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Evaluation of energy performance for compressed air stations

压缩空气站能源绩效评价

(English Translation)

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Contents

Foreword

SAC/TC 145 is in charge of this English translation. In case of any doubt about the contents of English translation, the Chinese original shall be considered authoritative.

This standard is drafted in accordance with the rules given in GB/T 1.1-2020.

This standard was proposed by China Machinery Industry Federation.

This standard was prepared by SAC/TC 145(National Technical Committee on Compressor of Standardization Administration of China).

Introduction

Compressed air stations (air compressor systems) serve as essential infrastructure in modern factories, encompassing air compressor units, compressed air purification equipment, control systems, heat recovery systems, pipe networks, and more. The compressed air produced is one of the main driving forces in modern industry, widely used in various sectors of the national economy. Currently, the compressed air stations in China have low overall operation efficiency, lacking quantitative evaluation indicators and methods of energy efficiency of the system. In response to and implementation of policy requirements, this document is formulated to facilitate the transition from individual energy-saving to full-process and system-wide energy-saving as compressors are key energy-consuming equipment, guiding industry equipment upgrades and enhancing system energy efficiency.

This document specifies the evaluation of energy performance for in-service, newly built/renovated and accepted compressed air stations, including assessments of energy efficiency level, energy efficiency and energy benefit. It provides evaluation indicators and value determination rules based on measured energy conversion efficiency, as well as energy efficiency grades. The energy performance outlined in this document truthfully reflects the actual operational levels of compressed air stations, aiding manufacturers, design units, energy-consuming units, and energy-saving service providers of compressed air stations in establishing energy-saving targets. It provides guidance to compressed air stations on benchmarking management of operational energy efficiency, determining energy efficiency levels, identifying energy-saving opportunities, calculating energy-saving benefits, and conducting activities such as energy-saving monitoring, energy assessment, green manufacturing evaluation, and energy-saving management, thereby promoting continuous optimization and energy efficiency improvement of compressed air stations.

Evaluation of energy performance for compressed air stations

1 Scope

This document specifies the evaluation objects and boundaries, overall requirements, evaluation index system and value determination rules for the evaluation of energy performance of compressed air stations, gives the corresponding evaluation methods, and specifies the evaluation procedures and criteria for results formation.

This document is applicable to energy performance evaluation activities for compressed air stations, composed of air compressors driven by the motor with a discharge pressure range of 0.25MPa-1.6MPa, featuring air supply flow rate of not less than $4m^3/min$ and a total operating power of not less than 37kW.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes the requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

GB/T 3853, *Displacement compressors - Acceptance tests*

GB/T 4975, *Displacement compressors vocabulary - General*

GB/T 5226.1, *Electrical safety of machinery - Electrical equipment of machines - Part 1: General requirements*

GB/T 13277.1, *Compressed air - Part 1: Contaminant purity classes*

GB/T 16665, *Monitoring and testing for energy saving of air compressor unit and air distribution system*

GB 17167, *General rules for energy measuring instrument equipping and managing of energy user*

GB 18613, *Minimum allowable values of energy efficiency and energy efficiency grades for motors*

GB 19153, *Minimum allowable values of energy efficiency and energy efficiency grades for displacement air compressors*

GB 22207, *Safety requirements for displacement air compressor*

GB 30253, *Minimum allowable values of energy efficiency and energy efficiency grades for permanent magnet synchronous motors*

GB 30254, *Minimum allowable values of energy efficiency and energy efficiency grades for high-voltage three-phase cage-type induction motors*

GB 50029, *Code for design of compressed air station*

JB/T 7664, *Compressed air treatment - Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in GB/T 3853, GB/T 4975, GB/T 13277.1, GB/T 16665, GB 19153, GB 50029 and JB/T 7664 and the following apply.

3.1

compressed air station

air compressor system

a functional group of subsystems comprised of integrated sets of components, including all air compressor units, compressed air purification equipment, power supply and distribution systems, cooling systems, monitoring systems, ventilation systems, heat recovery systems, and pipes, air storage tanks, valves, instruments as well as other required auxiliary equipment for transporting compressed air before the compressed air supply mains.

3.2

energy efficiency factor *e*

a dimensionless factor quantifying the energy efficiency grade of a compressed air station (3.1)

3.3

output work efficiency of a compressed air station

the ratio of the potential energy in the output compressed air to the electrical energy consumed in the production of compressed air from the compressed air station (3.1).

NOTE: The potential energy of compressed air is the power capacity of compressed air and the potential power capacity relative to the actual ambient atmospheric state

3.4

multiple work efficiency of a compressed air station

output work efficiency of a compressed air station (3.3) after the conversion considering the factors of heat recovery and utilization, air supply parameters (total oil content and humidity of compressed air) of the compressed air station (3.1)

3.5

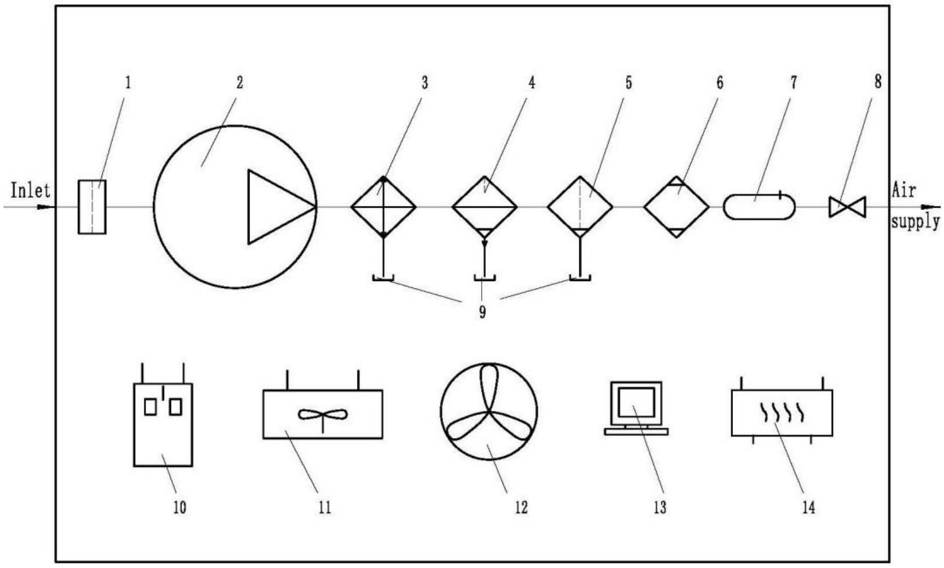
rated demand flow rate

the maximum supply flow rate of the rated demand specified by the user to the design of a compressed air station (3.1)

4 Evaluation objects and boundaries

4.1 The evaluation objects for the energy performance of compressed air stations comprise compressed air stations in service operation (hereinafter referred to as in-service stations), newly built and accepted compressed air stations (hereinafter referred to as new stations) and retrofitted and accepted compressed air stations (hereinafter referred to as retrofitted stations).

4.2 The system boundary schematic diagram for the evaluation of energy performance of compressed air stations is shown in Figure 1.



Index number description:

1 - Air filter;
2 - Air compressor;
3 - Cooler;
4 - Air-water separator;
5 - Compressed air filter;
6 - Compressed air dryer;
7 - Air tank;
8 - Valves and pipelines;
9 - Condensate drain traps;
10 - Electronic control system;
11 - Cooling system;
12 - Ventilation system;
13 - Monitoring system;
14 - Heat recovery equipment.

Figure 1 Schematic diagram for system boundary of compressed air stations

5 General requirements

5.1 The compressed air station should be as specified in GB 50029.

5.2 The safety performance of electrical devices and mechanical equipment of the compressed air station shall be as specified in GB 50029, GB 22207 and GB/T 5226.1.

5.3 The compressed air station shall specify the parameters of the compressed air demanded by production; the compressed air pressure, purity class and volume flow rate supplied shall meet the requirements of users.

NOTE: The compressed air purity class refers to the humidity and liquid water class, total oil content grade and particle class specified in GB/T 13277.1.

5.4 The air compressors, compressed air dryers, compressed air filters used in the compressed air station shall comply with applicable product standards.

5.5 The energy efficiency of the displacement air compressor used in the compressed air station shall be as specified in GB 19153.

5.6 The energy efficiency of motors, permanent magnet synchronous motors and cage three-phase high voltage induction motors used in compressed air stations shall conform to the provisions of GB 18613, GB 30253 and GB 30254, respectively.

5.7 All equipment and systems in the compressed air station shall be kept in intact condition.

5.8 The equipping of energy measuring instruments of the compressed air station shall conform to GB 17167, GB 50029 and GB /T 16665.

6 Evaluation index system and value determination rules

Evaluation of energy performance of compressed air stations comprises assessments of energy efficiency level, energy efficiency, and energy benefits. Corresponding evaluation indexes and value determination rules are specified in Table 1.

Table 1 Evaluation index and value determination rules

Evaluation Contents	Evaluation Indexes	Value determination rules	
		Calculation method of the index value	Unit
Energy efficiency level	Energy efficiency grade	Judging according to the provisions in Table 2, in which, the calculation of the energy efficiency factor shall accord to the provisions in Annex A	—
Energy efficiency	Power transmission efficiency	According to the provisions in Annex B	%
Energy benefit	Specific electrical energy consumption	According to the provisions in GB/T 16665	$kW·h/m^3$

Table 2 Energy efficiency grade of the compressed air station

Energy efficiency grade	Energy efficiency factor of the compressed air station(*e*)
1	e⩾20
2	15⩽e<20
3	10⩽e<15
4	5⩽e<10
5	0⩽e<5

7 Evaluation methods

7.1 Evaluation of energy performance for compressed air stations shall be carried out under normal operation conditions.

7.2 When the compressed air station comprises two or more independent production systems, the evaluation of energy performance shall be conducted separately for each independent system.

7.3 When a compressed air station outputs compressed air with varied humidity /liquid water classes and/or total oil content classes, energy performance evaluation shall be conducted only after parameter conversion of the provisions as specified in Annex B.

7.4 The energy performance for compressed air stations shall be measured according to the provisions in GB/T 16665. Measurements in the in-service stations, new stations and retrofitted stations shall be carried out in accordance with the following provisions.

a) The in-service stations shall be measured during normal production of users, selecting the full period of a year, a quarter, a month, a week, a day, or a representative and typical cycle. The measurement time shall be continuous for no less than 24 hours.

b) The new stations and retrofitted stations shall be measured after the construction and commissioning of the compressed air station. When the design conditions of the normal production of the compressed air station are all rated demand flow rate conditions, evaluations should be carried out under the rated demand flow rate conditions. When the design conditions of the normal production of the compressed air station include part demand flow rate conditions, evaluations should be carried out under both the rated demand flow rate conditions and the part demand flow rate conditions. The measurement conditions shall meet the following provisions:

1) Rated demand flow rate conditions: 100% rated demand flow rate;
2) Part demand flow rate conditions: select one in the order of 30%, 50%, 70% or 90% of the rated demand flow rate, ensuring that the air supply flow rate is not smaller than the minimum air flow rate required and all air compressors are not running at full load at the same time;
3) Air supply flow rate range: air supply flow rate under the measurement conditions with a maximum deviation of ±5%;
4) Air supply pressure range: required air supply pressure with a maximum deviation of ±5%;
5) Inlet temperature range of the compressed air station: 5℃-40℃;
6) Measurement time: not less than 2h; when the air compressed station is equipped with an adsorption compressed air dryer, the measurement time shall also not be less than the half-cycle time of the actual operating conditions of the dryer.

8 Evaluation process

The flowchart of evaluation of energy performance for compressed air stations is shown in Figure 2.

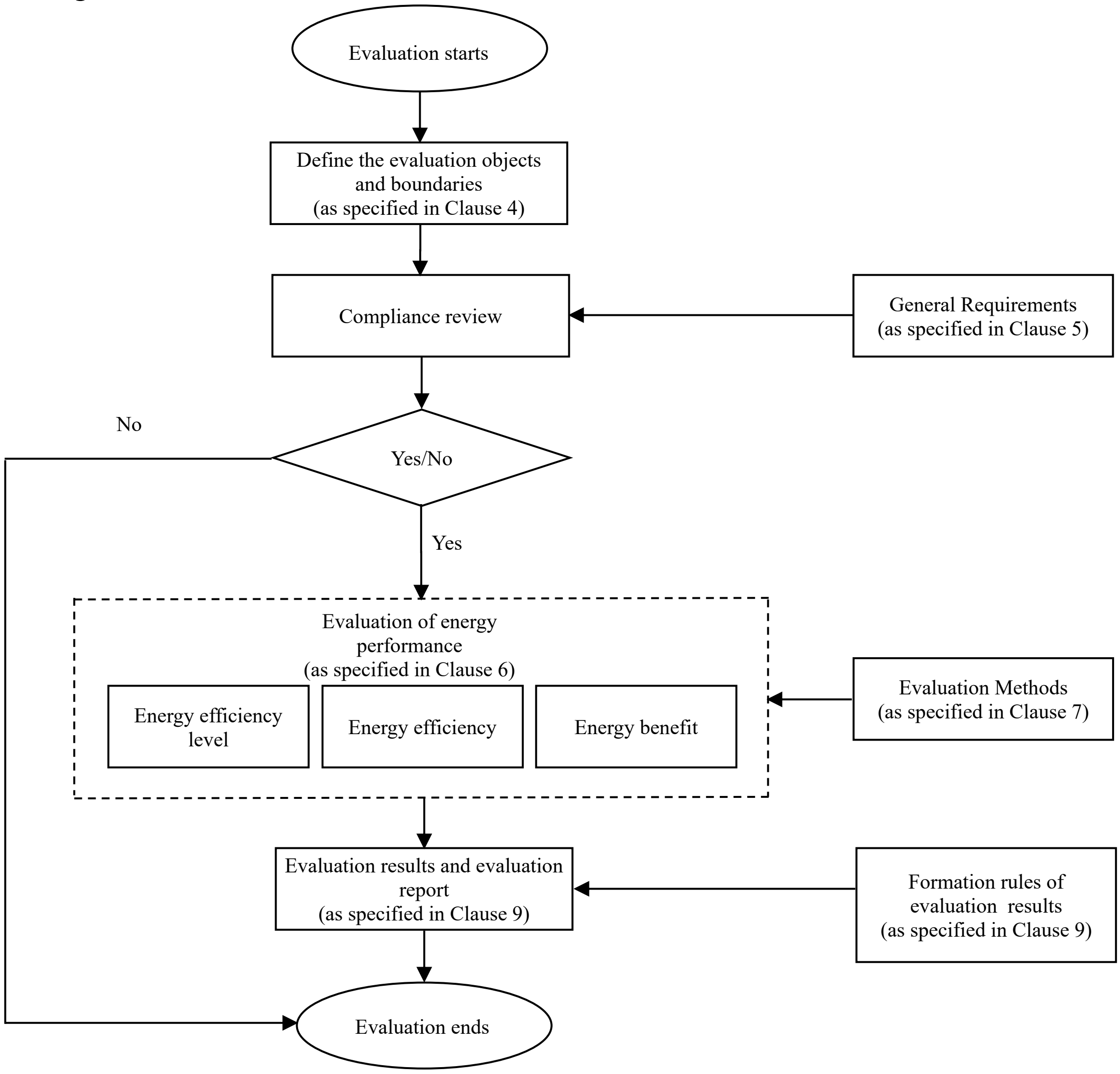


Figure 2 Flowchart of evaluation of energy performance for compressed air stations

9 Formation rules of evaluation results

9.1 There are 5 levels of the energy efficiency grade of the compressed air station, where Grade 1 represents the highest energy efficiency.

9.2 The energy efficiency Grade 1 of the compressed air station represents the leading level; Grade 2 the advanced level, Grade 3 the energy-saving level, and Grade 5 the baseline level.

9.3 The energy performance evaluation report for the compressed air station shall be prepared, including but not limited to:

——basic information on the compressed air station;

——evaluation scope of the compressed air station and standards referenced;

——evaluation time and location;

——evaluation department and personnel information;

——evaluation contents, including energy efficiency level, energy efficiency and energy benefit;

——evaluation results.

9.4 In case the energy efficiency level of the compressed air station is lower than the baseline level, corrective measures shall be implemented to improve station performance.

Annex A
(normative)
Calculation of energy efficiency factor of a compressed air station

A.1 The energy efficiency factor of the compressed air station is calculated according to Formula (A.1) and rounds to 1 decimal place:

$$e = \frac{\eta - \eta_b}{\eta_a - \eta_b} \times 20 \quad \cdots\cdots\cdots\cdots (A.1)$$

where

e - Energy efficiency factor of a compressed air station, dimensionless;

η - Multiple work efficiency of a compressed air station, %;

η_a - Baseline output work efficiency of the energy efficiency Grade 1 of a compressed air station, %;

η_b - Baseline output work efficiency of the energy efficiency Grade 5 of a compressed air station, %.

A.2 Multiple work efficiency of a compressed air station η shall be calculated according to Annex B.

A.3 Baseline output work efficiency of the energy efficiency Grade 1 of a compressed air station η shall be calculated according to Formula (A.2):

$$\eta_a = c \times \left[(-0.1511) \times \left(\ln(Q_Z)\right)^2 + 2.9182 \times \ln(Q_Z) + 50.2450\right] \quad \cdots\cdots\cdots\cdots (A.2)$$

where:

η_a - Baseline output work efficiency of the energy efficiency Grade 1 of a compressed air station, %;

c - Quality influence coefficient of compressed air, dimensionless, values are selected according to Table A.1;

Q_Z - The average air supply flow of the compressed air station during the measurement period, in cubic meters per minute (m^3/min); when the average air supply flow is greater than $800m^3/min$, $800m^3/min$ is set for calculation.

A.4 Baseline output work efficiency of the energy efficiency Grade 5 of a compressed air station η_b shall be calculated according to Formula (A.3):

$$\eta_b = c \times \left[(-0.1663) \times \left(\ln(Q_Z)\right)^2 + 3.2296 \times \ln(Q_Z) + 32.8424\right] \quad \cdots\cdots\cdots\cdots (A.3)$$

where:

η_b - Baseline output work efficiency of the energy efficiency Grade 5 of a compressed air station, %.

c - Quality influence coefficient of compressed air, dimensionless, values are selected according to Table A.1;

Q_Z - The average air supply flow of the compressed air station during the measurement period, in cubic meters per minute (m^3/min); when the average air supply flow is greater than $800m^3/min$, $800m^3/min$ is set for calculation.

Table A.1 Quality influence coefficient of compressed air c

Air supply humidity and liquid water grade[a]	Quality influence coefficient of compressed air c	
	Total oil content of compressed air[a] is greater than $0.01mg/m^3$	Total oil content of compressed air[a] is less than or equal to $0.01mg/m^3$
Below Grade 6	$0.95^{-0.6}$	$0.95^{0.4}$
Grade 5 or 6	1	0.95
Grade 4	0.95	0.95^2
Grade 3	0.95^2	0.95^3
Grade 2	0.95^3	0.95^4
Grade 1	—	0.95^5
[a] All are user demand parameters.		

Annex B
(normative)
Calculation of power transmission efficiency and comprehensive power transmission efficiency of compressed air station

B.1 When the energy performance of the compressed air station is measured according to 7.4 a), the power transmission efficiency η_w is calculated according to the provisions in GB/T 16665.

B.2 When the energy performance of the compressed air station is measured according to 7.4 b), the power transmission efficiency is calculated according to the following provisions respectively.

a) In case the design conditions during normal production are all rated demand flow rate conditions, the power transmission efficiency is calculated according to Formula (B.1):

$$\eta_{\mathrm{w}} = \eta_{\mathrm{w1}} \quad \cdots\cdots (B.1)$$

where:
η_w – Output work efficiency of a compressed air station, %;
η_{w1} – Power transmission efficiency at rated demand flow rate conditions, which is calculated according to the provisions in GB/T 16665.

b) In case the design conditions during normal production are partial demand flow rate conditions, the power transmission efficiency is calculated according to Formula (B.2):

$$\eta_{\mathrm{w}} = 0.95 \times (0.5 \times \eta_{\mathrm{w1}} + 0.5 \times \eta_{\mathrm{w2}}) \quad \cdots\cdots (B.2)$$

where:
η_w – Output work efficiency of a compressed air station, %;
η_{w1} – Power transmission efficiency at rated demand flow rate conditions, which is calculated according to the provisions in GB/T 16665;
η_{w2} – Power transmission efficiency at partial demand flow rate conditions, which is calculated according to the provisions in GB/T 16665.

B.3 The comprehensive power transmission efficiency is calculated according to Formula (B.3):

$$\eta = \eta' + 0.1 \times \eta_{\mathrm{R}} \quad \cdots\cdots (B.3)$$

where:
η – Multiple work efficiency of a compressed air station, %;
η' – Equivalent power transmission efficiency of the compressed air station, %. When the output of the compressed air station is the same air supply parameter, $\eta' = \eta_{\mathrm{w}}$; when the output of the compressed air station is multiple different air supply parameters, the η' is calculated according to Formula (B.4);
η_R – Heat energy recovery and utilization rate, %. The heat energy recovery and utilization rate of the in-service stations is calculated according to the provisions in GB/T 16665. When measured according to 7.4 b), the heat energy recovery and utilization rate is calculated according to the design parameters.

NOTE: Heat energy recovery is not included in the internal utilization of the compressed air station.

B.4 When a compressed air station outputs compressed air with different humidity and liquid water grades and (or) different total oil content grades, it shall be converted to the equivalent power transmission efficiency with humidity and liquid water grades of "Grade 5 or Grade 6" and total oil content greater than 0.01 mg/m^3 according to Formula (B.4):

$$\eta' = \sum(\eta_{wi} \times \frac{\theta_i}{m_i \times n_i}) \quad \text{(B.4)}$$

where:

η' - Equivalent power transmission efficiency, %;

η_{wi} - Power transmission efficiency of output end i, which is calculated according to Formula (B.5);

θ_i - Air supply proportion of the channel i, which is calculated according to Formula (B.6);

m_i - The conversion factor of the total oil content of the compressed air of the ith channel, when the required total oil content of the compressed air is less than or equal to 0.01mg/m^3, set m_i=0.95, otherwise set m_i=1;

n_i - The Conversion factor of humidity and liquid water grade of compressed air of the ith channel, which is selected according to Table B.1.

$$\eta_{wi} = 16.67 \times \frac{p_{Zx} \times Q_{Zi} \times t \times \ln[(p_{Zi}+p_{Zx})/p_{Zx}]}{E_i} \times 100\% \quad \text{(B.5)}$$

where:

Q_{Zi} - Average air supply flow of the ith channel during the measurement period, in cubic meters per minute (m^3/min);

p_{Zx} - Inlet pressure of the compressed air station (absolute pressure), in megapascal (MPa);

p_{Zi} - Air supply pressure (gauge pressure), in megapascal (MPa);

t - Measurement time, in hour (h);

E_i - Total comprehensive electrical energy consumption of the ith channel during the measurement period, in kilowatt hour (kW·h), which is calculated according to the proportion of air supply. If the channel has independent energy-using equipment, the electrical energy consumption of this independent equipment shall be measured and counted.

$$\theta_i = \frac{G_{Zi}}{G_Z} \quad \text{(B.6)}$$

where:

θ_i - Air supply proportion of the ith channel, %;

G_{Zi} - Air supply of the ith channel during the measurement period (calculated according to the inlet state of the compressed air station), in cubic meter (m^3);

G_Z - Air supply of the compressed air station during the measurement period (calculated according to the inlet state of the compressed air station), in cubic meter (m^3), $G_Z=\sum G_{Zi}$;

Table B.1 Conversion factor of humidity and liquid water grade of compressed air

Air supply humidity and liquid water grade[a]	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5 or grade 6	Below grade 6
Value of n	0.95^4	0.95^3	0.95^2	0.95	1	$0.95^{-0.6}$
[a] All are user demand parameters.						

B.5 The conversion of the specific electrical energy consumption to power transmission efficiency of the compressed air station with the same supply parameters is calculated according to Formula (B.7):

$$D = 16.67 \times \frac{p_{Zx} \times \ln[(p_Z+p_{Zx})/p_{Zx}]}{60 \times \eta_w} \times 100\% \quad \text{(B.7)}$$

where:

D - Specific electrical energy consumption of the compressed air station, in kilowatt-hours per cubic meter (kW·h/m^3);

η_W - Output work efficiency of a compressed air station, %;

p_{Zx} - Inlet pressure of compressed air station (absolute pressure), in megapascal (MPa);

p_z - Air supply pressure of compressed air station (gauge pressure), in megapascal (MPa).