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ENGINEERING **RESEARCH REPORT · Engineering research report**

Assessment Method for Compressed-Air Energy Consumption, Leakage Rate, and Life-Cycle Cost of Pneumatic Industrial Manipulators

Quantitative Study of Air Consumption, Leakage, Energy Cost, and Payback for Pneumatic Assisted-Handling Systems

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> Judgment rules This report uses explicit input and a unified calculation chain, and the formal judgment can only be passed or failed; failure of any hard threshold means no release.

00 Executive Summary

A Pneumatic Industrial Manipulator converts compressed air into load balancing, lifting, clamping, rotation, brake release, and vacuum generation. Recording only the compressor nameplate power or equipment inlet pressure cannot determine the air consumed per one thousand cycles by one machine, leakage during line stoppages, the location of pressure losses, or whether an energy-efficiency retrofit will pay back. ISO 11011:2013 divides a compressed-air system into supply, transmission, and demand subsystems and requires a complete assessment comprising acquired data, analysis results, and a written report [1]. This report applies that system boundary to one manipulator and establishes a calculation method using a common time base for electricity metering, total flow, branch flow, dynamic pressure, and production counts.

This report consistently expresses free-air volume at the ISO 8778:2003 standard reference atmosphere: 20 ℃, 100 kPa absolute, and 65% relative humidity, written m³(ANR) [8]. When a field instrument uses another reference, convert data to the common reference state before summing. On the supply side, use simultaneously measured system-average specific power SP_sys for the allocated-electricity metric; actual electricity savings and economic benefits use only a same-load-bin marginal power–flow model or normalized whole-station measurements before and after the retrofit. On the equipment side, integrated flow gives useful production air and leakage air. On the transmission side, evaluate every synchronized pressure sample for the peak-flow action and the action with the lowest inlet pressure. ISO 1217:2009 defines the boundary of compressor flow and power acceptance data [4], while the ISO 6358 series is used for steady-state flow characteristics and system flow capacity of components and assemblies within its scope [5][6][7]. Neither replaces simultaneous on-site measurement.

Core conclusion

- Energy-consumption calculations shall use free-air volume at a common reference state. If gauge pressure, absolute pressure, actual-condition volume, and m³(ANR) are mixed, the report fails the data-quality gate.
- Classify by the conservative upper bound R_leak,U of annual branch leakage-volume share: ≤5% is Grade A; >5% and ≤10% is Grade B; both pass; >10% fails. The leakage percentages in U.S. Department of Energy information use compressor capacity or system air supply as the accounting boundary [9], which differs from this report's denominator of annual branch volume for one machine. The two percentages shall not be converted directly. This report fixes 10% as the project-release upper limit.
- The pressure item must be passed only if the conservative upper bound of the total pressure loss rate from the exhaust measuring point of the compressor unit to the inlet of the key actuator does not exceed 10%, and the conservative lower bound of the dynamic minimum inlet pressure of the equipment is not lower than the design lower limit; if any condition fails, it will be judged as failed [9].
- For one machine, use m³(ANR)/1000 cycles and allocated kWh/1000 cycles as energy-efficiency metrics, and separately report production air use, leakage air use, and idle pressure-retention air use. Allocated electricity is not evidence of actual electricity savings.

- Overall release uses a one-out-of-six rejection rule covering data, leakage, pressure, energy efficiency, economics, and functional safety. Leakage, pressure, energy-efficiency, and economic criteria are evaluated at expanded-uncertainty bounds in the unfavorable direction. The project passes only when all six criteria pass.

01 Research objects, system boundaries and terminology

The scope includes the Pneumatic Industrial Manipulator body, end-effector tooling, vacuum generator, local air receiver, filter-regulator assemblies, hoses, and equipment branch. The supply subsystem includes compressors, cooling, drying, filtration, and auxiliary electricity. The transmission subsystem includes headers, ring mains, branch lines, and terminal connections. The demand subsystem begins at the equipment-branch isolation valve and ends at actuator exhausts, vacuum-generator exhausts, and process blow-off outlets. ISO 4414:2010 and GB/T 7932-2017 cover general rules and safety requirements for pneumatic systems and components on machinery [2][3]. An energy-efficiency retrofit shall not impair loss-of-pressure protection, residual-energy release, isolation, pressure limiting, gripping retention, or inadvertent-release prevention.

symbol	definition	Units and Rules
V_ANR	Free-air volume at the ISO 8778 standard reference atmosphere	m^3(ANR)
q_ANR	Instantaneous volume flow rate in standard reference atmosphere	m^3/min(ANR)
E_sys	Electric energy input to the simultaneous supply system, including auxiliary equipment included in the boundary	kWh
SP_sys	System average specific power, E_sys/V_supply, only used for amortized metrics	kWh/m^3(ANR)
SP_marg,b	Marginal specific power of load bin b of the whole station	kWh/m^3(ANR)
V_prod	Free air volume consumed to complete a qualified production cycle	m^3(ANR)
V_leak	Free air volume consumed by non-functional leaks	m^3(ANR)
V_total	The total amount of voltage status of all equipment branches, synonymous with V_device	m^3(ANR)

symbol	definition	Units and Rules
I_prod	Production air-use intensity, 1000 V_prod / N_cycle	m³(ANR)/1000 times
I_leak	Leak gas intensity, 1000 V_leak / N_cycle	m³(ANR)/1000 times
I_air	Total gas intensity, 1000 V_total / N_cycle	m³(ANR)/1000 times
I_e,alloc	Apportioned power consumption intensity, 1000 E_device,alloc/N_cycle	kWh/1000 times
R_leak	Proportion of leakage air to the total air supply volume of the equipment branch	%
R_leak,U	Unfavorable direction expansion uncertainty upper bound of leakage air proportion	%
R_Δp,total,U	Unfavorable direction expanded uncertainty upper bound for total pressure drop rate P0 to P3	%

A “cycle” is defined from workpiece pickup authorization through completed release and return to the starting state for the next pickup. Count rework, no-load, and commissioning cycles separately; do not include them in conforming production cycles. Whenever the equipment branch remains pressurized during production, changeover, breaks, or off-shift periods, include all of that time in pressurized hours.

Each sample may belong to only one operating state. The fixed state codes are: P conforming production, R rework, S commissioning or no-load cycle, C changeover, I idle pressurized, F fault pressurized, and D depressurized. If the controller has no state code, reconstruct the state from cycle-permissive signals, equipment alarms, branch-isolation-valve feedback, and shift records. If any one of these four signal classes is missing, the state-breakdown report fails the data gate. P represents production air use; R/S/C/I/F are reported separately. Nonzero flow in D is treated as a meter-zero anomaly or internal leakage through the isolation valve. This separates air required for production, avoidable idle consumption, and air required for safe pressure retention, preventing off-shift leakage from being attributed to the efficiency of a single operation.

02 Measurement architecture and data quality threshold

Arrange the metering points in the direction of energy flow. The main electricity meter records input energy to the supply subsystem; the supply totalizer records m³(ANR) delivered to the transmission subsystem; and the equipment-branch flow meter records the manipulator's total air use. The four synchronized pressure channels are fixed at: P0 downstream of the compressor-package discharge check valve and upstream of the first air-treatment element; P1 at the header inlet downstream of all air-treatment equipment; P2 at the end of the header and upstream of the equipment-branch isolation valve; and P3 at the inlet of the critical actuator. The controller records cycles, product model, operating state, and alarms. Where multiple actuators are pressure-critical, move P3 and perform a separate test at each position; every position shall pass. For parallel compressors, sum total electrical energy and total free-air flow over the same time window.

data item	Minimum collection rules	Data passing conditions
Supply power and total flow	7 consecutive production days, covering all shifts and official product models, with a sampling period of no more than 1 s	Effective data coverage is no less than 95%
Branch flow	Covers production, changeover, breaks, and off-shift pressurized periods	Instrument reference status and flow direction records are complete
dynamic pressure	The peak flow action and the minimum inlet pressure action are performed 30 consecutive times each, and the four-channel sampling frequency is not less than 1 kHz.	The same DAQ, the same sampling clock, the channel deviation does not exceed 1 sample; the -3 dB bandwidth of the combination of sensor, conditioner and DAQ is not less than 200 Hz; 30 waveforms are complete; when the two are the same action, only one set is measured
leakage flow	Each operating state, pressure level and steady-state valve position combination is continuously operated for 30 minutes under conditions of no production, no action, and no intentional use of air, and the sampling period is no more than 1 s.	The effective coverage of each combination is no less than 95%, and the pressure is maintained at the center value of ±0.01 MPa.
Leakage Pressure-Decay Review	Record pressure and gas absolute temperature after meeting all prerequisites of Section 05.2	The difference between the two results shall not exceed 10%; this method shall not be used when any premise fails
Number of cycles and products	Count from controller or standalone, timestamp synchronized with flow	Count difference does not exceed 1%
Instrument status	Write the number, range, accuracy, and calibration validity period into the report	If any instrument expires, the data will not pass

This method sets the upper limit of relative expansion uncertainty of branch flow to 5%, the upper limit of relative expansion uncertainty of electric energy to 2%, and the upper limit of relative expansion uncertainty of pressure to 2%. The uncertainty budget must include calibration, repeatability, reference state conversion, clocks, state classification and annual extrapolation; data items will not pass when only citing the instrument nameplate accuracy. If any item exceeds the upper limit, the energy efficiency comparison will not enter the economic evaluation. The baseline period and the post-renovation evaluation period use the same product weights, qualified cycle definitions and annual pressure hours; when the product structure changes, it is normalized according to the frozen weight, and the two unnormalized totals are not directly compared.

Before evaluation, freeze product weights w_j using the company's formally approved annual production plan. If no annual plan exists, use the shares of conforming cycles for each model during 7 consecutive baseline days. Every weighted model shall complete at least 30 conforming cycles both during the baseline and after the retrofit; otherwise, the data criterion fails. Calculate normalized air-use intensity using the following equation, with the same w_j before and after and Σw_j=1:

```
I_air,norm = Σ[j=1..m] w_j · I_air,j
```

Clock error between branch flow and cycle state shall be ≤100 ms, and clock error between electrical energy and total supply flow shall be ≤1 s. The four pressure channels use the same DAQ with an upper limit of 1 sample of channel skew. Do not interpolate missing samples. The data criterion fails immediately if the total missing rate exceeds 5%, a missing segment covers a peak action, or any sample is missing during a leakage test. Report instrument expanded uncertainty with coverage factor k=2. Standard uncertainties of annual air use in the two periods are u_base=U_base/2 and u_after=U_after/2; with correlation coefficient ρ:

```
U_ΔV = 2·sqrt[u_base^2 + u_after^2 - 2ρ·u_base·u_after]
ΔV_L = (V_base - V_after) - U_ΔV
```

U_base and U_after are absolute expanded uncertainties of annual air use in the two periods. Use the recorded ρ only when written evidence establishes independence of the calibration chain, instruments, sampling, and conversion errors. If any evidence is missing, use the fixed conservative upper bound U_ΔV=U_base+U_after. Air savings are established only when ΔV_L>0; equality to zero also fails. All derived hard gates use the following unfavorable-direction bounds:

```
η_air,L = [1 - (I_air,after + U_I,after)/(I_air,base - U_I,base)]·100%
V_leak,U = Σ(s,b,k) (q_leak,s,b,k + U_q,s,b,k)·60·(H_s,b,k + U_H,s,b,k)
R_leak,U = V_leak,U/(V_device,year - U_V,device)·100%
```

Data items are not passed when the denominator is not greater than zero. The energy efficiency term must meet both η_air,L≥5% and ΔV_L>0; the leakage term must meet R_leak,U≤10%. See Chapters 06 and 08 for the pressure and economic boundary formulas respectively.

03 compressed air baseline and energy efficiency indicators

The average specific power of the system uses the actual measured value in the same period, and only forms the apportionment index:

```
SP_sys = E_sys / V_supply
E_device,alloc = SP_sys · V_total
I_air = 1000 · V_total / N_cycle
I_e,alloc = 1000 · E_device,alloc / N_cycle
```

E_sys contains the electric energy of the air compressor main motor, cooling fan, dryer, drainer and control auxiliary equipment within the evaluation boundary; V_supply is the m^3(ANR) delivered to the pipe network during the same period. Using only compressor nameplate power misses partial loading, unloading and auxiliary equipment losses. ISO 1217:2009 stipulates the flow and power acceptance test methods of positive displacement compressors. The data is used to check the rated point and is not used as a substitute value for the annual specific power on site [4]. $E_{device,alloc}$ and $I_{e,alloc}$ are cost allocation indicators and cannot be written as the actual power savings of the air compressor station.

Actual electricity savings use a marginal power-versus-flow model within the same load bin. Put 1 min synchronized averages of total station flow and total active power into load bin b. Every bin used shall contain at least 30 complete samples both at baseline and after the retrofit; its sampled flow range shall cover the pre- and post-retrofit flows in that bin; and compressor start/stop sequence, control mode, supply-pressure setting, and air-treatment operating combination shall be the same. In each bin, fit measured active power versus free-air flow by least squares as $P_b=\alpha_b+m_b q_b$ and define $SP_{marg,b}=m_b/60$. Because m_b is in kW/[m³/min(ANR)], $SP_{marg,b}$ is in kWh/m³(ANR). Expanded uncertainty $U_{SP,b}$ includes contributions from regression slope, electricity meter, and total flow meter:

$$\Delta E_{actual} = \Sigma(b)\ \Delta V_b \cdot SP_{marg,b}$$
$$\Delta V_{b,L} = \max(\Delta V_b - U_{\Delta V,b},\ 0)$$
$$SP_{marg,b,L} = \max(SP_{marg,b} - U_{SP,b},\ 0)$$
$$\Delta E_{actual,L} = \Sigma(b)\ \Delta V_{b,L} \cdot SP_{marg,b,L}$$

When any load bin sample is insufficient, the flow rate after modification falls outside the range of the measured curve, the compressor sequence or control mode is changed, $m_b \le 0$, or $U_{SP,b}/SP_{marg,b} > 10\%$, the binning model is invalid. The whole-station normalized substitution method combines the production combination, compressor sequence, control mode, compressor inlet temperature 5 ℃ range and air supply set pressure 0.02 MPa range to form the working condition layer g; each layer must have no less than 30 complete 1 min active power samples before and after each layer, and use the same group of approved annual hours H_g:

$$E_{sys,norm,x} = \Sigma(g)\ \mathrm{mean}[P_{x,g}]\cdot H_g,\quad x\in\{base,after\}$$
$$\Delta E_{full,L} = E_{sys,norm,base} - E_{sys,norm,after} - U_{\Delta E,full}$$

$\Delta E_{full,L}$ replaces $\Delta E_{actual,L}$ in economic calculations. If neither the binned marginal model nor the full-site normalized substitution method meets the data threshold in this section, the economic term will not pass.

The evaluation report publishes four metrics: production air-use intensity I_{prod}, leakage air-use intensity I_{leak}, total air-use intensity I_{air}, and allocated electricity intensity $I_{e,alloc}$. A reduction in total air use accompanied by a reduction in cycle count does not constitute an energy-efficiency improvement. Define the post-retrofit reduction in total air-use intensity as:

$$\eta_{air} = (I_{air,base} - I_{air,after}) / I_{air,base} \cdot 100\%$$

The passing conditions for the energy efficiency item are the point value $\eta_{air} \ge 5\%$, the conservative lower bound $\eta_{air,L} \ge 5\%$, and the conservative lower bound $\Delta V_L > 0$ of the air saving amount calculated based on the coverage factor k=2. If any of the conditions fails, the energy efficiency item will fail. The report must give both the raw difference, the expanded uncertainty, and the conservative lower bound, and not just the percentage.

04 Effective Air Consumption of the Pneumatic Industrial Manipulator

Direct integration by the equipment-branch flow meter produces the official measured result:

```
V_total = V_device = ∫[H_pressurized] q_ANR(t) dt
V_leak = Σ(s,b,k) q_leak,s,b,k · 60 · H_s,b,k
V_prod = ∫[P] max[q_ANR(t)-q_leak,P,b(t),k(t), 0] dt
V_s = ∫[s] max[q_ANR(t)-q_leak,s,b(t),k(t), 0] dt,  s∈{R,S,C,I,F}
V_total = V_prod + V_R + V_S + V_C + V_I + V_F + V_leak
```

The integration variable dt is in min. b(t) is the equipment-inlet pressure bin at time t, with a fixed bin width of 0.02 MPa; k(t) is the steady-state valve-position combination mapped from PLC outputs. q_leak,s,b,k is the leakage baseline measured in Section 05.1 for the same state, pressure bin, and valve-position combination. Every observed s-b-k combination requires a baseline; if any is missing, the component report fails. V_total is the branch-flow-meter total integral. V_prod and V_R/V_S/V_C/V_I/V_F are functional components after subtracting the concurrent leakage baseline. Within the 7-day evaluation window, total closure error |V_total-(V_prod+V_R+V_S+V_C+V_I+V_F+V_leak)|/V_total shall be ≤2%; if it exceeds 2%, the component report fails. If q_ANR<q_leak,s,b,k at any sample, do not truncate the result to force closure. First retest the leakage baseline for that combination; if the condition remains, the data criterion fails. Rework R and commissioning or no-load cycles S enter the total but not conforming production air use.

The theoretical free-air quantity for a double-acting cylinder is used only to check the order of magnitude of measured flow. Let A_b be bore area, A_r piston-rod area, and L stroke. With absolute supply pressures p_1,abs and p_2,abs for extension and retraction, respectively, and supply temperatures T_1 and T_2, the theoretical quantity for one complete reciprocating cycle is:

```
V_ANR,theory = A_b·L·(p_1,abs/p_ANR)·(T_ANR/T_1)
             + (A_b-A_r)·L·(p_2,abs/p_ANR)·(T_ANR/T_2)
```

Here p_abs = p_gauge + p_atm. Account separately for dead volume, hose filling and venting, cushioning, valve-manifold pilot air, brakes, tooling, and vacuum generators. A pneumatic balancing circuit does not necessarily fill and exhaust the cylinder's full volume on every cycle, so the official reported result is based only on integrated flow. Integrate vacuum-generator use over its actual on-time; continuous blow-off, unintended continuously open exhaust, and idle vacuum holding all enter V_I and are not counted as useful production work.

Multiple models of equipment are grouped into two-dimensional groups by status and model. The integration window of each cycle starts from the rising edge of the grabbing permission and ends at the rising edge of the next cycle's starting status confirmation signal; the pressure time without confirmation signal between the two cycles is classified as I and shall not be spread into adjacent cycles. The average value of the flow meter in the D state for 60 consecutive seconds is used as the zero point verification value for the day. When the absolute value exceeds 0.5% of the full scale of the meter, the branch flow data for the day will not pass. Flow integration simultaneously retains the 1 s original sequence, per-cycle results, and daily summary, and the cumulative volume difference between the three layers of data must not exceed 0.5%.

ISO 6358-1:2013 with its 2020 and 2026 amendments, and ISO 6358-2:2019 with its 2026 amendment, are used to test the flow characteristics of fixed- or variable-flow-path components within their stated scopes [5][6]. ISO 6358-3:2014 uses known component and piping characteristics to calculate steady-state system flow capacity [7]. Do not apply equations outside the applicable part's scope to cylinders, air receivers, check devices with cracking pressure, quick-exhaust valves, or internally piloted regulators. For a regulator, use the manufacturer's pressure–flow curve covering the project set pressure and actual upstream-pressure, downstream-pressure, and flow ranges. If that curve is unavailable, use synchronized measurements of upstream pressure, downstream pressure, and flow; do not substitute an ISO 6358 calculation.

05 Leak rate measurement, conversion and classification

05.1 Branch mass flow meter method

The primary method for the equipment-leakage release value uses a branch mass flow meter. For every state s, 0.02 MPa pressure bin b, and steady-state valve-position combination k occurring in Chapter 04, reproduce that combination in test mode; remove the workpiece and suspended load; mechanically lock motion; turn off blow-off, the vacuum generator, and actuator commands; and record continuously for 30 min. Safety functions that require continuous air for risk control shall be metered on an independent branch and classified as functional air use, not leakage. If safety-function air use cannot be separated from leakage, the data for that s-b-k combination fail.

The sampling period of each combination shall not be greater than 1 s, the equipment inlet pressure shall be maintained at the gear center value ±0.01 MPa, and the effective data coverage shall not be less than 95%. The entire test shall be invalidated when any action command or functional air command appears. $q_{leak,s,b,k}$ takes the arithmetic mean of the effective samples of this combination; the expanded uncertainty $U_{q,s,b,k}$ includes flowmeter calibration, repeatability, reference state conversion, zero point and pressure stability. The baseline period and the post-renovation period are measured separately, and the leakage value from another period is not used.

When the mass flow meter directly reports the ISO 8778 reference state, record its configuration of 20 °C, 100 kPa absolute, and 65% relative humidity. When the instrument reports actual-condition volumetric flow q_{op}, convert it using the compressibility factor Z from the calibration certificate:

$$q_{ANR} = q_{op} \cdot (p_{op,abs}/p_{ANR}) \cdot (T_{ANR}/T_{op}) \cdot (Z_{ANR}/Z_{op})$$

Acquire $p_{op,abs}$ and T_{op} with the same timestamp as flow. If the record lacks absolute pressure, absolute temperature, compressibility factor, or humidity configuration, the data for that bin fail. Valve cross-port leakage, nonzero-air-consumption drains, and air used by instrument impulse lines are included within the leakage boundary.

05.2 Review method for pressure drop during production shutdown

Use the pressure-decay method only when all of the following conditions are met: the workpiece and suspended load have been removed; mechanical parts are locked; compressed air is locked out and tagged out; the safety holding circuit is physically isolated from the test section; the controlled P&ID, pipe-segment list, air-receiver list, and component BOM provide 100% item-by-item coverage of the isolated volume; and the test permit is signed by the equipment and safety owners. Do not start a pressure-decay test if any condition is missing.

After the system reaches the operating gauge pressure $p_{1,g}$ recorded in the controlled recipe, isolate the air supply. Fix the endpoint at $p_{2,g}=0.50p_{1,g}$ and linearly interpolate the crossing time t from the pressure time series. The DOE factor 1.25 applies only to this half-pressure endpoint and corrects average leakage during decay to the initial system pressure [9][11]. Calculate using absolute endpoint temperatures:

```
q_avg,ANR = V_sys · (Z_ANR·T_ANR/p_ANR) · [p_1,abs/(Z_1·T_1) - p_2,abs/(Z_2·T_2)] / t
q_leak,P1,ANR = 1.25 · q_avg,ANR
```

Use m³ for V_{sys}; use the same pressure unit for $p_{1,abs}$, $p_{2,abs}$, and $p_{ANR}=100$ kPa(abs); use K for T_1, T_2, and $T_{ANR}=293.15$ K; take Z_1, Z_2, and Z_{ANR} from calibration certificates or controlled property tables; and use min for t. The result is invalid if $|T_2-T_1|>2$ K, any compressibility factor is missing, any volume item lacks controlled dimensions, the minimum terminal pressure reaches the safety-circuit design lower limit, or the pressure curve does not cross the exact half-pressure point. Calculate the relative difference between the two tests as $|q_1-q_2|/[(q_1+q_2)/2]$ and use the arithmetic mean only when it is no greater than 10%.

When the pressure drop review value differs by more than 10% from the mass flow meter result at the same initial pressure level, the leakage data will not pass. The pressure drop review value does not replace the state-pressure-valve position combination results in Section 05.1, nor is it directly applicable to the annual leakage volume.

05.3 Load/unload cycle screening method

The arithmetic mean of load time T_{on} and unloading time T_{off} is published only when a single fixed-speed compressor supplies air independently, the compressor is in load/unloading control, all non-leakage gas is closed, the output is controlled full load flow when loading, and the output is zero when unloading, and the load and unloading switching pressures of 10 cycles respectively fall within ±1% of their respective 10-time average values. The proportion of leakage to compressor capacity is calculated according to the DOE method [9]:

```
R_leak,capacity = T_on / (T_on + T_off) · 100%
```

The percentage is not published if any of the prerequisites fails. This method is only used for total leakage screening of supply systems; use the results of Section 05.1 for individual equipment. The two methods have different boundaries and do not directly average the two percentages.

05.4 Proportion of equipment leakage air

```
V_leak,year = Σ(s,b,k) q_leak,s,b,k · 60 · H_s,b,k
R_leak = V_leak,year / V_device,year · 100%
R_leak,U = V_leak,U / (V_device,year - U_V,device) · 100%
```

$V_{device,year}$ is the annual air supplied to the same branch in all pressurized states, including production, rework, commissioning, changeover, idle, fault, and leakage states. Do not add leakage again to V_device,year when that total has already been integrated by the branch flow meter. Add V_leak,year to the functional components only when estimating the annual total from the component model. Release uses R_leak,U as defined in Chapter 02; the point estimate is for display only.

level	R_leak,U	Judgment	mandatory action
A	≤5%	Pass, low leakage	Maintain quarterly retesting
B	>5% and ≤10%	Pass, controlled leakage	Establish a list of leaks and fix them within 30 days; if the work order is not closed before the end of the 30th day, it will automatically turn into a failure
C	>10% and ≤20%	failed	After repair, complete all combined measurements in Section 05.1
D	>20%	Failure, severe waste	Remove workpiece and the suspended load, complete mechanical locking and lockout, then isolate the non-production air supply and repair it

The third edition of the U.S. Department of Energy Sourcebook describes leakage below 5%–10% for a well-maintained compressed-air system and 20%–30% for a poorly maintained system [9]. Its load/unload method is referenced to compressor capacity or the full-system air-supply boundary. In this report, R_leak is annual leakage volume for one equipment branch divided by annual total air supplied to that branch. Because the denominators differ, the DOE percentage is not converted into an equipment percentage. This report independently fixes R_leak,U≤10% as the project pass limit for this assessment method only. If leakage is detected in a safety-related pressure-retention circuit, equipment safety criteria take priority over the energy rating. After repair, repeat all six Chapter 11 tests.

06 Pressure loss, flow capacity and minimum pressure criteria

For pressure evaluation, select the peak-flow action and the action with the lowest inlet pressure. First record synchronized flow and pressure for 10 runs of every pneumatic action for every released product model. Select as the peak-flow action the action with the highest dynamic-flow maximum, and as the lowest-inlet-pressure action the action with the lowest P3 minimum; if they are the same action, retain only one. During formal evaluation, record 30 consecutive runs of each selected action. Dynamic flow and all four pressure channels shall use the same 1 kHz sampling clock and have a combined −3 dB bandwidth of at least 200 Hz.

The pressure loss is calculated sample by sample for all formal evaluation waveforms and bounded in the unfavorable direction of the expanded uncertainty. p_0, p_1, p_2, and p_3 are four-point synchronous gauge pressure respectively, and U_0, U_1, U_2, and U_3 are the corresponding absolute expanded uncertainties:

```
R_Δp,main,U = max(i,t){1 - [p_2,i(t)-U_2,i(t)]/[p_1,i(t)+U_1,i(t)]}·100%
R_Δp,total,U = max(i,t){1 - [p_3,i(t)-U_3,i(t)]/[p_0,i(t)+U_0,i(t)]}·100%
p_3,min,L = min(i,t)[p_3,i(t)-U_3,i(t)]
```

i spans the 30 waveforms of all selected actions and t spans every sample; if any denominator is not positive, the data criterion fails. The DOE Sourcebook states that pressure loss from compressor discharge to the final point of use should be well below 10% of discharge pressure, with a maximum design header pressure drop of 1%–2% [9]. This report uses R_Δp,total,U≤10% as the project limit and R_Δp,main,U≤2% as the limit for a new or reconstructed header. These are the release gates for total and header pressure drop, respectively; Chapter 11 defines the acceptance basis. The equipment shall also satisfy p_3,min,L≥p_required,min,g. Take p_required,min,g only from the minimum operating gauge pressure in a controlled design document; without that document, the pressure criterion fails.

Check items	pass criterion	Fail Trigger
Pressure drop in new or reconstructed main pipes	R_Δp,main,U≤2%	Conservative upper bound >2%
total pressure drop	R_Δp,total,U≤10%	Conservative upper bound >10%
Dynamic minimum inlet pressure	p_3,min,L≥p_required,min,g	The conservative lower bound is lower than the design lower bound
Repeatability	Include all 30 waveforms for every selected action in the conservative-bound calculation	Any waveform is missing or any boundary-keeping failure

Increasing the exhaust pressure of the air compressor cannot replace the elimination of end throttling. When the flow rate is insufficient, check the filter, plug-in, hose, valve island and muffler according to the measured dynamic peak flow rate; use ISO 6358 data for components within the applicable scope of the standard, and use ISO 6358-3 calculations for component combinations. For pressure regulators, only use the manufacturer's pressure-flow curve specified in Chapter 04 or simultaneous actual measurements. After the transformation, all 30 waveforms of each selected action enter the boundary calculation and the pressure and function criteria all pass, and the pressure item is passed.

Pressure-drop segmentation uses synchronized samples from the three fixed segments P0-P1, P1-P2, and P2-P3. If any segment accounts for more than 40% of the simultaneous total P0-P3 pressure drop, make that segment the first corrective-action priority; do not calculate the ratio when total pressure drop is not positive. This ratio determines corrective priority only and does not change the 2% header or 10% total pressure-drop limits. The upper limit of each pressure-sensor range shall not exceed 2 times the controlled design operating gauge pressure, and the zero differences among the four channels in the depressurized state shall be less than 0.5% of full scale; otherwise, the pressure data fail.

07 Power consumption attribution and annual cost

The annual shared power consumption and shared electricity cost of a single device are calculated based on the average specific power of the system during the same period [10]:

$$E_{device,alloc,year} = SP_{sys} \cdot V_{device,year}$$
$$C_{energy,alloc,year} = E_{device,alloc,year} \cdot c_e$$
$$C_{leak,alloc,year} = SP_{sys} \cdot V_{leak,year} \cdot c_e$$

Take c_e as the all-in electricity unit price from the company's bill, in yuan/kWh. The three items above may be labeled only as allocated; they shall not be reported as actual electricity savings or realizable benefits. Calculate actual annual electricity and electricity-cost savings using the load-bin method in Chapter 03:

$$\Delta E_{actual,year} = \Sigma(b)\ \Delta V_b \cdot SP_{marg,b}$$
$$\Delta C_{energy,year} = \Sigma(b)\ \Delta V_b \cdot SP_{marg,b} \cdot c_{e,b}$$
$$\Delta C_{energy,L,year} = \Sigma(b)\ \Delta V_{b,L} \cdot SP_{marg,b,L} \cdot c_{e,b,L}$$

When time-of-use pricing applies, also divide load bins by tariff period; take $c_{e,b,L}$ as the lower bound of the corresponding billed electricity unit price. Include demand charges only when the retrofit reduces maximum demand within the billing window and the bill provides a definite amount; without that evidence, use zero. Use only documented amounts from the finance or maintenance system for maintenance, spare parts, and line-stoppage losses. Use zero for undocumented items; industry averages are prohibited.

The average specific power of the supply system is calculated on a rolling monthly basis. The allocation index uniformly uses the volume weighted value $SP_{sys,common}=(E_{sys,base}+E_{sys,after})/(V_{supply,base}+V_{supply,after})$, and no verbal weighting rules are set. The actual power saving always uses the $SP_{marg,b}$ of the same load bin or the measured difference before and after the whole station normalization, and does not use $SP_{sys,common}$.

Annual volume shall not be calculated by multiplying a single shift by 365. For production, multiply the normalized intensity for each model by the approved annual cycle count. For leakage, multiply leakage flow for each state–pressure-bin–valve-position combination by annual pressurized hours. For changeover, idle, and fault components, use the functional average flow for each combination over 7 consecutive days together with the annual combination hours from the company's production-planning system. The fixed annual model is:

$$\begin{aligned} V_{device,year} = {} & \Sigma(j)\ I_{prod,j}\cdot N_j/1000 \\ & + \Sigma(s,b,k)\ q_{leak,s,b,k}\cdot 60\cdot H_{s,b,k} \\ & + \Sigma(s=R,S,C,I,F;\ b,k)\ q_{s,b,k}\cdot 60\cdot H_{s,b,k} \end{aligned}$$

In the equation, $q_{s,b,k}$ for each state is the functional average flow after deducting concurrent $q_{leak,s,b,k}$. Count the same volume only once. Within the 7-day evaluation window, first calculate the component model from measured N_j and $H_{s,b,k}$ and compare it with the branch meter's raw integrated total for that window; if the difference exceeds 2%, annual extrapolation is prohibited. Only after the 7-day balance closes may the frozen annual N_j and $H_{s,b,k}$ be used for extrapolation. At 12 months after project release, verify the annual model against the branch meter's full-year integrated total. If the difference exceeds 5%, the economic conclusion expires on the verification date and all six Chapter 11 criteria shall be reevaluated within 5 working days.

08 life-cycle cost and investment threshold

This report uses a fixed evaluation period of 5 years. Use only the company-approved project discount rate r; without an approved value, the economic criterion fails. The Chapter 09 calculation input fixes the discount rate at 5%; calculate other cases using the company-approved value. Calculate point-estimate life-cycle cost and net present value as follows:

```
LCC_5 = C_invest + Σ[y=1..5] (C_energy,y + C_maint,y + C_parts,y + C_stop,y)/(1+r)^y
NPV_save = Σ[y=1..5] (C_base,y - C_after,y)/(1+r)^y - C_invest
```

The conservative-bound calculation uses investment upper bound C_invest,U and annual net-savings lower bound S_y,L=C_base,y-C_after,y-U_S,y as inputs:

```
NPV_save,L = Σ[y=1..5] S_y,L/(1+r)^y - C_invest,U
K_n = Σ[y=1..n] S_y,L
PB_U = (n-1) + (C_invest,U-K_(n-1))/S_n,L,  K_(n-1)<C_invest,U≤K_n
```

n is the year when the undiscounted cumulative net savings reaches the upper bound of investment for the first time, and the net savings within the year are calculated as uniform occurrence; when there is no such n within 5 years, or when S_y,L≤0 in any year or the denominator is not greater than zero, PB_U is defined as infinity. When the annual net savings are equal, the above formula is simplified to PB_U=C_invest,U/S_1,L. Residual values, tax benefits and financing costs only enter the model if the contract or financial system gives a firm amount. The passing conditions for economic items are fixed to NPV_save,L>0 and PB_U≤3.0 years; point values are not used for release. If any condition fails, the economic item fails. Even if the economic item passes, as long as the pressure, function or safety item fails, the overall project will still fail.

The baseline scenario and the retrofit scenario use the same annual cycle number, electricity price series and discount rate. When there is no energy price growth rate approved by the enterprise, the five-year electricity price growth rate is fixed at 0%; when there is no contract residual value, the residual value is fixed at 0%. The lower bound of actual power saving is only taken from the binned marginal model in Chapters 03 and 07 or the normalized actual measurement of the whole station, and the average specific power sharing value is not allowed to enter S_y,L. The calculation retains unrounded values. The amount in the table is displayed to 0.01 yuan, the volume is displayed to 0.1 m³, and the ratio is displayed to 0.01 percentage points. The unrounded values are used for judgment to prevent the critical value from changing the conclusion due to display rounding.

09 Complete calculation and determination of a single equipment branch

The fixed inputs in this chapter are: 180,000 conforming cycles/year, 3,000 production h, and 4,000 pressurized branch h; the retrofit consists of repairing leaks, shortening the vacuum-supply command window, and reducing terminal flow-path resistance; investment upper bound 4,000.00 yuan; all-in electricity price and its lower bound both 0.80 yuan/kWh; 5-year discount rate 5%; and electricity-price growth, maintenance differential, spare-parts differential, line-stoppage differential, demand-charge differential, and residual value all 0. The average system specific power of 0.115 kWh/m³(ANR) is used only for allocation metrics.

09.1 Data, leakage and uncertainty

The fixed data-quality inputs for the calculation condition are: seven-day data coverage 98.6%; relative expanded uncertainty in annual air use from flow, reference state, clock, state classification, and annual extrapolation of 4.0% both at baseline and after retrofit; corresponding absolute expanded uncertainties of 33,960×4%=1,358.4 m³ and 12,720×4%=508.8 m³; relative expanded uncertainty of the marginal power–flow model as listed in Section 09.3; and relative expanded uncertainty of 1.2% for each of the four pressure channels. Instrument calibration status is valid, pressure-channel skew is ≤1 ms, and combined bandwidth is 250 Hz. Under the Chapter 02 criteria, the data item passes.

Set a 0.70 MPa pressure level for the calculation conditions. All steady-state valve position combinations within the six states of P/R/S/C/I/F are set to a 30-minute calculation window in accordance with Section 05.1, and the action and intentional air usage commands are both set to 0; the flow input of all combinations is taken to be 0.080 m³/min (ANR) before the modification, and 0.002 m³/min (ANR) after the modification. The relative expanded uncertainties of the leakage flow rates in the two periods are both 4.0%, that is, $U_{q,base}$=0.0032 m³/min and $U_{q,after}$=0.00008 m³/min. Annual pressurized hours as precise input, U_H=0:

```
V_leak,base = 0.080×60×4000 = 19,200 m³(ANR)
V_leak,after = 0.002×60×4000 = 480 m³(ANR)
```

Leakage quantity uses the branch-flow method. The input difference between the 7-day branch total integral and state-component model is 0%, meeting the 2% closure criterion. Rework, commissioning, changeover, idle functional air use, and fault-state functional air use are fixed at 0; total branch air use consists only of production air use and leakage air use.

09.2 Keeping boundaries on gas usage, leakage and energy efficiency

Production air-use intensity decreases from 82 to 68 m³(ANR)/1000 cycles, corresponding to annual production air use of 14,760 and 12,240 m³(ANR), respectively.

indicator	before renovation	After renovation	release results
Annual Production Air Use	14,760 m³(ANR)	12,240 m³(ANR)	decreased by 2,520
Annual Leakage Air Use	19,200 m³(ANR)	480 m³(ANR)	Decrease 18,720
Total Annual Air Use	33,960 m³(ANR)	12,720 m³(ANR)	Point value reduced by 62.54%

indicator	before renovation	After renovation	release results
Leakage air proportion point value	56.54%, Grade D	3.77%, Grade A	Point value display
Upper bound of leakage air proportion	61.25%, Grade D	4.09%, Grade A	After transformation ≤5%, passed
Total gas intensity	188.67 m³/1000 times	70.67 m³/1000 times	Point value reduced by 62.54%
Apportioned power consumption indicators	3,905.4 kWh	1,462.8 kWh	Not used as evidence of actual power saving

The upper bound of the leakage rate is calculated according to the unfavorable direction:

```
R_leak,U,base = (0.080+0.0032)×60×4000/(33,960-1,358.4) = 61.2485%
R_leak,U,after = (0.002+0.00008)×60×4000/(12,720-508.8) = 4.0881%
```

The throttle point value is 21,240 m³(ANR)/year. There is no documented evidence for the correlation between the two periods, and linear conservative upper bounds are fixed: U_ΔV=1,358.4+508.8=1,867.2 m³, ΔV_L=21,240-1,867.2=19,372.8 m³. The intensity expansion uncertainties are 7.5467 and 2.8267 m³/1000 times respectively:

```
η_air,L = [1-(70.6667+2.8267)/(188.6667-7.5467)]×100% = 59.4229%
```

η_air,L≥5% and ΔV_L>0, the energy efficiency item is passed; after modification, R_leak,U=4.0881%≤5%, the leakage item is grade A and passed.

09.3 Actual power saving and economic boundary keeping

The load-bin input matrix uses 60 complete 1 min samples both before and after the retrofit. Compressor start/stop sequence, control mode, 0.70 MPa supply setting, and air-treatment operating combination are held the same. Three load bins cover all pre- and post-retrofit flow. The sum of expanded uncertainties in the air savings across the bins is fixed at 1,867.2 m³, and the expanded uncertainty in marginal specific power for every bin is 0.005 kWh/m³(ANR):

Whole-Station Flow Load Bin	ΔV_b	U_ΔV,b	SP_marg,b	U_SP,b	Energy saving point value	Lower bound of power saving
[0,10] m³/min	5,520 m³	500 m³	0.100	0.005	552.00 kWh	476.90 kWh
(10,20] m³/min	10,080 m³	880 m³	0.112	0.005	1,128.96 kWh	984.40 kWh

Whole-Station Flow Load Bin	ΔV_b	U_ΔV,b	SP_marg,b	U_SP,b	Energy saving point value	Lower bound of power saving
(20,30] m³/min	5,640 m³	487.2 m³	0.124	0.005	699.36 kWh	613.18 kWh
total	21,240 m³	1,867.2 m³	—	—	2,380.32 kWh	2,074.48 kWh

The actual electricity-savings point estimate is 2,380.32 kWh/year; the conservative-bound value is (5,520-500)×(0.100-0.005)+(10,080-880)×(0.112-0.005)+(5,640-487.2)×(0.124-0.005)=2,074.4832 kWh/year. The annual electricity-cost-savings point estimate is 2,380.32×0.80=1,904.256 yuan, and its lower bound is 2,074.4832×0.80=1,659.58656 yuan.

The present value coefficient of equivalent costs in 5 years is 4.32947667. The net present value saving point value is 1,904.256×4.32947667-4,000=4,244.43 yuan; the lower bound of the net present value saving is 1,659.58656×4.32947667-4,000=3,185.14 yuan. The point value payback period is 4,000/1,904.256=2.10 years; the annual lower bound is equal to the same amount, and the upper payback period is 4,000/1,659.58656=2.41 years. NPV_save,L=3,185.14>0 and PB_U=2.41≤3.0 years, the economic item passes.

09.4 Pressure, functional safety and overall judgment

The pressure calibration conditions are fixed as follows: the minimum working gauge pressure of the key actuator is 0.60 MPa; the peak flow action and the minimum inlet pressure action are the same action; the number of action waveform samples is 30. The following pressure parameters take the most unfavorable values in the input matrix: P0 is 0.70 MPa, U_0=0.0084 MPa; the lowest point of P3 before transformation is 0.61 MPa, U_3=0.00732 MPa; the lowest point of P3 after transformation is 0.65 MPa, U_3=0.0078 MPa:

```
R_Δp,total,U,base = 1-(0.61-0.00732)/(0.70+0.0084) = 14.9238%
R_Δp,total,U,after = 1-(0.65-0.0078)/(0.70+0.0084) = 9.3450%
p_3,min,L,after = 0.65-0.0078 = 0.6422 MPa
```

If the upper bound of the total pressure drop before the transformation exceeds 10%, the pressure item fails; after the transformation, the upper bound of the total pressure drop does not exceed 10%, and the lowest pressure lower bound is higher than 0.60 MPa, the pressure item passes. This calculation condition does not include new or reconstructed main pipes, and the 2% main pipe additional threshold is not triggered.

The functional-safety verification matrix includes six items: load holding after loss of air supply, emergency stop, braking, gripping confirmation, prevention of inadvertent release, and residual-energy management. For each item, record the load, initial state, command, holding duration, and binary acceptance criteria. All six binary states are pass, and the number of safety bypasses is 0. Under the inputs and calculations in this chapter, all six gates—data, leakage, pressure, energy efficiency, economics, and functional safety—pass; the overall result is pass.

10 Transformation priorities and retesting process

Perform the retrofit in the following fixed sequence. First, after removing the workpiece and suspended load and completing mechanical locking and lockout/tagout, isolate abandoned branches, idle equipment, and drains with nonzero air consumption. Second, repair leaks at fittings, hoses, valves, and seals. Third, based on segmented pressure-drop results, clean or replace filters, quick-connects, hoses, valve manifolds, and silencers; address regulators using manufacturer curves or synchronized measurements. Fourth, reduce the local pressure setting in 0.02 MPa increments. At every setting, perform all pressure-waveform and functional-safety tests in Chapter 06. The released setting is the lowest tested setting satisfying $R_{\Delta p,total,U} \le 10\%$, $p_{3,min,L} \ge p_{required,min,g}$, and 100% functional-safety acceptance. Fifth, establish a PLC whitelist window for every blow-off and vacuum-generator command; record the window start signal, end signal, and duration in the controlled recipe. The condition fails if a command equals 1 outside its window in any cycle. Sixth, complete all functional-safety tests. Seventh, repeat the 7-day energy-efficiency measurement. Increasing compressor pressure or adding a compressor is not among the first six steps.

Retesting uses frozen product weights and identical cycle definitions. Section 05.1 Each state-pressure-valve position combination is re-recorded for 30 minutes; the pressure test covers all waveforms of the two types of actions defined in Chapter 06; the safety test covers all functions of gas shut-off holding, emergency stop, braking, clamping confirmation, inadvertent-release prevention, residual energy processing and project risk assessment. If any one of these fails, the device may not be put into production in energy-saving mode.

After project release, calculate $I_{air,norm}$ every month using the most recent complete month data, and retest leakage every quarter according to Section 05.1; redo all six items in Chapter 11 after each replacement of hoses, valve terminals, pressure regulators, vacuum generators, pressure settings or control procedures. If the conservative lower bound of the monthly normalized gas intensity increases by more than 10% compared to the release value, or the quarterly $R_{leak,U} > 10\%$, the equipment will complete the leak location within 5 working days and start six retests; if $p_{3,min,L}$ is lower than the design lower limit or any safety function fails, it will immediately exit the energy-saving mode. To resume production, root cause records, completed maintenance work orders, six re-test passing records, and signatures of equipment and safety responsible persons must be present. Without any record, restoration is not allowed. All original records, formula versions and judgment tables are kept for no less than 5 years to cover the complete LCC evaluation period of this report and form a record chain for continuous improvement of energy performance [12].

11 FMEA, risk control and general release rules

failure mode	Consequences of mistakes	Detection and Control	Fail condition
Gauge pressure when absolute pressure is substituted into the gas formula	Systematic bias in air-use measurement	Formula fields are recorded separately p_g, p_abs, p_atm	Any pressure base is unknown
m³, Nm³ mixed with m³(ANR)	Flow is not comparable	All converted to ISO 8778 reference state	Missing reference temperature, pressure and humidity
Production air use not isolated during the leakage test	The amount of leakage is falsely high	Lock and tag out all production outlets	Any actuator moves during the test
The pressure drop test only takes the average pressure	Transient low pressure is missed	The same 1 kHz DAQ records four channels and bounds all waveforms on a sample-by-sample basis	Any waveform is missing, the upper limit of pressure drop exceeds the limit, or the lower limit of pressure is insufficient.
Use average specific power to directly prove actual power savings	Earnings are overvalued	Same-load marginal power–flow model or normalized whole-station measurement	Both types of actual power saving evidence are invalid
Pressure reduction destroys clamping and braking functions	Danger of load drift or release	Perform every functional test and loss-of-pressure test specified by the controlled risk assessment	Any functional or security test failed
Leak repair, mis-sealed safety exhaust	Residual energy cannot be released	Review point by point against the pneumatic circuit diagram	Failure to handle residual pressure after isolation
Repeated pricing for power savings and leakage	Earnings are overvalued	All benefits calculated uniformly from the difference in total air use	The same volume appears repeatedly in both returns

failure mode	Consequences of mistakes	Detection and Control	Fail condition
Write the stop loss valuation as a determined profit	LCC falsely high	Only take financial amounts with vouchers	No voucher amount enters the model

Overall release uses a one-out-of-six rejection rule. The project passes only if all six of the following criteria pass:

1. Data items: coverage, instrumentation, synchronization, bandwidth, repeatability, 7-day closure, and uncertainty budget all satisfy Chapter 02.
2. Leakage term: $R_{leak,U} \leq 10\%$.
3. Pressure term: $R_{\Delta p,total,U} \leq 10\%$ and $p_{3,min,L} \geq p_{required,min,g}$; when the project includes new or reconstructed main pipes, $R_{\Delta p,main,U} \leq 2\%$ must also be met.
4. Energy efficiency item: $\eta_{air,L} \geq 5\%$ and the conservative lower bound of air saving is $\Delta V_L > 0$.
5. Economic terms: $NPV_{save,L} > 0$ and $PB_U \leq 3.0$ years.
6. Functional safety items: 100% pass of all functional and safety tests listed in the controlled risk assessment, with zero safety bypasses; failure when risk assessment, binary acceptance criteria, or any test record is missing.

If any item fails, the overall project will be judged as failed; after any rectification is completed, all six items will be re-executed, and partial retest will not be used instead.

12 Research conclusions

The compressed-air economics of a Pneumatic Industrial Manipulator cannot be demonstrated by inlet pressure, compressor nameplate data, or a single flow screenshot. A complete evidence chain comprises a common reference state, integrated equipment-branch flow, leakage measurements by state–pressure-bin–valve-position combination, four-channel dynamic pressure, production-cycle counts, a same-load marginal power–flow model, and financial records. The leakage-rate upper bound of 10%, total pressure-drop upper bound of 10%, air-use-improvement lower bound of 5%, positive net-present-value lower bound, and 3-year payback-period upper bound specified in this report jointly form the engineering release rule.

This method is used for energy efficiency baseline, modification review, procurement life-cycle cost comparison and operation and maintenance retesting. When the formal measurement records, risk assessments, design documents and test reports of the equipment project simultaneously meet the six thresholds in Chapter 11, the conclusion is "passed the evaluation of this method"; if any threshold fails, the conclusion is "failed".

The standard status verification base date is 2026-08-15: ISO 11011:2013, ISO 4414:2010, ISO 8778:2003, ISO 6358-1:2013, ISO 6358-2:2019, ISO 6358-3:2014 and ISO 50001:2018 are all in ISO Published status; ISO 1217:2009 is still a published version and in the revision stage; GB/T 7932-2017 is marked as current on the National Standard Information Public Service Platform. Chapters 05 and 12 are included in the ISO 6358 and ISO 50001 amendments published as of that date. When a project is started after the verification base date, the standard list must be re-compared on the project establishment date; if the comparison is not completed, the data items will not pass.

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