Development of a Standards and Labeling Program for Air Compressors in India

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List of abbreviations

AQSIQ	General Administration of Quality Supervision, Inspection and Quarantine
BIS	Bureau of Indian Standards
CAGI	Compressed Air and Gas Institute
CAGR	Compound Annual Growth Rate
cfm	Cubic feet per minute
CFVN	Critical flow Venturi nozzles
DoE	Department of Energy (US)
EE	Energy Efficiency
EU	European Union
FIDE	Fideicomiso para el Ahorro de Energía Eléctrica
FCRI	Fluid Control Research Institute
HP	Horsepower
IS	Indian Standard
ISO	International Organization for Standardization
kW	Kilowatt
MEPS	Minimum Energy Performance Standard
NABL	National Accreditation Board for Testing and Calibration Laboratories
OEM	Original equipment manufacturer
Pa	Pascal
SAC	Standardization Administration of China
S&L	Standards and Labeling
SPC	Specific Power Consumption

Executive Summary

Air compressors are a widely used type of equipment that rely on electricity or fuel to pressurize air for use in industrial, agricultural, pharmaceutical, and other applications. The organized market for air compressors in India was more than 100,000 units in FY2018-19, and with a government focus on 'Make in India' and establishing India as global manufacturing hub for export, sales are expected to grow in the coming years. Air compressors thus represent a promising area of focus energy efficiency policies and associated climate gains.

CLASP worked with PwC India to conduct comprehensive technology and market assessments for air compressors in India, to inform efficiency standards development and a labeling program. Using both surveys and in-person interviews of manufacturers and their associations, we examined the air compressor market in order to understand product segmentation, projected growth rates, and prevalent technologies.

Air compressors can be categorized as positive displacement units (reciprocating or rotary) and dynamic units (centrifugal). The Indian market is dominated by positive displacement compressors, which comprise 99% of the market. Air compressors with motor capacity up to 30 kW are primarily manufactured in India and make up most of the market, while a significant share of the higher capacity compressors are imported. The report further categorises the air compressor market based on technology, lubrication, cooling method and drive speed.

The report also analyses national and international test standards for air compressors, and assesses domestic testing capacity. It reviews international labeling policies adopted in the European Union, China, the U.S., and other leading economies, finding that the labeling program in most countries is based on ISO 1217. The report proposes to base the labeling program in India on Indian Standard IS/ISO 1217, and isentropic efficiency is identified as the energy performance metric.

Based on an assessment of energy efficiency values shared by manufacturers for 1,196 models, energy efficiency metrics are proposed for an Indian efficiency standard, and the associated electricity and GHG savings are projected. The proposed labeling program focuses on positive displacement units. Dynamic air compressors are not proposed for labeling due to their minimal market share of less than 1%, and because they require a different efficiency metric. Based on analysis of energy performance data, separate star rating tables are proposed for air- and water-cooled compressors.

Modelling of the efficiency levels indicates that they would cumulatively avoid 8.41 TWH of electricity use and 6.9 $MtCO_2$ emissions through 2030.

1. Air Compressor

An air compressor is a device that converts power using an electric motor, diesel or any other form of energy into potential energy stored in pressurized or compressed air. Compressed air's potential energy is harnessed in variety of applications, such as industrial, agricultural, scientific, medical, etc. Typical industrial applications of compressed air can be in pneumatic equipment - tools and appliances, robotics, process requirements – packaging, spraying, cleaning, etc.

Figure 1: Typical industries with compressed air requirement

Textile	Oil & Gas	Power Generation	Automotive	Mining	Chemicals
Pharmaceuticals	Food & Beverages	Agriculture	Waste Management		

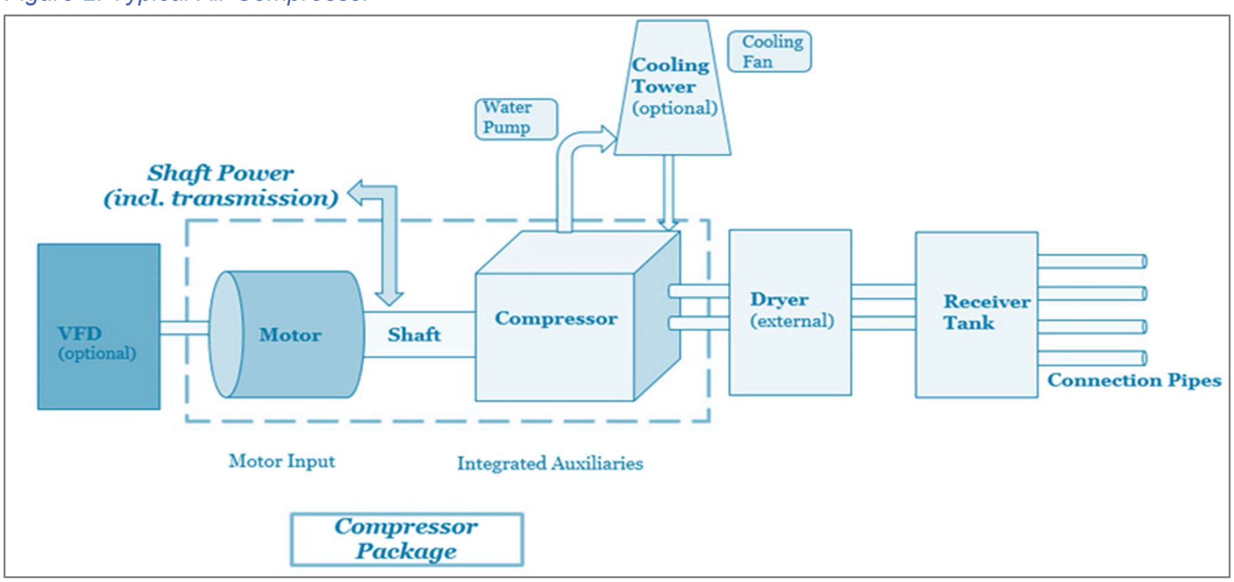
Working of air compressor

Generally, an air compressor is divided into three major parts – *power source*, *compression system* and *storage & delivery*. Power source can comprise of electric motor or an engine. The compression mechanism could be a *piston, rotating impeller*, *vane, rotary screw, etc.* depending on the choice of technology and application. Compressing mechanism compresses atmospheric air by using energy from the power source. The storage and air delivery system are used for the meeting compressed air demands at various use points.

In the process of air compression, air is pulled inside a limited space mechanically by means of piston, impeller, or vane. In simpler terms, free or atmospheric air is compressed reducing its volume and increasing its pressure. The processes undergone by air is shown in Figure 2.

Intake → Compression → Filtration & Cooling → Storage

Figure 2: Typical Air Compressor



The dotted part in Figure 2 comprising of the motor and compressor system with its in-built functionalities is collectively referred as compressor package. This representation has also been used to define the scope of the labeling program for the air compressors, as discussed in later sections of this report.

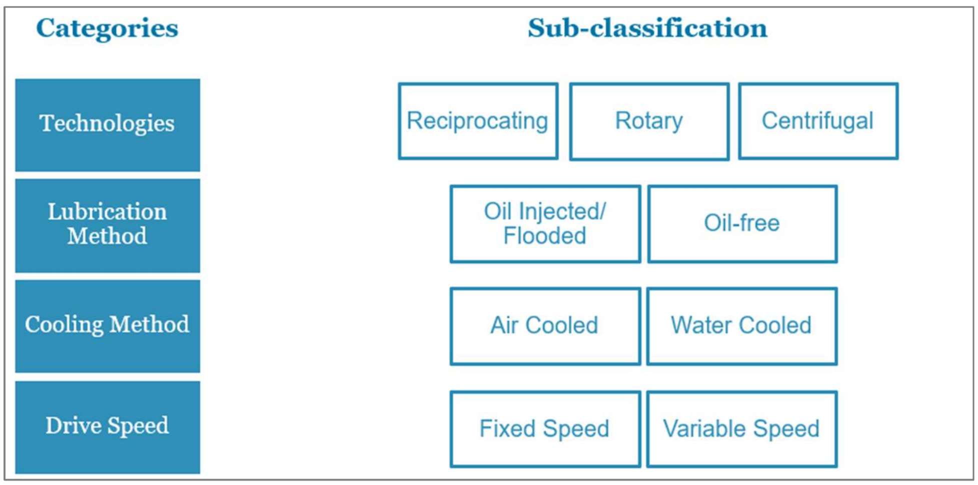
Air compressor classification

Air compressors can be broadly categorized into positive displacement and dynamic compressors, based on its principle of operation.

- **Positive Displacement compressors** work with a constant flow irrespective of outlet pressure to draw atmospheric air into one or more of the compression chambers. As the volume of each chamber decreases, the air is compressed internally until the pressure reaches the designed build-in pressure ratio. Then, the valves open and the air is discharged into the outlet system.
- **Dynamic Compressors** work on constant pressure to increase air velocity, which is then converted to increased pressure at the outlet. During dynamic compression, air is drawn between the blades on a rapidly rotating impeller accelerating it to a high velocity. Then, the air is discharged through a diffuser, where the kinetic energy is transformed into static pressure.

Air compressors can be categorized into following sub-categories as shown in figure 3:

Figure 3: Air Compressor Classification



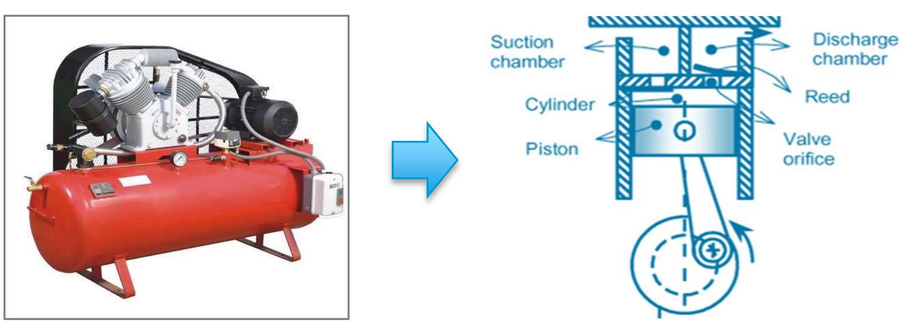
Compressor Technologies

Reciprocating Compressors

Reciprocating air compressor is a type of positive displacement machine, most widely used in the industry. It is a low capacity (low airflow) air compressor and designed to operate at low, medium or high operating pressure.

Air compression is achieved as a result of piston movement. The compression can be single or multi stage with single or multiple cylinder configurations.

Figure 4: Typical Single Stage, Single Cylinder Reciprocating Air Compressor

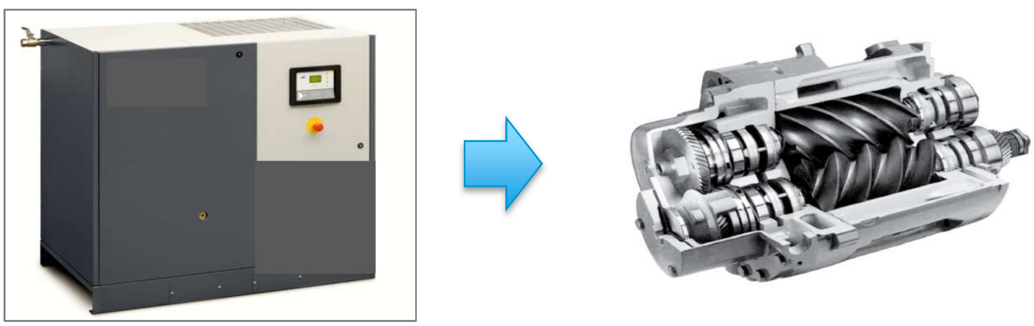


- **Single or multiple cylinder**: Single cylinder machines have one suction, compression and discharge area. Multiple cylinder machine has up to six cylinders with their pistons connected to crankshaft for compressing air or gas. The former is generally air-cooled, while latter is generally water cooled.
- **Single or multi-stage:** Multi-stage compressor comprises of two or more cylinders, each with different diameter as compared to single stage which may have single or multiple cylinders but of same diameter. Multi-stage machines are used for high pressures and are characterized by lower discharge temperature compared to single-stage machines. The benefit of multi stage machines is the reduced pressure differential across cylinders, which reduces the load and stress on compressor components such as valves and piston rings.

Rotary Compressors

Rotary compressors use rotors instead of pistons to compress air. These are generally used for low to medium capacity (low to medium capacity) and pressure applications where continuous discharge flow is required. The most common type is the helical screw design which uses two asymmetrical rotors to compress the air. Rotors rotate in opposite directions to compress the trapped air.

Figure 5: Typical Screw Type Rotary Air Compressor



Centrifugal Air Compressors

A centrifugal compressor is a type of dynamic compressor, or turbo compressor which work at a constant flow, at a constant pressure. It operates on the principle of transfer of energy from a rotating impeller to air. Air is drawn towards the center of the impeller due to centrifugal force. This radial movement of air results in a pressure rise and the generation of kinetic energy. Before the air is led into the center of the impeller, the kinetic energy is also converted into pressure by passing through a diffuser and volute.

They are suited to high volume applications, especially where oil free air is required. The centrifugal is a continuous duty compressor with few moving parts. It is particularly suited to high volume applications, especially where oil free air is required.

Figure 6: Schematic diagram of a Centrifugal Air Compressor

Cooling Method

Air-cooled: Typically, smaller capacity compressors are air-cooled using a fan, which is an integral part of the belt-drive flywheel. This fan blows cool air across the outside finned surfaces of the compressor cylinder or casing.

Water-cooled: These are of two types with respect to the water-cooling system installed either outside or built-in with the package of the compressor. The built-in system has cooling water jackets around the sealed cover of compressor to extract heat released.

Lubrication Method

In **lubricated compressors**, the lubricant or oil must be separated from the discharge air whereas in non-lubricated compressors provide oil free discharge air.

Non-lubricated compressors are useful for providing air for instrumentation and for processes where quality of air is essential. However non-lubricated machines have higher specific power consumption (kW/cfm) as compared to lubricated types.

Drive Speed

Variable speed drive compressors have an electronic power converter integrated or functioning as one system with the motor driving the compression element. It continuously adapts to the electrical power supplied to the motor in order to control the mechanical power output of the motor according to the torque-speed characteristic of the load being driven by the motor.

Fixed speed machine has a single speed motor operation.

Comparison of air compressor technologies

The Table 1 below presents the summary of air compressor technologies and major manufacturers in the country. The three main types of compressor as prevalent in the Indian industry have been compared. The data is obtained from responses to questionnaire based survey and in depth discussions with manufacturers, as well as market research reports.

Table 1: Comparison of major air compressors technologies

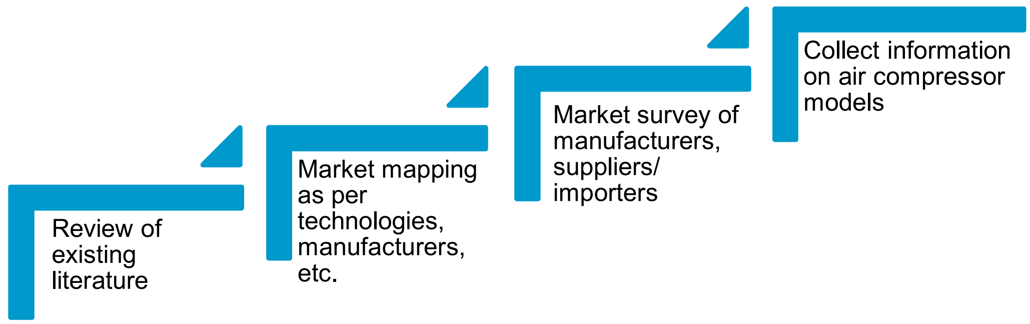
	Reciprocating	Rotary	Centrifugal
			
Mechanical Functionality	Positive displacement	Positive displacement	Dyanamic
Application	Pneumatic air-powered tools, dentistry, oil refinery, gas pipeline, chemical plants, etc.	Food packaging, automated manufacturing systems, etc.	Ventilators, Combustion System, Pneumatic powder blower conveyors
Typical Capacity range (cfm)	Up to 400 cfm	Up to 4000 cfm	Above 4000 cfm to 35,000 cfm
Typical kW range (kW)	0.37 kW to 30kW	2.2 kW to 500 kW	140 to 3500 kW
Capacity characteristic	Low to Medium Flow rate Medium to High Pressure	Low to Medium Flow rate Low to Medium Pressure	High Flow Rate and Medium Pressure
Market characterization	More than 60% of the market is unorganized and are used for small capacity purposes such as garages, etc.	Almost the whole market is organized as only larger companies manufacture due to its complex design and high investment.	Fully organized market as the product has complex design and is used in large scale industries.
Major Players in Indian Market	ELGi Anest Iwata BAC Ingersoll Rand Atlas Copco FS Curtis	Atlas Copco ELGi Kaeser Ingersoll Rand Kirloskar Pneumatics Chicago Pneumatics	Atlas Copco Ingersoll Rand

2. Market Assessment

Approach & Methodology

A robust approach comprising both primary and secondary data collection was adopted for collecting relevant market data. The following data collection steps were used:

Figure 7: Data collection steps



The information about the market of air compressor was collected as follows:

- Secondary research and analysis including market reports available in public domain, articles, journals, and web-based sources.
- Primary research through engagements with manufacturers and key experts in the industry, in-depth interviews, and questionnaire-based survey.
    - A questionnaire was shared with all major manufacturers to gather the required information in a structured manner. The questionnaire included questions on the following key areas:
        - **Sales Data:** Technology wise units sold, segmentation by pressure and capacity ratings
        - **Performance Testing Data:** Test standard followed, nature of tests conducted, type of test facility used
        - **Product Specifications and Characteristics**: Operating pressure, rated cfm, packaged power, specific power consumption, cooling and lubrication method, and any other additional features

Market Characteristics

Market size

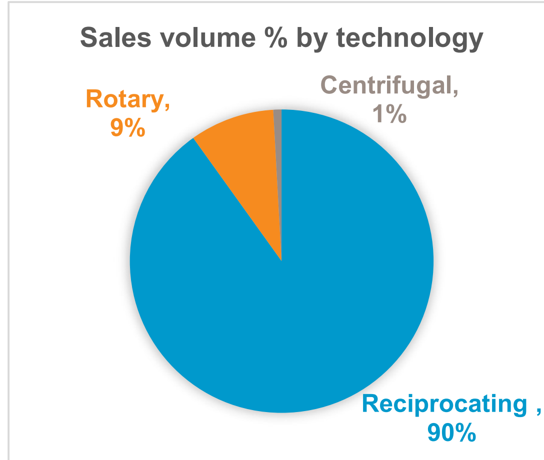
The air compressor market in India is driven by end use sectors such as textiles, cement, agriculture, automobile, pharmaceutical, mining etc. **With rapidly increasing disposable income and India aiming to become a global manufacturing hub, the air compressor market is bound to expand.**

The size of organized market for air compressors in India was approximately 1.10- 1.35 lacs[1] in 2018-19. The break-up for the annual sales air compressor types for the organized market as follows:

- Reciprocating is approx. 100 - 120 thousand units
- Rotary is approx. 10 - 15 thousand units
- Centrifugal is approx. 1 thousand units

[1] As per findings from market survey (consultations and questionnaire based survey)

Figure 8: Sales distribution by technology



Based on the discussion with manufacturers, the size of unorganized market for air compressors in India is approximately 2 lacs. Most of this market belongs to small reciprocating compressors from 0.37 – 1.5 kW. These compressors are used in small and medium-sized businesses. Some of the uses of light industrial air compressors include powering tools in auto repair shops, garages, manufacturing facilities, and construction sites, spraying crops and ventilating silos in agricultures facilities, operating laundry presses in dry cleaners, etc.

For the purpose of Standard and Labeling (S&L) program, only reciprocating and rotary compressors have been considered as they together comprise 99% of the market. Centrifugal compressors have not been considered due to very small market share (less than 1%).

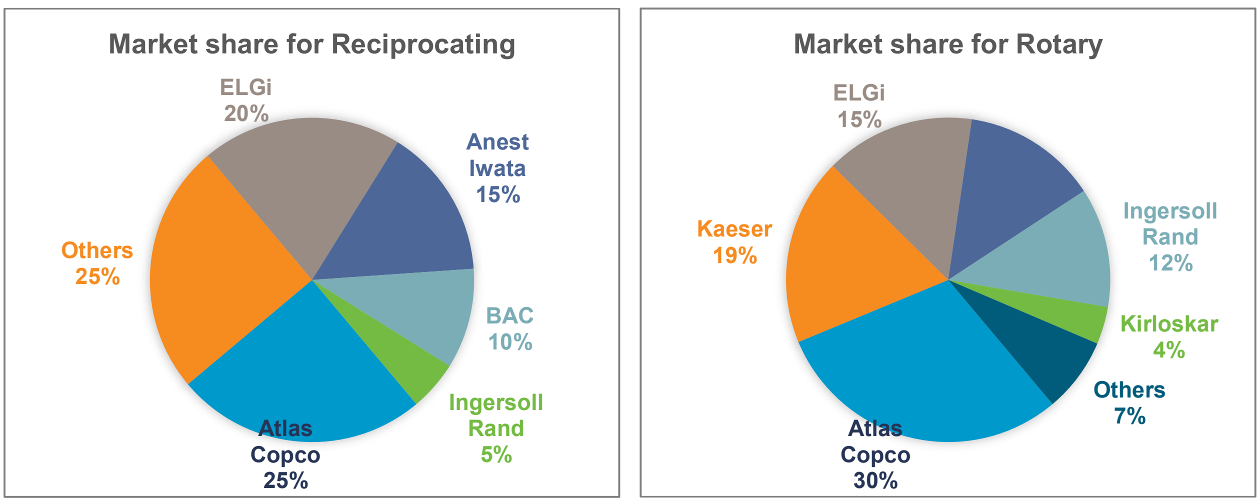
Key Players – Organized Market

ELGi, Atlas Copco, Ingersoll Rand, Kaeser and Anest Iwata are the major players representing 75% of market share in rotary and reciprocating type air compressors in India. Other players include Chicago Pneumatics, FS Curtis, Kirloskar Pneumatics, BAC compressors and Burckhardt compression.

Market Share

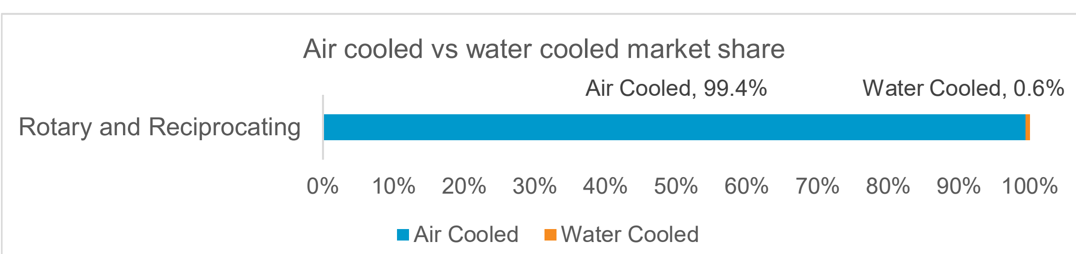
The organized market share by brands/manufacturers for 2018-19 is shown in figure 9[2].

Figure 9: Market share of air compressors manufacturers for 2018-19 (Organized Market)



The market share for air cooled and water cooled air compressors is shown in figure 10 based on the survey.

Figure 10: Market share of air cooled vs water cooled positive displacement compressors.



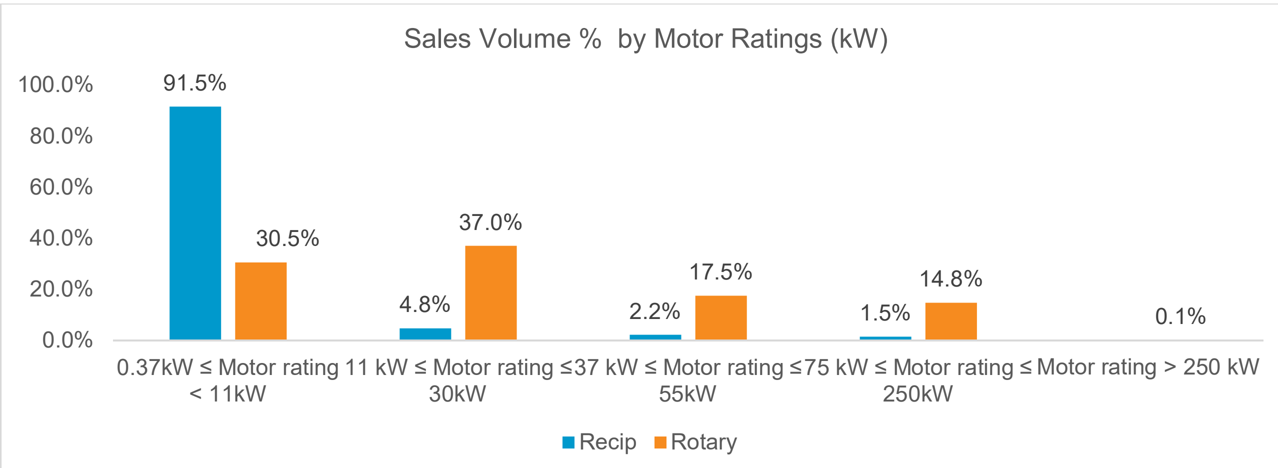
[2] Sales figures have been provided by selected manufactured in questionnaire format. For remaining manufacturers, sales numbers were arrived based on discussions during consultation meetings.

Air Compressor Sales by Motor Ratings

Air compressors are available in rated power ranging from fraction of a kilo-Watt to higher sizes bordering on hundreds of kilo-Watts. Based on discussion with manufacturers, the motor ratings were classified into bands well recognized and prevalent in the industry. The market assessment finds the below distribution of sales across the motor rating bands in 2019:

- **Reciprocating air compressors** with motor rating less than 11 kW were reported to have highest sales by volume and with motor ratings greater than 11 kW is low (<10%)
- Annual sales for **rotary air compressors** were maximum for motor ratings between **12 to 30 kW**.

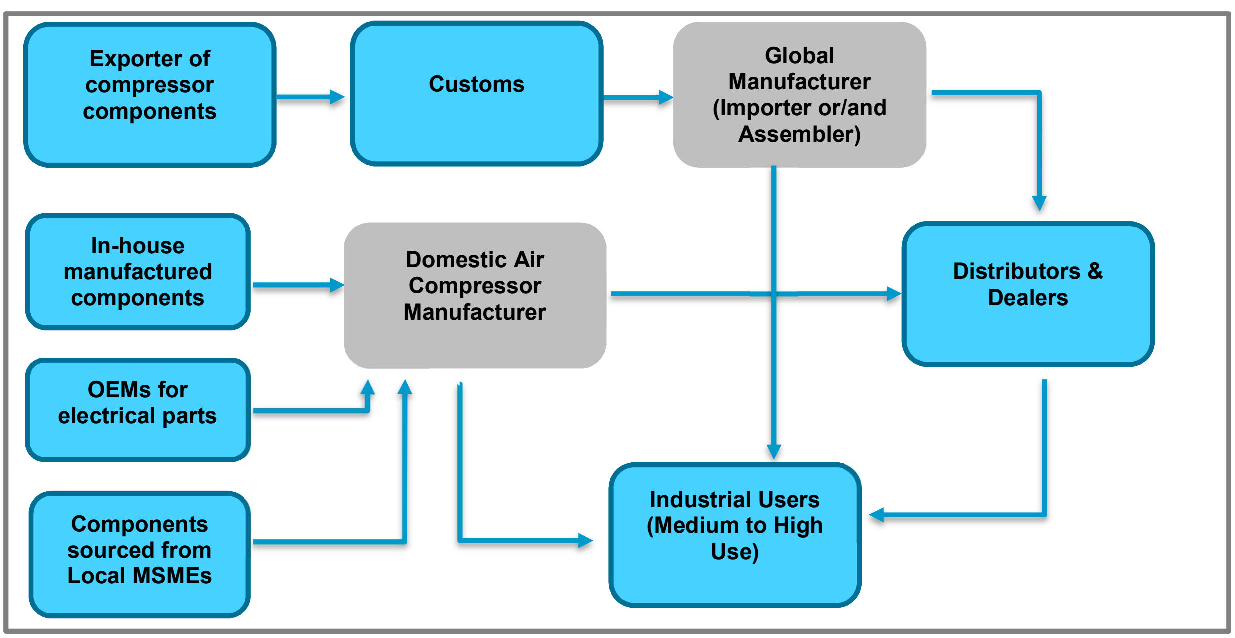
Figure 11: Sales Volume by Motor Ratings[3]



Supply Chain

From the consultations with manufacturers, it is concluded that dealer distribution network is used predominantly for air compressor distribution while few compressor sales are done directly by OEMs.

Figure 12: Supply Chain of Air Compressors



[3] As per questionnaire data received from 3 manufacturers.

Reciprocating compressors for capacity up to 30 kW is manufactured in India by most major players using components manufactured in in-house facilities or procured from domestic OEMs. Rotary compressors are generally imported as packages which include all major components and are assembled in local facilities. The detailed supply chain of air compressors components is described in Table 2.

Table 2: Supply chain of air compressor components

Component	Recip.	Rotary	Supply Chain
Motor	Domestic OEMs	Imported	The motors used by reciprocating compressors manufacturers are procured from domestic OEMs whereas it is imported by rotary manufacturers such as Ingersoll Rand, FS Curtis, etc. generally from China.
Pistons; Piston Rod; Connecting rod; Cylinder liner; Cylinder Head; Crank shaft; Frame and crankcase	In-house/ Local MSME	-	The reciprocating air end components for smaller capacities are produced domestically and is often exported to global markets.
Air End/Impeller; Heat Exchanger; Intercoolers and After coolers; Main bearing and End bearing; Oil pump, Water Pump; Compressor casing; Electronic controller	-	Imported/ in-house	Most of the global manufacturers import the rotary air end along with other major components from China and assemble them in their domestic manufacturing facilities. ELGi is the only major manufacturer to produce all rotary components domestically.
Piping, Intake valve, Delivery valve, relief valves	In-house/ Local MSME	In-house/ Local MSME	Small components are domestically produced or outsourced to local vendors by both rotary and reciprocating manufacturers.
Receiver Tank	Local MSME	-	It is generally outsourced to local vendors.

3. Review of Performance Standards

This chapter reviews and compares the performance test standards for rotary and reciprocating air compressors. The review covers both Indian and International standards relevant to the Indian air compressor market. Table 3 below provides a list of the relevant standards.

Table 3: Relevant standards for positive displacement air compressors

Standard	Published	Title
IS 5456	2006	Testing of Positive Displacement Type Air Compressors and Exhausters - Code of Practice
IS/ISO 1217 with Amendment 1 (2016)	2009	Displacement compressors — Acceptance tests; Amendment 1: Calculation of isentropic efficiency and relationship with specific energy

Comparative assessment of performance standards

The table below provides a comparison of two relevant standards i.e., IS 5456:2006 and IS/ISO 1217:2009 and highlights the major difference in measurement and calculation of performance parameters such as Power (W), Specific power consumption (kW/cfm) and Isentropic Efficiency.

Table 4: Comparison of test standards for positive displacement air compressors

Parameter	IS 5456: 2006	ISO 1217: 2009	Remarks
Scope	Reciprocating and Rotary type positive displacement	Packaged displacement compressor	*IS 5456 doesn't explicitly specify auxiliary equipment and does not define packaged compressors*
Test type	Type test and Routine test – Type test carried out on new design or major design changes Routine test carried on a model for acceptance by purchaser. Test conducted: • Mechanical and Endurance tests • Capacity (FAD) • Shaft power and Total power consumption • Specific power consumption • Max. operating speed • Volumetric & overall efficiency of machine • Lubricating oil consumption	Acceptance test – It used to validate compressor performance against specified/ guaranteed data. Test conducted: • Measurement of Volume flow rate • Measurement of Packaged input power • Specific power consumption • Shaft speed • Measurement of Pressure • Temperature	*IS 5456 is more rigorous test standard compared to ISO 1217 as it includes mechanical endurance testing, loading and unloading mechanism testing, etc.*

Parameter	IS 5456: 2006	ISO 1217: 2009	Remarks
	• Testing of loading & unloading mechanism • Flow of cooling water with rise in Temperature	• Other measurements such as condensation rate, humidity etc.	
Power calculation	Shaft power of prime mover including transmission losses Total Input Power is not defined clearly. Example: Drive Motor Rating = 30 kW Drive Motor Efficiency = 92% **Shaft Power** (full load) = 30 KW	Packaged power includes input power of prime mover and auxiliaries driven by separate prime mover Example: Drive Motor Rating = 30 kW Motor Efficiency = 92% Motor Input Power = 30/92% = 32.6 kW Auxiliaries Power = 1 kW Packaged Input Power = 32.6 + 1 = 33.6 kW	*Overall package includes energy consumption of auxiliaries in ISO 1217 while it is not explicitly specified in IS 5456. Both motor efficiency loss and power consumed by auxiliaries are not considered in Shaft power.*
Specific Power Consumption (S.P.C)	The standard has no expression or formula to define specific power consumption of the compressor. Example (contd.): Operating Pressure = 7 bar Rated Capacity (cfm) at Operating Pressure = 187 cfm Shaft Power (full load) = 30 KW S.P.C = 30/187 = 0.16 kW/cfm	Defines specific power consumption of the packaged compressor is as Packaged power input divided by volume flow rate. Example (contd.): Operating Pressure = 7 bar Rated Capacity (cfm) at Operating Pressure = 187 cfm Packaged Input Power **=** 32.6 + 1 = 33.6 kW S.P.C = 33.6/187 = 0.18 kW/cfm	*SPC for packaged power as defined in ISO 1217 is more relevant as it considers motor losses and energy consumed by auxiliaries.*

Parameter	IS 5456: 2006	ISO 1217: 2009	Remarks
Isentropic Efficiency	The standard provides a formula for Isentropic work and specifies the overall efficiency which is the ratio of theoretical power required to compress the amount of air actually delivered to input power to the compressor. Example (contd.): Calculating Isentropic Efficiency using Shaft Power Isentropic Power = 22.97 kW Shaft Power (full load) = 30 KW Isentropic Efficiency = (22.97 / 30) * 100% = **76.56 %**	Defined as ratio of the required isentropic power to measured power for the same specified boundaries with the same gas and the same inlet conditions and outlet pressure. It includes total input power of the package as one of the specified boundaries. Example (contd.): Isentropic Power = 22.97 kW Packaged Input Power (full load) **=** 33.6 kW Isentropic Efficiency = (22.97 / 33.6) * 100% = **68.38 %**	*ISO 1217 Amd-1: 2016 clearly defines isentropic efficiency, its calculation method and tolerances allowed. Also, there is a significant difference in efficiency value considering shaft power in IS 5456 as compared to ISO 1217.*
No load power tolerance	**± 20 %**	**± 10 %**	*IS 5456 allows large deviation in no load power measurement.*

Bureau of Indian Standards (BIS), national standard making agency in India, has been working towards harmonization of IS 5456 with ISO 1217. One of the possible reasons behind the same could be higher adoption of ISO 1217 by the manufacturers. Based on discussions and decisions made at the BIS Technical Committee on Compressors, Blowers and Exhausters, the BIS is proceeding with harmonizing IS 5456 with ISO 1217. The detailed review of the ISO 1217 and IS 5456, together with the BIS's approach towards harmonizing the standards, is presented in Annexure D.

As a result of this technical committee meeting, BIS adopted ISO 1217 as Indian Standard under the dual number IS/ISO 1217 and published the document in December 2019. Also, IS/ISO 1217 will be amended to incorporate Amendment 1 of ISO 1217.

Test procedure adopted by manufacturers

Based on consultations with manufacturers and analysis of questionnaire data, the key performance standards used by the air compressor industry in India were identified. The table below presents test procedures and testing capacity of key manufacturers[4].

Table 5: Test procedures adopted by manufacturers

Parameter	Category	Manufacturer A	Manufacturer B	Manufacturer C	Manufacturer D
Test standards referred for	*Reciprocating*	IS 5456	ISO 1217	IS 5456	Information not provided

[4] Manufacturers' identity has not been disclosed in order to maintain confidentiality.

Parameter	Category	Manufacturer A	Manufacturer B	Manufacturer C	Manufacturer D
performance tests	*Rotary*	ISO 1217	ISO 1217	ISO 1217	
Tests performed	*Safety*	Yes	Yes, Hydro testing	Yes	*No*
	Quality	Yes	Yes Assy Inspection, Material TCs	Yes	*Yes*
	Performance	Yes	Yes Flow, Power, Spec Power	Yes	*Yes*
	Other	Information not provided	Yes Noise, Air quality	Yes	Information not provided
Test labs used for air compressor testing	*In-house testing*	*Yes*	Yes	Yes	Yes
	Third-party	*No*	No	Yes	No
Accreditation		Department of Scientific and Industrial Research (DSIR) accreditation for R&D facility	Department of Scientific and Industrial Research (DSIR) accreditation for R&D facility	Information not provided	Information not provided
Testing Capacity		2400 / month	1000 / month	Information not provided	Information not provided

The test standards followed by manufacturers are IS 5456 and ISO 1217. Both standards cover performance testing for reciprocating and rotary technologies (positive displacement compressors). Some of the manufacturers follow IS 5456 for reciprocating compressors and ISO 1217 for rotary. The overall adoption of IS 5456 was found to be low in comparison to ISO 1217 in the industry due to issues related to tolerances, definitions, power calculation amongst others. Also, only four certification marks licenses have been issued by Bureau of Indian Standards (BIS) under IS 5456 till date.

Testing facilities in India

Air compressor testing in India is predominantly dependent on in-house testing and third party laboratories are only used for calibration of test equipment and for quality check requested by the user.

FCRI (Palakkad) is an established third party test facility with NABL[5] accreditation for air compressors performance testing. The below table presents a list of manufacturers with accreditation status of their in house testing laboratory in India. [6]

[5] National Accreditation Board for Testing and Calibration Laboratories
[6] During the technical committee meeting, manufacturers were requested to suggest BEE about any other known third party laboratories in India. The same shall be added after the comments of manufacturers are received by BEE.

Table 6: List of testing laboratories

Sr. No.	Name of laboratory/Manufacturers	Accreditation	Location
Manufacturers' laboratories			
1.	Ingersoll Rand	N/A	Ahmedabad
2.	ELGi equipments	N/A	Coimbatore
3.	Kaeser	N/A	Pune
4.	Anest Iwata	NABL	Noida
Third Party laboratories			
5.	Fluid Control Research Institute (FCRI)	NABL	Palakkad

4. Review of International Labeling Programs

European Union (EU) Lot 31 eco-design regulation

Scope

EU has eco-design regulation (MEPS) for air compressors. The program covers rotary air compressors with volume flow rate between 5 to 1280 l/s (10 to 2712 cfm) and reciprocating air compressors with volume flow rate between 2 to 64 l/s (4 to 135 cfm). Both fixed speed and variable speed drive compressors are included for the rotary type. The program requires compressors to be driven by three-phase electric motor.

Status

The eco-design regulations for rotary and reciprocating air compressors are effective from January 1, 2018.

Measurement and calculation of energy efficiency parameter

The eco-design regulation on air compressors is based on Isentropic Efficiency at full load conditions. The isentropic efficiency is calculated using the below mentioned formula:

Table 7: Isentropic efficiency formula for Fixed and Variable speed compressors in EU regulation

<table>
<tr><th>Case</th><th>Formula</th><th>Definitions</th></tr>
<tr><td>Fixed Speed Rotary and Piston Standard[7] air compressors (air cooled oil-injected)</td><td>$\eta_{isen} = \frac{o.35 * V_1 * (p_2^{0.2857} - 1)}{P_{real}}$</td><td>$\eta_{isen}$ = isentropic efficiency;
V_1 = inlet volume flow rate (l/s), at full load;
P_2 = absolute outlet pressure (bar), at full load
P_{real} = basic package compressor electric input power (kW), at full load</td></tr>
<tr><td>Variable Speed Rotary air compressors (air cooled oil-injected)</td><td>$\eta_{isen} = \sum_{i=1}^{n} (\eta_{isen,i} * f_i)$</td><td>$\eta_{isen}$ = isentropic efficiency at volume flow rate of 100%, 70% or 40% of volume flow rate at full load outlet pressure

f_i = weighing factor, according to table below

<table><tr><th>Volume flow rate (% of full load)</th><th>Weighing factor (f_i)</th></tr><tr><td>100%</td><td>25%</td></tr><tr><td>70%</td><td>50%</td></tr><tr><td>40%</td><td>25%</td></tr></table></td></tr>
</table>

Eligibility requirements

The EU program has minimum energy efficiency requirements for each compressor type defined in the scope. The program provides regulation curve equation to calculate minimum eligible isentropic efficiency with volume flow rate at full load as the input parameter. Air compressors with isentropic efficiency more than the value determined using the regulation equation would meet the eligibility requirements. The table shown below provides the equations of energy efficiency requirements which are effective from January 1, 2018.

[7] Standard air compressors refers to a basic package compressor designed to supply air, sucked in from the surrounding environment, at outlet pressure levels between 7 to 14 bar(g).

Table 8: EU Lot 31 minimum energy efficiency requirements for standard air compressors

Standard air compressor type	Formula to calculate the minimum isentropic efficiency, depending on flow rate (Vi) and proportional loss factor (d)	Proportional loss factor (d) used in the formula
Fixed speed rotary standard air compressor	(-0.928 1n2 (Vi) + 13.911 ln (Vi) + 27.110) + (100 - (-0.928 1n2 (Vi) + 13.911 ln (Vi) + 27.110) * d/100	d = -5
Variable speed rotary standard air compressor	(-1.549 1n2 (Vi) + 21.573 ln (Vi) + 0.905) + (100 - (-1.549 1n2 (Vi) + 21.573 ln (Vi) + 0.905) * d/100	d = -5
Piston standard air compressor	(8.931 ln (Vi) + 31.477) + (100 - (8.931 ln (Vi) + 31.477) * d/100	d = -5

The equations in above table are regulation curves which are formulated using regression equation along with improvement factor as d-value.

Regulation curve = regression curve + (100 - regression curve) * d / 100

Above regulation equation provides an improvement option through the d-value. The distance of the regression curve from 100%-isentropic efficiency line has been considered as representative for losses. The d-value is used to make relative changes to improve the baseline efficiency.

Improvement regulation two years later

The EU Lot 31 regulation also provides the equations for improvement of energy efficiency. These regulations would come into effect from January 1, 2020. The equations have been shown in the below table. The d-value has been set to zero, implying an efficiency improvement of 5% across every volume flow rate segment as compared to 2018.

Table 9: EU Lot 31 improvement option from 1/1/2020 for standard air compressors

Standard air compressor type	Formula to calculate the minimum isentropic efficiency, depending on flow rate (Vi) and proportional loss factor (d)	Proportional loss factor (d) used in the formula
Fixed speed rotary standard air compressor	(-0.928 1n2 (Vi) + 13.911 ln (Vi) + 27.110) + (100 - (-0.928 1n2 (Vi) + 13.911 ln (Vi) + 27.110) * d/100	d = 0
Variable speed rotary standard air compressor	(-1.549 1n2 (Vi) + 21.573 ln (Vi) + 0.905) + (100 - (-1.549 1n2 (Vi) + 21.573 ln (Vi) + 0.905) * d/100	d = 0
Piston standard air compressor	(8.931 ln (Vi) + 31.477) + (100 - (8.931 ln (Vi) + 31.477) * d/100	d = 0

Operating Conditions

The operating conditions specified by the regulation for conducting measurement of full and part load isentropic efficiency are as per ISO 1217:2009

The isentropic efficiency is calculated at the following conditions:

- Operating pressure at full load
- Volume flow rate at full load pressure
- Packaged power at full load pressure

United States Department of Energy (US DoE) regulation

Scope

US Department of Energy passed a regulation on MEPS for air compressors. The regulation is based on the EU Lot 31 program and uses the same efficiency metrics. The scope of the regulation covers only Screw (Rotary) compressors which are driven by brushless electric motors. The regulation is applicable to compressors having full load operating pressure between 75 – 200 psig (5.1 – 13.7 bar). The capacity of the compressors with either full load actual volume flow rate between 35 – 1250 cfm or Motor nominal horsepower between 10 -200 hp (7.5 – 150 kW).

Status

The regulation on minimum energy efficiency requirements came into effect on 10th March 2020 and mandatory compliance is expected to come into force in January 2025.

Eligibility requirements

The US regulation has based their minimum energy efficiency requirements with the help of the regression equations from the EU Lot 31 program. The baseline energy efficiency criteria have been set at a less stringent level in comparison to EU program.

The regulation provides regression equations to calculate minimum eligible isentropic efficiency with volume flow rate at full load as the input parameter. Air compressors with isentropic efficiency more than the value determined using the regulation equation would meet the eligibility requirements. The table shown below provides the equations of energy efficiency requirements:

Table 10: Eligibility criteria as per US regulation on air compressors

Equipment Class	Standard Level (Package isentropic efficiency)	η_{Regr} (Package isentropic efficiency Reference Curve)	d (Percentage Loss Reduction)
Rotary, lubricated, air-cooled, fixed-speed	η_{Regr} + (1- η_{Regr}) * (d/100)	-0.00928 *1n^2(.4719 * VI) + 0.13911* ln(.4719 * VI) + 0.27110	-15
Rotary, lubricated, air-cooled, variable-speed	η_{Regr} + (1- η_{Regr}) * (d/100)	-0.01549 *1n^2(.4719 * VI) + 0.21573 * ln(.4719 * VI) + 0.00905	-10
Rotary, lubricated liquid- cooled, fixed-speed	.02349 + η_{Regr} + (1- η_{Regr}) * (d/100)	-0.00928 * 1n^2(.4719 * VI) + 0.13911 * ln(.4719 * VI) + 0.27110	-15
Rotary, lubricated, liquid- cooled, variable-speed	0.02349 + η_{Regr} + (1- η_{Regr}) * (d/100)	-0.1549 * 1n^2(.4719 * VI) + 0.21573 * ln(.4719 * VI) + 0.00905	-15

Operating Conditions

The operating conditions specified by the regulation for conducting measurement of full and part load isentropic efficiency are as per ISO 1217:2009

The isentropic efficiency is calculated at the following conditions:

- Operating pressure at full load
- Volume flow rate at full load pressure
- Packaged power at full load pressure

China Energy Label

Scope

China has introduced both MEPS as well as mandatory comparative label for air compressors. The scope of the labeling program covers the below mentioned types of air compressors:

1. Direct drive portable reciprocating piston
2. Reciprocating piston mini type
3. Oil-free reciprocating piston
4. Stationary reciprocating piston
5. Oil injected screw
6. Oil injected single screw
7. Oil flooded sliding vane

The scope for each compressor type varies, but the label applies to certain compressors as low as 0.18 kW and up to 560 kW (approximately 0.25 to 750 hp), and from 0.25 to 1.40 MPa (approximately 2.5 to 14 bar).

Status

The regulation on energy efficiency of air compressors was first executed by China in 2003. Later in 2009, it was revised as the regulation for minimum allowable values of energy efficiency and energy efficiency grades for displacement air compressors.

Eligibility requirements

The regulation is based on specific power consumption (kW/(m^3/min)) as energy efficiency evaluating parameter. The efficiency values are segregated based on number of stages, lubrication, motor power, and full load operating pressure for each type of compressor covered under the scope.

The comparative label of air compressors in China has three energy efficiency grades with Grade 1 being highest efficiency and Grade 3 being lowest efficiency. Specific power values are specified against a particular motor rating and rated discharge pressure. In order to be eligible for an efficiency grade, the evaluating values of the air compressor should have specific power not greater than the value specified for that grade. Grade 3 serves as the minimum allowable energy efficiency values. In other words, the Grade 3 is MEPS baseline.

Target Minimum Allowable Values of Energy Efficiency is specified for each motor rating along with the three efficiency grades. These values will substitute the lowest efficiency grade i.e. Grade 3 as the new MEPS level after the regulation is implemented for 4 years.

Energy efficiency grades for stationary reciprocating piston air compressors is shown in table 10..

Table 11: Sample EE grades from Chinese regulation for stationary reciprocating piston air compressors

Drive Motor Input Power Rating (kW)	Energy Efficiency Grade	Rated Discharge Pressure (bar)										
		7			8		10			12.5		
		Input Specific Power kW/(m3/min)										
		Water cooled	Water cooled	Air cooled	Water cooled	Water cooled	Water cooled	Water cooled	Air cooled	Water cooled	Water cooled	Air cooled
		Oil lubricated	Oil free	Oil lubricated	Oil lubricated	Oil free	Oil lubricated	Oil free	Oil lubricated	Oil lubricated	Oil free	Oil lubricated
18.5	1	6.2	6.36	6.69	6.62	6.79	7.42	7.56	7.84	7.84	8	8.28

	2	6.81	6.99	7.35	7.27	7.46	8.15	8.31	8.62	8.61	8.79	9.1
	3	7	7.24	7.6	7.47	7.72	8.34	8.63	9.06	9.32	9.65	10.13
	Target MEPS	6.93	7.17	7.52	7.4	7.64	8.26	8.54	8.97	9.23	9.55	10.03
22	1	6.17	6.33	6.66	6.58	6.75	7.38	7.53	7.81	7.8	7.96	8.24
	2	6.78	6.96	7.32	7.23	7.42	8.11	8.28	8.58	8.57	8.75	9.05
	3	6.97	7.21	7.57	7.43	7.69	8.3	8.59	9.02	9.28	9.6	10.08
	Target MEPS	6.9	7.14	7.49	7.36	7.61	8.22	8.5	8.93	9.19	9.51	9.98

Although the table extends up to 560 kW rating, but values till 22 kW rating are shown for illustrative purpose Table 10 is specific to stationary reciprocating piston types. However as per the regulation the EE grade are different for each types of air compressors.

Operating Conditions

The operating conditions are not clearly mentioned in the regulation.

Mexico Energy Label

Scope

Mexico has voluntary endorsement label for Screw (Rotary) type of air compressors. The authority implementing the regulation is FIDE (Fideicomiso para el Ahorro de Energía Eléctrica). The scope of the regulation covers screw air compressor driven by electric motors between the ratings 3 hp to 600 hp (approx. 2.24 to 447 kW). The regulation also specifies the supply rated voltage of 208- 230V or 460V with a frequency of 60 Hz. The regulation is applicable to compressors with or without integrated dryers.

Status

The regulation on voluntary endorsement of air compressors was introduced in 2012. The document "FIDE Seal Specification No. 4142" specifies the labeling criteria and other requirements of the label.

Eligibility requirements

The energy efficiency labelling parameter used by the Mexican program is 'Specific Input Power' which is same as specific power consumption (kW/(m^3/min)). The labelling requirements specify the maximum permissible value for specific input power for every motor rating from 3 hp to 600 hp. The air compressor should have a specific input power equal or less than the indicated value in the following table:

Table 12: Mexican label evaluation criteria for Rotary air compressors

Power Electric Engine kW (HP)	Specific Power Maximum Entry kW / 100 cfm	Power Electric Engine kW (HP)	Specific Power Maximum Entry kW / 100 cfm
2.24 (3)	21.49	**74.60 (100)**	20.90
3.73 (5)	21.48	**93.25 (125)**	20.74
5.60 (7)	21.46	**111.90 (150)**	20.59
7.46 (10)	21.44	**130.55 (175)**	20.44
11.19 (15)	21.41	**149.20 (200)**	20.29
14.92 (20)	21.38	**186.50 (250)**	19.98
18.65 (25)	21.35	**223.80 (300)**	19.68
22.38 (30)	21.32	**261.10 (350)**	19.38

29.84 (40)	21.26	**298.40 (400)**	19.07
37.30 (50)	21.20	**335.70 (450)**	18.77
44.76 (60)	21.14	**373.00 (500)**	18.46
55.95 (75)	21.05	**447.60 (600)**	17.85

Operating Conditions

The requirements specify the specific input power to be measured and calculated at nominal capacity and operating pressure at full load conditions.

Comparative assessment of international labeling programs

The table below provides a comparative snapshot of different international labeling programs. It also highlights key advantages and limitations of each of these programs.

Table 13: Comparison of International Labelling programs for air compressors

Country	EU	USA	China	Mexico
Coverage	**Rotary and Reciprocating** -Air cooled -Oil lubricated	**Screw (Rotary)** -Air / liquid cooled -Oil lubricated	**Rotary and Reciprocating** -Air / Water cooled -Oil lubricated / Oil free	**Screw (Rotary)**
Mandatory/ Voluntary	Mandatory	Mandatory	Mandatory	Voluntary
Policy Type	Endorsement label; MEPS	Endorsement label; MEPS	Comparative label	Endorsement label; MEPS
Test standard referred	ISO 1217	ISO 1217	GB 19153-2009	CAGI / PNEUROP PN2CPTC2 Replaced by ISO 1217
Implementing Authority	European Commission	US Department of Energy	General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ); Standardization Administration of China (SAC)	FIDE
Benchmarking Parameter	Isentropic Efficiency		Specific power consumption	Specific power consumption
Advantages	• Direct comparison between models • Specifies operating conditions for measurement of isentropic efficiency		• Covers entire scope of displacement compressors and their sub types	• Using motor ratings simplifies comparison • Single table for entire category

Country	EU	USA	China	Mexico
Limitations	• Requires tested and verified data for regression curves to be accurate • Coefficients of the regression curves would change as more data is added		• Highly data intrinsic • Defined only for certain pressure values • Unclear operating conditions • Boundary between product types not defined • Many tables for each category	• SPC compared at full load doesn't create common basis for all as compressor might operate between different pressures and SPC computed would change

5. Energy Efficiency Metric for Star Label

The labeling program for air compressors in India is proposed for positive displacement type (reciprocating and rotary). Dynamic air compressors (centrifugal/axial) are not proposed for the labeling program as its market share is less than 1% and the performance standard to measure its efficiency is also different i.e. IS 14641 Turbocompressor — performance test code.

The performance data of various parameters were sought from the manufacturers on a structured questionnaire. The following testing parameters were requested for all positive displacement air compressors models:

1. **Full Load Operating Pressure:** The test shall be carried out as per IS/ISO 1217 section 5.2.
2. **Rated Volume Flow Rate at Full Load Operating Pressure:** The test shall be carried out as per IS/ISO 1217 section C.2.2.
3. **Total Package Input Power at Rated Capacity and Full Load Operating Pressure:** The test shall be carried out as per IS/ISO 1217 section C.2.4.
4. **Specific Power Consumption at Rated Capacity and Full Load Operating Pressure:** The test shall be carried out as per IS/ISO 1217 section C4.4.

The summary of the performance data analyzed for developing the labeling program is shown below in table 14:

Table 14: Summary of performance data received from questionnaire based survey

Type	No. of Manufacturers	No. of models	Air Cooled models	Water Cooled models	Motor Ratings kw (HP)		Pressure @ Full Load (bar)		Rated Capacity (cfm)	
					Min	Max	Min	Max	Min	Max
Recip.	5	248	239	9	0.37 kW (0.5 HP)	44.7 kW (60 HP)	5	60	1.6	227
Rotary	6	948	649	299	2.2 kW (3 HP)	500 kW (670 HP)	1.5	15.5	8.5	2443
Positive displacement	**7**	**1196**	**888**	**308**	**0.37 kW (0.5 HP)**	**500 kW (670 HP)**	**1.5**	**60**	**1.6**	**2443**

A total of 1196 data points from 7 manufacturers were collected from the manufacturers through questionnaire survey based on the parameters mentioned above. The performance data was analyzed to identify appropriate efficiency parameter for formulation of labeling program and propose energy performance thresholds. The data for air-cooled and water-cooled air compressors was separately analyzed as different components are used in their design. This leads to variation in total package input power for air cooled and water cooled variant of the model/series. Hence, separate rating plan based on cooling method was proposed.

Energy efficiency of air compressors can be expressed using various parameters. Commonly used parameters include Specific Power Consumption (S.P.C) and Isentropic Efficiency. After a detailed review of International (ISO), national standards (IS) and the global labeling program of positive displacement air compressors, Isentropic Efficiency (at full load) was identified as a more appropriate benchmarking parameter for the labeling program in India for the following reasons:

- **Direct comparison of performance -** Isentropic efficiency can only have values between 0 and 1 whereas specific power consumption does not allow direct comparison. For example, Compressor that compresses air from 1 bar to 10 bar and other that compresses from 1 bar to 8 bar cannot be compared using S.P.C. due the different inlet and outlet conditions. But isentropic efficiency gives definite value for each of the compressors. The table 15 demonstrates the same using justified values.

Table 15: Example for S.P.C. vs Isentropic Efficiency

	Compressor A	Compressor B	Compressor C
Air compression	1 bar to 10 bar	1 bar to 10 bar	1 bar to 9 bar
S.P.C.	7.87 (kW/m3/min)	8.23 (kW/m3/min)	7.5 (kW/m3/min)
S.P.C Comparison	A is more efficient than B		Cannot be compared to A or B
Isentropic Efficiency @ Full load conditions	**69%**	**66%**	**68%**
Isentropic efficiency comparison	A is most efficient		

- **Removes pressure from the comparison –** Isentropic power is specified at full load operating condition whereas S.P.C is specified for specific inlet and outlet pressure.

- **Less sensitive to deviations –** As isentropic efficiency is the ratio of ideal process to the real process under the same conditions, it has less sensitivity as compared with S.P.C.

The isentropic efficiency was calculated at full load operating pressure and rated volume flow rate to compare the performance of air compressors.

Calculation of Isentropic Efficiency of fixed speed positive displacement air compressors:

$$\eta_{isen} = \left(\frac{0.165 * q_{V1}(cfm) * \left(P_2(bar)^{0.2857} - 1 \right)}{P_{real}\,(kW)} \times 100 \right) \%$$

Where:
η_{isen} = isentropic efficiency of the air compressor[8]
q_{V1} = inlet volume flow rate (cfm), at full load (measured);
P_2 = operating pressure (bar), at full load (measured);
P_{real} = package input power (kW), at full load (measured)

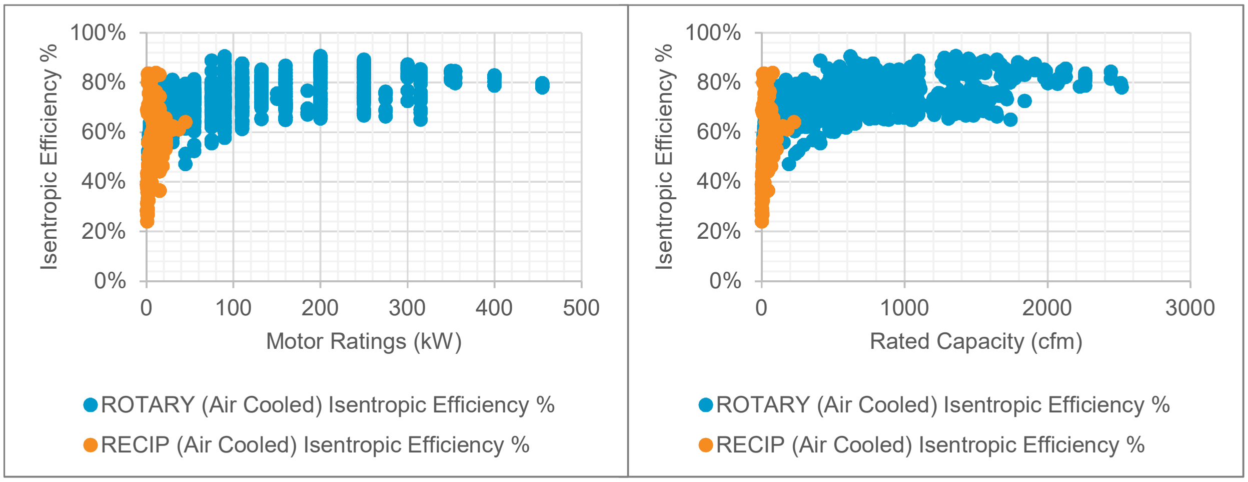
Comparison of Isentropic Efficiency with motor ratings and rated capacity at full load pressure is provided in figure 12 and 13, respectively. Performance analysis of air compressors indicate the below trends:

- Isentropic efficiency increases with increasing motor ratings which is attributable to reduced share of motor losses at higher capacities
- Isentropic efficiency in reciprocating compressors is lesser as compared to rotary compressors at higher capacity and motor ratings.

[8] The formula assumes that air is compressed from atmospheric inlet conditions and its isentropic exponent, κ is equal to 1.4.

Figure 13: Isentropic Efficiency & Motor Ratings (Reciprocating & Rotary Air Compressors)

Figure 14: Isentropic Efficiency and Rated Capacity (Reciprocating & Rotary Air Compressors)



Further, it is proposed that air compressor can be classified according to the nominal rating of the drive motor within different ranges, which is mostly followed by the industry and is well understood by the manufacturer and the buyer.

Performance data of air cooled and water cooled air compressors was analyzed to propose energy performance thresholds as mentioned in table 16 and 17. Motor ratings with similar efficiency ranges were grouped together as demonstrated in the figures 14 and 15. Also, the star rating levels within each motor rating band was proposed in a way that highest number of models are allotted 2 star rating and only less than 15% achieve 5 star rating. The scatter plots shown in the figures 14 to 16 are based on calculated isentropic efficiency at full load conditions and rated drive motor ratings in kW for both reciprocating and rotary type air compressors.

Figure 15: Efficiency plot air cooled positive displacement air compressors (till 55 KW)

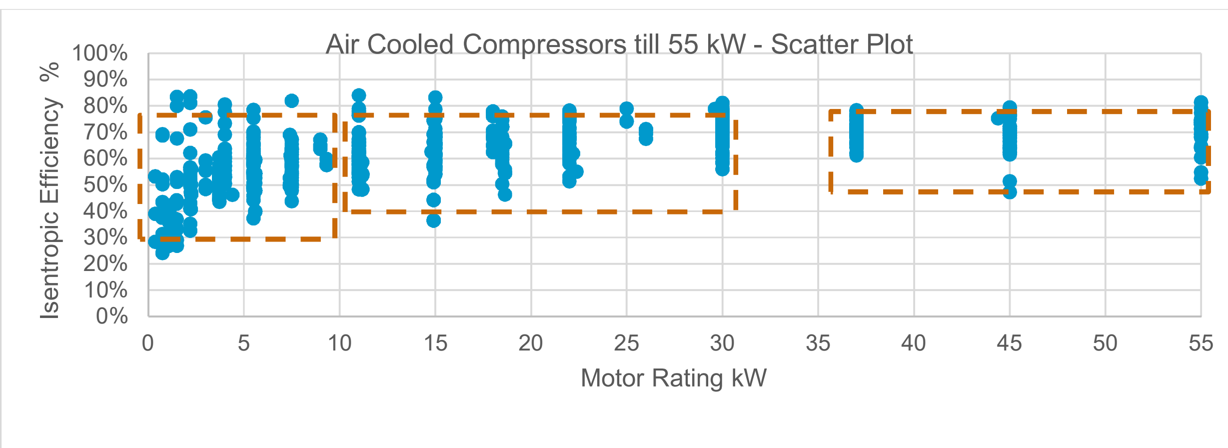


Figure 16: Efficiency plot air cooled positive displacement air compressors (75 - 350 kW)

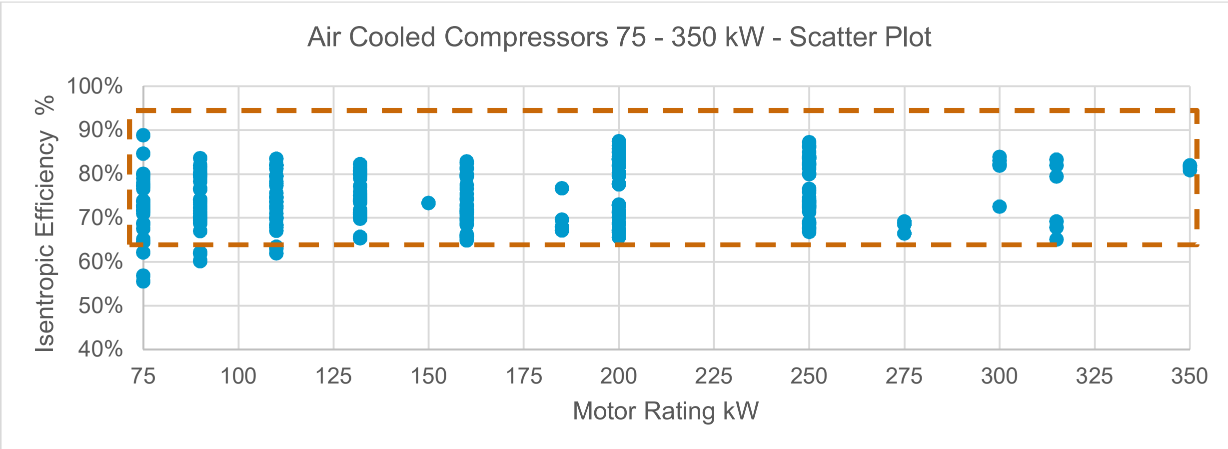
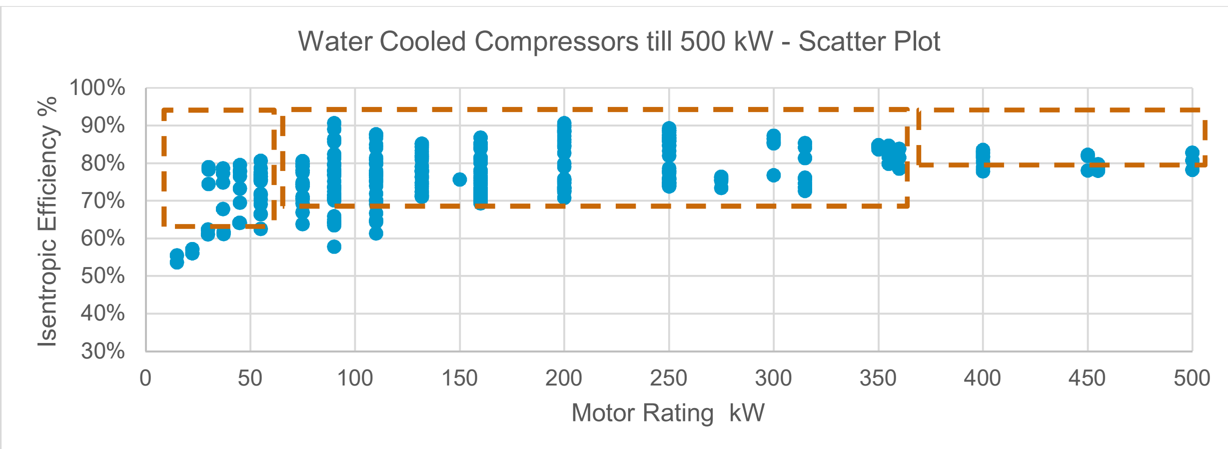


Figure 17: Efficiency plot water cooled positive displacement air compressors (till 500 KW)



Technology subtypes such as variable speed drive, oil-free and low pressure (1.5 to 5 bar) air compressors have less than 5% share of the total market. Also, these technologies are specialized as per buyers' specifications and should not compared using the in the same rating plan. Energy efficiency labelling is not recommended in these types as these are generally a business to business market segment where the buyer specifies the product characteristics and the manufacturer then produces the product. Hence, these types are excluded from the proposed scope of the labeling program.

The scope of labeling program for electrically driven positive displacement air compressor is proposed to cover the following:

1. **Rotary and Reciprocating air compressors**
2. **Only Fixed Speed compressors**
3. **Only Oil-lubricated/Oil-injected compressors**
4. **Air Cooled and Water Cooled with separate rating criteria**
5. **Full Load Operating Pressure greater than equal to 5 bar[g]**
6. **Motor Rating from 0.37 kW to 500kW**.

Based on the analysis of energy performance data as shown in scatter plot in figure 15 to 17, the proposed star rating plan for Air Cooled and Water Cooled positive displacement air compressors (reciprocating and rotary) for the voluntary phase of the labeling program is shown in table 16 and 17 respectively. The rating plan specifies the upper and lower thresholds of Isentropic Efficiency (at full load) according to the nominal motor rating ranges.

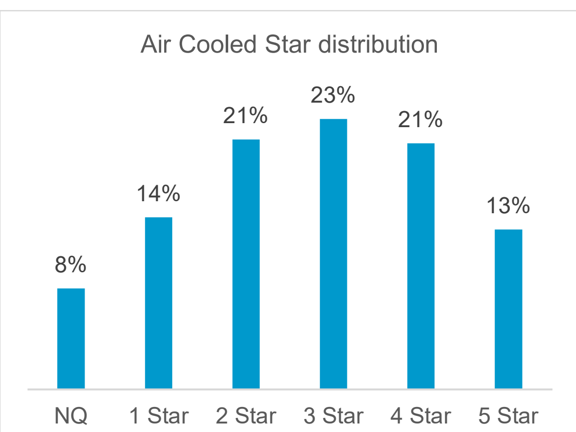
Table 16: Star rating plan for air cooled positive displacement air compressors

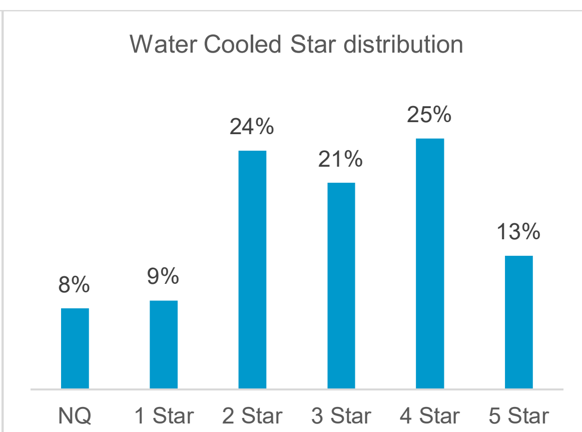
Range of Isentropic Efficiency η_{isen} % w.r.t Motor Rating – Air Cooled					
Star Rating	Motor Ratings (kW)				
	0.37kW ≤ Motor rating < 11 kW	11 kW ≤ Motor rating < 37 kW	37 kW ≤ Motor rating < 75 kW	75 kW ≤ Motor rating < 200 kW	200 kW ≤ Motor rating ≤ 500kW
1	$44 \leq \eta isen < 50$	$54 \leq \eta isen < 60$	$66 \leq \eta isen < 70$	$70 \leq \eta isen < 74$	$73 \leq \eta isen < 77$
2	$50 \leq \eta isen < 56$	$60 \leq \eta isen < 66$	$70 \leq \eta isen < 74$	$74 \leq \eta isen < 78$	$77 \leq \eta isen < 81$
3	$56 \leq \eta isen < 62$	$66 \leq \eta isen < 72$	$74 \leq \eta isen < 78$	$78 \leq \eta isen < 82$	$81 \leq \eta isen < 85$
4	$62 \leq \eta isen < 68$	$72 \leq \eta isen < 78$	$78 \leq \eta isen < 82$	$82 \leq \eta isen < 86$	$85 \leq \eta isen < 89$
5	$\eta isen \geq 68$	$\eta isen \geq 78$	$\eta isen \geq 82$	$\eta isen \geq 86$	$\eta isen \geq 89$

Table 17: Star rating plan for water cooled positive displacement air compressors

Range of Isentropic Efficiency η_{isen} % w.r.t Motor Rating – Water Cooled			
Star Rating	Motor Ratings (kW)		
	30 kW ≤ Motor rating < 75kW	75 kW ≤ Motor rating < 200kW	200 kW ≤ Motor rating ≤ 500kW
1	$68 \leq \eta isen < 72$	$73 \leq \eta isen < 77$	$75 \leq \eta isen < 79$
2	$72 \leq \eta isen < 76$	$77 \leq \eta isen < 81$	$79 \leq \eta isen < 83$
3	$76 \leq \eta isen < 80$	$81 \leq \eta isen < 85$	$83 \leq \eta isen < 87$
4	$80 \leq \eta isen < 84$	$85 \leq \eta isen < 89$	$87 \leq \eta isen < 91$
5	$\eta isen \geq 84$	$\eta isen \geq 89$	$\eta isen \geq 91$

The below graphs show the distribution of models into star rating slabs based on the present performances level of available product in the market. The number of models used in these graphs for air cooled and water cooled types are 888 and 308 respectively. Non-qualified (NQ) category comprises of models which fail to qualify the minimum requirements of the program i.e. 1 star. However, these models are allowed for sale in the voluntary phase of the labeling program and are disqualified after program transitions to mandatory phase.





6. Potential Energy Saving and GHG reduction

This chapter estimates the energy and Greenhouse Gas (GHG) savings from the labeling program, based on the following assumptions–

Table 18: Assumptions for baseline scenario 2020

Baseline Scenario for Air cooled compressors				
	Average energy consumption (KWh/yr.)	**Market share (%age)**	**Sales figure for all segments (2020)**	**CAGR till 2030 for all segments**
NQ	42752.14	8%	117.8 thousand units	03.83%
1 star	39390.24	14%		
2 star	37030.01	21%		
3 star	34922.20	23%		
4 star	32868.27	21%		
5 star	31989.71	13%		
Baseline Scenario for Water cooled compressors				
	Average energy consumption (KWh/yr.)	**Market share (%age)**	**Sales figure for all segments(2020)**	**CAGR till 2030 for all segments**
NQ	832266.92	8%	711 units	03.83%
1 star	761106.42	9%		
2 star	722837.33	24%		
3 star	688235.16	21%		
4 star	656796.61	25%		
5 star	642131.05	13%		

- *The market share for each segment has been considered same as baseline scenario for the subsequent years till 2030.*
- *CAGR assumption is based on Index of Industrial Production (IIP) data published by Ministry of Statistics and Programme Implementation for the last 8 years.*
- It is assumed that voluntary phase of the program is 2 years and after which it is made mandatory, hence eliminating the nonqualified (NQ) slab.
- Annual Energy Consumption for particular star rating is calculated weighted average of share, operation hours, load and power consumption data of models with 7 bar rated full load pressure.

Table 19: Estimated Electricity and CO2 savings from the labeling program

Savings by 2030	Electricity Savings (TWh)	CO_2 savings (MT CO_2)
Air cooled	7.67	6.29
Water cooled	0.74	0.61
Total	8.41	6.9

The cumulative savings as a result of the proposed air compressor labeling program is estimated to be 8.41 TWh and 6.9 MtCO2 by 2030.

Figures 17 and 18 show the cumulative energy and GHG saving potential by 2030 from the air compressors labeling program in India.

Figure 18: Potential cumulative energy saving till 2030

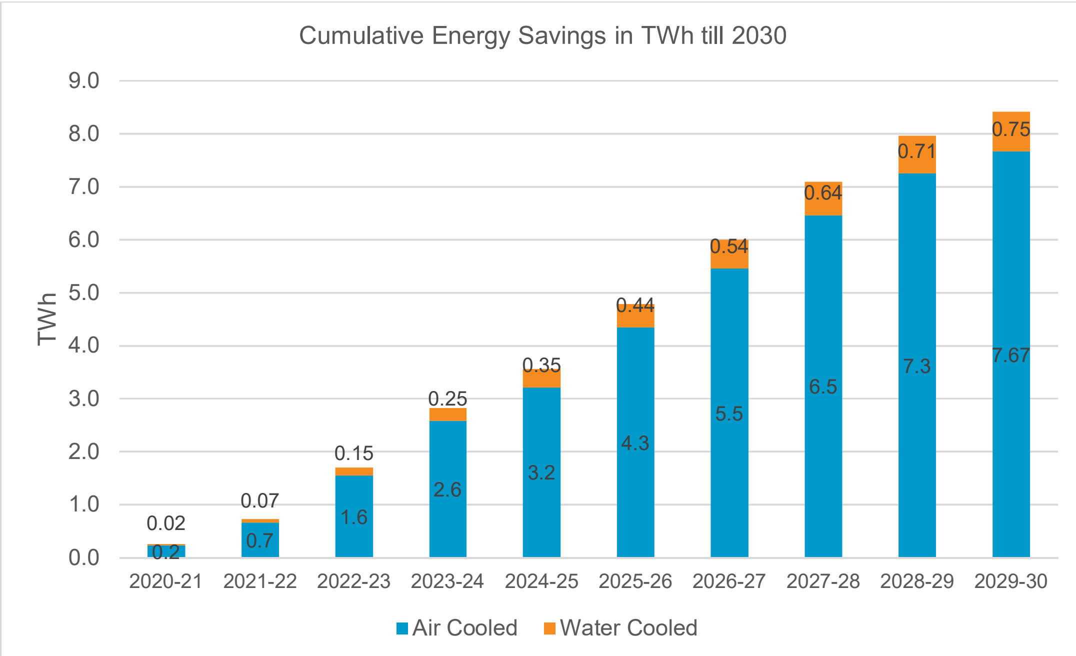
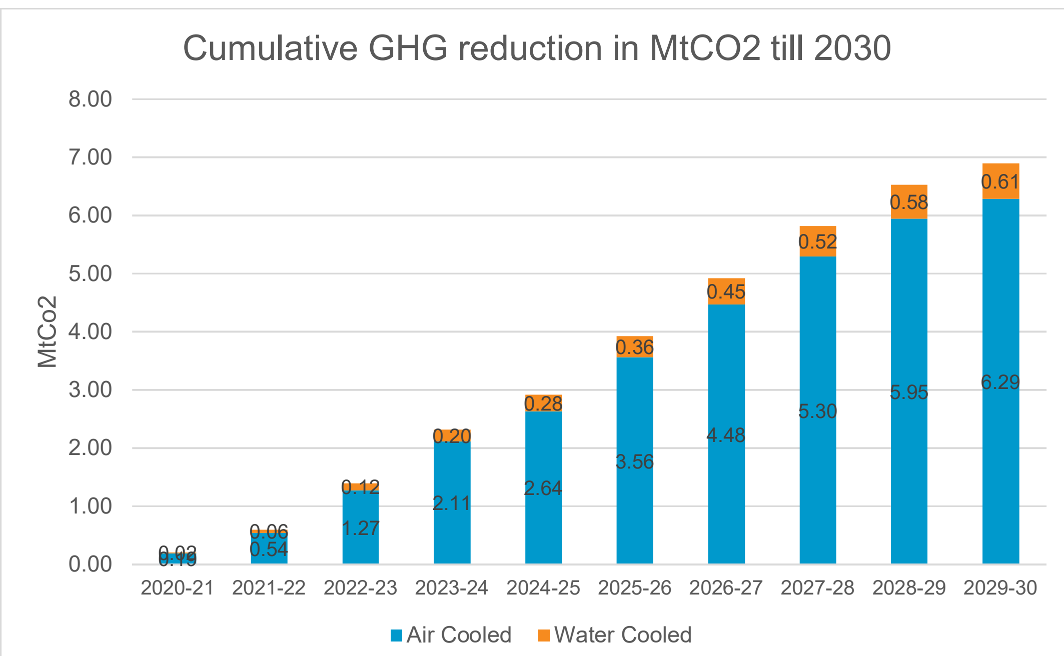


Figure 19: Potential cumulative GHG reduction till 2030



Annexure A: Air compressor components and auxiliaries

Prime Movers

Prime mover is a machine used to provide power source to drive the air compressor. It is used to generate torque and power to start the compressor, accelerate it to full speed, and keep it working under various operational conditions. A prime mover could be any one of the following machines: electric motors, diesel or natural gas engines, steam turbines and gas turbines. The most commonly used prime mover is an electric motor as it provides an economical and reliable means to efficient power.

Control system

Control system are on-board computers used to regulate the pressure by matching the compressor supply with system demand. It helps to optimize compressed air as a utility. It is typically included in the package of the compressor. Major functions of the control system are to start/stop, load/unload, modulate, vary displacement and vary speed. Some advanced control systems may also be provided by manufacturers as an add-on to the standard package.

Auxiliaries

Auxiliaries are equipment used for various purposes such as treatment of compressed air, smooth running of system, maintenance of proper delivery pressure and air. Auxiliary equipment includes remote aftercoolers, intercoolers, filters, separators, dryers, heat recovery equipment, lubricators, pressure regulators, air receivers, and condensate drain traps.

- **Inlet Air Filters:** Most air compressors have filter to protect the compressor from atmospheric airborne particles. Sometimes further filtration is needed to protect equipment which are installed downstream of the compressor.

- **Intercoolers:** These are heat exchangers installed in most multi-stage compressors to remove waste heat of compression between the stages of compression. Intercooling affects the overall efficiency of the compressor.

- **Aftercoolers**: These are heat exchangers for cooling the discharge from the air compressor and also to remove moisture. It is installed after the last stage of compression. The temperature of the air increases as air is compressed. Aftercoolers are used to reduce temperature. As the air temperature is reduced, water vapor in the air is condensed, separated, collected, and drained from the system. Most of the industrial systems, except those that supply heated process air require aftercooling. Aftercooler can be part of the package in some compressor while others might separately install it outside.

- **Moisture Separators:** It is installed after each intercooler or aftercooler to remove condensed moisture. Lubricant-injected compressors have lubricant separator installed immediately after the compressor discharge to separate the injected lubricant before it is cooled and recirculated to the compressor.

- **Compressed Air Filters:** Filters are used to remove any one or more of these: solid particles, moisture, odors and lubricants. Depending on the contaminant type and level of air purity required, different types and levels of filtration are used. Particulate filters are used to remove solid particles, coalescing filters to remove lubricant and moisture, and adsorbent filters for tastes and odors. Filtration should be done only to the level require as increases pressure drop and resultant energy consumption.

- **Dryers:** As air is compressed, its temperature rises, and condensation of water vapor present inherently in air could cause corrosion and contamination at end use points. Dryers are used to remove water vapor from the compressed air to prevent its condensation in tanks, pipes, hoses and tools. The types of dryers are categorized into two: primary, which includes coalescing, refrigerated, and deliquescent; and secondary, which includes desiccant, absorption, and membrane.

- **Heat Recovery:** More than 80 percent[9] of the electrical energy going to industrial air compressor is available as heat for recovery. This heat is recovered and used for heating water or air. The heated air can typically be used for heating warehouses, production areas, drying air for paint spraying, pre-heating combustion air and as air curtains. This extracted heat also improves air quality and lubricant life.
- **Air Receivers:** An integral part of a compressor, commonly referred as vessel or tanks, air receivers are used to store compressed air to meet peak demand events. It acts as a buffer between the compressor and fluctuating pressure caused due to changing demand. Using air receiver reduces energy consumption by allowing compressors to operate in smaller pressure band and preventing pressure fluctuations and frequent motor start.

[9] CAGI | Improving compressed air sourcebook pdf

Annexure B: Air Compressor Performance Parameters

The below definitions as in accordance with IS/ISO 1217.

Packaged Air Compressor

As per IS/ISO 1217 section 3.1.13, it is defined as a compressor with prime mover, transmission, fully piped and wired internally, including ancillary and auxiliary items of equipment and being stationary or mobile (portable unit) where these are within the scope of supply.

Volume Flow Rate

As per IS/ISO 1217 section C.2.2, it is defined as the air compressed and delivered at the standard discharge point, referred to conditions prevailing at standard inlet point. It is measured at terminal outlet of packaged compressor.

Full Load Operating Pressure

As per IS/ISO 1217 section 5.2, it refers to the discharge pressure, determined at full-load conditions.

Packaged Input Power

As per IS/ISO 1217 section C.2.4, it is the sum of the electrical power inputs to the prime mover and any ancillaries and auxiliaries driven from the compressor shaft or by a separate prime mover.

Specific Power Consumption

As per IS/ISO 1217 section C4.4, it is defined as compressor power input in kW (refers to packaged power) per unit of compressor actual volume flow rate.

Isentropic Power

As per Annexure H specified in ISO 1217 Amendment 1: 2016, it is power that is theoretically required to compress an ideal gas under constant entropy, from given inlet conditions to a given discharge pressure.

Isentropic Efficiency

As per Annexure H specified in ISO 1217 Amendment 1: 2016, it is ratio of the required isentropic power to measured power for the same specified boundaries with the same gas and the same inlet conditions and outlet pressure. It is expressed as percentage given by the formula:

$$\eta_{isen} = \left(\frac{P_{isen}}{P_{real}} \times 100\right) \%$$

Annexure C: Selection of Air Compressor

Selection of a suitable air compressor is dependent on several factors. The following criteria or the key parameters which a user generally looks for while selecting an air compressor are as listed below:

Application Industry: Compressed air usage (6 hrs/day or intermittent), Demand Profile (eg. constant or significant variation), type of industry and quality of air required.

↓

Location of Air Compressor: Basement, outdoor or indoor, e.g. Air Cooled compressors shall not be placed in a closet or basement.

↓

Pressure Requirement: The maximum operating pressure must match or exceed the pressure requirement of the pneumatic equipment's maximum pressure requirement.

↓

Requirement of Air Flow: Caluclation of actual air flow rate requirement

↓

Motor horsepower selection: Post air flow and pressure requirement calculation, consumers prefer to select cost effective and motor with lower SPC (specific power consumption)

↓

Selection of Size of Air Tank: Air tanks help eliminate pulsation in air line and provide storage when demand exceeds compressor capacity. Its selection is based on space available.

↓

Operating Duty Cycle: Depending on the use of compressed air and amount of time a compressor will be required to deliver pressurized air within a total cycle time is taken into consideration.

↓

Initial purchase price: Rotary and centrifugal compressors tend to be more expensive than reciprocating compressors but deliver non-pulsating output. Total cost of ownership including electricity cost should also be accounted.

Appendix D: Review of Test Standards

Review of ISO 1217:2009 and its Amendment-1 in 2016

ISO 1217:2009 specifies methods for acceptance tests regarding volume rate of flow and power requirements of displacement compressors. The standard includes the following:

- Operation and test conditions which apply when a full performance test is specified.
- Correction of measured values to specified conditions and comparison of the corrected values with the guarantee conditions.
- Methods for determining the value of the tolerances to be applied to the measurement of flow, power and specific power.

The types of displacement compressor covered under the scope of the standards are:

- Liquid-ring compressor
- Bare displacement compressor
- Electrically driven packaged compressor
- Internal combustion engine-driven packaged compressor
- Electrically driven VFD compressor

Tests prescribed

IS 1217: 2009 specifies test protocols, measurement and calculation procedures, correction and comparison of test results with specified values for three parameters which are related to the performance of air compressors:

a) Volume flow rate

b) Compressor input power

c) Specific energy requirement

d) Isentropic Efficiency (Annexure H added in amendment 1 in 2016)

Method of measurement of parameters

Measurement of pressure

The total pressure defined in the standard is the sum of static and dynamic pressure. It shall be measured using a Pitot tube. The standard also specifies a general guideline for mounting and calibrating instruments. The measuring instruments shall have an accuracy of ± 1%. Appropriate corrections shall be made to column reading and dead-weight gauges.

Measurement of temperature

Temperature is measured by instruments such as thermometers, thermo-electrical instruments, resistance thermometers or thermistors and thermocouples. The measurement shall be done by inserting the measuring device into the pipe or pockets and should not be lifted out of the medium during the measurement. The instruments used should be certified or calibrated. Instrument accuracy should be ± 1K.

Measurement of flow rate

The two testing methods referred for measurement of flow rate are ISO 5167-1 and ISO 9300. Either of the methods can be used to determine free air delivery for the acceptance test of air compressors.

Table 20: Comparison between the two normative references for measurement of flow rate

Parameters	ISO 5167-1	ISO 9300
Measurement device	ISO 5167-1 specifies the methods of measurement of flow of fluids. This measurement is to be conducted using **pressure differential devices** such as nozzles, orifices and venturi tubes.	On the other hand, ISO 9300 specifies the method to determine the mass flow rate of gas. The standard is applicable to **Critical flow Venturi nozzles (CFVN)** only.
Flow Measurement	The device creates a pressure difference which is measured by wall pressure tapping with at least one reading of upstream and downstream flow. The rate of flow is determined using the static pressure difference, fluid characteristics such as density and viscosity and the conditions of flow. The computation of flow rate is then a purely arithmetic and depends on pressure difference, internal diameter of upstream pipe and Reynolds number.	The venturi nozzle is used to accelerate the gas to the critical velocity at throat (narrow end of nozzle) of the venturi nozzle at which the flow rate is maximum for the existing upstream conditions. The measurements required are gas pressure, temperature or upstream density of CFVN.
Tolerance	The standard provides a method for calculating uncertainties.	The standard specifies that the CFVN used in the measurement must be directly calibrated adequate number of times to produce accurate results within certain limits.
Conditions	It is important to note that the standard assumes that the measuring device is geometrically similar to one on which calibration has been carried out and that the conditions of use are the same.	Comparing CFVN to pressure differential meters, it can be noted that in CFVN, the flow is directly proportional to nozzle upstream pressure whereas in the latter, it is square root of differential pressure.

Measurement of power and energy

The standard specifies the following ways to measure compressor power:

- Direct measurement using a torque meter
- Indirect measurement by determining the electrical input to driving motor
- Using certified performance characteristics of the driving prime mover

The shaft power of an electrically driven compressor shall be determined by measuring the electrical power supplied and multiplying by the motor efficiency value obtained from the certified calibration of the motor. Electrical power to the machine shall be measured from input terminal along with the voltage drop consideration across supply cables and measuring devices.

The standard mentions about the loading changes for different readings. In case of 3 phase motors, two wattmeter method is suggested for measuring power.

Computation of specific energy requirement

The test result shall be computed by calculating the arithmetic average from the accepted readings, except for flow measurement which shall be measured from the specified standards.

The specific energy consumption of the packaged compressor is found as a ratio of Packaged power input to volume flow rate.

Computation of Isentropic Efficiency

The calculation of isentropic efficiency was introduced in the standard through an amendment in 2016 as Annexure H of the standard. The new Annexure H replaced the previous definition of Isentropic power and

Isentropic efficiency which considered shaft power in the calculation. The new definition describes isentropic efficiency as the ratio of the required isentropic power to measured power for the same specified boundaries with the same gas and the same inlet conditions and outlet pressure. The standard also provides examples of the specified boundaries such as shaft power of bare compressor or motor power of the package including inlet and discharge losses or total input power of the package.

The Annexure H defines Isentropic power as power that is theoretically required to compress an ideal gas under constant entropy, from given inlet conditions to a given discharge pressure.

The formula mentioned in the Annexure H to calculate Isentropic Power is described below.

$$P_{isen} = q_{V1} \,.\, P_1 \,.\, \frac{\kappa}{\kappa - 1} \,.\, \left[\left(\frac{P_2}{P_1} \right)^{\frac{\kappa-1}{\kappa}} - 1 \right]$$

Where:
qV1 is the volume flow rate (m3/s)
p1 is the absolute pressure at the inlet (Pa)
p2 is the absolute pressure at the discharge (Pa)
κ is the isentropic exponent (ratio of specific heats)

Correction of measured values

The standard considers that test conditions are not always consistent with specified conditions so, test results are corrected using appropriate correction factors and then compared with the specified performance values. The corrections are applicable to volume flow rate and shaft power and specific energy requirement.

Test conditions

The standard defines the reference test conditions in Annexure F. It specifies that the compressor shall operate at full load during the test.

The reference standard inlet conditions specified in the standard are be as follows:

Table 21: Reference conditions for testing as per ISO 1217

Parameters	Values
Inlet air pressure	100 kPa [1 bar]
Inlet air temperature	20 °C
Relative water vapour pressure	0
Cooling water temperature	20 °C

Tolerances specified

The acceptable limits of deviations of test parameters from the specified values is mentioned in the table below:

Table 22: Max deviations of parameters from specified values as per ISO 1217

Parameters	Tolerance
Inlet pressure	± 10 %
Discharge pressure	± 2 %

External coolant quantity	± 10 %
Inlet temp. of external air coolant	± 10 K
Inlet temp. of external liquid coolant	± 5 K
Liquid injection temperature	± 5 K
Shaft speed	± 4 %
Gas constant × compressibility factor, R × Z	± 5 %

The acceptable deviations in test results from the specified values is mentioned in the table below:

Table 23: Maximum deviations permissible at test as per ISO 1217 and Amendment 1

Volume flow rate at specified conditions, q_v (cfm)	Volume flow rate %	Specific energy requirement %	Power requirement (at zero volume flow rate or at pressure ratio of 1)	Corresponding Isentropic Efficiency (η_{isen}) tolerance %	
				Lower η_{isen}	Upper η_{isen}
$0 < q_v \leq 17.5$	±7	±8	±10	-7.4	8.7
$17.5 < q_v \leq 53$	±6	±7	±10	-6.5	7.5
$53 < q_v \leq 530$	±5	±6	±10	-5.7	6.4
$q_v > 530$	±4	±5	±10	-4.8	5.3

Review of IS 5456:2006

This standard prescribes type tests and routine tests for both reciprocating and rotary type positive displacement air compressors

Type test carried out on new design or major design changes. Routine test carried on a model for acceptance by purchaser.

Tests prescribed

Type test constitutes the following tests and measurements:

- Mechanical and Endurance tests
- Capacity (FAD)
- Shaft power consumption
- Specific power consumption
- Max. operating speed
- Volumetric & overall efficiency of machine
- Lubricating oil consumption
- Testing of loading & unloading mechanism
- Flow of cooling water with rise in Temperature

Routine test constitutes the following:

- Capacity
- Speed
- Specific power consumption in the case of electrically driven compressors and specific fuel consumption with other drives at full load.

Method of measurement of parameters

Measurement of pressure

Pressure is measured by instruments such as calibrated bourdon gauges, dead weight gauges, mercury manometers, barometer.

Delivery Pressure — shall be measured by a bourdon gauge placed on the main receiver which is nearest to the compressor.

Intermediate stage pressure — must be measured according to the contractual clause. The calibrated bourdon type pressure gauges shall be mounted on the inter-cooler between the various stages of the compressor to obtain the inter-stage gauge pressure.

Suction Pressure — The intake pressure shall normally be measured with the manufacturer's standard intake filter.

Atmospheric Pressure—The atmospheric pressure shall be determined by means of a mercury in-glass barometer which shall be read up to 0.5 mm.

Measurement of temperature

Temperature is measured by instruments such as mercury thermometer, Thermocouple, Resistance thermometer, and Thermistors. The measurement shall be done by inserting thermometer directly into the air stream, where possible. When this is not possible, the thermometer wells shall be of thin steel or brass tube which may be welded or brazed to a hole pierced in the pipe.

Measurement of flow rate

The air flow measurement shall be carried out in accordance with IS 10431. Although the latest amendment to IS 5456 shall refer to IS 1217. Hence, it shall follow IS 5167-1 and IS 9300, which were described earlier.

Measurement of power

The standard specifies to measure motor shaft power using torsion meter, or determined from efficiency of calibrated motor tested as per IS 325, or tested from relevant IS standards for prime mover other than electrical drive.. The standard does not clearly define the component included in the total power consumption. Also, it does not use input power of motor in power calculation, thus not considering the efficiency of motor. The measurement of Total power consumption is not specified clearly and doesn't include power consumption by auxiliaries. It only states about taking appropriate correction factors in case power consumption of compressors is declared jointly with motor.

Specific power consumption

The standard has no expression or formula to define specific power consumption of the compressor.

Test conditions

The standard refers the test conditions to be as close to the contract values specified by the supplier for performance guarantee. The routine tests can be conducted at supplier or buyers' site as per mutual agreement. If not specified, all tests shall be conducted at suppliers' site. The site owner shall be responsible for providing the test equipment and material for conducting the tests. The compressor shall be run enough to reach the steady state conditions. It specifies that sufficient number of readings shall be taken for each load to produce accurate results.

Tolerances specified

The acceptable limits of deviations for testing conditions from the specified values is mentioned in the table below:

Table 24: Max deviations from corrected test value and contract value as per IS 5456

Parameters	Tolerance
Inlet pressure	±8 %
Pressure ratio	±5 %
Shaft speed	±4 %
Inlet water temperature	±5°C
Coolant flow rate	±10 %
Difference between the coolant and air temperature	±10 %
Voltage	±5 %
Frequency	±1 %

The acceptable tolerance limits of results from specified values as per IS 5456 is mentioned below:

Table 25: IS 5456: Maximum deviation allowed from contract values for test results

Compressor shaft input	At 100% Flow Rate		At 50% Flow Rate		No Load Power
	Flow rate	SPC	Flow rate	SPC	
Below 10 kW	±6	±7	--	--	±20
10 to 100 kW	±5	±6	±7	±7	±20
Above 100 kW	±4	±5	±5	±6	±20

Annexure E: BIS TCM for IS 5456 revision

Amendments discussed in BIS technical committee meeting for IS 5456:2006

Bureau of Indian Standards (BIS) is currently in the process revising the standard IS 5456. It conducted a technical committee meeting on Compressors, Blowers and Exhausters on 20th September 2019. The project team was invited to give an update about the labelling program on air compressors and share our views on the existing standards both Indian and International.

The key discussion points and outcomes of the meeting have been presented below:

- The committee recognized that IS 5456 has limited compliance and requires amendment to bring it at par with international practices. The committee also recognized that the standard would require significant amendments in order to accomplish the same.
- The committee discussed the applicability of IS 5456 since ISO 1217 also applies to positive displacement compressors and is more preferred by industry. It was agreed by the members that since IS 5456 covers the type test as well as the routine test, the standard is more comprehensive than ISO 1217 which is an acceptance test.
- The committee decided to retain IS 5456 and revise the standard.
- The committee also decided to adopt ISO 1217:2009 as a dual standard IS/ISO 1217.

The key amendments in IS 5456 as discussed by the committee are mentioned below:

- The members agreed that the scope of IS 5456 would provide reference to IS/ISO 1217 for acceptance test of air compressors.
- The members agreed that IS 5456 would give reference to IS/ISO 1217 for terminologies and definitions.
- The members also agreed to change the present normative reference IS 10431 – measurement of air flow – with IS/ISO 1217. Since ISO 1217 refers to ISO 5167-1 and ISO 9300, any one of them could be used for flow measurement.

As a result of this technical committee meeting, BIS adopted ISO 1217 as Indian Standard under the dual number **IS/ISO 1217** and published the document in December 2019.