

# Compressed Air Systems (CAS) Audit Standard

A standard for the auditing of the energy efficiency of electric motor-powered compressed air systems

Version 1.1

Updated June 2015, to align with AS/NZS3598.1:2014 and AS/NZS3598.2:2014



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## 0.0 Purpose Statement

This Compressed Air Systems (CAS) Audit Standard (“Audit Standard”) is provided by the Energy Efficiency and Conservation Authority (EECA), for the purpose of providing a quality ‘whole-system’ auditing methodology for compressed air systems in common use in New Zealand industry.

It is expected that, when used by suitably qualified parties (such as an accredited CAS auditor), adherence to this Audit Standard will provide the procurer of the audit with confidence that the services received are of high quality

## 0.1 Compressed Air Systems Audit Standard

The Audit Standard is designed to guide the collection and analysis of compressed air system data for the purpose of identifying opportunities for improving the system’s energy efficiency and providing relevant technically and commercially sound recommendations.

The Audit Standard is technology-neutral and measurement-method neutral, although the measurement methods used will be important in the context of the scope and measurement accuracy required of an audit.

This Audit Standard should be read in conjunction with AS/NZS3598.1:2014 (Commercial Buildings) and AS/NZS 3598:2014.2:2014 (Industrial and Related Activities), which provide the basic framework within which all energy audits should be undertaken.

## 0.2 Disclaimer

As owner of this Audit Standard, EECA will exercise due care in ensuring that it is maintained as fit for purpose.

However, EECA accepts no responsibility or liability for any direct or consequential loss or damage resulting from, or connected with, the use of this Audit Standard by any party.

Further, this Audit Standard does not seek to represent the obligations of any parties entering into any agreement for services relating to a compressed air system audit.

## 0.3 Further information

EECA has commissioned the Energy Management Association of New Zealand (EMANZ) to maintain this Audit Standard, in conjunction with relevant industry stakeholders.

If you have questions in relation to this Audit Standard, you may email [info@emanz.org.nz](mailto:info@emanz.org.nz) , including reference “CAS Audit Standard” in the subject line. You may request to be notified when a new version is created.

The current version of the Audit Standard and other relevant information is available by visiting [www.emanz.org.nz](http://www.emanz.org.nz).

# 1.0 Overview of the Compressed Air Systems Audit Standard

Compressed air systems are used extensively in industry to provide compressed air for pneumatic applications such as pneumatic actuating of valves and cylinders, and for pneumatic motors. There are also several compressed air uses in industry that in most cases can be considered misuses, which includes applications such as product cooling and cleaning.

This Audit Standard provides an approach to compressed air system auditing and analysis. The objectives of the standard are to:

- a) Provide the framework for the systematic collection of data relevant to the efficient operation of compressed air systems, and;
- b) Enable the compressed air system auditor to analyse the performance of the compressed air system, identify potential electricity savings and provide sound recommendations for implementation of energy efficiency initiatives.

In addition, Appendix 7 includes a recommended report outline for the purpose of assisting concise, consistent and complete presentation of the analysis, findings and recommendations arising from a compressed air system audit.

## 1.1 Scope of the Audit Standard

The scope of the Audit Standard includes compressed air systems that transport compressed air<sup>1</sup> within a network to perform various industrial end tasks. A separate EECA audit standard exists for fan systems.

Assessing the efficiency of a compressed air system amounts to assessing the system's efficiency in *performing the task that the compressed air is serving*.

The boundary of the system concerned extends from the power and air inputs to the air compressor to the point where the business purpose<sup>2</sup> of delivering the compressed air is achieved.

The system boundary is therefore defined by the points beyond which any change to the system no longer has any effect on the business purpose that the system is serving. Figure 1 shows the components within a typical system boundary.

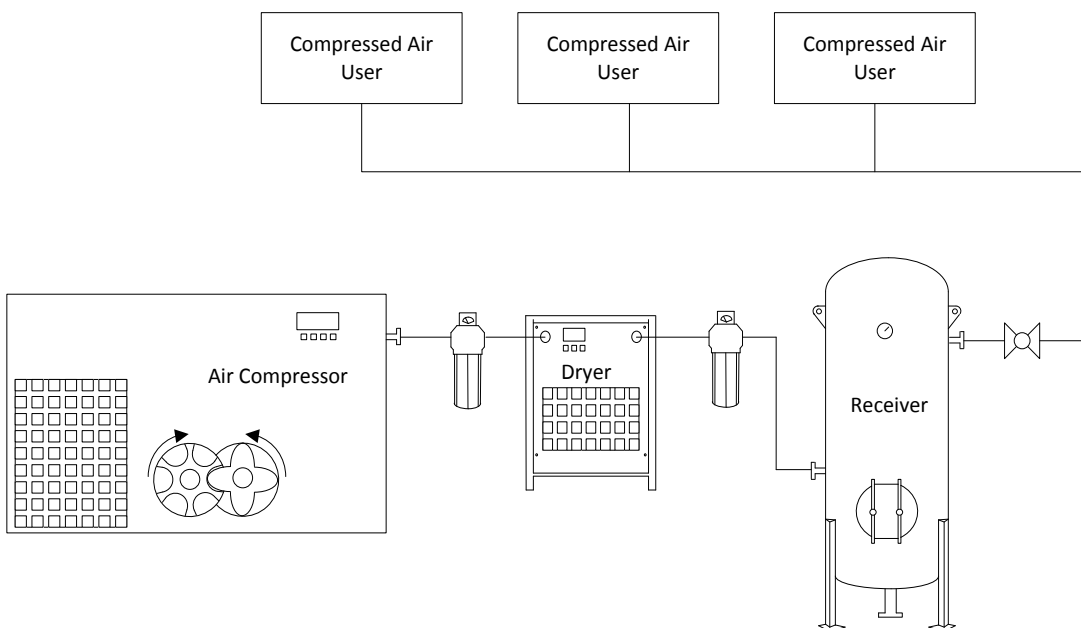


Figure 1: Compressed Air System Boundary

<sup>1</sup> Refer to Appendices 5 and 6 for definitions of compressed air, as well as concepts and descriptions of terms used in this document.

<sup>2</sup> An example of a 'business purpose' is the pneumatic pumping required for a necessary process within a manufacturing system

## 1.2 Accuracy and Measurement

This Audit Standard includes guidance on the expectations of audits conducted according to two generalised levels of accuracy requirements — a ‘base level’ and an ‘investment level’. These levels are representative of the two ends of an accuracy requirement continuum. Where on that continuum the audit fits is a matter for agreement between the auditor and the client, and will be determined by the client’s purpose in commissioning the audit.

A ‘base level’ audit is broadly equivalent to a Type 1 audit under AS/NZS3598.2:2014, while an ‘investment level’ is equivalent to a Type 3 audit, especially where a significant program of measurement and monitoring is applied.

This Audit Standard is compressor technology neutral, but indicates some preferences with regard to the measurement methods and associated equipment appropriate for the accuracies required. The implications of measurement accuracy on audit accuracy are described in Appendix 4.

Type 1 ‘base level’ audits are primarily intended to identify areas of inefficiency and opportunity in the system. A typical base level audit generally does not include extensive use of flow, temperature, pressure and power measurement equipment.

A Type 1 ‘base level’ audit may be the appropriate level to use to define the scope and measurement requirements of a subsequent ‘investment level’ audit of the same system.

## 2.0 Planning the Audit

### 2.1 Audit Objectives and Scope

Each audit should be scoped and designed according to the client's requirements. Consulting with the client to identify and record the client's objectives is a critical prelude to defining the scope of the audit and the associated measurement requirements.

An audit for a client who is seeking only to understand where the compressed air system's efficiency opportunities exist in a factory may have lesser scope and measurement requirements than an audit that is required for a client who needs the audit findings as crucial inputs into a potential efficiency upgrade investment.

The measurement accuracy requirements should be discussed and agreed at the outset with the client, and will inform the decisions regarding methodology and equipment used for the audit.

Agreement on audit objectives and scope should include agreement on the content and structure of the audit report that will be subsequently presented to, and discussed with, the client.

AS/NZS 3598.2:2014 should be used to guide expectations for both the client and the audit team in terms of what is expected from the audit and required of the audit team.

### 2.2 Business Context

The business context of the compressed air system(s) to be audited, or what is required of the system(s) in the wider business operation, needs to be established in order to define the measurement requirements for the audit and any post-implementation phase.

As the principal purpose of the audit is to provide information that will identify ways to improve the efficiency of the compressed air system, the demand on the system and what business needs are driving that demand must be understood from the outset<sup>3</sup>. This is important for meaningful monitoring of the compressed air system's energy performance, after implementation of any changes.

When planning the audit, the relationship between the output of the compressed air system (and therefore the energy input to the system) and the business driver of the compressed air system should be identified. The driver may be measured through one of a range of factors, such as hours of operation, production input (e.g. daily kg of material) or production output (e.g. daily kg of product).

## 2.3 Resources and Responsibilities

### 2.3.1 Resource Requirements

The audit scope and accuracy requirement agreed with the client will determine the people and other resources required to perform the audit. The audit quotation presented to the client (which will form the basis of the service agreement subsequently established with the client) needs to include an assessment of the resource requirements.

Irrespective of whether a 'base level' or 'investment level' audit is required, a fully competent CAS auditor should be engaged for the audit.

An equally-competent CAS auditor should be available to provide peer review of critical parts of the analysis and findings of investment-level audits.

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<sup>3</sup> For example, the demand on a compressed air system may be the pneumatic pumps within a process manufacturing wood pulp. The business context is wood pulp manufacture, not merely the operation of the pneumatic pumps.

### 2.3.2 Audit Functions and Responsibilities

The audit requires 'management' and 'expediting' functions to be performed and, where an audit team is involved, it requires an allocation of the various audit responsibilities. The functions included within each of those areas are as follows:

**Audit Managing:** to ensure that the audit overall is managed to deliver a quality output, on schedule. This includes ensuring that:

- a. the audit is appropriately scoped and priced;
- b. the audit resource requirements are accurately identified;
- c. a service agreement is established with the client;
- d. audit tasks are allocated to appropriately skilled individuals;
- e. a clear work schedule exists for the onsite activities and delivery of the final audit report;
- f. the client delivers on its responsibilities under the service agreement;
- g. any third-party contracts are facilitated and managed; and
- h. the client- and peer reviews (as required) are completed.

**Audit Expediting:** to ensure the required data is collected according to the audit scope and objectives, in a manner that is consistent with the requirement of this Audit Standard. Expediting includes:

- a. liaising with the site operations, maintenance and engineering staff to ensure site procedures are recognised in the logistics of the audit;
- b. collection and analysis of the audit data;
- c. obtaining peer review of findings (depending on audit scope and objectives); and
- d. drafting and finalising the audit findings and recommendations.

It is expected that these functions will be performed by a CAS auditor certified or accredited by an independent certification body or reputable professional association.

### 2.3.3 Communications

An initial meeting between the audit manager and relevant site management should clarify the audit objectives and scope.

A second meeting, including the audit expeditor and site management and operations staff, should be used to:

- a. review any preliminary (pre-audit) information that has been collected;
- b. assist refinement of the measurements, tools and methods required for the audit to ensure client expectations will be met; and
- c. ensure that there is an understanding of what resources are required onsite as well as employee involvement.

## 2.4 Audit Costing

Costing of the compressed air system audit is an important part of the audit planning process.

For an investment-level audit, the cost will depend on the size of the site, the number of compressed air systems and system boundaries that have been defined in the scope, the level and duration of energy, flow and pressure measurements required, and any third-party contractors required to undertake measurements. It might also need to include recognition of post-audit performance monitoring that may be required by the client.

For a base-level audit, the measurement and reporting requirements will be significantly less — with a flow-on effect on the auditing cost estimate.

The quoted cost to the client should also take into consideration any support available from third parties. For instance, there may be services or funding provided by air compressor manufacturers, energy retailers, and potential project grants from EECA or other parties.

## 2.5 Audit Approach in Summary

Figure 2 outlines the general audit approach that should be followed. It commences with client consultation regarding the objectives and scope of the audit (as covered in 2.1 above).

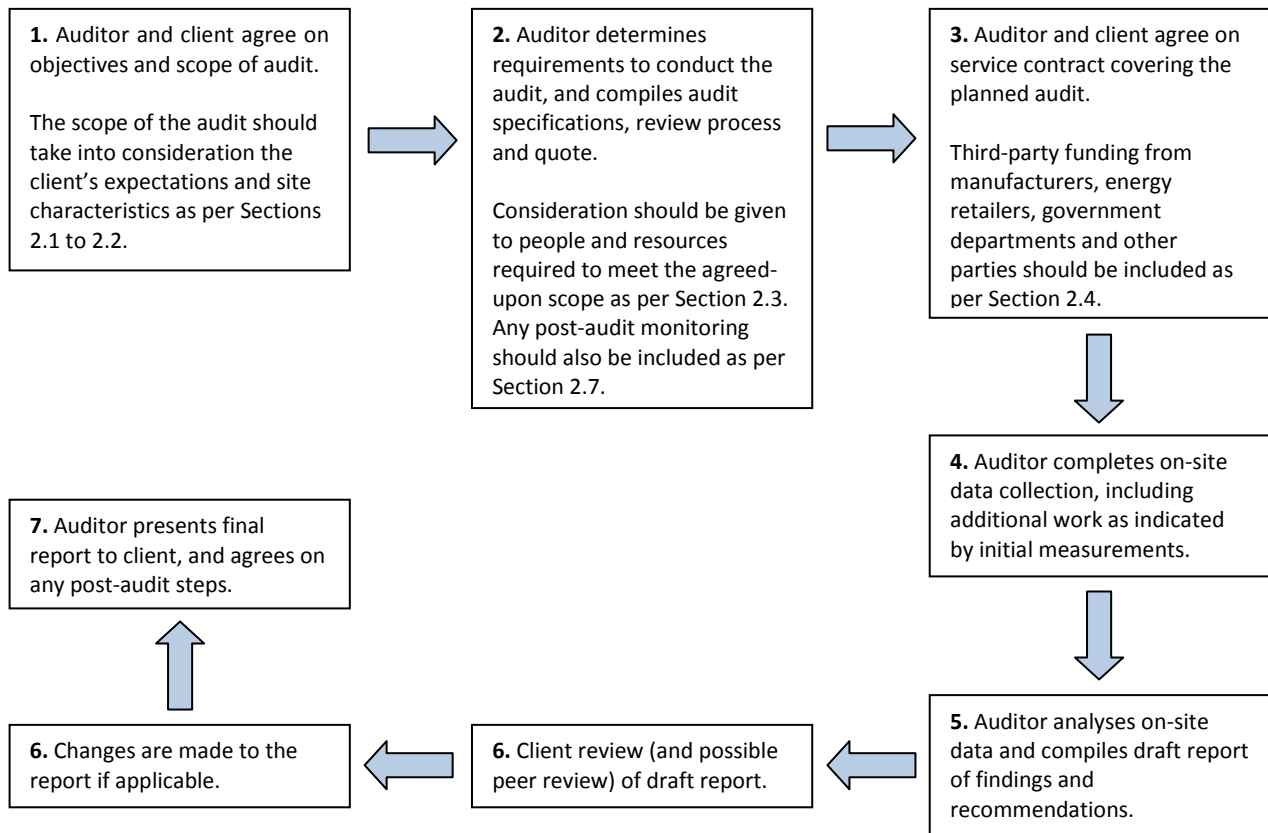


Figure 2: Flow Diagram of Audit Approach

## 2.7 Post-implementation Monitoring

An audit will generally be followed by implementation of recommended corrective actions.

Post-implementation monitoring of electricity usage relative to the compressed air system requirements or business driver is generally important to the client to enable the value of post-audit design or operations changes to be measured on an ongoing basis.

The nature of the post-implementation monitoring should be established as part of the audit planning, as it is likely to influence some aspects of the audit design and location of temporary or permanent measurement equipment. The key driver of compressed air system electricity input should govern the nature of the monitoring, whether that driver be production output, another input or merely hours of operation.

In the event that the client requests a post-implementation verification audit, the scope and nature of that audit should be agreed between the client and auditor at the prior to the commencement of the original audit process.



## 3.0 On-site Measurements and Data Collection

This section details the measurement requirements for a compressed air system audit conducted to investment-level accuracy. It also provides some guidance on what may be sufficient when auditing to the (lower) base level of accuracy.

In the first part, the measurement methods are outlined, followed by the measurement requirements for the site and systems being audited.

For a Type 3 'investment grade' audit, the processes laid out in AS/NZS3598.2:2014 should be followed in terms of the planning and execution of monitoring. Specifically, attention should be paid to the following sections of the Standard:

- Section 11.6.3 Data collection
- Section B3 Data Measurement Plan

### 3.1 Accuracy of measurement equipment

All equipment used by the auditor to carry out the audit shall at all times be maintained to the relevant standards and manufacturers' specifications.

### 3.2 Measurement Methods

There is a range of measurement methods available to auditors. Judgement is required to select the appropriate measurement technology, depending on the particular compressed air installation and the technologies being used.

#### 3.2.1 Electricity Usage Measurements

For 'investment level' audits, the input power to each compressor should be measured at a point that excludes other extraneous load. Ideally, for each air compressor, a three-phase electricity meter (with data-logging capability) should be used to directly record kilowatt (kW) and kilowatt hour (kWh) usage.

Particularly where the compressed air system has variable demand requirements, it is recommended that the power readings are logged at intervals of not greater than 10 seconds. It may also be beneficial to log data for other system components such as air dryers.

If the electricity line charges are based on kilovolt-ampere (kVA) measurement and the site does not have power factor correction upstream of the air compressors, kVA demand should be either directly measured or otherwise assessed.

Measurements should be taken for a period of time sufficient to capture the 7-day operational pattern of the compressed air system. In addition, in order to put the weekly profile into an annual usage context, it is necessary to obtain an annual profile of production and/or electricity use. Investment-level accuracy of the annual usage estimate requires consideration of both the weekly and annual profile data.

For 'base level' audits, the 'Baseline Consumption Table' provided in Appendix 3 identifies the data required to estimate a compressed air system's annual electricity use without the use of electrical data logging.

#### 3.2.2 Pressure Measurements

Pressure should be measured at the compressor: at points where the main users of compressed air exist; and other locations where pressure drops are likely to be observed (e.g. in long pipe lengths).

Depending on the type of pressure gauge and practical matters such as the relative locations of the pressure recording points and the air compressors, pressure loggers may also be used, though this is not mandatory.

For a base-level audit, it is recommended that values are noted if there are gauges already in the network.

#### 3.2.3 Flow Measurements

Knowledge of the air flow is important to understand a compressed air system's delivery performance. Intrusive flow meters may be used, although installation can be difficult or disruptive to production. Permanent embedded (intrusive) flow measurement equipment also provides a practicable solution as it provides for auditing measurements and ongoing monitoring. Non-intrusive ultrasonic flow meters are a very useful tool in determining system characteristics.

Where specific data is available on flow rate (e.g. a Compressed Air and Gas Institute (CAGI) data report for positive displacement machines), this may be used as a guide for calculating the flow rate.

It may be beneficial to measure flow at specific parts of the compressed air system if flow interruptions are expected.

Because air demands may be dynamic, periodic and transient, such local flow measurements should be taken over a period that captures the full range of operating requirements. Periods of maximum and minimum demands also need to be captured.

### 3.2.4 Air Leak Detection

For an 'investment level' audit of a compressed air system, it is expected that ultrasonic leak detection (performed by an appropriately skilled operator) is performed to quantify air leakage. Operators of the ultrasonic equipment, and those undertaking the analysis of the leak detection survey, should be trained to an appropriate level according to Recommended Practice SNT-TC-1A or an equivalent standard.

For 'base level' audits it is not expected that an ultrasonic survey is undertaken, although an estimation of air leaks may be appropriate. One method for estimating air leaks is by using the 'after-hours' method. For this method, the on-load and off-load air compressor cycle times are measured at normal operating pressure, but with all the regular compressed air consuming processes not occurring. It can then be assumed that all demand is due to air leaks. The following equations can be used to determine air leaks:

$$\text{Leakage Percentage (\%)} = (\text{Time On-Load}) / (\text{Time Off-Load} + \text{Time On-Load})$$

$$\text{Leakage (m}^3\text{/min)} = \text{FAD (m}^3\text{/min)} \times \text{Leakage Percentage (\%)}$$

This method will not be applicable where speed-regulated compressors are installed; however, air leaks may still be estimated using 'decay methods'.

### 3.2.5 Electricity Cost Estimation

Wherever the audit findings are likely to be used in any investment analysis undertaken by the client, the electricity costs used in valuing the electricity consumption of the compressed air system should be based on future contract or forecast prices and adjusted for any other relevant variable pricing factors, as agreed with the client.

For the purposes of a 'base level' audit, if the client does not have a standard electricity cost figure for project analysis purposes, it is generally acceptable to use the most recent 12 months' gross average electricity cost (total cost divided by total energy consumed) for the valuing of electricity use. Demand savings do not need to be quantified but if measures are expected to have a significant impact on demand this should be identified.

For an 'investment grade' audit, savings should be calculated taking into account the variations in cost of electricity with time of day and time of year. The effect of any demand and/or capacity charges should also be accounted for. Where differences in electricity use are being valued, the valuation needs to consider that some elements of the delivered electricity price may be independent of the consumption level. Any fully fixed elements of the electricity price need to be removed from the cost used to value a consumption difference. If relevant, the effect of power factor on delivered electricity costs to the compressed air system should be recognised. On most electricity distribution networks, a premium is chargeable if a power factor of less than 0.95 is measureable at the site-entry metering point. The absence of power factor correction equipment on the site would normally result in a recommendation to the client to investigate the economics of correcting that situation.

### 3.2.6 Works Cost Estimates

Particularly where the audit is undertaken for investment proposal purposes, the findings will include recommendations for works to be performed to exploit efficiency opportunities.

With guidance from the client with regard to whom to consult with, it is expected that compiling budget estimates for such recommendations will require consultation with a range of equipment suppliers or maintenance engineering companies. The level of accuracy of the cost estimates should meet the client's requirement. In compiling a cost estimate for an investment grade audit, consideration should be given to all of the following factors (ref Section 9.2.2. of AS/NZS3598.2:2014):

- a) Site establishment costs
- b) Scaffolding and craneage
- c) Works by other trades (e.g. demolition, asbestos removal, builder's works)
- d) Builder's margins

- e) Project management fees
- f) Commissioning costs (often not fully allowed for under quotations)
- g) Cost impact of having to conduct work after hours
- h) Development approval costs and authority fees
- i) Latent defects in the existing plant

## 3.3 Compressed Air System Measurements

### 3.3.1 Site-level Data Collection

Appendix 1 contains a form outlining the key site-level data that should be recorded for the audit, irrespective of the accuracy level of audit concerned.

### 3.3.2 Business Requirement of the System

Understanding the requirement that the business has for the compressed air system being audited is a prerequisite to identifying areas of inefficiency. It is useful to commence the audit with quantification of that requirement, which necessitates collection of the following information:

- the functional (flow and pressure) requirements of the system relative to the main business driver (e.g. production); and
- any changes to system design since installation, and the reasons why.

A compressed air system schematic is important to provide a clear picture of the interrelationships between the system components and how the requirements may be delivered.

### 3.3.3 Operating Characteristics

An understanding of the actual (as opposed to the required) operating characteristics requires data collection across the demand, network and supply components of the system, and quantifying the relationship between electricity use and the relevant business driver of system demand.

Appendix 2 contains forms that identify the data required to gain such an understanding and that are potentially useful for an 'investment level' audit. More detail on the measurements of that data is provided below.

For 'base level' audits, Appendix 3 provides several forms that identify:

- a minimum level of data needed to estimate a compressed air system's annual electricity use; and
- a checklist that could be used to assess the key components of the system as they affect system efficiency.

Air compressor run-hour data should be verified by site personnel wherever possible, as the economics of potential efficiency opportunities will depend heavily on that information.

### 3.3.4 Electricity Use and Business Driver Relationship

For investment-level audits, the baseline electricity usage measurement obtained from the audit should quantify the Compressed Air System Electricity Intensity (CEI), expressed as total air compressor electricity consumption per unit of the productive business driver (e.g. kWh per kg of production output). In addition, the audit should determine (and quantify) any relationship between the CEI and different levels of production activity.

The nature of the monitoring should be governed by the key driver of the compressed air system electricity input, whether that is another production input, output or merely hours of operation.

For the purposes of measuring the CEI, all compressors used in supplying the production process should be included in the measurements. Exceptions may be small compressors in workshops or remote locations.

### 3.3.5 Demand Measurements

It is important to begin analysis from the demand side of the compressed air system, as this dictates air volume, pressure and quality requirements on compressor capacity. For each system being audited, where practical, record:

- Types of application the air is being used for, such as:
  - Air tools, spray painting
  - Duster orifices
  - Stirring / agitation

- Air transportation
- Solenoids, valves, cylinders
- Instrumentation; check pressure regulation and filtration
- Air-use isolation practices;
- Inappropriate uses;
- Peak-load shedding practices; and
- Air leakage, estimating each leak rate where practicable.

### 3.3.6 Network Measurements

It is recognised that, because of the range of configurations of filters, receivers and dryers, allocating equipment between supply and network can be arbitrary. Although the role of filters and receivers at various points in a system varies, they will be addressed within the network sections of this standard, dryers will be addressed within the supply-side sections.

The focus of the compressed air network measurements is to identify:

1. the causes of any pressure drop between the compressor or dryer outlet and the point of use, and;
2. the actions required to reduce that loss to an acceptable level (less than a 10% supply pressure loss).

For each system being audited, record key characteristics of the compressed air network, giving consideration to:

- pipework configuration and sizing — note unnecessarily long pipe runs or unsuitable joints;
- areas of high pressure/frictional losses including those resulting from under-sized pipework;
- the level of system maintenance practiced;
- critical valves and in-line filtration — correct sizing, orientation and pressure drops; and
- pressure regulators and receivers — note location relative to compressors and work stations.

Note that identifying areas of high pressure loss and frictional loss may require additional software assistance. There are several software packages that may aid in identifying potential network inefficiencies.

### 3.3.7 Supply Measurements

The compressed air supply system measurements cover three broad aspects:

1. The environment around each compressor (compressor room/s);
2. Moisture separators and dryers, and;
3. The air compressors themselves.

For each system being audited, record key characteristics of the compressed air system supply side, giving consideration to:

- Nameplate information of each air compressor, including model, type, rated air flow;
- Air compressor motor information, including kW rating;
- Air compressor motor electrical logging for the period specified through the audit scoping;
- Air compressor environment, including intake, exhaust and ambient air temperatures and description of compressor ventilation;
- Pressure setpoints of each air compressor;
- Compressor operation scheduling and compressor control, particularly with respect to the 'trim' compressor;
- The level of air compressor maintenance which takes place;
- Condensate drains / oil separators — suitable installation, type and control, leakage; and
- Dryer information — type, rated capacity, other relevant information such as dew point.

## 4.0 Data Analysis

For a 'base level' compressed air system audit, observations and measurements are relatively low in detail, and analysis consequently relies on significant assumptions. In many cases, it will be impossible to make any further conclusions about the operation of the system without equipment to take more in-depth measurements.

For an 'investment level' compressed air system audit, observations and measurements must be in much higher detail than for a 'base level audit'. This minimises assumptions that must be made for subsequent analysis.

### 4.1 Demand versus Requirements

Optimisation of compressed air demand requires the analysis of its use. Solutions to improve the efficiency of compressed air use include<sup>4</sup>:

- Automated isolation of compressed air users;
- Mitigate inappropriate uses of compressed air;
- Reduction of compressed air consumption by users;
- Reduction of pressure requirements by users;
- Reduction of air flow requirements by users; and
- Reduction in compressed air leaks.

Any improvement in the use of compressed air on the demand side ultimately reduces the energy input required from air compressors within a system.

When looking to reduce the air flow through a system, extra consideration must be given to the devices that may be affected by this flow reduction. Reducing the flow rate through some compressed air-using devices can reduce their effectiveness and in some cases damage them. It is important to understand the entire compressed air system's operation before recommending any flow reductions or control changes.

#### 4.1.1 Inappropriate End Use and User Isolation

Since compressed air is a relatively expensive form of energy, its use should be minimised to applications that require its use. Since compressed air is relatively accessible it is often used due to its relative simplicity. In many instances the application of compressed air can be considered inappropriate, and there is often a more energy-efficient alternative. If inappropriate end-use of compressed air is identified by quantifying the energy consumption associated with the air flows, the client should be made aware that they should investigate alternatives. Refer to Appendix 5 for some examples of inappropriate compressed air uses.

#### 4.1.2 Air Leakage

Air leakage of up to 10% can occur even in efficient compressed air systems - leakage above that rate can be very costly. Analysis of air leakage requires an estimation of the amount of leakage (flow loss) and an estimation of the cost associated with this loss. This can be based on the turndown efficiency of the trim compressor as described in Appendix 5.

In the case of an investment-level audit, it is expected that an ultrasonic survey is undertaken. In this case, the flow rate and cost must be estimated for each individual leak discovered. Each leak should be described in an air leak report so that repair can be conducted in a timely fashion. A report should contain the following information for each leak:

- Picture of leak (often tagged for ease of identification);
- Description of location;
- Pressure at location;
- Leak rate;
- Energy cost, and;
- Cost of repair.

Documentation of these leaks is a very important part of air leak management and ideally should be compatible with site maintenance programmes. The repair of each leak should be documented so that the effectiveness of air leak detection and repair can be monitored.

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<sup>4</sup> Although not an air or energy efficiency measure, opportunities to schedule compressed air system operation outside electricity network peak charge periods should also be noted

## 4.2 Compressed Air System Network

Analysis of a compressed air system network requires the determination of air delivery efficiency. This requires the measurement of pressure losses and flow through different sections of the network.

Solutions to improve the efficiency of compressed air delivery include:

- Reducing pressure drops across incorrectly installed valves or dirty filters;
- Reducing system pressure drops as a result of excessive frictional losses (often caused by undersized pipework);
- The optimising of pipe configuration;
- Improved network maintenance; and
- Ensuring sufficient air receiver capacity.

It is difficult to determine the efficiency of compressed air delivery without accurate measurements of flow and pressure.

If it is noted that network maintenance practices are poor, it is suggested that a percentage improvement in system energy efficiency can be expected as a result of improved practices.

## 4.3 Compressed Air System Supply

Analysis of a compressed air system supply requires a review of the suitability and controls of the compressors; the performance of the **dryers, condensate drains and oil-water separators**; and compressor maintenance practices.

### 4.3.1 Air Compressor Suitability and Controls

Each air compressor in a compressed air system must be assessed for its suitability within the system, as must the control of each compressor in a multiple compressor system. Different compressors, capacity control methods, and multiple-compressor control systems are identified in Appendix 5.

That assessment requires a thorough understanding of the air demand requirements, and the compressor and control systems specifications. If control inefficiencies are found during the analysis, they should be identified and included in the audit report.

For investment-level audits, it is important to datalog the coincident power (kW) demand of each compressor.

For, base-level audits, data plate information and catalogue information can provide the kW power draw at a given pressure and outlet flow. If there is reason to verify the data plate specific power figure of a compressor at a particular pressure setting, power and flow measurements will be required..

### 4.3.2 Dryers, Condensate Drains and Oil-Water Separators

Unless excluded from the audit scope, the operation of auxiliary supply-side systems that affect the efficiency of compressed air supply should be assessed. Dryers, condensate drains and oil-water separators are particularly important.

**Dryers** perform a crucial service in removing moisture from the air and (ideally) they will have been sized to provide air quality to a production requirement. They should operate to meet the air quality demand, and the audit should investigate the energy efficiency of achieving that. Dryer operation can normally be optimized by adjusting the dew point (for refrigerant dryers) or changing regeneration cycle (for desiccant dryers). Refer to Appendix 5 for further details of different dryer types.

**Drains** provide for the removal of condensate from the compressed air system. Poorly maintained drains can waste a significant amount of air and energy.

There are four main types of condensate drain;

- Manual drains: valves are manually opened by operators;
- Level (or zero air loss) drains: float-activated drains that remove condensate without air leakage; and
- Automatic drains: solenoid valve opens at regular intervals,

The audit should consider the efficiency risks associated with each type in the system concerned. Manual drains can be prone to being left open; level drains and automatic drains provide efficiency opportunities – with appropriate maintenance and valve settings.

**Oil-Water Separators** remove the oil from the collective condensate drains, preventing contamination of the of the waste water drainage. The audit should assess the efficiency of the operation of these systems.

#### 4.3.3 Air Compressor Maintenance

There is a direct link between compressor maintenance and compression efficiency. It is important for an auditor to identify whether maintenance appears to be carried out appropriately.

The audit should identify whether a routine maintenance schedule is in place, and the extent to which the scope and frequency of the scheduled maintenance aligns with that recommended in the manufacturers' documentation. The maintenance schedule should include:

- Compressor mechanical components;
- Lubricant condition;
- Heat-exchange surfaces;
- Compressor motor and drive condition;
- Drive-belt condition and tensioning; and
- Cooling system operation.

### 4.4 Inter-relationships

A compressed air system analysis may identify an efficiency opportunity in one part of the system that (if taken) will have an impact on the value of an opportunity in another part of the system. When quantifying such savings opportunities, it is important to identify whether the quantity includes or excludes the effect of the inter-relationship.

An efficiency opportunity that is quantified on the assumption that an inter-related opportunity is also taken, should be notated as a 'dependent' opportunity. That is, the savings quantified is dependent on uptake of the related opportunity.

As significant generators of heat, compressors can be heat sources to other processes on the client's site. Compressed air systems audits should include the identification of opportunities for the installation of energy recovery systems.

### 4.4 Air Balance and Energy Balance

In line with the requirements of AS/NZS3598.2:2014, all grades of audit should establish an energy-end use balance to ensure that the system energy use is well understood and properly reconciled. For a compressed air system this also means that an air-balance is required.

For a basic grade energy audit, it is sufficient for these balances to be built up from observations and projections of system operation. For an investment grade audit, the measurement process should be designed to inform the energy and air balances. Note that for air compressors with heat recovery a more complex balance will arise, including consideration of the capture and utilisation of waste heat.

For guidance on the requirements for energy and air balances, refer to the following sections of AS/NZS3598.2:2014:

- Section 11.6.4 Analysis
- Section 11.6.6 (a) (ii)

For investment grade audits, it is essential for the energy balance and air balances to include consideration of time varying demands, and indeed reconciliation of such demands is of considerably greater use than a simple annual pie chart. An example of what a time-of-use energy balance would look like is shown below:

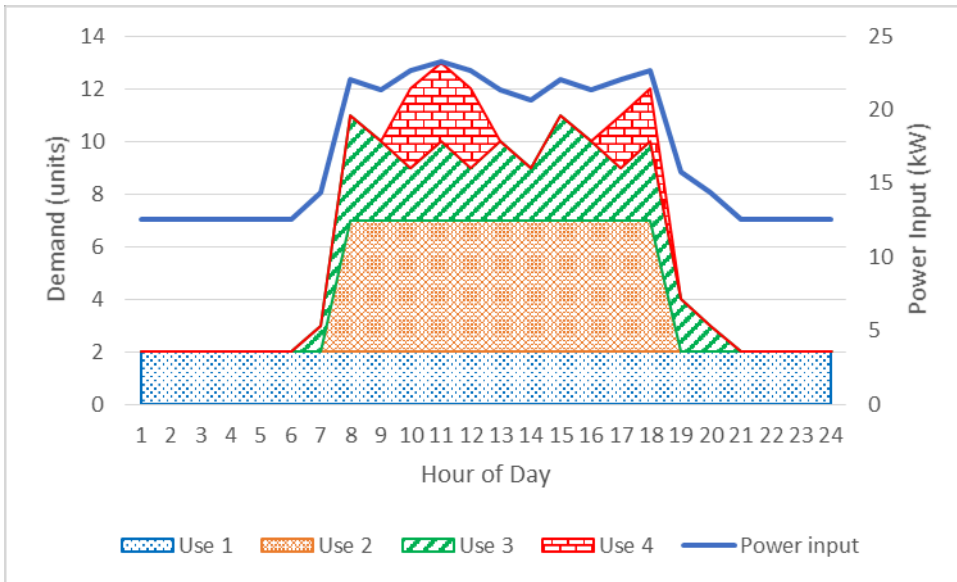


Figure 3. Example of a time of use energy use breakdown

For all audit types, the end-use balance must be used as the basis from which savings calculations are made.



## 5.0 Measures

For an energy audit to be of value, it is essential that measures are well framed. The framework for useful energy efficiency measures is laid out in AS/NZS3598.2:2014, which should be followed closely.

### 5.1 Type 1: Basic Energy Audit ('basic grade')

For a Type 1: Basic Energy ('basic grade'/'base level') measures should be based on:

- Indicative savings calculated based on rules of thumb or basic calculation, reconciled to the energy end-use breakdown and the air balance;
- Typical paybacks for nominated measures
- At least 80% of savings measures with simple paybacks of less than 2 years quantified to a broad level of accuracy
- At least half of measures with simple payback of greater than 2 years quantified to a broad level of accuracy

The audit should include identification of measures that could be better qualified with additional measurement or investigation.

The guiding standard for the presentation of measures in a basic grade audit is AS/NZS359.2:2014 Section 11.4 in general and Section 11.4.6 in particular. The definition of "broad level of accuracy" can be found in Section 5.1 of the Standard.

### 5.2 Type 3: Precision Subsystem Audit ('investment grade')

For a Type 3: Precision Subsystem ('investment grade'/'investment level') audit, measures meet the following parameters:

- Measures to be quantified and specified to the extent necessary for a recommendation to be made;
- Energy savings to be quantified to a medium or higher level of accuracy
- Energy savings reconciled against the energy balance and air balance.
- Cost of implementation based on a complete view of costs as discussed in Section 3.2.6 of this document
- Cost savings to include energy and non energy savings (e.g. maintenance)
- Electricity demand savings to be separately identified within the electricity cost savings estimates
- Payback to be calculated for each measure
- Measures to be presented in a logical implementation sequence.

The guiding standard for the presentation of measures in an investment grade audit is AS/NZS3598.2:2014 Section 11.6 in general and Section 11.6.6 in particular. The definition of "medium" and "higher" levels of accuracy can be found in Section 5.1 of the Standard.

## Appendix 1 — Site Information Form

<b>Business Name</b>	
<b>Site physical address (Street, Suburb, City)</b>	
<b>Nature of site / business operation</b>	

<b>First day of onsite loggings</b>	
<b>Final day of onsite loggings</b>	
<b>Production during period of loggings</b>	
<b>Electricity Supplier</b>	
<b>Power factor correction equipment in use</b>	
<b>Delivered electricity cost per kWh</b>	

<b>Site contact 1:</b>	<b>Name</b>	
	<b>Designation</b>	
	<b>Telephone (DDI)</b>	
	<b>Email</b>	
<b>Site contact 2:</b>	<b>Name</b>	
	<b>Telephone (DDI)</b>	
	<b>Email</b>	

<b>Comments:</b>

## Appendix 2 — System Data Collection Forms

Air Users			
User Name / System Reference	Description / Comments	Pressure Measurement	Flow Measurement
Air Leaks			
Description	Leak Estimate	Comments	
Operational Information			
Production Information			
Other notes			

Network Schematic			
System Reference		note: include dimensions, valves, receivers, joints etc.	
Pipework / Valve Information			
Pipework		Valves and Filters	
Material		Valve and filter types (refer schematic)	
Size Range (refer schematic)			
Joint Types (refer schematic)			
<i>Pipe Section</i>	<i>Measured Pressure Losses</i>	<i>Valve / Filter</i>	<i>Measured Pressure Losses</i>
Other notes (e.g. receiver capacities, regulators)			
Operational Information			
Maintenance Information			
Other notes			

Compressed Air Supply Information			
		Unit	Comments
<b>Air Compressor Details</b>			
System Reference			
Manufacturer			
Model			
Serial			
Compressor Type			
Operating Pressure Setpoints		barg	
Rated Air Flow		m <sup>3</sup> /min	
Rated kW		kW	
<b>Air Compressor Room</b>			
Outside Ambient Temperature		°C	
Intake Air Temperature		°C	
Ventilation (forced/non-forced)			
Cooling air ducted (Yes/No)			
Condensate Drains			
<b>Dryer Information</b>			
Manufacturer			
Model			
Dryer Type			
Pressure Dewpoint		°C	
<b>Measurements</b>			
Electrical Meas. / Logging Ref.		kW	
Flow Meas. / Logging Ref.		m <sup>3</sup> /min	
Pressure Meas. / Logging Ref.		barg	
Temp. Meas. / Logging Ref.		°C	
<b>Operational Information</b>			
Annual run hours		hours	
Maintenance Information			
Production Information			
Other notes			

# Appendix 3 — Type 1: Basic Energy Audit ('basic grade'/'base level') Data Collection Form

One per compressed air system

Baseline Consumption Table

CA System: 1		Description: (e.g.) Factory CAS						
<b>Fixed-Speed Compressors</b>								
Comp. ID	Model	Type	Rated (kW)	Proportion of Time On-Load	Off-Load Run Factor*	Annual Run Hours	Off-Load Power Contribution**	Annual Usage (MWh)***
#1 (e.g.)	ABC 123	Lubr. Screw	75	0.7	0.3	4000	0.09	237
#2								0
...								0
<b>Variable Flow Compressors</b>								
Comp. ID	Model	Type	Rated (kW)	Average Output	Annual Run Hours	Annual Usage (MWh)****		
#3 (e.g.)	CBA 321	VSD Screw	55	0.75	4000	165		
#4						0		
...						0		
							Allowance for dryers and/or cooling (extra 10%)	40
							<b>Total</b>	<b>442</b>

\*Proportion of rated power consumption compressor uses when un-loaded. Lubricated rotary vane = 0.5; Lubricated screw = 0.3; Non-lubricated screw or rotary = 0.2, Reciprocating or centrifugal = 0.1

\*\*Off-Load Power Contribution = (1 - Proportion of Time On-Load) x Off-Load Run Factor

\*\*\*Annual Usage = {(Rated kW x (Proportion of Time On-Load + Off-Load Power Contribution)) x Annual Run Hours} / 1000

\*\*\*\*Annual Usage = (Rated kW x Average Output x Annual Run Hours) / 1000

## Compressed Air System Base-Level Assessment Checklist

	Efficiency Opportunity Element	Opportunity for Efficiency Improvement			
		LOW	MED	HIGH	Comments
<b>DEMAND</b>	System/machine isolation	Solenoid or auto shut-off	Manual shut-off	No shut-off	
	Inappropriate use of compressed air	e.g. controlled nozzles	e.g. unregulated blowing	e.g. liquid agitation	
	Excess pressure requirement <sup>5</sup>	≤0.5 bar	1.0 bar	≥1.5 bar	
	Air leakage	<10%	10%-20%	>20%	
<b>NETWORK</b>	Condensate drainage method	Non-leak automatic	Timed drains	Manual drains	
	Leak and other maintenance management	e.g. contracted routine testing	Irregular	Minimal effort, repairs as needed	
	System pressure drop	≤0.5 bar	≤1.0 bar	>1.0 bar	
<b>SUPPLY</b>	Air compressor maintenance	Regular, contracted	Irregular, not contracted	Corrective only	
	Primary air compressor control method	VSD/variable flow	Intake modulation	Load/unload	
	Multiple air compressor control method	VSD and PLC controller	PLC	Pressure cascade	
	Compressor room temperature (°C over ambient)	≤5°C	≤10°C	>10°C	
	Air intake quality	Ducted clean air	Dusty intake	Very dusty intake	
	Compressor operating pressure	≤6.5 bar	≤7 bar	>7.0 bar	
	Air treatment; dryers	Refrigeration	Heat of compression	Desiccant purge dryer	
	Pressure drop across dryer and filter	≤0.3 bar	≤0.4 bar	>0.4 bar	

<sup>5</sup> Includes opportunities related to pressure regulation for lower-pressure applications.

## Appendix 4 — Measurement Accuracy Implications

Consideration of measurement accuracy should be aligned with the latest applicable AS/NZS3598.2:2014 (Industrial and Related Activities) measurements section.

**Special Note: The following information about accuracy may be useful, however falls outside the requirements of AS/NZS3598.1:2014 (Commercial Buildings) and AS/NZS3598.2:2014 (Industrial and Related Activities):**

When considering an overall audit accuracy requirement, the effect of cumulative measurement errors and manufacturer data inaccuracies must be taken into account.

As an example, the power savings achieved by operating an air compressor at a reduced upper activation pressure compared to a high upper activation pressure can be estimated using the fractional power savings equation. The components of the fractional savings equation are used below to demonstrate how to assess the effect of each component's accuracy on the overall accuracy:

$$\text{Frictional Savings} = \frac{\left(\frac{P_{high}}{P_1}\right)^{0.286} - \left(\frac{P_{low}}{P_1}\right)^{0.286}}{\left(\frac{P_{high}}{P_1}\right)^{0.286} - 1}$$

Where:

- $P_{high}$  = upper compressor activation pressure (bar, absolute)
- $P_{low}$  = lower compressor activation pressure (bar, absolute)
- $P_1$  = inlet air pressure (typically 1.0 bar absolute)

The total accuracy of the combined equation can be expressed as follows:

$\frac{\Delta x}{x}$  Where  $\Delta x$  is the 'maximum inaccuracy' possible for a given absolute measurement  $x$ .

For each term of the fractional savings equation, the maximum possible percentage errors are added.

$$\frac{\Delta P_{high}}{P_{high}} + \frac{\Delta P_{low}}{P_{low}} + \frac{\Delta P_1}{P_1}$$

An example of how a percentage error term can be evaluated is as follows:

If a data logger used for electrical power measurement has a rated accuracy of  $\pm 0.01\text{kW}$  and an average absolute measurement of  $12\text{kW}$  has been recorded, the maximum percentage error would be:

$$\frac{\Delta \text{Power}}{\text{Power}} = \frac{0.01\text{kW}}{12\text{kW}} = 0.083\%$$

Alternatively, if the data logger stated an accuracy of  $\pm 0.2\%$ , the term  $\frac{\Delta P}{P}$  would simply equal  $0.2\%$ .

Adding each percentage error term for each measurement used within an equation provides the total maximum possible percentage error for a given calculation.

Other potential sources of error include:

- Air compressor manufacturer data
- Assessment of drive system efficiency, for example a VSD setup
- Assessment of motor efficiency

Error can be minimised by taking as many relevant measurements as practical; for example, the operating point and motor efficiency of an air compressor can be more accurately determined by measuring air flow rate, differential pressures and motor electrical power consumption.



Given that accuracy is a combination of a number of variables, the auditor needs to be aware of the main sources of inaccuracy for the measurements and system concerned.

## Appendix 5 — Glossary of Terms

**Air Compressor** — In the context of this document, an air compressor is defined as a mechanical device used to impart motion on gases, increasing their pressure by a ratio of over 1.2 (higher than for a fan or a blower).

**Air Compressor Efficiency** — The power imparted to the air divided by the air compressor input power.

**Air Filter** — Device used to separate particulates from the compressed air stream, such as moisture or lubricant.

**Air Receiver** — Otherwise known as an accumulator, a receiver is a vessel used for storage of compressed air so that peak demand requirements can be met without excessive localised pressure fluctuations.

**Airline Coupling** — Refers to the connecting joint between multiple air lines, such as push-pull fittings or screw connections.

**Annual run hours** — The total hours each year that the compressor motor is running.

**Baseline Consumption** — Estimated compressed air system annual energy consumption.

**Blower** — In the context of this document, a blower is defined as a mechanical device used to impart motion on gases, increasing their pressure by a ratio of between 1.11 and 1.2 (higher than for a fan). In other words, a blower moves volumes of a gas with moderate increase of pressure. Use of the word 'blower' refers to a lobe, rotary screw, rotary vane, side channel or other blower type.

**Branched Compressed Air System** — A branched system has several compressed air lines feeding out to each compressed air user without a central line feeding back on itself (as opposed to a ring main compressed air system).

**Compressed Air** — In the context of this document, air that has been compressed to a pressure at least 20% higher than atmospheric.

**Compressed Air User** — Any device relevant to the business operation, that requires the use of compressed air to perform an appropriate task, such as pneumatic actuation.

**Compressed Air System** — An air compressor or group of air compressors along with the other components relevant to the compressed air. Some of these components include the motors, filters, air dryers, accumulators, airlines and valves.

**Compressed Air System Energy Intensity (CEI)** — The energy intensity of a compressed air system with respect to a related key business driver, e.g. kWh per kg of production.

**Differential Pressure, Filter** — The difference in pressure between a filter's inlet and outlet.

**Desiccant** — Material that is used in some air dryers due to its porous structure and ability to extract water vapour from air.

**Dew Point** — Temperature at which air moisture will begin to condense at a given pressure.

**Drain** — Compressed air system component used to remove water condensate from air lines.

**Duration Curve** — A graph depicting the amount of time that compressed air demand exceeds a certain value.

**Fan** — In the context of this document, a fan is defined as a mechanical device used to impart motion on gases, increasing their pressure by a ratio of up to 1.11. In other words, a fan moves large amounts of gas with low increase in pressure. It can generally be said that a fan's purpose is to mobilise air rather than to compress it. Fans are addressed in a separate audit standard.

**Free Air Delivery (FAD)** — The air delivery rate achieved by an air compressor at its rated speed and under set conditions, often measured in normalised  $\text{m}^3/\text{min}$ .

**Flow Balance** — A diagram or table showing the measured or estimated compressed air flows through different parts of a compressed air system.

**Gauge Pressure** — The pressure as measured by a gauge installed on a compressed air system. Note that the value is relative to atmospheric pressure and is therefore 1 bar less than an absolute pressure measurement.

**Key Business Driver** — The parameter against which the compressed air system's energy consumption is measured for benchmarking and monitoring purposes. This determines the Compressed Air Energy Intensity (CEI) of the system. An example of this may be production (kg).

**kVA** — Common unit for apparent power, which is the total power that appears to be flowing from a source to a load.

**kW** — Common unit for real power, which is the actual net power that is flowing from a source to a load.

**Load/Unload Control** — Air compressor control method where the compressor runs at full-load or at no-load while the motor remains at a constant speed.

**Modulating Control** — Air compressor control method where the demand is met by regulating the compressor's output via inlet throttling or compression chamber reduction (Turn valve).

**Motor Efficiency** — The motor efficiency is defined as the energy delivered from the motor to the coupling divided by the energy delivered to the motor.

**Peak Load** — The peak power consumption of a site. This often determines the demand charges incurred by the site and should therefore be taken into account when considering the operating times of compressed air systems.

**Pneumatics** — The use of pressurised gas (in this context air) to generate mechanical motion.

**Power Factor** — Ratio of real power to apparent power.

**Power vs. FAD Graph** — Graph depicting a compressor's ability to 'turn down'. The graph typically has a relatively straight line, the slope of which can be considered the 'turndown efficiency'.

**Ring Main Compressed Air System** — A ring-main system has one main compressed air line which loops back on itself, with lines coming off this feeding out to each compressed air user (as opposed to a branched compressed air system).

**Shaft Input Power** — The power delivered to the shaft of an air compressor.

**Specific Power** — A common measure of air compressor effectiveness, usually in the form of kW/m<sup>3</sup> per min.

**Start/Stop Control** - Air compressor control method where demand is met by switching the compressor on or off.

**System Boundary** — Boundary defined by the auditor, which encompasses the compressed air system components to be analysed.

**Trim Air Compressor** — Compressor that meets the variable component of compressed air demand. This is as opposed to base-load compressors which operate at their capacity. Note that any compressed air flow reductions are assumed to come off the supply of the trim compressor.

**Turndown Efficiency** — The ability of a compressor to decrease its power consumption with diminishing air demand, typically measured in kW/m<sup>3</sup> per min. Note that a compressor's turndown efficiency is the slope of its Power vs. FAD graph.

**Valve** — Device that directs flow into an alternative path or that restricts flow, typically used to shut off flow completely in the case of compressed air systems.

**Variable Speed Control** — Air compressor control method where the speed of the air compressor is varied to meet the compressed air demand.

**Variable Speed Drive (VSD)** — A variable speed drive (VSD) is a system for controlling the rotational speed of the electric motor to match (in this context) the air flow demand.

**Venturi** — Device used to alter the pressure through a tube by restricting gas flow.

# Appendix 6 — Recommended Report Outline – Type 3: Precision Subsystem Audit ('investment grade'/'investment level'). Ref AS/NZS3598.2:2014

This appendix provides a recommended outline of the structure and contents of the report used for reporting of the process, findings and recommendations from an audit, conducted according to this Compressed Air Systems Audit Standard.

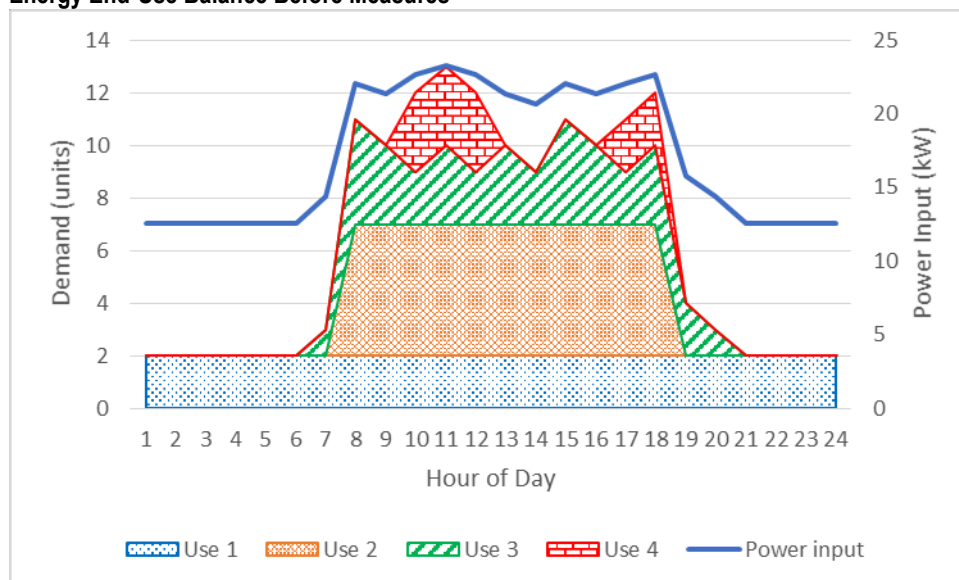
The following describes the recommended structure and content of the audit report, section by section.

## Executive Summary

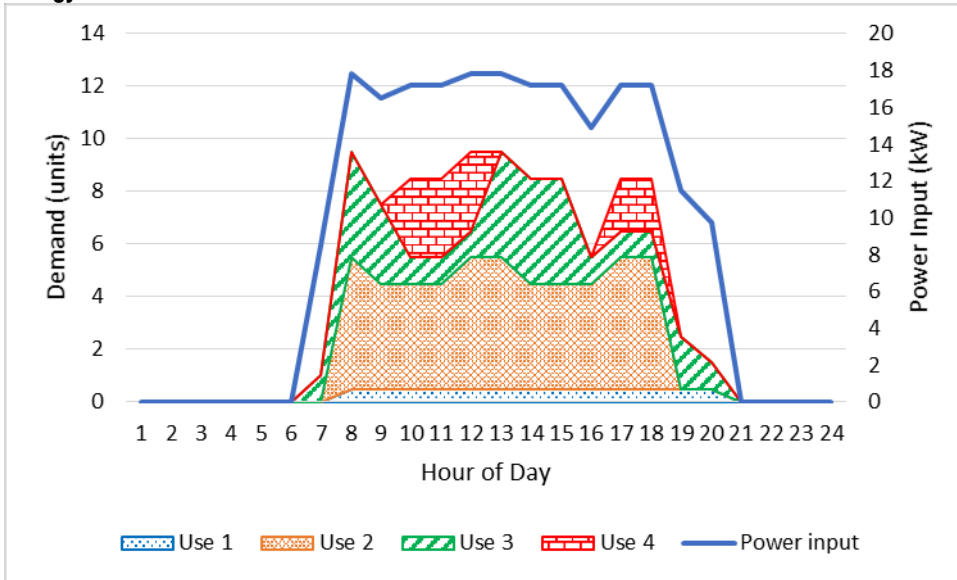
- Identify the organization, date of audit, name of person who commissioned the audit and the identity and location of the system being audited.
- Comment on the performance of the system relative to benchmarks of average and best practice
- Identify the energy use of the existing system and the associated cost, the key measures proposed and the change in these figures arising from the proposed measures.
- Provide a table of the proposed measures including identification, for each measure, of the associated capital cost, energy saving (kWh and \$), demand saving (kVa/kW and \$), maintenance or other operational savings, and payback.
- Provide a graphical summary of the energy end-use breakdown of the system before and after the propose measures.
- State the energy tariffs used for calculations and the GST status of dollar figures throughout the report.

Recommendation Identifier and Report Section Ref	Depend-ency	Electricity Saving (kWh p.a.)	Demand savings (kW/kVa)	Annual cost saving (\$)	Implementation Cost (\$)	Simple payback period (years)
<b>Shorter payback measures (&lt;4 years)</b>						
Rec #1 Sec x.x.x						
Rec #2 Sec x.x.x						
<b>Longer Payback Measures (&gt;4 years)</b>						
Rec #3 Sec x.x.x						
Rec #4 Sec 4.x.x						
<b>Energy Management Measures</b>						
Rec #5 Sec x.x.x						
Rec #6 Sec x.x.x						

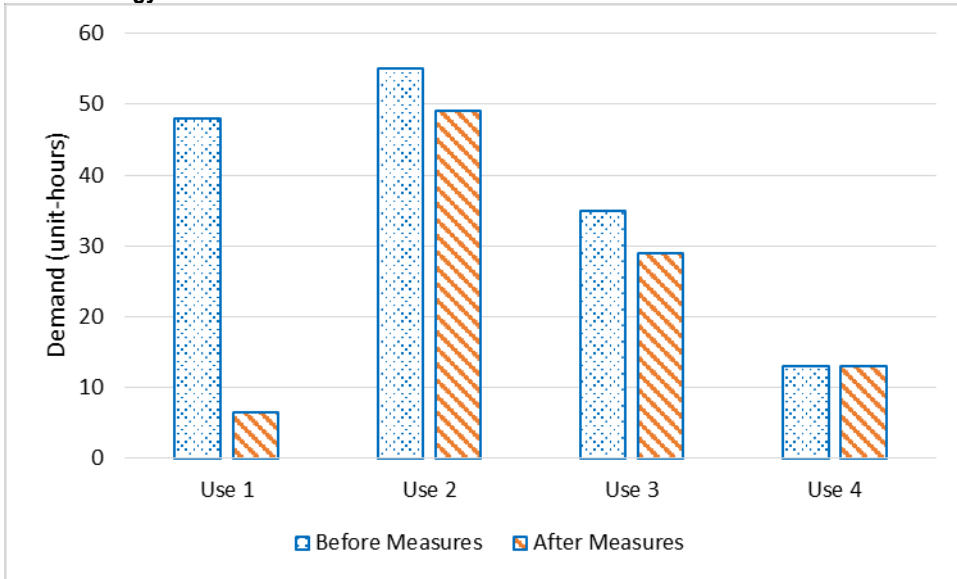
**Energy End-Use Balance Before Measures**



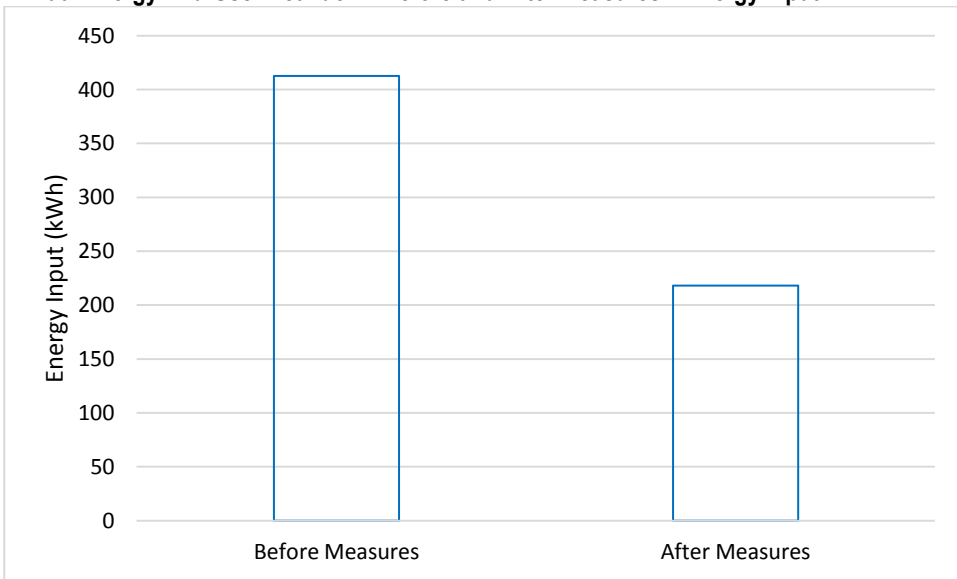
**Energy End-Use Balance After Measures**



**Annual Energy End-Use Breakdown Before and After Measures – Demand Side**



**Annual Energy End-Use Breakdown Before and After Measures – Energy Input**



## 1. Business Context

This section should cover basic information about the business and the objectives and scope of the audit.

### Basic information

Include here the:

- identity of the client and site location for which the audit is performed;
- date of the compressed air systems audit
- name of the client manager and other key personnel interfacing with or assisting the compressed air system audit;
- name, credentials and contact details of the compressed air system auditor.

### Site operating characteristics

Describe here the operating characteristics of the site, including:

- a brief outline of the current operations of the plant, with description of the main site activity that the compressed air systems are required to support;
- the effects of any expected future changes to the nature or volume of the site activity that may have an effect on the site compressed air system requirements.

### Objectives and scope of the audit

Describe here:

- the objectives of performing the audit. For example, it may be to provide the client's management with a general understanding of areas of potential (as would be expected from a base-level audit) or it may be to support a capital expenditure proposal on a substantial refurbishment or redesign;
- the scope of the audit (all or a selection of systems on the site)
- any useful background to the objectives and scope, including any prior scoping work and key clauses from any agreement between the client and the auditor;

## 2. Compressed Air System Overview

Include a high-level description of the system, identification of the business drivers and the means by which the audit results can be extrapolated to annual operating characteristics.

### Description and requirements

Include a description of the compressed air system(s) and its configuration, with reference to schematic drawings in an appendix to the report.

Describe the requirements that the business expects from the audit, including:

- a description and quantification (air flow and pressure) of what the compressed air system(s) needs to deliver to enable the business to operate efficiently;
- identification of the site activity (e.g. production output or raw material input) that will be used as the key driver of compressed air system use and that will be used in the energy intensity measure for the compressed air system;
- identification of whether the compressed air system requirements can be characterised as constant demand, multi-stage demand or variable demand;
- information on the operating profile of the main site activity (e.g. volume of production), showing weekly and monthly/seasonal profiles;
- any relevant benchmark information that may be available from site history or from intercompany comparisons on the compressed air system's energy intensity; and
- description of any management policies or practices (e.g. safety or community matters) that influence the compressed air system design or operational requirements.

### Baseline energy intensity

This involves quantification of the relationship between the site activity (e.g. production output or raw material input) identified as the key driver of the compressed air system and the system's electricity usage, using the daily data collected during the audit period.

This should include the:

- method for quantifying the daily site activity driving the compressed air system energy usage;
- method for quantifying the daily kWh usage from the air compressor data-loggings or other measurements taken during the audit, and;
- the audit-period average and of the compressed air system electricity intensity value (the baseline CEI) for the period of the audit.

Having each day's value of the CEI relationship may enable the effect of variations in activity level on the CEI to be quantified and included in any subsequent analysis of the system where the activity level is different from the average during the audit period. The relevance of the individual day's CEI figures will be dependent on the driver and the ability to obtain activity levels of sufficient accuracy on a daily scale.

If the client considers activity figures too commercially sensitive for inclusion in the report, include only the baseline CEI.

### **3. Audit Measurement Methods**

This section should cover the measurement methods used during the audit and identify (and rationalise) any variations between the actual measurement methods and those recommended in the Audit Standard.

#### **Leakage measurement**

Include here a description of the measurement method and any subcontracted service used in the process. For example:

- describe how the overall contribution of leaks was quantified, using the 'after-hours' method or by summation from the results of a leak survey, or;
- if an ultrasonic detection method was used to detect leaks:
  - the equipment used;
  - the date of the survey (particularly if referencing a prior survey); and
  - the identity and credentials of the person who performed the service.

#### **Electricity usage measurement**

Include a description of electricity measurement methods used for the audit period, including any metering installed for subsequent (post-implementation) performance monitoring and the extent of any reconciliations performed between temporary and permanent meters.

For each compressed air system involved, describe:

- the metering and data recording methods used, and the units measured;
- the air compressor motors logged; and
- the period(s) and duration(s) of the measurements.

Inclusion of demand duration curves and flow balances are useful ways to describe and assist analysis of system demand.

#### **Electricity cost measurement**

Describe the method of quantifying the unit cost of electricity as appropriate for valuing any reduced consumption resulting from implementing a recommendation.

Costs should be based on future price expectations and recognise the fixed and variable (per-kWh) components of delivered electricity prices. Where the client is subject to time-of-use and/or peak demand pricing, consideration should also be given to the time periods in which the systems operate, and therefore in which any energy savings are likely to occur. These considerations are most relevant when the audit results are to be used for investment proposal purposes.

#### **Pressure measurement**

Include here:

- a description of the pressure and pressure-difference measurement methods used for each of the measurement locations;
- the method and currency of the calibration of the pressure measurement instruments;
- identification of where pressure differences are estimated, the method of estimation and reason for estimation.

## **Flow measurement**

Include here information on:

- the location and timing of any flow measurements taken;
- the flow measurement method and technology employed (intrusive or other),
- the method and currency of the calibration of the pressure measurement instruments; and
- identification of where flows are estimated, the method of estimation and reason for estimation.

## **Measurement of inappropriate use**

Describe here how the flow rate and energy waste from inappropriate uses was identified, and how the energy use of the alternative technologies and energy sources is quantified.

## **Estimates of implementation costs**

Provide here the method or methods used to estimate the costs of implementing the actions included in the recommendations. This should include:

- the sources of the cost estimates;
- the level of accuracy that can be expected; and
- whether or not any preferred suppliers are involved.

## **4. Audit Findings**

For each of the systems within scope, this section should describe, analyse and quantify opportunities for efficiencies in a logical sequence from demand through the network to supply. Discussion of opportunities for change should include consideration of other viable options along with the recommended action.

For each recommended action, there should be:

- a description of the efficiency opportunity;
- transparent calculations of the energy and other savings potential;
- a cost estimation of implementing the proposed action;
- a simple payback period (or other net benefit measure), as applicable to the audit scope/accuracy requirement;
- identification of any alternatives to the recommended action; and
- identification of dependencies, where a particular recommendation may be dependent on the implementation of some other recommendation or other plan

The detailed cost-benefit calculations that support each recommendation should be included as part of an appendix.

### **System demand side**

From the measurements of flow and pressure at key points of demand on the compressed air system, and from the (power) demand profile taken at the air compressor motor, discuss the various opportunities relating to system features driving demand.

#### **Peak load trimming or shifting**

Include here a description of any opportunities related to trimming or shifting of peak demand of compressed air use.

#### **Inappropriate end uses**

Identify and describe the applications where the use of compressed air is not the most appropriate (energy-efficient) means of achieving the business purpose. For each material case of inappropriate use:

- describe the application and end-uses concerned;
- the volume of air flow associated with the inappropriate use;
- the realistic options available to the client to remedy the situation and the savings achievable by taking such actions; and
- the recommended (most cost-effective practicable) action.

#### **Isolation opportunities**

Identify and describe the applications where the compressed air users can be isolated between their operating periods.

#### **Pressure reduction**

Identify and describe the applications where the localised pressure can be reduced. These are distinct from the opportunity to reduce pressure at the supply source, as an opportunity to reduce pressure system-wide would be covered in the 'supply side' section of the report.

#### **Flow reduction**



Identify and describe the applications where the localised flow can be reduced. These are distinct from the opportunity to reduce flow at the supply source, as an opportunity to reduce flow system-wide would be covered in the 'supply side' section of the report.

### **Air leakage**

Identify and quantify the total amount of leakage, and specify the priorities in terms of leak repairs, prevention and ongoing timely (efficient) detection. Note that air leak reports containing detailed descriptions of each leak are often provided as a separate document for convenience, or in the appendices.

Ideally, an air leak report will contain pictures of each identified air leak, along with:

- Location;
- Equipment;
- Fault, e.g. air leaking from drain;
- Estimated flow;
- Repair required; and
- Estimated kW waste associated with leak based on the 'trim' compressor's turn-down efficiency.

## **System network**

### **Pipework condition and configuration**

Describe the audit findings relating to:

- the physical condition of the network;
- any pipework features significantly impacting on demand or pressure; and
- pipework maintenance practices.

For each of the above main findings:

- quantify the effects on associated pressure and/or flow. For example, quantify the pressure losses resulting from the condition of the particular configuration, constrictions, length or corrosion feature.

### **Pipework sizing**

Include here the audit findings relating to pipe sizing. In particular, identify:

- the extent and location of undersized pipework;
- the effect on pressure and/or flow of each incorrectly sized section of pipework.

This information should lead to calculations of potential savings, and identification and costing of cost-effective solutions.

### **Air receivers, valves and filters**

Include a discussion regarding any receivers, valves and/or filters being used, and the purpose of their use. In addition, quantify the effects on pressure and/or flow associated with the use, misuse, and poor maintenance of valves and filters.

Where a recommendation is made, include a description of the valve or filter concerned, the effect of the recommendation on pressure and/or flow, a budgetary cost of the solution and the payback for the client.

## **System supply side**

The supply side of the compressed air system (the motor, compressor and air quality system) meets demand that is the sum of the productive requirements of the business as well as the demand from sub-optimal uses and waste.

This section of the report should focus on the supply-side solutions that are economic once the downstream demand has been specified, net of the demand from sources that will be eliminated by the economic solutions specified in earlier recommendations.

The demand profiles obtained from the electrical loggings, and the analysis conducted on the downstream demand drivers, should provide the basis for identification of the supply-side opportunities.

### **Dryers and separators**

Include here the findings from the audit regarding dryers and separators. In particular, consider:

- the suitability of the dryer to the quality and quantity of the air demand;
- excessive pressure drop across any of the equipment;
- any efficiency effects relating to the relative locations of separators, dryers and compressors (or after-coolers);
- any issues identified relating to poor ventilation of refrigerant dryers, and the possible downstream effects; and
- environmental hazards such as contaminants not removed before 'clean' condensate water is released into the drains.

### **Air compressor electricity demand characteristics**

Provide a summary (e.g. a table) of the key information collected and derived from the compressor motor electricity-use logging and any other metering of the compressor motor over the audit period.

This information should include: average power loading (kW) and a description of any flow control method used at the compressor outlet. The logging records should be included in an appendix to the report.

Also include information on air compressor configuration, drives and drive couplings.

### **Air compressor performance capability**

Using air compressor design information and relevant available air delivery data, describe air compressor performance capabilities relative to the system requirements and actual demand. Refer to data sheets provided in appendices.

Include here an analysis of the efficiency-related observations from the electricity consumption profiles of the compressors, including matters arising from:

- the load/unload cycle times;
- the compressor unload and reload pressure setpoints;
- how the peak loading relates to the optimum operating band; and
- the method of compressor/compressor-bank control.

For each compressor/motor setup, the information should include: rated power of motor (kW); compressor output flow at rated load (m<sup>3</sup>/min); compressor efficiency at full load (%); and the compressor's average turn-down efficiency.

**Compressor operating temperature.** From the room and discharge air temperature recordings during the audit, include

- The effect of higher than ambient temperatures on the compressor performance efficiency.
- That Intake air should be maintained as near to ambient as possible, here an assessment of:
- The importance of cooling air from the coolers being effectively exhausted to avoid temperature build up.
- The effect of the measured operating temperature on compressor drive motor efficiency or reliability
- the opportunities for reducing operating temperature, such as improving the temperature or flow of cooling air flow to oil coolers or aftercoolers; and
- any opportunities for the capture of waste heat for use in other processes.

Note that drive motors generally have an operating temperature limit of 40 – 45 °C, and that if the room temperature is close to that range a recommendation (such as forced ventilation) should be included in the report.

### **Compressor air intake pressure**

Cover here the audit findings on air intake pressure and the condition of related intake filters, including:

- any reasonable options for normalizing air intake pressure to improve compressor efficiency;
- opportunities for more frequent intake filter changes, or other changes to the maintenance regime.

### **Recommendations arising**

From the opportunities identified relating to the operation of the compressors, include here a brief description and the net benefit of each of the actions recommended.

For each, quantify the kW, annual kWh and annual cost savings opportunities and describe the supply-side changes (including estimated costs) required to achieve those savings.

The detail cost-benefit information to support each recommendation should be included as an appendix.

## **5 Ongoing Performance Monitoring**

In this section of the report, consider and recommend what ongoing compressed air system performance measurement systems should be put in place by the client. The electricity consumption of the CAS directly reflects the efficiency of the performance of the total system and must be measured on an ongoing basis to enable the client to understand the effects of any changes made and also ensure that:

- the savings being targeted by the changes are truly captured, and
- timely corrective actions to be taken to rectify identified inefficiencies.

Recognising the need to measure power consumption of each air compressor to establish the baseline CEI, the recommendations here in relation to electricity metering should be influenced by the metering decisions taken at the commencement of the audit and discussed earlier.

The Audit Standard outlines the options for ongoing electricity usage metering.

## 7 Appendices

The appendices should include:

1. Schematic of each of the compressed air systems;
2. Audit data records, including relevant pressure, flow or electrical loggings;
3. Air leak detection report with details of each identified leak; and
4. Cost-benefit details of options and recommendations.

In relation to the cost-benefit details, particularly where the audit will be used to support business investments, the relevant appendix should provide a summary of the data and calculations performed for each option and recommendation. In addition, this should be accompanied by:

- any supplier or installer quotations that support the implementation cost estimates, and any assumptions that could materially affect the accuracy of the payback period; and
- where there are several options for the same outcome, clearly highlight these options as being mutually exclusive.

This level of detail can be important to the subsequent development of an investment proposal.

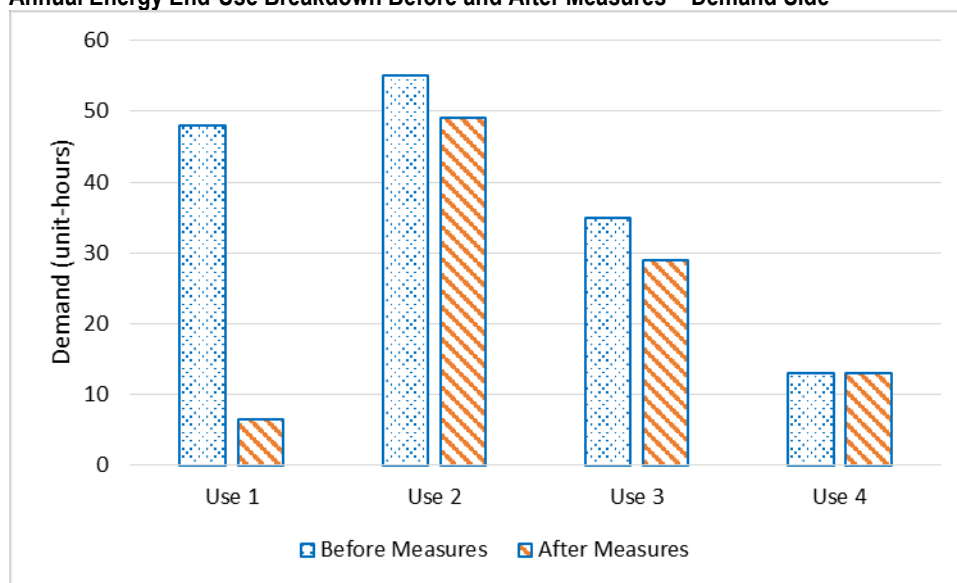
# Appendix 7 - Recommended Report Outline – Type 1: Basic Energy Audit ('basic grade'/'base level')

## Executive Summary

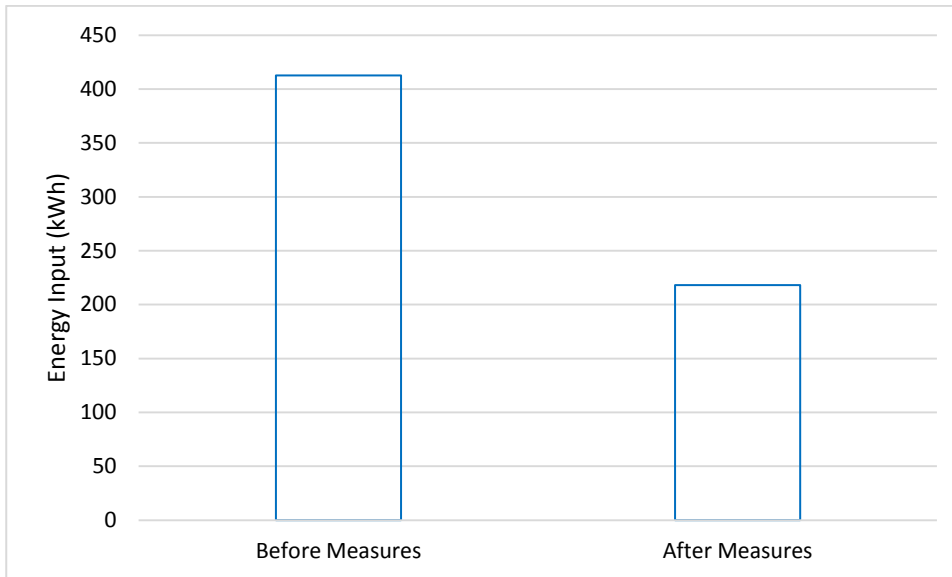
- Identify the organization, date of audit, name of person who commissioned the audit and the identity and location of the system being audited.
- Comment on the performance of the system relative to benchmarks of average and best practice
- Identify the energy use of the existing system and the associated cost, the key measures proposed and the change in these figures arising from the proposed measures.
- Provide a table of the proposed measures including identification, for each measure, of the associated capital cost, energy saving (KWh and \$), demand saving (kVa/kW and \$), maintenance or other operational savings, and payback.
- Provide a graphical summary of the energy end-use breakdown of the system before and after the proposed measures.
- Provide a commentary on the need for and scope of any more detailed investigations recommended to enable a proper business case to be generated.
- State the energy tariffs used for calculations and the GST status of dollar figures throughout the report.

Recommendation Identifier and Report Section Ref	Electricity Saving (kWh p.a.)	Annual cost saving (\$)	Implementation Cost (\$)	Simple payback period (years)
<b>Short Payback Measures (&lt;2 years)</b>				
Rec #1 Sec x.x.x				
Rec #2 Sec x.x.x				
<b>Longer Payback Measures (&gt;2 years)</b>				
Rec #3 Sec x.x.x				
Rec #4 Sec 4.x.x				
<b>Energy Management Measures</b>				
Rec #5 Sec x.x.x				
Rec #6 Sec x.x.x				

**Annual Energy End-Use Breakdown Before and After Measures – Demand Side**



**Annual Energy End-Use Breakdown Before and After Measures – Energy Input**



## 1. Business Context

### Basic Information

Include relevant information as outlined from Appendix 1 of the Audit Standard.

### Site Operating Characteristics

Describe the nature of the site's business operation, and how each system audited relates to the site's operation.

Identify and describe any future plant changes that will likely change the site's operating characteristics or have an effect on the systems audited.

### Objectives and Scope of the Audit

Describe the objectives of the base-level audit, the systems included in the scope and level of investigations that were performed.

In describing the scope, identify also the systems that have been excluded from the scope, the reason for them being excluded, and an estimate of their capacity and annual energy use.

Include a description of what methods used to assess the operation and performance of the systems.

Where there are more than one independent CAS on a site, sections 2 and 3 following should be repeated for each system

## 2. System Overview

Describe the CAS in the context of the site's operation.

Describe this in terms that the client will recognise and include:

- what the business driver is for the system (e.g. production output or material input); and
- the current annual volume of that driver.

From this calculate the energy intensity of the system (kWh per unit of throughput/business driver)

Summarise the energy use of the compressors, in tabular form.

**Baseline Consumption Table**

<b>CA System: 1</b>		<b>Description: (e.g.) Factory CAS</b>						
<b>Fixed-Speed Compressors</b>								
Comp. ID	Model	Type	Rated (kW)	Proportion of Time On-Load	Off-Load Run Factor*	Annual Run Hours	Off-Load Power Contribution**	Annual Usage (MWh)***
#1 (e.g.)	ABC 123	Lubr. Screw	75	0.7	0.3	4000	0.09	237
#2								0
...								0
<b>Variable Flow Compressors</b>								
Comp. ID	Model	Type	Rated (kW)	Average Output	Annual Run Hours	Annual Usage (MWh)****		
#3 (e.g.)	CBA 321	VSD Screw	55	0.75	4000	165		
#4						0		
...						0		
Allowance for dryers and/or cooling (extra 10%)								40
<b>Total</b>								<b>442</b>

\*Proportion of rated power consumption compressor uses when un-loaded. Lubricated rotary vane = 0.5; Lubricated screw = 0.3; Non-lubricated screw or rotary = 0.2, Reciprocating or centrifugal = 0.1

\*\*Off-Load Power Contribution = (1 - Proportion of Time On-Load) x Off-Load Run Factor

\*\*\*Annual Usage = {(Rated kW x (Proportion of Time On-Load + Off-Load Power Contribution)) x Annual Run Hours} / 1000

\*\*\*\*Annual Usage = (Rated kW x Average Output x Annual Run Hours) / 1000

### 3. Audit Findings

#### Overall findings

Describe the overall efficiency of the system and briefly outline the opportunities that will be discussed in more detail in subsequent sections.

If applicable, refer to system layout schematics in the appendices.

#### System demand opportunities

Outline the aspects of the demand side of the system that have opportunity for improving the energy intensity of the system.

Also refer to the relevant base-level system checklist in the appendices.

#### Demand Initiative 1

Describe the initiative in detail, with estimations of energy use savings, energy cost savings, implementation cost of the initiative, and the estimated project payback period. State assumptions made in the estimates and calculations, but no need to show calculation details unless important to illustrate the methodology used.

#### Demand Initiative 2 ...etc.

#### System Network opportunities

Outline the aspects of the system 1 network that provide opportunities for improvement.

Also refer to the relevant base-level system checklist in the appendices.

#### Network Initiative 1

Describe the initiative in detail, with estimations of energy use savings, energy cost savings, implementation cost of the initiative, and the estimated project payback period. State assumptions made in the estimates and calculations, but no need to show calculation details unless important to illustrate the methodology used.

[Network Initiative 2 ...etc.](#)

### **System supply opportunities**

Outline the aspects of the supply side of system 1 that provide opportunities for improvement. Also refer to the relevant base-level system checklist in the appendices.

#### [Supply Initiative 1](#)

Describe the initiative in detail, with estimations of energy use savings, energy cost savings, implementation cost of the initiative, and the estimated project payback period. State assumptions made in the estimates and calculations, but no need to show calculation details unless important to illustrate the methodology used.

#### [Supply Initiative 2 ...etc.](#)