A Study of Energy Efficiency Standardization for the Integrated Compressed Air Equipment (ICAE) in China

Bo Hu and Xiaoming Sun

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Hu Bo[1] and Sun Xiaoming[2]

1 CLASP
2 Hefei General Machinery & Electrical Product Inspection Institute

Abstract

The air compressor stock in China reached about 3 million in 2020. Air compressor systems are responsible for over 9% of electricity consumption in the industrial sector in China, amounting to roughly 550 TWh of electricity in 2023.

The air compressor system is composed of a complex combination of various components and equipment designed to deliver high-quality compressed air to industrial users in production activities and has higher energy-saving potential. The driving electric motor presents an improvement potential ranging from approximately 1.4% to 3%. There remains a notable opportunity for enhancing energy efficiency in air compressors by 10% to 20%. However, achieving such a substantial enhancement entails significant costs and may pose challenges to the economic feasibility for motors and compressors.

The significance of compressed air dryers has long been underestimated. However, analysis indicates a wide-ranging energy efficiency enhancement potential for dryers, ranging between 10% to 20%, or even greater, at reasonable costs.

According to the Chinese industry standard T/CGMA 033001-2018, the efficiency disparity between average and the most efficient compressed air systems can reach up to 45%.

Since 2000, with the further advancement of screw air compressor miniaturization technology, the market has witnessed the emergence of Integrated Compressed Air Equipment (ICAE) as a novel type of system-oriented product. ICAE offers numerous advantages, including tailored compressed air supply to match demands at the point of use, heightened energy efficiency for air compressors, enhanced drying processes, integration of centralized control technology and variable frequency speed regulation technology, reduced operating pressure, optimization of pipeline networks, enhanced leakage control, and utilization of compressed air heat recovery. Market research reveals that over 200 Chinese manufacturers produce and promote ICAE in the Chinese market. It is anticipated that ICAE will represent over 50% of the total number of air compressors.

Standardization efforts concerning energy are crucial for promoting ICAE in the market. China initiated the development of product standard for ICAE in 2023. The proposed standard encompasses the product scope, new energy efficiency metrics, testing conditions, testing and efficiency calculation methodologies, and a voluntary energy efficiency classification scheme.

In conclusion, China's consumption of compressed air energy is substantial, presenting significant potential for energy savings in systems. The market outlook for ICAE products is promising, and standardization efforts for ICAE products are imperative. It is recommended for Chinese policymakers to consider establishing mandatory energy efficiency standards for ICAE.

1 Background

The air compressor stock in China was about 3 million[1] in 2020. These systems account for over 9% of electricity consumption in the industrial sector[2], making them a key focus for energy-saving initiatives. Air compressor systems used roughly 550 TWh of electricity[3], leading to the emission of 313 million tons of CO2 in the year 2023. Enhancing the energy efficiency of air compressor systems is essential for China's dual carbon goal by 2060 and its strategy to double efficiency. This improvement not only reduces energy consumption and greenhouse gas emissions but also brings economic and operational benefits to industries. Integrating electric motors, air compressors, compressed air treatment, and centralized control, as well as other energy efficiency enhancement measures, presents significant potential for improving energy efficiency in the high-efficiency production process of compressed air.

2 Energy efficiency improvement potential analysis of air compressor systems

The air compressor system is composed of a complex combination of various components and equipment designed to deliver high-quality compressed air to industrial users involved in production activities. The scope definition of the system signifies varying potentials for efficiency enhancement, as well as the associated costs and complexities of implementing those improvements.

The electric motor serves as a crucial component for converting electrical energy into the mechanical energy required to drive the air compressor. Currently, the IE3 standard has become the minimum energy efficiency requirement for induction motors in China. The average difference in energy efficiency between grade 1 (IE5) and grade 3 (IE3) 4 poles induction motors is approximately 1.4% - 3%[5], implying limited potential for improvement in motor efficiency.

The air compressor is the main equipment used to generate compressed air, and it consumes the majority of the total power in the system. Different types of air compressors vary significantly in terms of energy efficiency. The 2019 edition of Minimum Energy Performance Standards (MEPS) for air compressors showed a 9.8% improvement compared to the 2009 edition. There is a 20% efficiency gap between grade 1 and grade 3, suggesting that there is still a potential for 10% to 20% improvement in energy efficiency for air compressors in existing compressed air stations[6].

The compressed air discharged from the air compressor outlet cannot be directly utilized due to its high temperature, typically ranging from 60°C to 160°C, and the presence of harmful contaminants for the production process. Therefore, it requires treatment and cooling before use. Untreated compressed air contains the following contaminants:

- Moisture: Air typically contains water vapor, which condenses into liquid water when hot compressed air is cooled. The dew point indicates the temperature at which water vapor in the air begins to condense and serves as a parameter for the moisture content. The pressure dew point represents the dew point temperature under the pressure of the compressed air. Generally, compressed air users require that no liquid water appears during transmission and usage.
- Oil: Air usually contains oil, and since most air compressors operate with oil, compressed air naturally contains oil content. The oil content serves as an indicator of the presence of oil in compressed air, existing in liquid, suspended, and vapor forms.
- Solid particles: Air contains various solid particulates, which may also be introduced into compressed air during the operation of air compressors.

The Chinese national standard GB/T 13277.1-2023 (Compressed air – Part 1: contaminants and purity classes) adopts the same standard for classifying compressed air quality as ISO8573-1:2010, with the most crucial humidity level illustrated in table 1.

Table 1. Compressed air humidity classification scheme

Grade	Pressure Dew Point °C	Liquid Water Mass Concentration (Cw) g/m3
0	Higher requirement than Grade 1	
1	≤-70	-
2	≤-40	
3	≤-20	
4	≤+3	
5	≤+7	
6	≤+10	
7	-	Cw≤0.5
8		0.5<Cw≤5
9		5<Cw≤10
X		Cw>10

Different manufacturing processes have varying requirements for the quality of compressed air, which in turn leads to different demands for the treatment of compressed air, resulting in varying energy consumption and efficiency losses in compressed air treatment. According to the on-site compressed air station testing conducted by Hefei General Machinery & Electrical Product Inspection Institute (GMPI), the energy consumption of compressed air treatment, especially dryers, is substantial, with the electricity consumption of compressed air dryers sometimes accounting for up to 20% or even more of the system. This is a factor that has often been overlooked in the past. The energy efficiency levels of different types of compressed air dryers can vary by 8% to 20%[7], offering significant energy-saving potential in compressed air production, gradually becoming recognized by users. In recent years, the production of energy-saving dryers has advanced rapidly.

There are three main methods for compressed air purifying and drying, namely adsorption drying, refrigeration drying, and membrane separation. The pressure dew point of refrigerated dryers is generally +2°C (1~5°C). This type of dryer dries the compressed air in two stages, with the incoming air in the first stage being cooled by the cold air leaving the dryer, removing about 60% of the water, while the remaining water is eliminated through refrigeration. The pressure dew point of adsorption dryers can reach -20°C to -80°C. The desiccant can be regenerated with or without heating. Depending on the regeneration method of the desiccant, the types of adsorption dryers include heatless, exter heated, blower heated, and heat of compression adsorption dryers.

The efficiency difference between refrigeration dryers and adsorption dryers is significant, and there is a notable variance in energy efficiency among different types of adsorption dryers (due to different drying processes). The industry standard JB/T 10526-2017 " Refrigeration Compressed Air Dryers for General Use" stipulates:

Table 2. Dryer specific power of refrigeration compressed air dryer

Pressure Dew Point Grade (GB/T 13277.1-2008)	Dryer Specific Energy Requirement (kW/(m3/min))			
	Nominal Volume Flow≤3 m3/min		Nominal Volume Flow>3 m3/min	
	Air cooling	Water cooling	Air cooling	Water cooling
6	0.4	-	0.25	0.21

The industry standard JB/T JB/T 10532-2017 “Adsorption Compressed Air Dryers for General Use” stipulates:

Table 3. Consumption of purified compressed air of absorption dryers

Dryer type	Consumption of purified compressed air
Heatless	≤25%
Exter heated	≤16%
Blower heated (with air consumption)	≤4%
Heat of compression (with air consumption)	≤5%

The different types of compressed air dryers have significant differences in energy consumption. Based on GMPI’s testing, using energy-efficient equipment can produce energy savings benefits no less than those of air compressors, and the return on investment is often shorter.

Table 4. Benefits analysis of efficient dryers

Efficient dryer	Cost (m3/min)	Annual electricity cost (RMB)	In-efficient dryer	Cost (m3/min)	Annual electricity cost (RMB)	Payback time (month)
Blower heated (without air consumption)	2600	1260	Heat-less	700	9000	4
			Exter heated	1200	7200	5
Heat of compression (with air consumption)	2300	2520	Heat-less	700	6300	7
			Exter heated	1200	5040	11
Heat of compression (without air consumption)）	3000	1008	Heat-less	700	6300	7
			Exter heated	1200	5040	9

The operational conditions of adsorption dryers have a significant impact on performance and energy consumption. The temperature variance of compressed air results in considerable differences in moisture content, thereby increasing the load differences on the dryers. In practical operation, the temperature of the compressed air often deviates significantly from the specified operating conditions. Therefore, in the air compressor system, the compatibility of the temperature parameters of the compressed air output by the air compressor with the dryers is importance, directly affecting performance and energy consumption of the whole system. The actual operational efficiency of dryers in air compressor systems is often notably low, with improper matching and equipment misalignment, significantly reducing efficiency.

The demand for compressed air in factories fluctuates constantly. Therefore, by monitoring the compressor system, adjusting pressure control, controlling dew points of dryers, reducing the energy consumption of standby (reducing idle power), optimizing the start-stop operation of air compressors, loading and unloading operations, and employing variable frequency speed control, energy savings of 10 to 25% can be achieved through centralized and optimized control of systems and equipment[7].

The integration of electric motors, air compressors, compressed air treatment, and centralized control, as well as other energy efficiency enhancement measures, presents significant potential for improving energy efficiency in the high-efficiency production process of compressed air.

A Chinese industry standard T/CGMA 033001-2018 "Guide to energy efficiency classification for compressed air stations" sets energy efficiency classification scheme for compressed air stations, which focuses on the general efficiency of the whole compressed air system. The efficiency difference between Grade 5 and Grade 1 is between 40% and 45%.

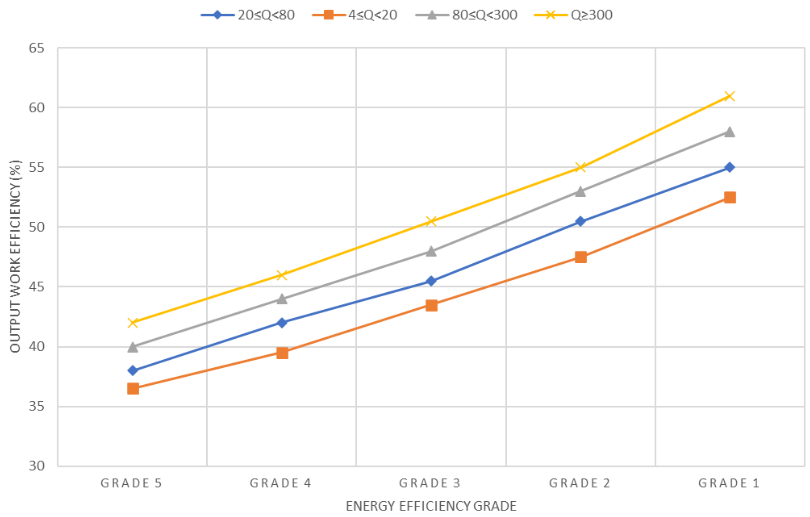

Fig. 1. Energy efficiency classification for compressed air station (-20℃≤pressure dew point<3℃)

*Q is the compressed air output flow

In the transmission and utilization stages of compressed air, measures such as reducing the operating pressure of compressed air, controlling leaks, and optimizing pipeline networks can lead to greater energy savings.

Additionally, air compressors release a significant amount of heat during operation, and by incorporating a well-designed heat recovery system, it is possible to recover more than 60% of this thermal energy for supplementary heating[8], industrial process heating, water heating, air recirculation heating, and preheating boiler makeup water.

3 Analysis of centralized and de-centralized compressed air production

The production and supply of compressed air in air compressor systems mainly involve two methods: (1) Centralized compressed air station: a complete system composed of multiple devices centrally produces compressed air and transports it to the points of use through a network of pipes; (2) Distributed compressed air equipment: compressed air is produced near the points of use.

Compressed air stations consist of multiple identical or similar compressor units, which centrally produce and supply compressed air. The advantage of this centralized setup is improved equipment management and maintenance. Additionally, large equipment producing compressed air demonstrates high energy efficiency, making it the preferred air supply method for large-scale air systems. However, this approach involves producing compressed air in one location and using it in another. Compressed air is mainly transported through ducted pipelines, which are typically long, resulting in significant pressure loss. Moreover, the compressed air operation requirements such as pressure and air quality vary at different points of use. The compressed air production system must meet the highest quality requirements of the points of use, leading to a certain degree of waste.

Compressed air stations must follow the design specifications outlined in GB 50029 "Code for Design of Compressed Air Station". The stations are designed by qualified design institutes, the equipment is procured by factories, installed on-site by station builders, and operated only after completion of commissioning by the equipment manufacturer. It serves as a foundational infrastructure in factory construction, with a lengthy construction process subjected to engineering supervision.

Distributed compressed air equipment produces and supplies compressed air near the points of use, meeting specific equipment requirements closely. It boasts minimal pressure loss, flexible layout, and convenient parameter adjustment. However, the downside lies in decentralized operation, inconvenient management, and relatively lower efficiency of small-scale equipment.

In Chinese industrial enterprises, compressed air production predominantly adopts centralized air supply through compressed air stations. This is due to the historical utilization of piston air compressors in distributed compressed air production. Piston air compressors have the disadvantages of lower reliability, complex maintenance requirements, high noise levels, significant vibrations, and low efficiency. Only when the air demand is minimal, micro piston air compressors are used for nearby gas supply. Since the year 2000, with the further advancement of screw machine miniaturization technology, its high reliability, high degree of automation, low noise, smooth operation, and simple daily maintenance advantages have gradually met and increased the demand for decentralized gas supply, giving rise to the emergence of Integrated Compressed Air Equipment (ICAE) as a new type of system-oriented product.

With the increasing automation of industrial production and growing market demand, the requirements for compressed air quality are also rising. Consequently, more air compressor manufacturers and energy service companies are developing and promoting intelligent and energy-efficient integrated equipment that combines compressors and purification equipment. This innovation aims to replace small, compressed air stations and address user challenges in the selection, procurement, and configuration of compressed air systems. These integrated systems, known as "Integrated Compressed Air Equipment" (ICAE), are gaining market acceptance and experiencing rapid growth and gradually expanding into medium to large facilities.,

ICAE products have emerged in the compressor industry in recent years due to technological advancements and enhanced automatic control technologies. They offer several advantages, including easy installation, high automation, and convenient use and maintenance, making them highly suitable for modest-scale compressed air applications. ICAE is poised to become widely utilized in industries such as small and medium-sized factories, construction projects, transportation, and service facilities. It holds promising prospects for rapid development and export, with vast application markets globally.

As a fully equipped product, ICAE obviates the need for users to undertake system design, separate procurement, installation, and configuration tasks, effectively replacing small, compressed air stations.

4 Market analysis of integrated compressed air equipment

The ICAE is a product that embodies inherent advantages in professional design and manufacturing.

- Matching demands and production for compressed air: ICAE features providing compressed air for specific equipment or applications.
- Enhanced energy efficiency for air compressors: the type and specifications of the air compressors are selected to meet the efficiency of the system.
- Improved drying process: the efficiency of the dryer can be optimized. Furthermore, by optimizing the parameters of the compressed air, the dryer can operate in an optimal state.
- Utilization of centralized control technology and variable frequency speed regulation technology: ICAE, as an integrated device, naturally possesses centralized control advantages, allowing for optimal selection of air compressors and dryers, as well as load adjustment through start/stop and variable speed modes, all while coordinating the operations of its own equipment to match the gas supply demands.
- Reduced operating pressure and optimized pipeline network for compressed air: ICAE can be closely located to the air-consuming equipment, lowering the required pressure. As an integrated equipment, it has shorter pipelines and reduced pressure drops. Hence, the air compressors in ICAE can operate at lower pressures, resulting in energy savings.

- Optimized leakage control: through the integration of ICAE, stable and reliable pipeline connections are achieved, along with the professional configuration of accessories such as pipe fittings, hose connectors, pressure regulators, condensate drains, and shut-off valves. This significantly reduces compressed air leakage losses.
- Utilization of compressed air heat recovery: through the integrated design of ICAE, compressed air heat can be optimally utilized in drying processes, while maximizing the configuration of compressed heat recovery devices.

According to the market survey conducted by Compressor Branch of China General Machinery Industry Association in 2022, the primary producers of ICAE are air compressor manufacturers. Incomplete statistics indicate that over 200 similar companies are currently producing ICAE. This product has become a hot topic in the industry and is widely showcased at various exhibitions. As the market continues to expand, the number of companies producing these types of products is increasing, and may soon include manufacturers of compressed air dryers and filters. Currently, there are approximately 600 manufacturers of air compressors, compressed air dryers, and filters nationwide. The survey also revealed that ICAE product are well-received among foreign enterprises, with some companies specializing in producing customized products for the international market.

According to the same survey, in five years, the quantity of ICAE products will account for over 50% of the total number of air compressors, with an annual electricity consumption reaching 100 TWh.

As a product, ICAE greatly simplifies the entire supply chain process with its independent production, sales, installation, and maintenance model. Compared to the traditional centralized air compressor station construction, the direct participation of ICAE manufacturers and users reduces the involvement of design institutes and integrators, thereby lowering costs and complexity while improving overall efficiency.

Furthermore, the management model of ICAE products brings significant improvements in user management costs and efficiency. With direct communication and collaboration with the manufacturing company, user management costs are substantially reduced, which in turn decreases the number of stakeholders and simplifies management coordination. This streamlined management structure helps enhance user satisfaction and experience, leading to higher management efficiency and lower overall costs.

Fig. 2. Typical ICAE products available on market

5 Standardization analysis of integrated compressed air equipment

As an important new type of product, the current lack of standardization for ICAE poses a series of negative impacts on users and market promotion.

Firstly, the absence of unified product standards leads to uneven product quality and performance in the market. Users find it difficult to accurately assess the merits of products when making purchasing decisions, increasing their decision-making inefficiency.

Secondly, the absence of energy efficiency standard makes it challenging for users to accurately evaluate the energy efficiency level of products, which is particularly crucial for products like ICAE that emphasize energy efficiency. This absence also weakens market transparency, hindering user recognition and selection of high-efficiency products.

Therefore, establishing standards for ICAE products is imperative. Firstly, developing product standards can clarify product requirements and testing methods, providing users with clearer product selection criteria. This helps users accurately assess product quality, reliability, and safety, enhancing user trust and satisfaction. Secondly, the establishment of energy efficiency standards can strengthen market competition and product optimization. With clear energy efficiency indicators, companies will be incentivized to develop more efficient ICAE products to reduce users' energy consumption and operational costs. Standards can also promote technological innovation and industry development, driving the entire industry towards low energy consumption and high efficiency.

Furthermore, implementing unified standards for ICAE products helps create a fair competitive market environment. Standardization can eliminate the presence of low-quality products in the market, raising the industry's overall level. Additionally, standardization helps eliminate technological barriers, fostering cooperation and communication among companies, accelerating industry progress and development. By establishing standards for ICAE products, we can provide users with more reliable and efficient choices, promote sustainable development in this field, and contribute to environmental protection.

To regulate ICAE, China initiated the development of its product standard in 2023, which will provide a technical foundation for the development of mandatory energy efficiency standard for ICAE.

5.1 Product scope

ICAE is a product that is designed, manufactured, and assembled by one manufacturer. It should be subject to market supervision in accordance with the production of products.

According to proposed product standard, ICAE product include air compressors, compressed air purification equipment (compressed air dryers, filters, and water separators), internal pipeline containers, and control systems. These products have a rated power of 1.5 kW to 355 kW and supplied air pressure ranging from 0.3 MPa to 1.6 MPa.

It encompasses the complete production process of compressed air, including compression and purification (water removal, oil removal, and dust removal). Additionally, it features a well-developed power drive, control, and load regulation control functionality.

ICAE is typically conveniently placed near air-consuming equipment or production process lines, or in locations that require only moderate to low air volume, allowing for localized compressed air production and decentralized air supply. It is designed to be located close to the workstations. Taking into consideration of safety requirements and eliminating the need for high-pressure systems, the product standard defines its pressure range for general power applications as 0.3 to 1.6 MPa. ICAE product standard encompassed most of the integrated equipment for producing compressed air.

5.2 Energy efficiency metric

Unlike the Chinese air compressor MEPS, which utilizes specific energy requirement as the energy efficiency metric, the proposed product standard employs output work efficiency as the energy efficiency metric for ICAE products. Output work efficiency refers to the ratio of effective energy contained in the outputted compressed air of ICAE products to the electrical energy consumed during compressed air production. The detailed definition of this metric is stated in article 3.6 of GB/T 16665-2017 “Monitoring and testing for energy saving of air compressor unit and air distribution system”, and the calculation formula for this output work efficiency will be presented below in this paper.

5.3 Testing condition

The specified operating conditions for ICAE products are as follows:

- a) Inlet air pressure: 0.1 MPa (absolute)
- b) Inlet air temperature: 20 ℃
- c) Inlet air relative humidity: 0
- d) Water cooling inlet water temperature: 20 ℃
- e) Air cooling inlet air temperature: the ambient temperature corresponding to the inlet air temperature of 20 ℃, measured in degrees Celsius (℃)
- f) Rated air supply pressure: as specified in Table 5, measured in megapascals (MPa)
- g) Compressor rotating speed: according to the rated speed specified in the technical documentation, measured in rotations per minute (r/min).

Table 5. Nominal compressed air pressure

Nominal compressed air pressure (MPa)						
0.3	0.5	0.7	0.8	1.0	1.25	1.4

5.4 Testing and efficiency calculation method

As the ICAE is considered a product, its testing method employs the same approach as the Chinese air compressor MEPS GB 19153-2019. However, based on the parameters derived from GB 19153 testing, the calculation of output work efficiency follows the formulas and procedures outlined below.

The output work efficiency (η) of the integrated unit should be calculated using formula (1):

$$\eta = 0.2778 \times \frac{G \times p_x \times ln[(p_Z + p_x)/p_x]}{E} \times 100\% \quad \text{......................(1)}$$

Where:

G - Total air supply volume of the ICAE measured during the specified time period, measured in cubic meters (m3).

E - Total electrical energy consumed by the ICAE measured during the specified time period, measured in kilowatt-hours (kW•h).

p_x - Inlet air pressure of the ICAE, measured in megapascals (MPa), absolute.

p_Z – Outlet air pressure of the ICAE, measured in megapascals (MPa), gauge.

The output work efficiency (η) of the variable speed ICACE should be calculated using formula (2):

$$\eta = \eta_f \times 0.5 + \psi \times \eta_m \times 0.5 \quad \text{......................(2)}$$

Where:

η_f - Output work efficiency of the full load operating cycle of the ICAE

η_m - Output work efficiency of the intermediate volume flow rate operating cycle of the ICAE ψ - Correction factor, dimensionless. When the adsorption dryer has dew point control function, ψ = 1.08; when equipped with a chilled and cooling dryer, ψ = 1.02.

When measuring, if the inlet air temperature deviates from the measurement conditions, the output work efficiency should be adjusted using formula (3):

$$\eta = \eta_a \times K \qquad \text{..............................(3)}$$

Where:

η_a - Measured output work efficiency of the ICAE

K - Inlet air temperature correction factor, dimensionless. When the air supply humidity level is grade 5 or 6, K = 1; when the gas supply humidity level is grade 1, 2, 3, or 4, K is calculated using formula (4):

$$K = 1 + 0.004 \times (t_x - 20) \qquad \text{..............................(4)}$$

Where:

tx - Inlet air temperature during the measurement of the ICAE, measured in degrees Celsius (℃).

5.5 Energy efficiency classification

Based on the current energy efficiency status of ICAE products, the product standard proposes energy efficiency classification schemes for ICAE products. There are a total of three energy efficiency grades, with grade 3 being the low-efficiency level and grade 1 being the high-efficiency level. The current efficiency classification scheme is voluntary.

The humidity level of compressed air, cooling method, total oil content level, volume flow rate, and rated air pressure have a significant impact on the energy efficiency level of ICAE products. Therefore, the draft product standard has developed the following energy efficiency grading scheme based on their influence on energy efficiency.

Five energy efficiency grading tables have been developed based on the humidity level from 1 to 6 (levels 5 and 6 are regulated by one table) from Table 1 mentioned above.

Each humidity level energy efficiency grading table is set based on the cooling method, total oil content level, volume flow rate, and rated air pressure. Figure 6 presents the energy efficiency grading table for ICAE products with a gas supply humidity level of 1.

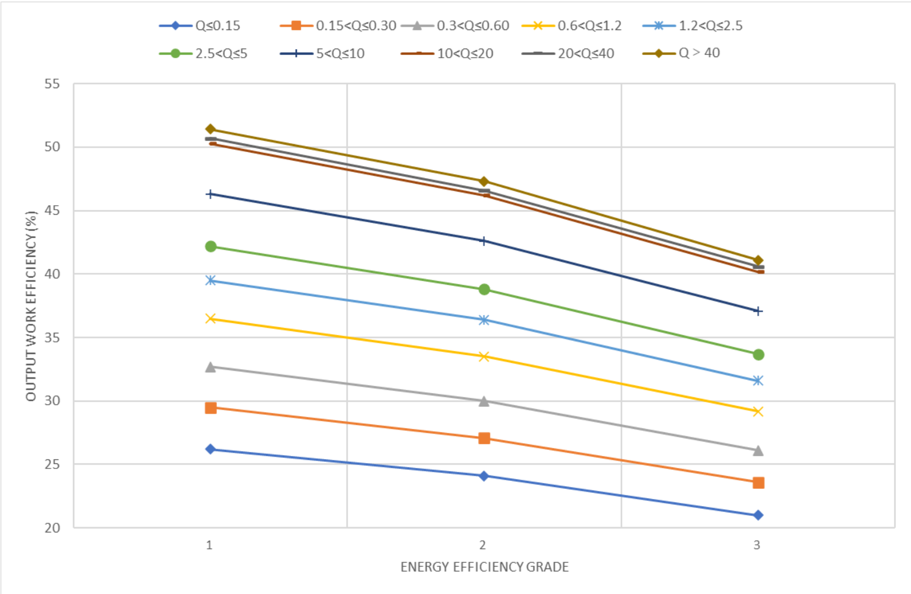

Fig. 3. Energy efficiency classification at different flow rate of ICAE with humidity level 1

*Q is the volumetric output flow rate

6 Conclusion and recommendations

1. **China's compressed air energy consumption is enormous, with significant energy-saving potential**: Compressed air plays a vital role in industrial production, but its energy consumption is considerable. Optimizing the energy efficiency of compressor systems can significantly reduce energy consumption, lower energy costs, and minimize negative environmental impact. As one of the world's largest industrial manufacturing countries, China holds enormous potential for optimizing the energy efficiency of compressed air systems, which is of great significance for promoting energy conservation and emission reduction.

2. **Market prospect for ICAE products is high**: Integrated and miniaturized compressed air systems have led to the emergence of ICAE products with huge energy-saving advantages in the market, demonstrating vast market prospects. With the rapid development of the Chinese economy and an increasing demand for green and environmentally friendly products, ICAE products will become an important choice for addressing energy consumption and environmental pollution issues.

3. **The development of ICAE product standard is on the way**: The newly proposed ICAE product standard has preliminarily standardized aspects such as product scopes, energy efficiency metrics, testing methods, and energy efficiency grading, providing relevant enterprises with a basis and direction for implementation. This will not only

help improve product quality and enhance market competitiveness of ICAEs, but also promote technological advancement, innovations in the industry, contributing to the healthy development of the sector.

4. **The formulation of mandatory energy efficiency standard for ICAE is needed**: As an independent end-use energy products in the early stage of market development, ICAE deserves the government for necessary regulatory and market incentives to foster a steady market growth. the formulation of mandatory energy efficiency standards for ICAE could support with the improvement of product quality, promoting industry development, helping users to make informed purchasing decisions, and accelerating the market transformation of air compressors towards ICAEs.

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