g. entrained air device.

### 8.8.4 Artificial demand

Using demand-side pressure data gathered during the assessment and the established demand-side target pressure resulting from the recommended system pressure profile, the potential reduction in artificial demand shall be calculated.

The assessment shall include

- a) an outline of specific remedial measures necessary to achieve and maintain the established demand-side target pressure for the system (or each demand sector), and
- b) the estimated energy savings from implementing such remedial measures.

## 8.9 Optimized air treatment

### 8.9.1 General

A system-wide compressed air treatment strategy shall be determined, taking into consideration end-use requirements, the current method of compressed air treatment, and pressure dew point data gathered during the assessment.

The energy and performance improvement opportunities resulting from specific remedial measures recommended to optimize air treatment shall be identified. The assessment shall include estimated energy savings for the optimized air treatment strategy as compared with the present method of operation.

### 8.9.2 Appropriate air purity

Consideration shall be given to the end-use applications of compressed air and their respective air purity requirements. Allowable contamination levels in the compressed air shall be established by an assessment team member with specialized knowledge applicable to the requirement, where these can affect the application. The methods adopted to remove contaminants such as particulate, moisture, total oil, and other relevant impurities can, if over specified, result in excessive pressure drop. Allowable contamination levels should be identified by application of the classification system identified in ISO 8573-1.

The air purity classification should be as indicated by the air treatment equipment manufacturer rather than by actual measurement unless this is identified as a requirement.

### 8.9.3 Redundant treatment equipment

The assessment shall

- a) evaluate the application of redundant air treatment equipment and end-use risk factors, and
- b) identify an appropriate strategy to eliminate any unnecessary air treatment equipment while ensuring that risk management objectives and compressed air system needs are satisfied.

### 8.9.4 Air treatment effect on pressure profile

Evaluation of the existing application of air treatment equipment and its impact on the system pressure profile shall be undertaken. Opportunities to eliminate pressure loss shall be identified. This shall

include an analysis of the dynamic interaction of supply-side air treatment equipment resistance with the compressors' changing airflow delivery and the impact on control signal pressure.

The pressure loss associated with the air treatment equipment within the transmission system shall be evaluated.

If it is found that unacceptable contaminants could be introduced downstream from the transmission system's compressed air treatment equipment, consideration should be given as to whether it is more appropriate to perform the necessary air treatment in closer proximity to the end-use requirement.

Point-of-use compressed air treatment equipment should be evaluated to verify that it is required and appropriate in the purity class produced. Analysis shall be undertaken of the treatment equipment's impact on the dynamic pressure profile and to determine whether it is suitably sized to support peak airflow rate of the end-use application while operating with a reasonable pressure loss.

Any recommended changes to the air purity specification in either the general compressed air system or at a point of use should be identified (see [Table C.8](#)).

### **8.9.5 Remedial measures and quantification of energy result**

A system-wide compressed air treatment strategy shall be developed, including specific remedial measures to optimize compressed air treatment.

The assessment shall include

- a) recommendations for supply-side treatment,
- b) sectioning of independent air treatment sectors if appropriate,
- c) air treatment applied to the transmission system, and/or
- d) point-of-use air treatment recommendations.

Based on measurements made and data collected during the assessment, the energy use of the existing method of compressed air treatment shall be calculated.

Considering the energy use of the proposed compressed air treatment strategy, an estimate shall be made of the net energy savings as compared with the existing method.

### **8.10 Reduced system operating pressure**

The assessment shall

- a) establish the recommended target pressure(s) for system operation,
- b) include an analysis of the recorded system pressure profile, apply the cumulative result of all remedial measures related to the system pressure profile, including mitigating the effect of pressure variations, drawdown events, dynamic pressure instability, pressure loss, and excessive end-use dynamic pressure loss, and establish specific recommendations for an appropriate system pressure profile,
- c) include the recommended demand-side target pressure(s) and pressure variation tolerance(s) for each various demand sector, and
- d) include an evaluation of the system operation at the reduced target pressure(s) and estimate the energy use reduction associated with the reduced target pressure(s).

## 8.11 Balance of supply and demand

### 8.11.1 General

The assessment shall

- a) provide an analysis of the compressed air system control methods necessary to maintain real-time balance between supply and demand with sufficient transmission capacity to move compressed air energy from supply to demand as required by the dynamic characteristics of the system,
- b) include an evaluation of the application of primary and/or secondary storage with appropriate control to support peak air demand and delay or eliminate the startup of additional compressor capacity in response to short-term demand events,
- c) provide an analysis of the total impact of compressed air demand reduction, including the elimination of inappropriate uses, leakage, and artificial demand, together with the impact of the recommended compressed air storage to reduce peak airflow supplied from generation, and
- d) provide an estimate of the projected demand profile with the implementation of recommended measures, taking into consideration the baseline demand profile.

### 8.11.2 Compressor control strategy

This analysis shall optimize compressor control strategy to the projected demand profile, taking into consideration the following:

- a) Shut down any compressors that are not needed to support the reduced demand profile.
- b) Where possible, operate compressors at their most efficient performance condition, which is typically at their full-load design point.
- c) Apply trim compressor capacity operating with the most efficient part-load capacity given the available mix of compressor sizes and control types.
- d) In multiple compressor systems, consider applying control automation to maintain supply-and-demand balance under normal variations in the demand profile.

### 8.11.3 Remedial measures

The assessment shall

- a) identify the necessary remedial measures to implement any proposed control strategy. The expected reduction in energy use savings shall be quantified,
- b) recognize that implementation of remedial measures will likely occur as an on-going process phased in overtime,
- c) include a description of the control strategy's flexibility to efficiently meet the demand profile as it may change within various stages of implementation, and
- d) include appropriate milestones and anticipated changes as implementation proceeds where specific changes to the implementation of the control strategy are necessary.

## 8.12 Maintenance opportunities

Recommendations shall consider that sustainable results related to maintenance opportunities frequently require on-going maintenance programs to be implemented. Recommendations on specific remedial measures and estimated energy reduction shall be provided. Remedial measures shall promote sustainable improvement of system performance and energy efficiency.

The assessment shall

- a) provide an evaluation of maintenance performed on the compressed air system and its effect on energy efficiency, performance, and reliability of the system,
- b) provide an evaluation of maintenance and installation of the compressor intake filter and piping to assess the impact on compressor capacity, reliability, and efficiency,
- c) provide the result of investigations on the installation and maintenance of condensate drain traps to assess compressed air waste and energy loss associated with improper operation of condensate drains,
- d) identify opportunities to improve performance and reliability, and shall estimate the impact on total energy use, and
- e) take into account that air compressor cooling frequently affects performance and reliability. Therefore, an evaluation of the interaction with other systems, such as heating, ventilation, and air conditioning (HVAC) equipment, which may impact performance and reliability, should be provided. This is only required if site-specific activities include maintenance actions affecting compressor cooling.

### **8.13 Heat recovery opportunities**

The assessment should

- a) include an analysis of the annual operating profile for applications that could potentially use heat recovered from the air compressors,
- b) include an estimate of the amount of recoverable heat based on a conceptual design of a suitable heat transfer system, and
- c) determine the net energy reduction accounting for energy use of auxiliary fans, pumps, heat pumps, or other equipment associated with a heat transfer system.

## **9 Reporting and documentation of assessment findings**

### **9.1 Assessment report**

The assessment report shall include the following information:

- a) executive summary;
- b) facility information;
- c) assessment goals and scope;
- d) description of system(s) studied in assessment and significant system issues;
- e) assessment data collection and measurements;
- f) data analysis;
  - 1) system profile, including pressure, flow, and power;
  - 2) recommended pressure profile;
  - 3) review of critical end uses and recommendations, if appropriate;
  - 4) quantification of waste due to leaks, artificial demand, and inappropriate uses, if any;
- g) annual energy use baseline;
- h) performance improvement opportunities and prioritization;

- i) recommendations for implementation activities;
- j) energy-saving opportunities;
- k) annexes for background and supporting information.

The assessment report shall identify the methods of calculation and software models used with assumptions clearly stated.

The report shall be presented as hard copy, electronic media, or any other suitable medium.

## 9.2 Confidentiality

Reports are the sole property of the client. Confidentiality should, therefore, be respected and appropriately safeguarded by the assessor(s) and any report recipients. Distribution of the report is at the discretion of the client.

## 9.3 Energy-saving opportunities

The report shall include the outcome of measurements in accordance with site-specific assessment goals, assessment plan of action, and statement of work. Any significant measurements or observations from completed action items shall be documented.

The report shall list all energy-saving opportunities that were identified during the assessment and data analysis. The energy-saving opportunities shall be prioritized based on impact, importance, and feasibility. Strategies to implement the improvements shall be identified.

## 9.4 Data for third-party review

The report or other documentation delivered with the report shall include sufficient raw data from the assessment so that the analyses performed in [Clause 8](#) can be confirmed by a third party. This documentation shall be structured so it can be easily accessed by verifiers and other persons not involved in its development.

## Annex A (informative)

### Introduction to energy assessment

#### A.1 Energy costs and carbon emissions

With a focus on measurement and improvement, an energy assessment starts with a detailed survey of a compressed air system with specific focus on increasing the efficiency of compressed air usage. Starting at the point of use and working back to the compressor house is a logical approach.

Using an industrial engineering approach, the aim is to “switch off” main air compressor drive motors by identifying solutions which both reduces the air demand on the compressed air system while maintaining production requirements. This significantly reduces factory electricity costs and cuts carbon emissions.

Key areas to consider are application of air at point of use, leakage, and operating pressure.

Once pressure requirements, actual air demand, and leakage have been identified and quantified, the most energy-efficient solution to reduce factory air consumption can be proposed. The reduction of leakage is extremely important. It cannot be completely eliminated due to the complexities of production equipment, which is where most of the leakage occurs, but it can be controlled.

#### A.2 Life cycle costs

Compressed air systems are considered to be a necessary utility across all industries and are estimated to consume some 5 % to 25 % of industrial electrical supply.

The interest in energy-efficient technologies is constantly rising and users are imposing demands on manufacturers of compressors and related equipment to develop technologies and tools for the optimization of existing compressed air systems and for the design of new and more efficient ones.

Today, investment is governed by life-cycle-cost analyses, especially with the supply of a new compressed air system. While energy efficiency is considered a major parameter in the design of new systems, significant energy savings can be realized in the optimization of existing compressed air systems.

#### A.3 Energy cost reduction

Energy cost reduction is usually the driving force behind assessments; however, the other benefits of having an assessment performed on a compressed air system are

- improved plant and process productivity,
- improved product quality,
- improved equipment reliability,
- reduced maintenance costs, and
- reduced scrap rates and costs.

Energy efficiency improvements also provide benefits to environmental issues.

## A.4 Assessment and measurement

The assessment needs to consider all elements of the compressed air system from generation to end use to be able to provide not only a current state of play but also recommendations on improvements. Whether the results indicate that leak management leads to the stated energy efficiency improvements or more sophisticated solutions such as energy-efficient electric motors or variable-speed-drive control systems are required, these all need to be part of an integrated solution. The data used are derived from measurements made from key areas of the compressed air system.

Today, many different methods are used to perform these measurements which can produce varying results. Interpreting these results is not easy for the compressed air user; therefore, a standard measurement practice is required.

## A.5 Reporting and action

The report is a stand-alone survey of the customer's current situation that can lead to identifying improvements. A non-exclusive list of management and technical actions is provided below as an indicator of energy-saving opportunities that can be gained from a compressed air system assessment.

Compressed air systems are extremely interactive and, often, several different actions are required in combination to achieve a successful outcome.

The options listed can provide solutions to an optimized system and achieve maximum savings when applied in a coordinated manner.

Management actions:

- Raise the awareness of all users to the proper use and cost of compressed air.
- Develop and implement a maintenance programme for the whole system.
- Install metering and implement monitoring.
- Use trained and competent personnel for installation, servicing, and system upgrades.
- Develop and implement a purchasing policy considering life-cycle costs.

Technical actions:

- Implement a leak reporting and repair programme.
- Do not pressurize the system during non-productive periods.
- Fit dryer controls (refrigerant and desiccant).
- Install compressor drive and intelligent system control measures.
- Implement measures that reduce compressed air demand and optimize production process.
- Install heat recovery measures, where appropriate, which may offset existing energy use.
- Identify and eliminate inappropriate compressed air uses.
- Improve distribution piping and eliminate excessive pressure drop.
- Reduce/stabilize operating pressure.
- Add additional storage (supply and point of use).
- "Rightsize"/replace compressors to improve supply-and-demand balance.

## Annex B (informative)

### Assessment activities — General

The following is for guidance to both the assessor and the client when developing the survey.

#### B.1 Information provided by site management

##### B.1.1 Company profile

Company profile (see [7.3](#)) details are shown as an indicative list in [Table B.1](#).

**Table B.1 — Company profile details - indicative list**

Company		
Address 1	Telephone	
Address 2	Fax	
City/Town	E-mail	
Region/County		
Post/Zip Code		
Compressed air system site address (if different than company address)		
Address 1	Tel	
Address 2	Fax	
City/Town	E-mail	
Region/County		
Post/Zip Code		
Personnel listing relevant to assessment		

##### B.1.2 Industrial sector in which the company operates

Characterization of the industrial sector (see [7.2](#)) includes information on product type which can be defined by standard industry codes.

##### B.1.3 Usage of compressed air

Compressed air usage information (see [7.5](#)) includes such uses as control/instrumentation, pneumatic tools, and processes. Some processes use large volumes of air for short periods of time and others for long periods of time. Such behaviours should be included.

##### B.1.4 Employees

Indicate the number of employees (see [7.3](#)) in the company (or in the business unit, subject to the assessment) at the end of the last financial year.

##### B.1.5 Working time

Those aspects making up the working time (see [7.2](#)) are indicated in [Table B.2](#).

**Table B.2 — Working time characteristics**

<b>Work cycle</b>	Identify shift pattern, e.g. daily/weekly	Days/7 day week	Annual total operational hours
Seasonal demand variation			

**B.1.6 Production**

Those aspects contributing to production information (see 7.2) are indicated in [Table B.3](#).

**Table B.3 — Production information**

	Shift	Week	Quarter	Year	Seasonal/Market influence
Volume/No. of fabricated products					
Product rejection rate					
Sales volume (currency/annum)					

**B.1.7 Facility**

A diagrammatic representation of the facility under assessment (see 7.3 and 7.4) should be generated to aid understanding of the relationship between all connected compressed air-related equipment.

**B.1.8 Ambient climatic conditions**

Seasonal ambient climatic conditions (see 7.19) are identified in [Table B.4](#).

**Table B.4 — Seasonal ambient climatic conditions**

	Spring	Summer	Autumn	Winter
Pressure				
Temperature				
Humidity				
NOTE Seasonal or, if considered relevant, more frequent recording (weekly, monthly) of rain, snow, or arid conditions can also be useful				

**B.1.9 Energy costs**

Typical energy costs (see 7.8) which are relevant to the assessment are indicated in [Table B.5](#)

**Table B.5 — Typical energy costs**

Electricity consumption related to the compressed air system	Time periods (to be quantified as relevant)				
	Weekly	Monthly	Quarterly/ Half-yearly	Annually	Other (to include production-affected time periods)
The following information is to be supplied by the site management, if known; otherwise, it should be identified during the assessment.					
	Compressors	Air treatment	Ventilation fans (compressor room)	Cooling pumps (liquid-cooled compressors)	Other
Share of load (power)					
Cost for load operation (currency/week)					
Cost of idling operation (currency/week)					
Specific power (energy/volume)					
Energy cost (currency/volume)					
Free air delivery (volume) per week (7 day); per year (52 weeks)					
Price of fuel					
Price of coolant					
Cost of consumable material					
Cost of spare parts, of disposal, of maintenance					
Cost of rental					

**B.1.10 Maintenance**

Typical information on the level of maintenance (see 7.18) is given in Table B.6.

**Table B.6 — Typical maintenance information**

Does a maintenance plan exist for the system or installation to be examined?		No	Yes
If "Yes", identify the last scheduled maintenance:		(month/year)	
Identify the maintenance frequency for the system or installation to be examined:			
Weekly	Monthly	Half-yearly	Annually
Other			
If "Other", provide details			
Identify leak management process		None	Frequency/Action
Identify if the system or installation has or is to be modified from the original installation, e.g. retrofitting or extending			
No	Yes, identify when:		(month/year)
If "Yes", identify the reasons:			
Changes in capacity		General modernization measures	
Repair of important components of the installation		Changes in the process flow	
Other:			
Identify operational reasons for the linking of specific system or installation components:			
None	Yes	If "Yes", provide details	
Identify "auxiliary circuits" or interfaces within the system or installation that may have effects on compressed air system(s) to be analysed:			
None	Yes	If "Yes", provide details	
Historical problems with the compressed air facility		e.g. abnormally high operating temperature in the summer, water/liquid oil in the pipes, freezing problems in the facility in winter, blockages, breakdown through high pressure drops, etc.	
		Provide details:	

**B.1.11 Assessment information**

Information on the commitment to assessment [see 7.1d)] is given in [Table B.7](#).

**Table B.7 — Assessment information**

Is there an established policy on any efficiency increase potential?		Yes	No
Site management assessment of the potential for increasing the efficiency of the system or installation	Energy savings	Percentage of the annual energy demand	
	Cost savings potential	Percentage of the total life cycle costs	
	Availability of budget		
	Payback criteria		
Previous assessment conclusions	Date of last assessment		
	Energy savings identified	Percentage of the annual energy demand	
	Cost savings achieved	Percentage of the total life cycle costs	
Comments:			

**B.1.12 Utilization ratio**

Information on the utilization ratio (see 7.7) of the system or installation in relation to the maximum compressor capacity or on the load profile of the system or installation is given in Table B.8.

**Table B.8 — Information on the utilization ratio**

The installation is run between ... and ... percentage of the maximum capacity.							
The following details apply:							
Daily profile:	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
When run continuously, a day profile is sufficient.							
Annual profile:	Spreadsheet form can be included						
Identify if a feedback control system is available for the system or installation under investigation							
No, the installation is run continuously.		Yes, in the following manner:					
		Manual control (gradual, cascade)					
		Automated control (continuous)					
		Continuous control is based on:					
		Speed control			Throttling		
		Bypass control					
		Other (provide details):					

## Annex C (informative)

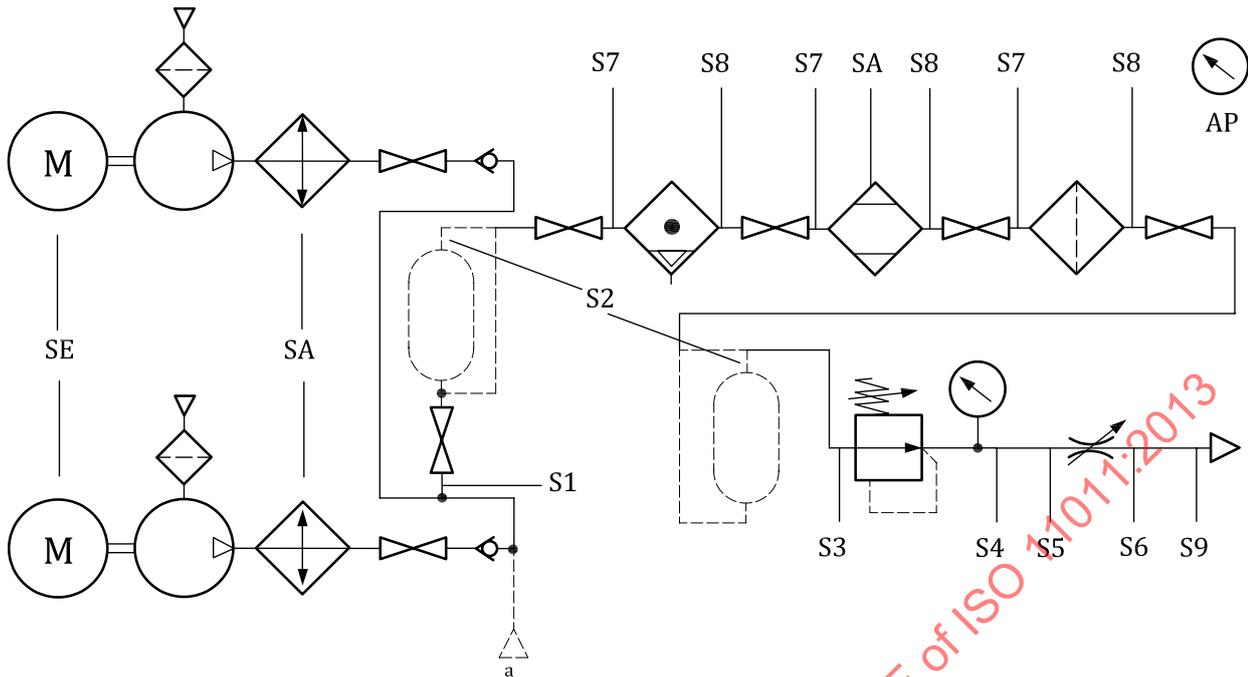
### Assessment activities — Supply

#### C.1 Test points

Supply-side test points (see 6.3.2, 6.4.2, and 6.5.2) should include points as listed in Table C.1 and identified in the examples given in Figures C.1, C.2, and C.3;

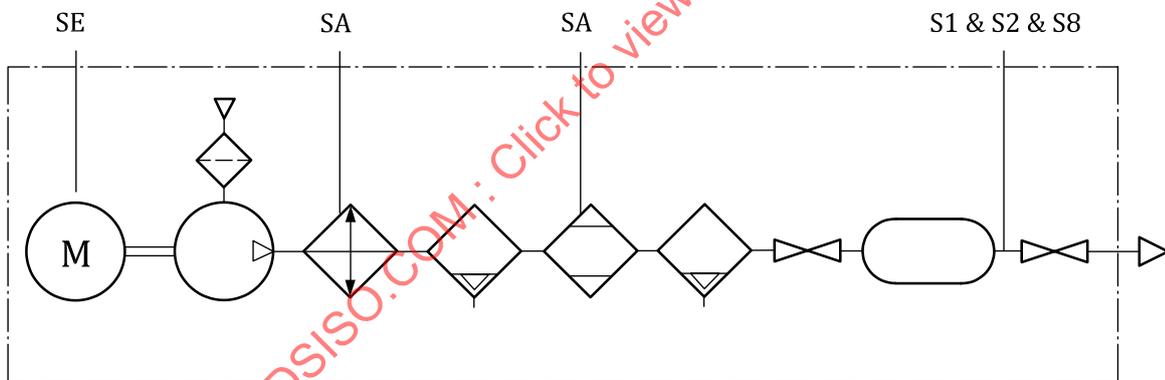
**Table C.1 — Supply-side test points**

Location	Location description	Pressure	Flow	Power
S1	compressor discharge			
S2	primary storage			
S3	upstream of pressure controls			
S4	downstream of pressure controls			
S5	upstream of flow controls			
S6	downstream of flow controls			
S7	upstream of supply-side treatment equipment			
S8	downstream of supply-side treatment equipment			
S9	supply to transmission and demand			
SE	compressor electrical input			
SA	air treatment electrical input			
AP	ambient air pressure			
a From other compressing plant where fitted.				

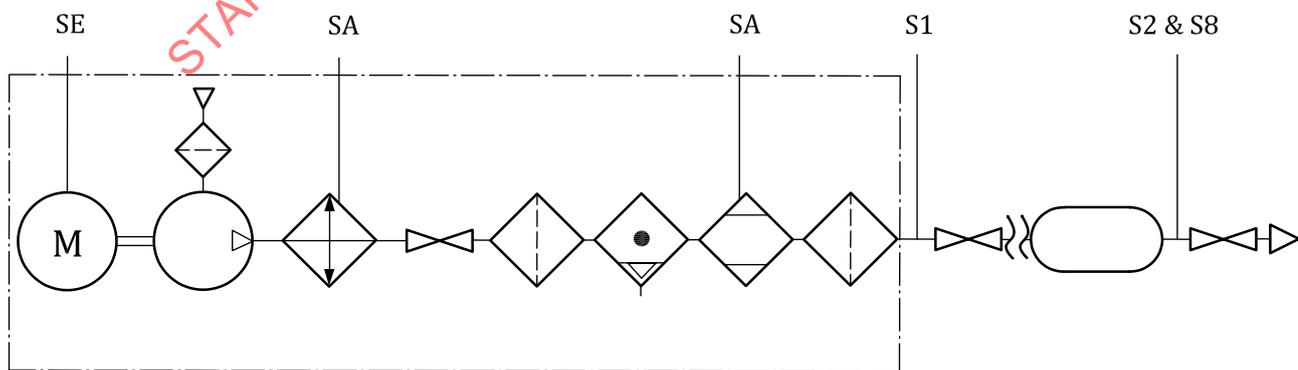


NOTE Air receiver location(s) “wet” or “dry” or “both” depend on system performance requirements.

**Figure C.1 — Typical stand-alone/compressor(s) linked to site air receiver(s) and air treatment**



**Figure C.2 — Typical receiver-mounted compressor with integral dryer**



**Figure C.3 — Typical packaged compressor with air treatment linked to site air receiver**

## C.2 Supply information

This characterizes the installed compressor formation.

### C.2.1 Global compressor information

Information related to the compressor(s) types (see 6.5.3) installed on site is given in Table C.2.

**Table C.2 — Global compressor information**

Total of all compressors installed										
Age of compressed air installation										
Less than 3 years			3 to 5 years			More than 5 years				
Compressor types installed										
	Stages	Lubricated		Coolant			Fixed	VSD <sup>c</sup>	Variable	
		Yes	No	Air	Water		Speed		Displacement	
					Open <sup>a</sup>	Closed	Oil			
Reciprocating										
Screw										
Vane										
Turbo	Centrifugal									
	Axial									
Other <sup>b</sup>										
<sup>a</sup> Open-circuit water coolant [see 6.5.3.1e)]. <sup>b</sup> Identify compressor type. <sup>c</sup> Variable-speed drive.										

### C.2.2 Individual compressors

Information related to individual compressors (see 6.5.3.1) is identified in Table C.3.

**Table C.3 — Individual compressor details**

Number of compressors ( <i>n</i> )	1	2	3	4	<i>n</i>
Manufacturer					
Model/Serial number					
Year of construction					
Voltage/Phases					

**Table C.3 (continued)**

Number of compressors ( <i>n</i> )		1	2	3	4	<i>n</i>
Power	Total (package)					
	Drive motor nameplate rating					
	Drive motor nameplate nominal efficiency, as a percentage					
	Fan motor nameplate rating (if applicable)					
	Fan motor nameplate nominal efficiency, as a percentage					
	Total package input power at zero flow					
	Total package input power at rated capacity and full-load operating pressure					
	Specific power - Specific package input power at rated capacity and full-load operating pressure					
Pressure						
Heat recovery	Discharge air temperature					
	Oil temperature					
Location						

**C.2.3 Total compressor capacity**

Compressor performance with respect to flowrate (see 6.4) as indicated by supplied or measured data are identified in [Table C.4](#).

**Table C.4 — Total compressor capacity**

Total:					
Individual compressor capacity ( <i>n</i> )	1	2	3	<i>n</i>	
Volume flowrate(s)					
Rated capacity at full-load operating pressure					
Pressure(s)					
Full-load operating pressure					
Maximum full-flow operating pressure					
Briefly describe what the different pressure values are required for.					

**C.2.4 Combustion engine-driven compressor**

Information on combustion engine-driven (see 6.5.3.2) compressor plant is given in [Table C.5](#).

**Table C.5 — Combustion engine-driven compressor details**

Number of engine-driven compressors ( <i>n</i> )	1	2	<i>n</i>
Manufacturer			
Engine model			
Engine, year of construction			
Maximum number of on/off cycles per hour			
Maximum amount of time off between cycles			
Engine power			