CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Final Report: Compressed Air Systems

Process 3: Air Compressors

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team July 2013

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Preface

The Codes and Standards Enhancement (CASE) initiatives present recommendations to support the California Energy Commission's efforts to update the Title 24 Standards to include or upgrade requirements for various technologies in California's Building Energy Efficiency Standards. The four California Investor Owned Utilities - Pacific Gas and Electric Company, San Diego Gas and Electric, Southern California Edison and Southern California Gas Company - sponsored this effort. The program goal is to prepare and submit proposals that will result in valuable, cost-effective enhancements to energy efficiency in buildings. This report, Compressed Air Systems, is one of several cross-cutting proposals now included in the 2013 Building Energy Efficiency Standards.

Executive Summary

This proposal outlines the first measures to affect compressed air systems in the Title 24 Building Energy Efficiency Standards. Two mandatory requirements apply to all new systems and existing systems making alterations/additions that have a combined horsepower (hp) rating of over 25 hp. Any existing system with centrifugal compressors is exempt from these requirements.

This proposal results in modifications to Section 120.6(e) of the Title 24 Building Energy Efficiency Standards, the Appendices, the Nonresidential Compliance Manual, and compliance forms.

Final Code Language

The first measure addresses the choice and sizing of the trim compressor, along with an appropriate amount of primary storage. Each system must be equipped with a trim compressor (or compressors) that can operate efficiently throughout its part-load range. Furthermore, this trim compressor should be sized large enough to avoid control gaps. Variable Speed Drive (VSD) compressors have been identified as technology that is compliant, but other technologies available now and possibly in the future can also be used to meet this requirement. If using a VSD compressor, the primary storage must have a capacity of at least one gallon for every actual cubic feet per minute (ACFM) of capacity of the trim compressor(s). If using another technology, the primary storage is at least two gallons for every ACFM of the trim compressor(s). Any existing system is exempt from these requirements if the change in capacity (either adding or replacing) is less than 50 percent of the existing system capacity.

The second measure mandates that system controls be installed for every multi-compressor system. A compliant control system will choose the most energy efficient combination of compressors for a given demand. This can be measured through a sensor or set of sensors and calculations. The acceptance test described in NA7.13 was developed to prove compliance for this measure.

Evolution of Requirements

These requirements have changed from the original CASE proposal submitted to the California Energy Commission (CEC) in November 2011, but the intent has remained the same. Some of the changes were minimal and added a bit of clarity (such as units to a specific measurement or a definition for a term). The majority of the large changes were submitted to the CEC with strong recommendation coming from Pacific Gas & Electric's (PG&E) utility incentive programs. A few meetings and email communications occurred during March and April 2012 to review these recommendations that the CEC has incorporated.

One major exception that was added excludes existing systems with centrifugal compressors from having to comply. Much of the mandatory requirements were not originally designed (or calculated) with centrifugal compressors in mind. Centrifugal compressors are typically custom-designed (or engineered) for each system. Utility representatives believed that changes to existing systems could result in a much higher payback period, possibly keeping system owners from making any upgrades/changes to the system. Some industry representatives felt that it was important that existing systems made upgrades, though seemed comfortable with possibly delaying this until the next code cycle. It was generally agreed that code that affected such custom and possibly complex systems required more research into cost-effectiveness.

Changes to the Trim Compressor and Primary Storage Requirement

The trim compressor requirement was arguably complicated and relied on two new terms (*largest net capacity increment* and *total effective trim capacity*), buried in the definitions (Section 101(b) in the Standards). The CEC agreed that these terms should be apparent and were moved into the actual code in Section 120.6(e)1.B.

However, even with this change, both utility and industry representatives agreed that the code could use further clarification, per meetings held in April 2012. This was addressed by adding an easier compliance pathway with a prescriptive option. This option calls for an appropriately-sized VSD compressor acting as the trim compressor. Instead of looking at the performance of the VSD compressor, this requirement assumes all VSD compressors perform efficiently enough at part-load, as long as it is large enough to cover control gaps. If using a VSD compressor, the full-load capacity must be 25 percent larger than the largest net increment between base combinations of base compressors. This 25 percent requirement was implemented because it gave a wider range where the VSD would perform efficiently and ideally cover any control gaps. To match this technology, the primary storage requirement was relaxed from two gallons per ACFM of trim capacity to one gallon per ACFM.

Further exceptions were also made for this requirement, in response to meetings held in April 2012. It was clarified that not only small changes to existing systems should be exempt, but also large changes that *reduce* the online capacity of the system. If further changes have *decreased* the supply side of the system, it is not the intent to force these systems to comply with the code.

Finally, another exception was added, exempting systems where the load does not fluctuate from this requirement. This requires approval from the CEC Executive Director.

Changes to the Controls Requirement

The phrase “approved controller” unintentionally implied that there was a list of controls that had been pre-approved and were compliant. This was not the intent of the requirement and this was removed.

Changes to the Acceptance Test

The Construction Inspection was not significantly changed, beyond the relocation of the requirement regarding the method for measuring/calculating the current air demand.

The Functional Test section now makes reference to a specific sensor to measure current air demand (“as measured by a flow sensor or otherwise inferred by system measurements”) in Step 1. This was added for clarity and further explained in the Compliance Manual.

Lastly, Step 2 was adjusted to be less restrictive and more useful. Prior to the change, it was originally restricted to run the system steadily at some point 50 to 85 percent of full load. After feedback, this was expanded to include any load, as long as this was an expected load at which the system would operate.

Energy Savings

The statewide impact of this code proposal are 4.86 gigawatt-hours per year (GWh/yr) and 0 million therms (MMTherms) per year of energy, and 0 megawatts (MW) of electrical demand. The net present value of life cycle energy cost savings over 15 years will be approximately $9.86 million.

Table 1. Compressed Air Systems Statewide Energy Impacts Estimate

Total Electric Energy Impacts (GWh/yr)	Total Power Demand Impacts (MW)	Total Gas Energy Impacts (MMtherms)
4.86	0	-

Final Adopted Language

Final adopted language for the standards, Reference Appendices, and Compliance Manual includes section number and original language in black font. Edits to the original language are notated as follows:

- Changes to the original 2008 Title 24 standards: single underline or ~~single strike-out~~
- Changes to the 45-day language: double underline or ~~double strike-out~~
- Changes to 15-day language: gray highlighted double underline or gray highlighted ~~double strike-out~~

Building Energy Efficiency Standards

(e) **Mandatory Requirements for Compressed Air Systems.**

All new compressed air systems, and all additions or alterations of compressed air systems where the total combined online horsepower (hp) of the compressor(s) is 25 horsepower or more shall meet the requirements of Subsections 1 through 3. These requirements apply to the compressors and related controls that provide compressed air and do not apply to any equipment or controls that use or process the compressed air.

EXCEPTION to Section 120.6(e): Alterations of existing compressed air systems that include one or more centrifugal compressors.

1. **Trim Compressor and Storage**.. The compressed air system shall be equipped with an appropriately sized trim compressor and primary storage to provide acceptable performance across the range of the system and to avoid control gaps. The compressed air system shall comply with subsection A~~.~~ or B below. ~~The compressed air system shall include one or more variable speed drive (VSD) compressors. For systems with more than one compressor, the total combined capacity of the VSD compressor(s) acting as trim compressors must be at least 1.25 times the largest net capacity increment between combinations of compressors. The compressed air system shall include primary storage of at least one gallon per actual cubic feet per minute (acfm) of the largest trim compressor; or, i. The compressed air system shall be equipped with an appropriate sized trim compressor and primary storage to provide acceptable performance across the range of the system and to avoid control gaps.~~

A. ~~ii.~~ The compressed air system shall include one or more variable speed drive (VSD) compressors. For systems with more than one compressor, the total combined capacity of the VSD compressor(s) acting as trim compressors must be at least 1.25 times the largest net capacity increment between combinations of compressors. The compressed air system shall include primary storage of at least one gallon per actual cubic feet per minute (acfm) of the largest trim compressor; or,

~~A.~~B. The compressed air system shall include a compressor or set of compressors with total effective trim capacity at least the size of the largest net capacity increment between combinations of compressors, or the size of the smallest compressor, whichever is larger. The total effective trim capacity of single compressor systems shall cover at least the range from 70 percent to 100 percent of rated capacity. The effective trim capacity of a compressor is the size of the continuous operational range where the specific power of the compressor (kW/100 acfm) is within 15 percent of the specific power at its most efficient operating point. The total effective trim capacity of the system is the sum of the effective trim capacity of the trim compressors. The system shall include primary storage of at least 2 gallons per acfm of the largest trim compressor.

~~iii. Single-compressor systems shall have a total effective trim capacity of no less than 30% percent of the rated compressor capacity.~~

~~iv.The system shall also include primary storage of at least 2 gallons per actual cubic feet per minute (acfm) of the largest net capacity increment.~~

EXCEPTION 1 to Section 120.6(~~c~~e)1: Compressed air systems in existing facilities that are ~~a~~adding~~ltering~~ or replacing less than 50~~%~~ percent of the ~~total capacity~~ online capacity of the system.

EXCEPTION 2 to Section 120.6(e)1: Compressed air systems that have been approved by the Energy Commission Executive Director as having demonstrated that the system serves loads for which typical air demand fluctuates less than 10 percent.

2. **Controls.** Compressed air systems with more than one compressor online, having a combined horsepower rating of more than 100 hp, must operate with ~~an approved~~ controller that is able to choose the most energy efficient combination of compressors within the system based on the current air demand as measured by a sensor.

3. **Compressed Air System Acceptance.** Before an occupancy permit is granted for a compressed air system subject to S~~s~~ection 120.6(e), the following equipment and systems shall be certified as meeting the Acceptance Requirements for Code Compliance, as specified by the Reference Nonresidential Appendix NA7. A Certificate of Acceptance shall be submitted to the enforcement agency that certifies that the equipment and systems meet the acceptance requirements specified in NA 7.13.

Reference Appendices

NA7.13 Compressed Air System Acceptance Tests

NA7.13.1 Construction Inspection

Prior to functional testing, a compressed air system ~~with 2 or more air compressors~~ must verify and document the following:

- Size (hp), rated capacity (acfm), and control type of each air compressor
- Total online system capacity (the sum of the individual capacities)
- System operating pressure
- Compressor(s) designated as trim compressors
- Method ~~and tools~~ for observing and recording the states of each compressor in the system, which shall include at least the following states:

  Off

  Unloaded

  Partially loaded

  Fully loaded

  Short cycling (loading and unloading more often than once per minute)

  Blow off (venting compressed air at the compressor itself)

~~Method and tools for measuring the current air demand as a percentage of the total system capacity, including any necessary calibrations.~~

NA7.13.2 Functional Testing

Step 1: Per the test methods outlined in the Construction Inspection, verify that these methods have been employed, so that the states of the compressors and the current air demand (as measured by a flow sensor or otherwise inferred by system measurements) can be observed and recorded during testing.

Step 2: Run the compressed air supply system steadily at as close to ~~a constant~~the expected operational load range as can be practically implemented ~~between 50% and 85% of total system capacity at the time~~, for a duration of at least 10 minutes.

Step 3: Observe and record the states of each compressor and the current air demand during the test. Step 4: Confirm that the combinations of compressors states meet the following criteria:

- No compressor exhibits short-cycling (loading and unloading more often than once per minute).
- No compressor exhibits blowoff (venting compressed air at the compressor itself).
- For new systems, the trim compressors shall be the only compressors partially loaded, while the base compressors will either be fully loaded or off by the end of the test.

Alternate Calculation Method (ACM) Manual

Not applicable.

Nonresidential Compliance Manual and Compliance Forms

The final Compliance Manual language and Compliance Forms can be found in Appendix A.

Energy Savings Estimates

The statewide energy savings required a variety of different inputs and estimates, as current and direct information was not available for compressed air. The savings methodology starts with an average of savings from the two measures (trim savings and controls savings) and the energy usage of compressed air systems (both for existing systems and new construction). This is then discounted for the various exceptions that exist for each measure (i.e. existing systems with centrifugal compressors are exempt from both measures).

Measure Savings

Both measures were modeled in the original CASE report, with savings based off of horsepower (whether it be the horsepower rating of the trim compressor, or the total horsepower rating of the system). Because various cases were modeled for each measure, an average was taken for each measure to help determine statewide energy savings. In both cases, a single annual energy savings per HP rating was determined.

Trim Compressor Savings

Trim Compressor Savings were calculated using spreadsheet analysis with typical performance curves for two types of compressors approximated with look-up equations. These performance curves come from AirMaster+ (which was used in the Smart Controls analysis as well). Based on these performance curves, an hour-per-hour demand profile was provided as the input and the energy usage for a VSD compressor and a constant-speed rotary screw compressor was compared for each hour. There were three different hour-per-hour demand profiles meant to provide a typical demand profile, a conservative profile, and a very conservative profile (one that did not fluctuate often). The savings from the conservative profile was chosen (Profile B, green in Figure 1). This is approximately 500 kWh/HP, annually.

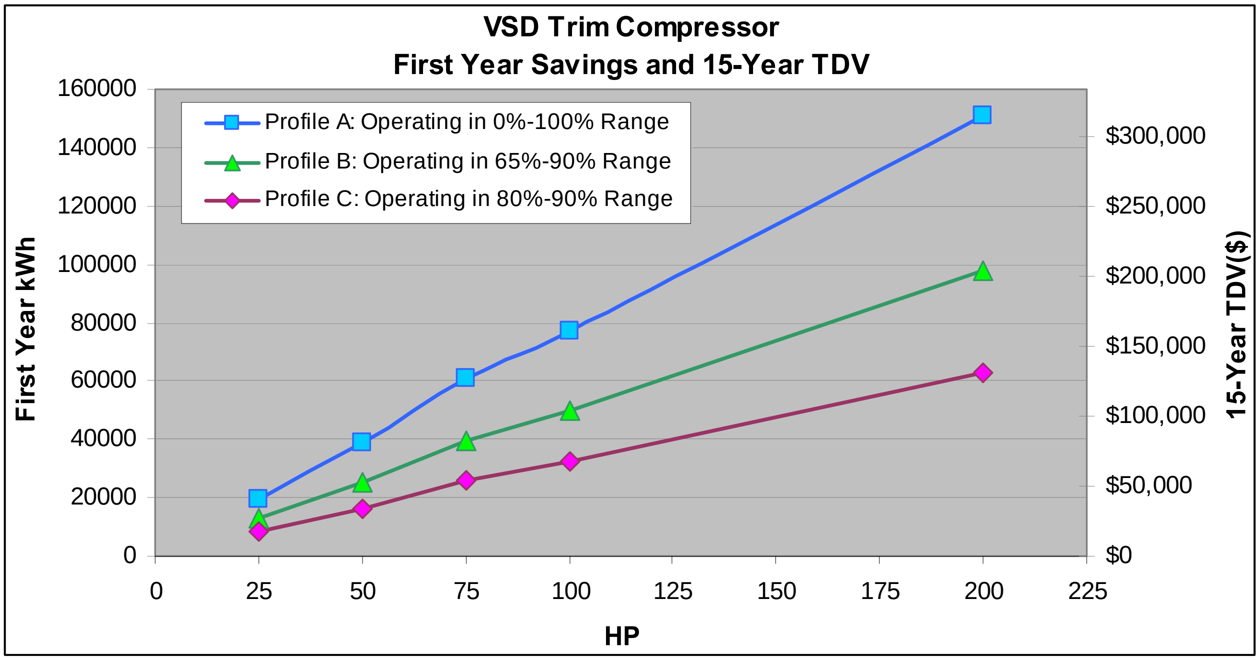

Figure 1. First Year Savings and 15-Year Time-Dependent Valuation for using a VSD Compressor as the Trim Compressor

Smart Control Savings

Four different systems (both in size and composition) were modeled, with savings assuming whether an auto-shutdown timer was implemented or not implemented in the baseline (see Table 2). The savings were varied and independent of system size. Savings were dependent on how well-matched the chosen set of compressors were to the varying load. Even still, an average was taken to help determine statewide energy savings. On the low end, a very steady system with a well-matched set of compressors could expect approximately 30 kWh/HP savings annually. On the high end, a system without an auto-shutdown timer originally could expect to see 210 kWh/HP savings annually. The average of these two savings amounts was used for the statewide savings analysis (120 kWh/HP).

Table 2. Modeled Savings for Smart Controls

	Baseline 1 2 compressors 125 hp total		Baseline 2 2 compressors 200 hp total		Baseline 3 2 compressors 450 hp total		Baseline 4 3 compressors 800 hp total	
Auto-shutdown Timer in Base Case?	no	yes	no	yes	no	yes	no	yes
Total Annual Savings (kWh)	31,738	8,788	27,890	4,940	74,048	7,025	197,733	25,812
Total 15 Year Savings (kWh)	476,072	131,817	418,355	74,100	1,110,725	105,380	2,965,991	387,180
Total 15 Year TDV ($) Savings	$67,941	$18,812	$57,523	$8,395	$155,499	$12,026	$418,515	$48,832

Statewide Energy Usage

Existing Compressed Air Systems

Existing energy usage of compressed air is calculated from the total existing Industrial Energy Usage in California (91,050 GWh, as determined by the Department of Energy[1]). This is discounted by figuring out the percentage of U.S. Industrial Energy Use for Compressed Air (9.38%, the ratio between the total Industrial energy use in the US, as determined by the Department of Energy[1], and the Compressed Air energy use in the US, from a Compressed Air Market Assessment done by Xenergy[2]). In California, existing compressed air systems use **4,486 GWh** annually.

New Compressed Air Systems

This information was calculated with the following information (and associated resources). Variables have been assigned to assist in presenting the calculation.

- **Value of New Industrial Building Starts for 2014 in California** (A = $1.4B)[3]
    - This is from the CA Department of Finance and is an estimate based off of trends.
- **Cost of Building a New Factory** (B = $100/sqft)[4]

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[1] U.S. Department of Energy. "Energy Consumption in California Industry." Clean Energy in My State. U.S. Department of Energy, 27 Mar. 2013. Web. 25 June 2013. <http://apps1.eere.energy.gov/states/industrial.cfm/state=CA>.

[2] Xenergy, Inc. Assessment of the market for compressed air efficiency services. Washington, D.C.: Office of Industrial Technologies, Office of Energy Efficiency and Renewable Energy, U.S. Dept. of Energy, 2001.

[3] California Department of Finance. "California Construction Data." *Department of Finance*. California Department of Finance, 24 Jan. 2012. Web. 13 Nov. 2012. <http://www.dof.ca.gov/HTML/FS_DATA/LatestEconData/FS_Construction.htm>.

- **Annual Energy density of an Industrial Building** (C = 130.82 kWh/sqft)[5]

    - This is based on averages of industrial facilities from the Department of Energy's (DOE) Industrial Assessment Centers (IAC) for all industrial buildings (>0 sqft, >100 kWh) in the US.

    - This is considered to be conservative because the IAC is limited to small- and medium-sized facilities. Larger facilities would likely have a higher energy density.

- **Percentage of Industrial Energy Use for Compressed Air** (D = 10.2%)[6]

    - This is based on a ratio between the total Industrial energy use in the US, as determined by the Department of Energy[7], and the Compressed Air energy use in the US, from a Compressed Air Market Assessment done by Xenergy[8]

    - This is lower than what was suggested by a white paper from the PG&E-sponsored Compressed Air Management Program (CAMP). [9]

Using *A* and *B*, we can find the floorspace of industrial new construction in 2014 (~14 million square feet), and the energy consumption of industrial new construction with *C* (260 GWh). Using *D*, this gives us about **171.8 GWh** of energy use for new compressed air systems in 2014 in California.

Exceptions

Existing Systems with Centrifugal Compressors

For both the trim and controls measures, existing systems that have one or more centrifugal compressors are exempt. This means that for existing systems, the energy use for which savings can be claimed needs to exclude the consumption from these systems.

This was done by using the study done by Xenergy in the Assessment of the Market for Compressed Air Efficiency Services. The sampling, presented in Table 3 below, puts 188 systems into different total horsepower buckets (the unknown systems were ignored). By assuming an average total horsepower rating for each of these systems, an approximation of energy use can be assumed for each bucket of systems.

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[4] RSMeans 2010. Costworks. 2010 4th Quarter Data. <http://www.meanscostworks.com/>.

[5] U.S. Department of Energy. "Industrial Assessment Centers Database." *Advanced Manufacturing Office: Industrial Assessment Centers*. U.S. Department of Energy, 26 Apr. 2012. Web. 13 Nov. 2012. <http://iac.rutgers.edu/database>.

[6] Qualmann, R. L., William Zeller, and Michael Baker. *Pacific Gas and Electric Company's Compressed Air Management Program: A Performance Assessment Approach to Improving Industrial Compressed Air System Operation and Maintenance*. Tech. San Francisco: Pacific Gas and Electric, 2002. Print.

[7] U.S. Department of Energy. "Energy Consumption in California Industry." Clean Energy in My State. U.S. Department of Energy, 27 Mar. 2013. Web. 25 June 2013. <http://apps1.eere.energy.gov/states/industrial.cfm/state=CA>.

[8] Xenergy, Inc. Assessment of the market for compressed air efficiency services. Washington, D.C.: Office of Industrial Technologies, Office of Energy Efficiency and Renewable Energy, U.S. Dept. of Energy, 2001.

[9] Qualmann, R. L., William Zeller, and Michael Baker. *Pacific Gas and Electric Company's Compressed Air Management Program: A Performance Assessment Approach to Improving Industrial Compressed Air System Operation and Maintenance*. Tech. San Francisco: Pacific Gas and Electric, 2002. Print.

Furthermore, an assumption was also made about large systems. The majority of systems over 750 hp will likely employ centrifugal compressors (as centrifugal compressors are typically over 300 hp and engineered for a large base load). In the context of this analysis, this means the largest total horsepower bucket (1000 hp) is excluded, along with approximately half of the second largest total horsepower bucket (500 to 999 hp).

Given these assumptions, about 20 percent of systems contain centrifugal compressors, which accounts for 48 percent of the existing energy usage. This means only **52 percent of the existing energy consumption** can be affected by these measures.

Table 3. Distribution of Compressed Air Systems by SIC and Total Horsepower of Compressors

SIC	TOTAL HORSEPOWER OF AIR COMPRESSORS					
	100	100 to 499	500 to 999	1000	Unknown	Total
20 Food and Kindred Products	5	10	4	1	0	20
22 Textile Mill Products	1	11	2	3	3	20
23 Apparel and Other Textile Products	12	6	0	0	2	20
26 Paper and Allied Products	1	10	1	6	2	20
28 Chemicals and Allied Products	3	4	2	3	8	20
29 Petroleum and Coal Products	2	7	1	4	8	22
30 Rubber and Miscellaneous Plastics	1	13	3	2	1	20
32 Stone, Clay, and Glass Products	1	8	2	5	4	20
33 Primary Metal Industries	2	11	3	3	1	20
34 Fabricated Metal Products	3	11	3	0	3	20
36 Electronic and Other Electric Equipment	4	11	2	1	2	20
Total	35	102	23	28	34	222

Source: Xenergy, Inc. Assessment of the market for compressed air efficiency services. Washington, D.C.: Office of Industrial Technologies, Office of Energy Efficiency and Renewable Energy, U.S. Dept. of Energy, 2001.

Excludes Systems Under 25 Horsepower

This specific exclusion was not included as the energy use from these systems is relatively negligible as compared to larger systems.

Trim Savings Only Applies to Trim Compressors

The trim compressor mandatory requirement includes savings that are dependent on the hp rating of the trim compressor (as opposed to the system hp rating). This means that both new and existing energy usage must be discounted for only the energy used by trim compressors.

From the same Xenergy study, a PG&E market study was conducted that took a count of systems and the number of compressors each system had. See Table 4 below.

Table 4. Number of Compressors in Customer Facilities

Number of Compressors	CA Market Assessment (n = 218)	PG&E Survey (n= 268)
1	7%	18%
2	25%	37%
3	21%	20%
4	19%	12%
5	9%	5%
6+	19%	8%

Source: Xenergy, Inc. Assessment of the market for compressed air efficiency services. Washington, D.C.: Office of Industrial Technologies, Office of Energy Efficiency and Renewable Energy, U.S. Dept. of Energy, 2001.

Using these numbers, Table 5 below was created with some assumptions. Given that the total number of systems was 268 and assuming that the 6+ bucket only has six compressors total, an approximation of the percentage of trim compressors can be made.

Table 5. Table Analysis of PG&E Survey Results

Number of Compressors	Percentage of Systems	Calculated Compressor Count	Assumed Trim Compressor Count	
1	18%	48	48	
2	37%	198	99	
3	20%	161	54	
4	12%	129	32	
5	5%	67	13	
6	8%	129	22	% Trim
	Total	732	268	37%

This also assumes that for every system, there is only one trim compressor. If it is assumed that every compressor is the same size (and energy usage), it can be further stated that **37 percent of the energy usage in compressed air systems is from trim compressors**.

Excludes Existing Systems Making Small Changes

Systems that are adding or replacing more than half of the original online system capacity must comply with the trim requirement. Systems decreasing in online system capacity or making an addition/replacement of less than half the online system capacity are excluded. The reasoning for this is that a large change would result in a more cost-effective application of the code.

There is not specific data on this exception, beyond a loose base on the lifetime of a compressor (10 to 20 years) and a conservative 20 percent of existing systems making upgrades to meet expanding demand. This means that **at least 25 to 35 percent of systems are making large changes** (which is very conservative).

Excludes Single Compressor Systems

This exclusion only applies to the Smart Controls requirement. Table 4 above, used to determine the percentage of compressors that are trim compressors, can also be used to determine the percentage of systems (and percentage of energy use) from multi-compressor systems.

Single-compressor systems account for 18 percent of systems, while the remaining 82 percent are multi-compressor systems. Making the same assumption that each of these compressors averages to the same energy consumption, **multi-compressor systems use 93 percent of the energy used for compressed air systems**.

Cumulative statewide impacts from this measure are presented in Table 6 below. Cumulative energy and water impacts are calculated based on all buildings constructed during the measure evaluation period (for this measure, 15 years). Cumulative electricity and gas savings (GWh and MMTherms) account for the lifetime savings (15 years) from the buildings constructed during the first year, plus the lifetime minus one year savings (14 years) from the buildings constructed during the second year, plus the lifetime minus two years savings (14 years) from the buildings constructed during the third year, and so on until the end of the evaluation period. Cumulative demand savings account for the reduction in demand from all buildings constructed during the measure evaluation period. It is assumed that the number of new construction starts will remain constant over time, thus the cumulative demand savings is calculated as the first year demand savings multiplied by the number of years

Table 6. Cumulative Statewide Impacts for Compressed Air Systems

	Sub-Measure	**Electric Demand (MW)**	**Electric Energy (GWh)**	**Gas Energy (MMTherms)**	**GHG Emissions Avoided (MTons CO_2eq) ***
First Year Impacts	Trim Compressor	N/A	12.96	N/A	5.66
	Smart Controls	N/A	10.26	N/A	4.48
Cumulative Impacts (over **15** Years)	Trim Compressor	N/A	1,555.2	N/A	679.6
	Smart Controls	N/A	1,231.2	N/A	538.0

* At 0.437 MTCO2e/GWh, and 5.32 MTCO2e /MMTherm. Source: AB 32 Scoping Plan Appendix G: Economic Analysis; page I-16: emission factor for grid power. Available online at: http://www.arb.ca.gov/cc/scopingplan/document/appendices_volume2.pdf

As a result of the first year of construction (2014) under the new requirements of the Trim Compressor measure, statewide TDV energy savings are estimated at 199,177,990 kBtu with a net present value of $17,727,748 using 15-year nonresidential TDV values.

As a result of the first year of construction (2014) under the new requirements of the Smart Controls measure, statewide TDV energy savings are estimated at 237,793,766 kBtu with a net present value of $ $21,205,629 using 15-year nonresidential TDV values.

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The Pacific Gas and Electric Company, Southern California Edison, Southern California Gas Company and San Diego Gas and Electric Company sponsored this report as part of the CASE (Codes and Standards Enhancement) project for the 2013 Building Energy Efficiency Standards. Stuart Tartaglia of PG&E was the project manager for this CASE project; Patrick Eilert is the program manager for the PG&E CASE program. Randall Higa is the program manager for the SCE CASE program. Ron Gorman was the program manager on behalf of the Southern California Gas Company and the San Diego Gas and Electric Company. The Heschong Mahone Group and Energy Solutions are the prime contractors and provided coordination of the residential and nonresidential CASE reports.

Russell Torres and Ransom Byers of Energy Solutions performed the analysis and reporting presented here. Energy Solutions provided technical and editorial review.

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Appendix A. Preliminary CASE Report

CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Compressed Air Systems

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team November 2011

This report was prepared by the California Statewide Utility Codes and Standards Program and funded by the California utility customers under the auspices of the California Public Utilities Commission.

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List of Tables and Figures

1. Introduction

This report is a part of the California Investor-Owned Utilities (IOUs) Codes and Standards Enhancement (CASE) effort to develop technical and cost-effectiveness information for proposed regulations on building energy efficiency design practices and technologies.

This report investigates the potential for additions to the Title 24 code regarding the efficiency of compressed air systems. This code proposal addresses the energy losses caused by inefficient part load use of the compressors supplying the system. Specifically this report proposes requirements for multi-compressor systems to use system master controls to limit the cases where compressors are unnecessarily run at part load. This report also proposes that all compressed systems include a compressor with a relatively constant specific power across a broad range of loads (such as variable-speed drive (VSD) compressor) to serve as a relatively efficient trim (ie part load) compressor. To prevent the savings of these measures from being compromised, this report also proposes that an already widely accepted minimum standard for primary air storage of 2 gallons per acfm trim be required. These requirements would apply to compressed air systems installed in new construction and to systems retrofitted in major renovations.

Throughout 2010 and early 2011, the CASE Team (Team) evaluated costs and savings associated with each code change proposal. The Team engaged industry stakeholders to solicit feedback on the code change proposals, energy savings analyses, and cost estimates. The contents of this report were developed with feedback from vendors, manufacturers, compressed air industry consultants, industry groups, utility and federal voluntary incentive programs, and the California Energy Commission (CEC) into account.

All of the main approaches, assumptions and methods of analysis used in this proposal have been presented for review at three public Stakeholder Meetings hosted by the IOUs. At each meeting, the CASE Team asked for feedback on the proposed language and analysis thus far, and sent out a summary of what was discussed at the meeting, along with a summary of outstanding questions and issues.

A record of the Stakeholder Meeting presentations, summaries and other supporting documents can be found at www.calcodesgroup.com. Stakeholder meetings were held on the following dates and locations:

- First Stakeholder Meeting: May 25, 2010, Webinar
- Second Stakeholder Meeting: January 19, 2011, Webinar
- Third Stakeholder Meeting: March 30, 2011, Webinar

2. Overview

2.1 Measure Title

Air Compressor Smart Controls and Trim Compressor Requirements

2.2 Description

The proposed code change would require all new industrial plants' compressed air systems to include at least one trim compressor that performs efficiently in part load conditions and primary storage, both sized appropriately to meet the minimum trim needs of any other compressors in the system. Multi-compressor systems would also be required to implement a smart system master controller.

Compressed air systems are typically sized (and often oversized) based on full load operating conditions and are designed to operate most efficiently at full load. However, the demand on most compressed air systems varies throughout the day and the system is often operating at less than full load. Some types of compressors are very inefficient at part loads and if not controlled properly a system could have several or all of its compressors simultaneously running at part loads, crippling the overall efficiency. These two measures would address these inefficiencies in the supply side of compressed air systems.

2.2.1 Variable Speed Drive Compressors

Variable Speed Drive (VSD) compressors use variable speed motors to modulate their output. The advantage of this is that it allows the compressor to have a relatively linear cfm output to kW input efficiency curve compared to other mechanism such as inlet modulation and load/unload operation. This makes VSDs ideal trim compressors, supplying the variable demand on top of the stable base demand.

This measure proposes that every compressed air system include at least one compressor that is efficient at part loads. It is possible that other types of compressors could have comparable part load performance, though at this time VSDs are the most common such technology. In order to address this, the proposed code language sets part load performance requirements rather than explicitly requiring VSDs.

2.2.2 Smart Controls

Smart controls consist of an independent control unit which can receive inputs from sensors and the compressors, make control decisions based on those signals, and return control signals to the compressors.

Historically, controls have been applied at the individual compressor level. Each compressor monitors the pressure at its own discharge header and cycles based on that reading. The only way to coordinate multiple compressor systems is for the system operators to base individual compressor settings on an overarching system control plan.

As mentioned in the previous section, poor part load performance can cause significant drops in efficiency. Smart controls can help improve efficiency by ensuring that at any given time the most appropriate set of compressors is being used to meet the current demand. Using smart controls will limit the number of compressors that are operating at sub-optimal efficiencies, so at worst a single compressor will be operating in an inefficient regime (and if paired with the trim compressor measure, then even that compressor will be relatively efficient).

One additional way in which isolated compressor controls contribute to inefficiency is by requiring a wide pressure control band. Each compressor has its individual control band dictating the points in which it loads and unloads (or the VSD speed, input modulation setting, etc.). For multiple compressors to operate in conjunction these bands must be staggered in an overlapping cascade, producing a much larger overall system pressure control band. Because the overall system pressure must be kept above some minimum level, the net effect is a higher average system pressure, which decreases the overall efficiency. Smart controls allow a much smaller single pressure band to be used to control all of the compressors.

2.3 Type of Change

The proposed measures would be mandatory requirements in a new section of Title 24 that would cover specific process loads. Title 24 does not currently cover compressed air systems.

2.4 Energy Benefits

Energy savings are realized at a compressed air system level, with typically one (though sometimes multiple) system in each building. However, factors such as building size have no direct relation to compressed air system size so the standard prototype buildings and savings by square foot are not applicable.

As there is no current standard in place for compressed air systems, energy savings estimates must be made relative to assumed common practice. These are outlined in the Methodology Section 3.2.1.

Per minimum unit energy savings for each measure are presented below. These savings values are presented below in Table 1.

Table 1: Per minimum unit energy savings for smart controls and trim compressors requirement.

	Electricity Savings (kWh/yr)	Demand Savings (W)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings	TDV Gas Savings
Smart Controls: savings per average system	4,940	0	n/a	$8,395	n/a
Trim Compressors: savings per average system (100 hp trim)	50,382	0	n/a	$104.498	n/a

The Analysis and Results section 4.1.1 and 4.1.3 outline the minimum expected energy savings and TDV benefit for individual systems in conservative savings scenarios.

Statewide savings estimates are still being refined. This report will be updated with the statewide savings values at a later date. An estimate of new construction for each scenario would result in a conservative estimate of statewide savings, though the CASE Team believes the actual savings for average systems will be considerably larger.

2.5 Non-Energy Benefits

Smart controls have the potential for numerous non-energy benefits. The most significant non-energy benefits include reduced maintenance costs due to reduced compressor run times and cycling, avoiding system management problems caused by control gaps, and potentially improving system uptime or even product quality by providing a more stable and consistent compressed air supply.

2.6 Environmental Impact

This measure would have no significant impact on water quality or consumption. It would not create a significant change in materials use, including use of Mercury, Lead, Copper, Steel, or Plastic.

2.7 Technology Measures

Measure Availability:

Smart controls are manufactured by both traditional compressor manufacturers and companies that focus specifically on controls. Examples include Pneulogic, EnergAir, Kaeser, FSElliot, etc. They are a relatively new addition to the market, but are increasingly being added to industrial repertoires.

The majority of compressor manufacturers now offer VSD compressors, including Atlas-Copco, Kaeser, Sullair, CompAir / Gardner Denver, etc.

Useful Life, Persistence, and Maintenance:

Smart controls are a new enough product that their full life expectancy is not yet clear. At this point in time most installations are less than a decade old, with few failures and replacements. A reasonable lifespan for smart controls is fifteen-years. Control performance is not expected to decrease with age. The energy and cost savings from controls would actually be expected to increase over time as other components in the system degrade or fall out of balance.

VSD compressors, and compressors in general have very long lifespans when properly maintained..

2.8 Performance Verification of the Proposed Measure

A fairly basic acceptance test is proposed for controls, requiring a check to ensure that the system can operate at some mid-range point efficiently. The ideal method to verify performance of compressed air systems would be long term monitoring over a week or longer. This would provide a much more accurate assessment of the setup and control as well as the match between air supply and demand, and could be added as a separate measure at a later date.

2.9 Cost Effectiveness

Smart controls (in multi-compressor systems) and efficient trim compressors are cost effective in the vast majority of practical scenarios. This measure would not be cost effective for systems with a constant rate of flow demand and operating near full load for all compressors. Cases such as this would be highly uncommon.

2.10 Analysis Tools

AirMaster+ was used to model system level savings for controls improvements. It is described in more detail in *Section 3.2.1 Controls Energy Savings*.

Spreadsheet analysis was used to evaluate savings for trim compressors and cost savings for both measures.

2.11 Relationship to Other Measures

This measure would have no direct impact on any existing measures or measures currently being proposed.

3. Methodology

3.1 Developing Code Change Proposal

3.1.1 Existing Conditions – Process Load Regulation

Most process loads (which are defined in Part 6 of Title 24 as energy loads that are "not related to the space conditioning, lighting, service water heating, or ventilating of a building as it relates to human occupancy") have historically been exempted from many of the Title 24 efficiency requirements, with the exception of the recently added requirements for refrigerated warehouses.

3.1.2 Existing Conditions – Compressed Air System Efficiency Regulations

Currently there are no federal or state energy efficiency requirements for compressed air systems. The closest regulations are those that apply to the motors powering compressor units. To the best of our knowledge, China is the only country that has implemented compressed air system minimum efficiency requirements [McKane 2005]. Some performance and design requirements for compressed air systems exist in California's mechanical and plumbing codes, but none of these address efficiency (see ASME B31.1-2004; IAPMO PS 42-96; NFPA 99C-2002; UL 252-2003; CGA V-1; CGA S-1.3; and Title 24: Part 4, Chapter 14; Part 5, Chapter 13)

Voluntary programs do exist to encourage compressed air system efficiency. The three primary areas of focus for these programs are education, audits, and incentives. Educational programs such as the courses taught by the Compressed Air Challenge[1] empower the individuals operating, overseeing, or selling these systems to take steps to improve efficiency on their own. Audit programs such as the one implemented by the Department of Energy Industrial Assessment Center provide detailed analyses of specific sites and recommendations for improvement. Incentive programs such as those administered by the California IOUs evaluate the potential savings for particular efficiency measures at specific sites and provide incentives for the successful implementation of those measures.

Additionally the International Organization for Standardization is developing ISO 50001, a standard for industrial energy management. ISO 50001 is currently in draft form and expected to be released in late 2011. Based on initial drafts and conversations with those involved in its development, the standard will provide guidance and best practices (and focusing on audits), but not set specific mandatory requirements for compressed air systems.

3.1.3 Measures Considered

Numerous strategies exist for improving compressed air system efficiency and many were considered as potential Title 24 measures. They ranged from variable speed drive compressors, lossless drains,

[1] The Compressed Air Challenge is a voluntary collaboration of industrial end-users; manufacturers, distributors and their associations; consultants; state research and development agencies; energy efficiency organizations; and utilities. The mission of the CAC is to be the leading source of product-neutral compressed air system information and education, enabling end users to take a systems approach leading to improved efficiency and production and increased net profits.

,cycling dryers, leak testing, performance monitoring, and total system efficiency metrics. Each was evaluated based on the following criteria:

1. Potential for impact
2. Applicability to the vast majority of systems
3. Ability to be codified
4. Simplicity for compliance
5. Opportunities to address system level issues under Title 24 that would not be possible in other regulation

If these measures are adopted, this would be the first time many of the users and manufacturers would be required to take into consideration and comply with Title 24 requirements. Therefore it was very important to emphasize simplicity. This point was raised repeatedly by stakeholders from the very beginning of the process. The decision was made to focus on a small number of broad measures rather than a large number of highly specific ones.

The two measures that showed the most promise for broad applicability to many systems and considerable savings were smart controls and variable speed drive (VSD) compressors. Smart controls have the potential for large energy savings as well as the potential to amplify the savings achieved from other efficiency measures. Smart controls also have significant non-energy benefits for the system, and the distinct advantage that there is no system that would lose efficiency from their implementation. VSD compressors also have large savings potential because of its steady efficiency across an expansive load range. VSD compressors are becoming common practice and are very frequently recommended by voluntary programs. As such they are well positioned for acceptance as a Title 24 requirement.

The Team recognizes that there may be other ways to achieve a reliable efficiency across a range of operating conditions. For example, the Team considered the option of increasing storage as a way of achieving reliable efficiency.. The results of the analysis are presented in section 4 this report. After the analysis was completed and reviewed by stakeholders, it was determined that increasing storage does not achieve the same scale of savings as VSD compressors and increasing storage is not applicable to every compressor.. Recognizing the possibility that multiple technologies could be used to achieve the desired results and to allow for flexibility in code compliance, the code change language requires a trim compressor that meets a part load performance metric rather than limiting the options to one or two specific technologies.

Many of the measures not included in this CASE study also have significant potential and should be considered in future code cycles. The full list of measures considered, along with commentary, is included in the Appendix.

3.2 Smart Controls Cost and Savings Analysis

Smart controls costs and savings are highly dependent on the details of the individual system and there exists no ‘typical’ system to use as a model. In order to address this, a set of conservative systems was selected to explore the boundary of cost effectiveness. These are relatively small systems, with few compressors, and moderately stable load profiles. Systems that are larger, more variable, less ideally sized for their load, or with a greater number of compressors, will have considerably more savings. The cost of controls for these systems is significant, but there are also significant energy savings that outweigh the incremental first cost. If the measure is cost effective in the most conservative cases, then the measure is cost effective in the vast majority of practical cases.

3.2.1 Energy Savings

To estimate energy savings, the CASE Team used AirMaster+ to model hourly energy use from representative compressed air systems operating under specific load profiles. Energy use was modeled using conventional controls and smart controls. Per-unit energy savings is the difference between energy consumption from these two configurations.

AirMaster+ was used to model energy savings because it is the industry-accepted standard modeling tool, and it has the functionality to conduct the analysis required to evaluate the cost-effectiveness of the proposed code change. AirMaster+ was developed as part of the Department of Energy's Industrial Technology Program. The outputs of the AirMaster+ models are energy consumption on a per hour basis.

The general approach taken for the energy savings modeling was to assume a given set of compressors and a load profile, and to calculate the energy use with and without the use of smart controls. The case without smart controls was modeled using a best-case simple cascade. The case with smart controls was modeled by taking the hourly simple cascade results and manually adjusting the demand to each compressor during the points that were not optimal, to mimic the functionality of smart controls.

Comparison with Proposed Code Requirements

It's important to note that the code requirements were refined after the initial energy analysis was complete. The energy analysis compares the performance of a smart control on four different baseline systems with the performance of a sequencer on these same systems. This approach allows for a comparison in energy use of particular systems, but some potential energy savings are not currently captured in the analysis.

In the baseline systems, the trim compressor is sized almost perfectly for the given trim load. Though somewhat ideal, this is atypical – the trim load can be estimated, but is difficult to plan for until all components of the system are operating. This is not to say that these configurations are unreasonable, but that these configurations are in fact quite conservative.

Furthermore, the trim compressor identified for each system was sized appropriately to avoid control gaps (see discussion in Section 3.3.3). If the trim compressor was not sized properly the system would not operate as efficiently outside of the chosen load profile because a base compressor would be forced to operate at part-load. While some systems use properly sized trim compressors, it is not unheard of for systems to have incorrectly sized trim compressors. This is another indication that the analysis is very conservative. More savings could be demonstrated given a different load profile and adjusting the trim compressor size.

Assumptions

Key assumptions made for all modeled systems include:

- System discharge pressure of 100 psig.
- Load profile generally 80% constant base load and 20% variable trim, with some greater variation at shift change.
- Primary receiver sized to 2 gal/cfm of trim load as designated by the load profile.
- 10% loss of total output due to leaks.
- Unloaded power for load/unload compressors is 25% of full load power.
- System in use 4160 hours/year (16 hours a day, 7 days a week.)
- Results are not dependent on Climate Zone.

Auto-shutdown timers, which turn a compressor off after it has been unloaded for a preset time period, are also an effective part of smart controls, but there was not a consensus on whether they should be considered typical practice as part of the basecase for this analysis. Therefore, the basecase was modeled both with and without auto-shutdown timers in the energy analysis.

For the cost effectiveness analysis, the team chose the conservative case (which assumes auto-shutdown timers exist in the basecase) to guarantee that the analysis does not overstate savings. Table 2 describes the representative systems used in the energy savings analysis, including compressor models and other hardware along with the base load and trim load (described in *acfm* or cubic feet per minute at the given pressure). Figure 1 presents the load profiles that were modeled.

Table 2: Specifications of Representative Systems

	Baseline System 1	Baseline System 2	Baseline System 3	Baseline System 4
Nominal Base Load (acfm)	400	800	1600	3200
Nominal Trim Load (acfm)	100	200	400	800
Primary Receiver Size (gal)	200	400	800	1600
Compressor 1	75 hp, load/unload, single stage, lubricant-injected, rotary screw	150 hp, load/unload, single stage, lubricant-injected, rotary screw	300 hp, load/unload, single stage, lubricant-injected, rotary screw	500 hp, inlet vane, multiple stage, centrifugal
Compressor 2	50 hp, load/unload, single stage, lubricant-injected, rotary screw	50 hp, load/unload, single stage, lubricant-injected, rotary screw	150 hp, load/unload, single stage, lubricant-injected, rotary screw	150 hp, load/unload, single stage, lubricant-injected, rotary screw
Compressor 3	n/a	n/a	n/a	150 hp, load/unload, single stage, lubricant-injected, rotary screw

Two load profiles were modeled for each system, a weekday profile and a weekend profile. The weekend profile was slightly smaller and slightly more variable than the weekday. While not all systems will differ in behavior on the weekend, this slight variation is a very small proxy for any deviation from expectations: such as the difference between the system designer's estimates and the actual system demands, change in demand over time, change in performance over time, etc.

The load profile shapes are the same for all of the systems, simply sized to match the sum of the nominal base and trim demands.

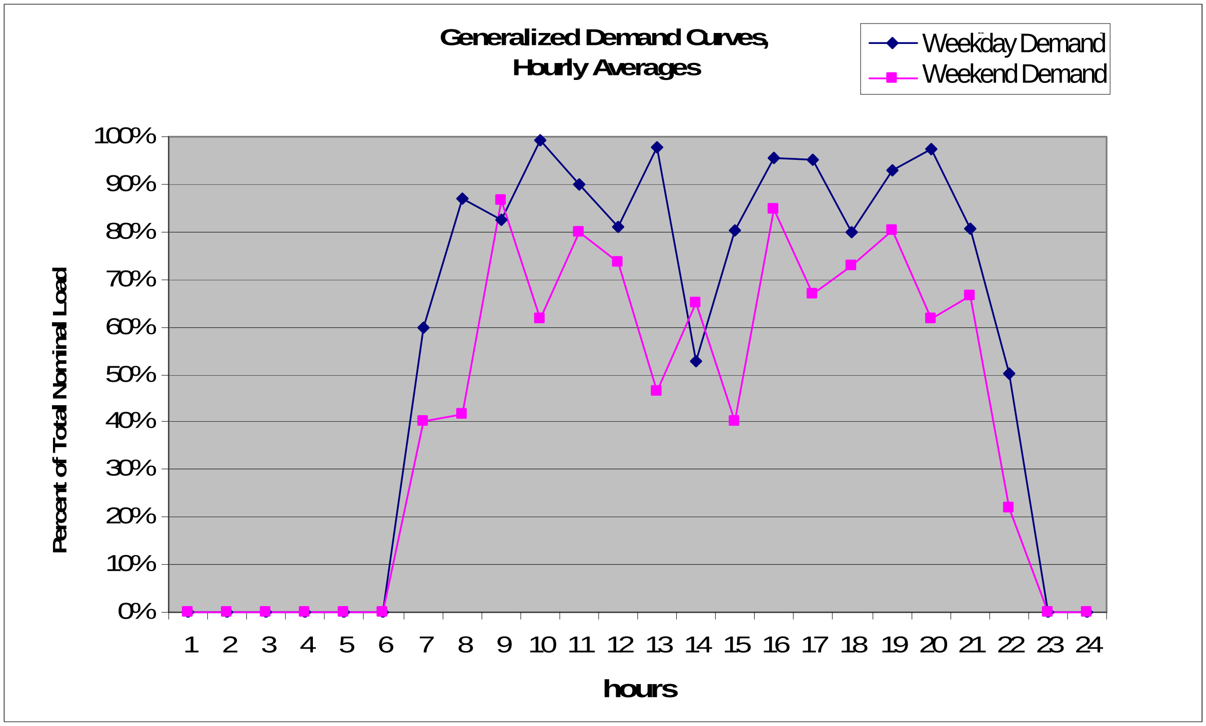

Figure 1: Modeled load profiles

3.2.2 Costs

Measure Costs

The incremental cost to add smart controls is the full cost to purchase and install the control system. Cost estimates for smart controls are based on the catalogs and estimates provided by three controls manufacturers. Costs can vary considerably depending on the specifics of the system to be controlled (number and types of compressors, control features, etc.). The cost estimates for the systems used in this analysis are displayed in Figure 2. The estimates include the cost for the hardware (control unit, compressor interface units, sensors) and the installation labor.

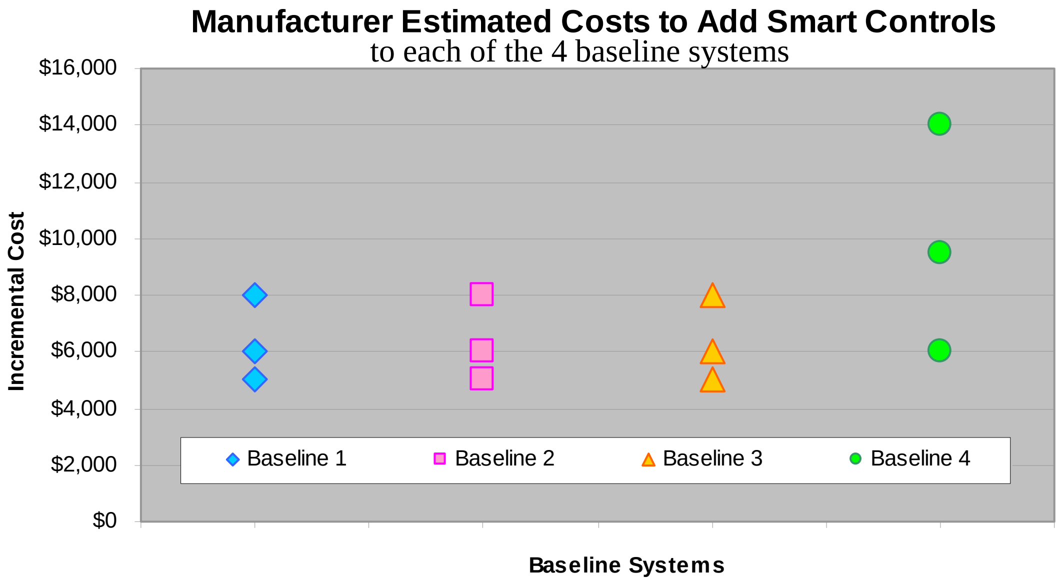

Figure 2: Cost to install a system to meet the minimum requirements of the smart controls measure for the 4 baseline systems as estimated by three manufacturers.

Maintenance Costs

Maintenance costs and savings are not included in the cost-effectiveness analysis, because the savings are assumed to at least balance out the costs. Based on stakeholder feedback, control systems such as these can require a small amount of maintenance, primarily adjusting control settings over time. Meanwhile, the controls can significantly decrease the maintenance cost for the compressors and other components of the system. Smart controls provide a greater awareness of the current state of the system, facilitating early detection of maintenance issues for the system as a whole. As a result, most systems would experience net maintenance cost savings.

3.2.3 Cost Effectiveness

The cost effectiveness of the measure was evaluated using the CEC LCC methodology, based on a 15-year nonresidential measure life.

3.2.4 Final Code Development

As mentioned previously, this is the first proposed measure for compressed air systems. Since compressed air systems have not been covered under Title 24 previously, the proposed language includes all of the relevant definitions and nomenclature. Translating the conceptual idea of how smart controls should be applied to compressor systems into clear and concise code language has required significant deliberation. In addition to proposing concise language, the goal was to propose a code that is relatively easy to comply with. This section discusses how the Team arrived at the definition of “smart controls”, the types of compressor systems the proposed change would apply to, and the proposed acceptance tests to ensure compliance.

Defining Smart Controls

In order to measure current demand of a compressed air system, a sensor (or sensors) need be installed. Sensors can measure a variety of things, including pressure, flow, temperature, power, and other metrics. However, which of these measurements is used, and how that translates into a demand signal, depends on the individual type of controller.

At a given demand, a smart controller will use the measured information along with knowledge of the compressors available, to determine the best combination of compressors necessary to supply the required airflow. The exact criteria used to make the selections are specific to the individual controllers and system design.

The intent of this measure is not to dictate the control mechanism or algorithm, but to simply mandate the use of some smart control system that is capable of such control.

Applicability

Smart controls are applicable across the board for multi-compressor systems. Even systems with just two compressors can operate more efficiently across a wide range of demands if a smart control is employed.

This code is recommended for all systems with a combined total compressor power over 100 hp. Smaller systems would also benefit and could be cost-effective, but advanced compressed air control is a fairly new market and currently only larger systems are well supported.

Acceptance Testing

In talking to controls manufacturers and other industry stakeholders, the CASE Team received feedback that it is not uncommon for controllers to be set up incorrectly.

There are a variety of ways that smart controls can measure current air demand and make decisions on what the best combination of compressors is for a given load. Variations in how different controls operate can lead to confusion in how the controls are commissioned. It also makes it difficult to establish a standardized way to test the controls. The Team also received feedback that there was no industry standard way to test a smart control. Given that it is not possible to prescribe a standard industry test for approved controllers but compliance could be an issue, an acceptance test must be provided.

An acceptance test consists of two components: The construction inspection, described before the system is installed, and a functional test following installation. The functional test, again, must confirm that the smart control is choosing an energy efficient combination of compressors based on input from a sensor measuring current demand. The construction inspection will be dependent on this functional test. A few functional tests are described in the following sub-section.

Functional Tests

Three functional tests were considered. Each of these tests is described below.

In depth *commissioning* would be most ideal functional test. The system would be measured and monitored for an extended period of time (at least 24 hours, but preferably a week or longer), showing the state of the system continuously over this period of time. Analyzing this information would show exactly how the controls work in real operating conditions.

A *ramp-up test* would evaluate the system at set levels throughout its entire range. This would force the system to demonstrate efficient operation for both the expected points of operation and possible future demand, should the load profile change. The construction inspection would include a form to demonstrate expected behavior at each level. One possible ramp-up test would run the system at increments of 10% of total system capacity.

Spot testing would run a system steadily at a single specific level, rather than across a wide range. This would provide a quick check to ensure that the system can operate at some mid-range point efficiently. The test would also offer a degree of freedom to choose which demonstration point to test.

In comparing the three different proposed functional tests, spot testing was chosen for the acceptance test. Proper commissioning, though preferable, is expensive, intrusive, and beyond the scope of a typical acceptance test. Commissioning is important and the CASE Team recommends it for consideration as a future measure, but is not appropriate at this time for smart controls. A ramp-up test is extensive and achieves the goal of testing the full system range but would require exceptions for a few special case compressed air systems that cannot achieve certain points (especially the low end of demand). Isolating these types of systems is difficult. Furthermore, this test still would take significantly more time than a typical acceptance test.

A spot test, as previously mentioned, allows the freedom to choose a convenient demonstration point and avoids potential disruption of sensitive equipment. It is also quick and low cost, but would still provide some assurance that the system is correctly installed and calibrated. If a system cannot at least pass the spot test, something is indeed amiss. Along with a spot test, a couple other checks can be implemented to further confirm that the system is operating properly, namely avoiding short-cycling and blowoff.

The spot check, while not the most comprehensive test, will effectively prevent poor operation and flawed setup without meticulously picking apart a system with a variety of time-intensive and potentially costly tests.

Construction Inspection

The construction inspection should confirm that the system can gather all the information to verify performance and pass the test. This information includes the current state of each compressor in the system and the current state (indicating demand) of the system as a whole. The CASE Team has discovered that different controller products offer various options for measuring the states of the compressors within a system and the system itself. Rather than requiring a specific set of equipment, suggestions are made with the ultimate plan being drafted by the system owner. Again, this allows flexibility for those controllers that already have system testing capabilities built-in, as well as options for more basic models.

Acceptance Test Costs

For the most part, the costs to perform the acceptance test are already built in to the measure costs outlined in Section 3.2.2. The industry quotes used to estimate cost already included labor to set up, test, and calibrate the controls.

3.3 Trim Compressor Requirements

The purpose of a trim compressor is to function well at part loads so that other compressors in the system can operate solely at their optimum performance points, typically fully loaded. This also allows a system to avoid ‘control gaps’ where no combination of compressors can achieve the exact necessary load without forcing one or more into an undesirable state such as short-cycling.

Every compressor can operate well over some range and there are a variety ways to achieve good performance over a large range. This analysis examines two of the most common: a VSD compressor and increasing the storage for a constant speed load/unload compressor.

3.3.1 Energy Savings

To determine the energy savings of requiring a VSD motor driven compressor as the trim compressor or additional storage in conjunction with the trim compressor, the CASE Team compared the performance of a baseline trim compressor with the proposed trim compressor configurations. Energy savings were calculated using three representative trim load profiles. By focusing on the trim load, the difference between single compressor systems and multi-compressor systems is eliminated.

The following baseline profiles were created based on examples from past utility incentive programs and select energy audits. They are scaled to represent fractions of full load of the trim compressor. Though it is difficult to assume a typical load profile, the profiles were carefully selected to represent two conservative baselines (see Profile B and C in Figure 3) and a mid-range variability baseline (see Profile A in Figure 3) to identify both a conservative savings estimate and a more typical savings estimate.

Profiles B and C have been scaled down by 10%. This is to account for oversizing of compressors. Typical practice is to oversize a system beyond the actual demand to ensure safe operation of the system. Stakeholder feedback confirms that 10% oversizing is a conservative figure.

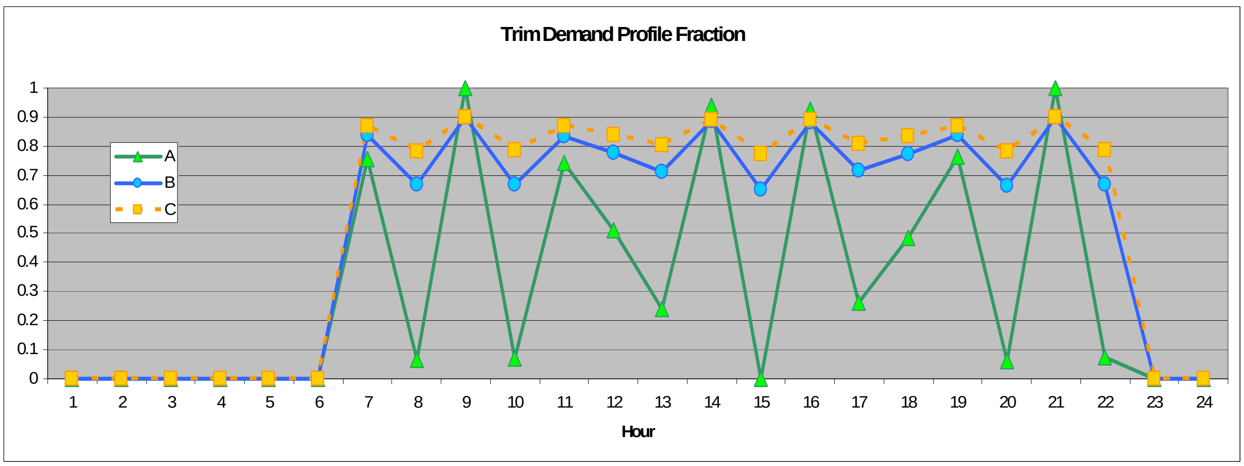

Figure 3: Trim Load Profiles (scaled) for use in energy analysis of trim compressor measures.

Compressor performance curves were used to determine energy use given a certain load. These curves are based off of data used in AirMaster+ for both constant speed compressors and variable speed compressors. For constant speed compressors, storage plays an important role in the performance (see Figure 4), more closely aligning the energy input to the airflow output as storage is increased. Based on stakeholder feedback and information gathered from utility incentive programs, the CASE Team is assuming storage of 2 gal/cfm of expected trim load in the base case. That is to say, if a system has an expected base load *B* and an expected trim load of *T*, the storage tank size is set at *2T* gallons.

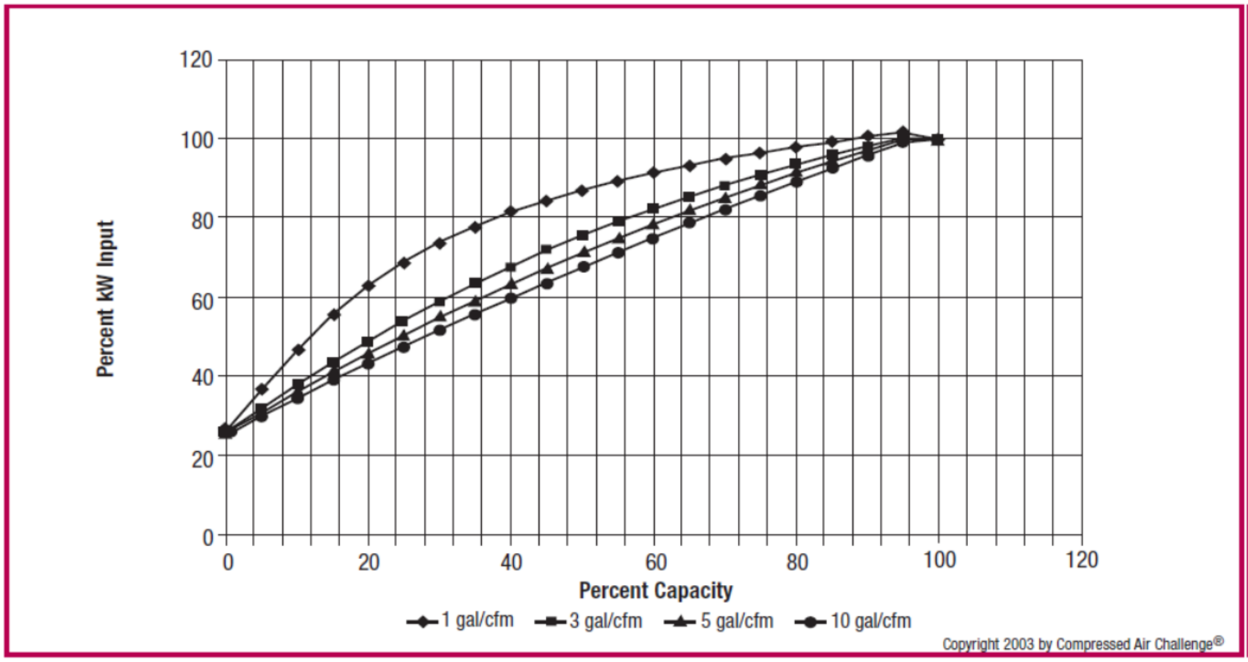

Figure 4: Percentage of energy input vs. capacity for lubricant-injected rotary screw compressors with varying amounts of storage. (CAC Sourcebook, 2003)

Given the expected load and the performance curves, the power (kW) input required by either a rotary screw load/unload or VSD compressor can be calculated for any given point in time. The hourly energy savings is the difference in energy consumption between the load/unload rotary screw (base case) and the chosen trim compressor configuration (either VSD or base case compressor with additional storage). Hourly energy savings are used to find time-dependent valuation savings, as per established CEC methodology.

3.3.2 Costs

Based on the methodology for energy savings, the CASE Team compared the average cost of a load/unload rotary screw compressor with the average cost of a similarly sized VSD motor driven compressor to determine the incremental measure cost. Based on interviews with stakeholders, VSD prices are trending down relative to constant speed compressors. However, to be conservative, this analysis is using the current cost of VSDs rather than forecasting the expected future reduction in VSD price.

Figure 5 shows incremental costs based on original prices and manufacturer-offered discount prices, but for this analysis, the full price costs are considered to continue being conservative. The costs for both types of compressors have been collected from just one manufacturer, but these have been vetted by representatives from other manufacturers and are considered to represent average costs. A trend line has been calculated from this data to show a relationship of VSD costs to horse power. This equation will be used to determine the incremental costs of trim compressors of a specific size.

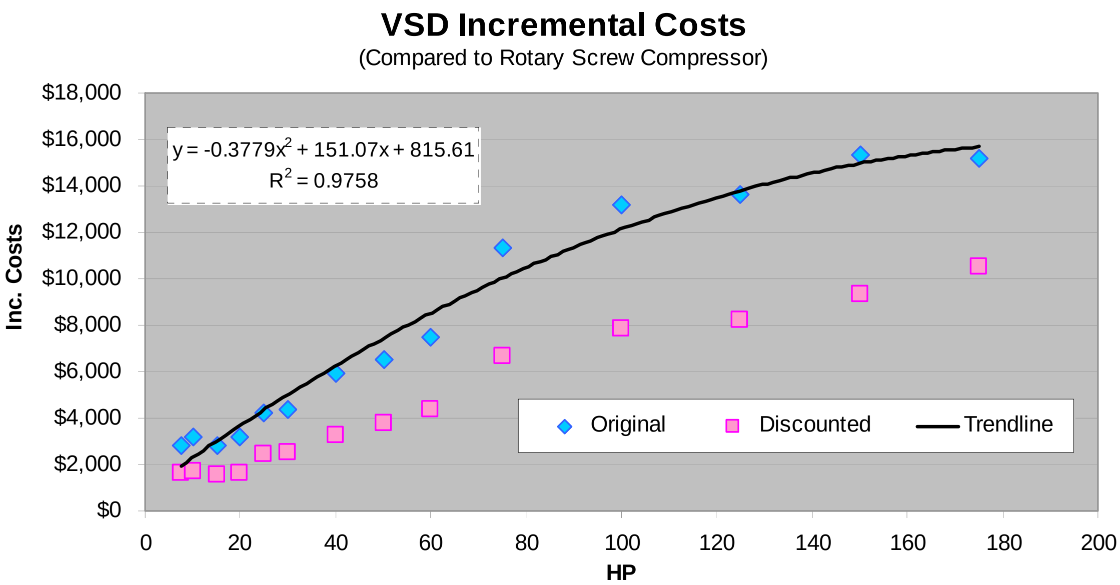

Figure 5: Incremental costs between a VSD compressor and a lubricant injected load/unload rotary screw compressor.

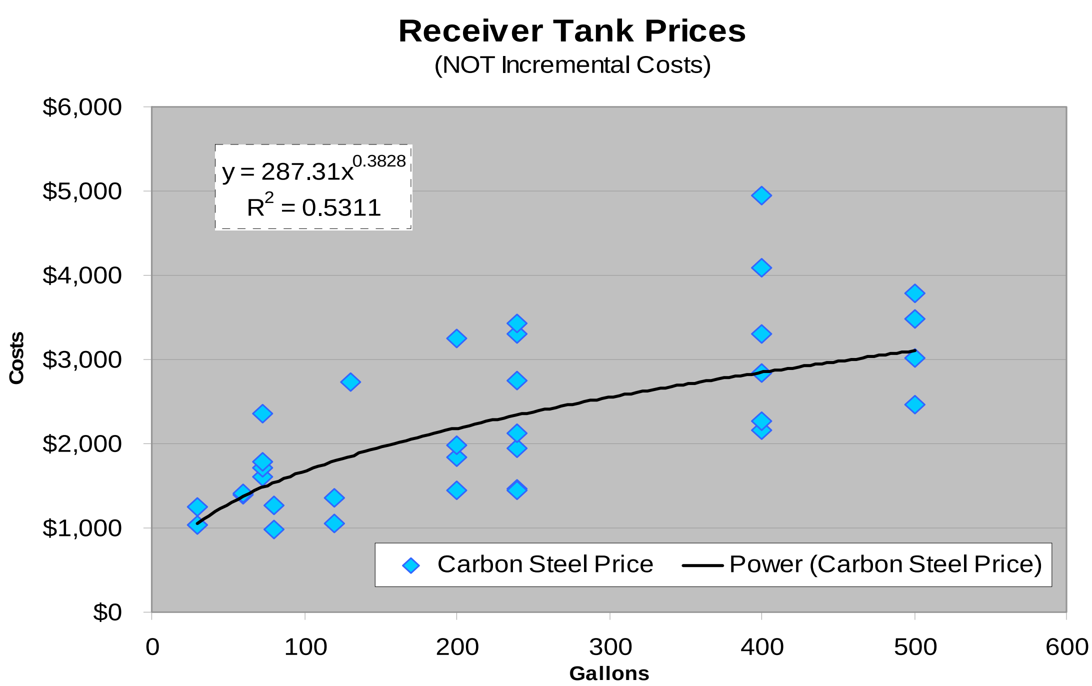

Figure 6: Costs for various carbon steel receiver tanks.

For the alternate compliance option to increase storage, the incremental cost is calculated as the difference between tanks of two different sizes (as the specific compressor used will not change). Similar to incremental VSD costs, a trendline has been calculated to aid in determining the incremental costs. Figure 6 shows the costs (not incremental costs) of receiver tanks. Using the rated airflow of the given trim compressor and this trendline, approximate incremental costs can be determined between two tanks of a calculated size.

3.3.3 Code Development

The goal of this code proposal is to ensure that control gaps and poor part load performance do not cause poor overall system performance. There are a number of different ways to achieve this and it is not the intent to prescribe a specific technology, but rather to create a structure for evaluating the needs of a system and the ability of specific compressors to meet that need.

System Needs and the "Largest Net Increment"

For any multi-compressor system there is discrete set of loads that can be provided solely by combinations of fully loaded base compressors. It is function of the trim compressor or compressors to fill and bridge between these points so that the system as a whole functions well over a full continuous range. As such it is important to size the trim compressor so that it is large enough to span the largest jump in capacity going from one combination of base compressors to the next. In other words, the trim requirement of a system is equal to the "largest net increment" in the difference in capacity of combinations of the base compressors.

This is a fairly intuitive concept and familiar to anyone working on compressed air system design, but is difficult to express in a precise mathematical fashion. In practice, with multi-compressor systems The CASE Team proposes a simple methodology be included in the compliance manual to guide users in determining the largest net increment for a set of base compressors:

1. Create a list of combinations of base load compressors and their total combined capacities.
2. Sort by total combined capacity.
3. Determine the largest increment between any two adjacent entries in the sorted list.

A summarized example of this is illustrated graphically in Figure 7 and detailed in Table 3. In this case a set of 50, 100, and 250 acfm base compressors have a largest net increment of 100 acfm. A trim compressor that is effective across a 100 acfm range would ensure that the system could function well across its range.

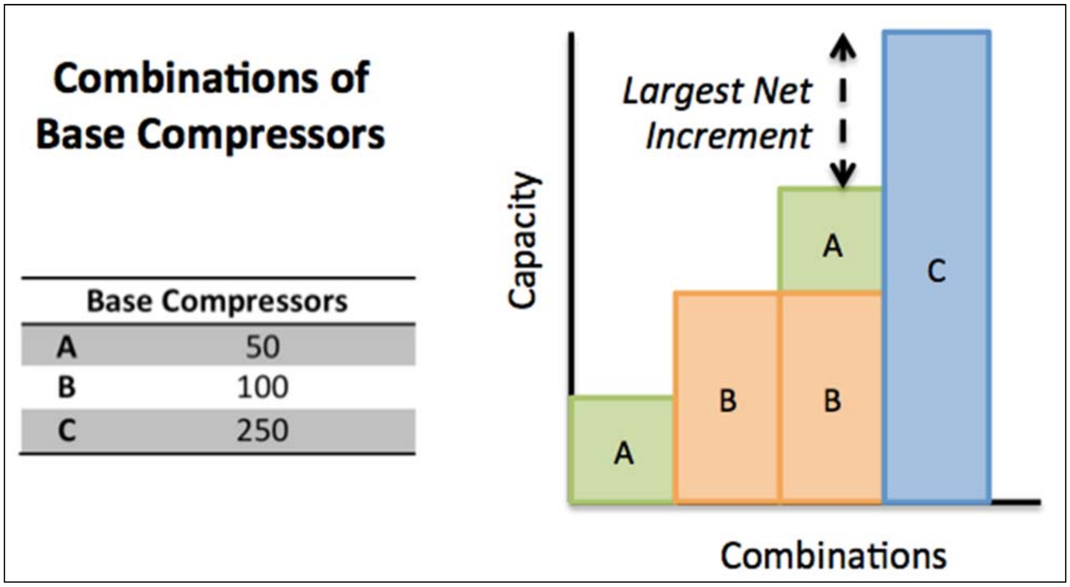

Figure 7: For this example system the Largest Net Increment would be 100 acfm.

Table 3: Ordered combinations of base compressors and the net increment capacity between these combinations.

Ordered Combinations and Net Increment		
Combinations	Net Capacity (acfm)	Net Increment (acfm)
-	0	0
A	50	50
B	100	50
A+B	150	50
C	250	100
A+C	300	50
B+C	350	50
A+B+C	400	50

As described at the beginning of Section 3.3.3, every compressor has some degree of flexibility in operation and output. A methodology is needed to evaluate and compare the efficiency of compressors at various output levels. The CASE Team proposes the use of an "effective trim capacity" metric. This would allow a functional trim output range for an individual compressor to be determined based on its published efficiency curve.

The effective trim capacity of a compressor is the range of outputs where its specific power is within a given percentage of its minimum (most efficient) point.

To determine the effective trim capacity of a compressor, following the steps below. Figure 8 is presented to graphically illustrate this process.

1. Obtain a published efficiency curve from the manufacturer or vendor (typically given as specific power in kW/100 acfm plotted against the output in acfm).
2. Determine the point with the lowest specific power (kW/100 acfm).
3. Multiply that lowest specific power by 1 + N%, where N% is the threshold value that dictates the stringency of the trim performance requirement. This specific power will be the compliance cutoff.
4. Find the continuous set of points below the compliance cutoff on the efficiency curve.
5. The capacity range covered by these set of points is the effective trim capacity of the compressor.

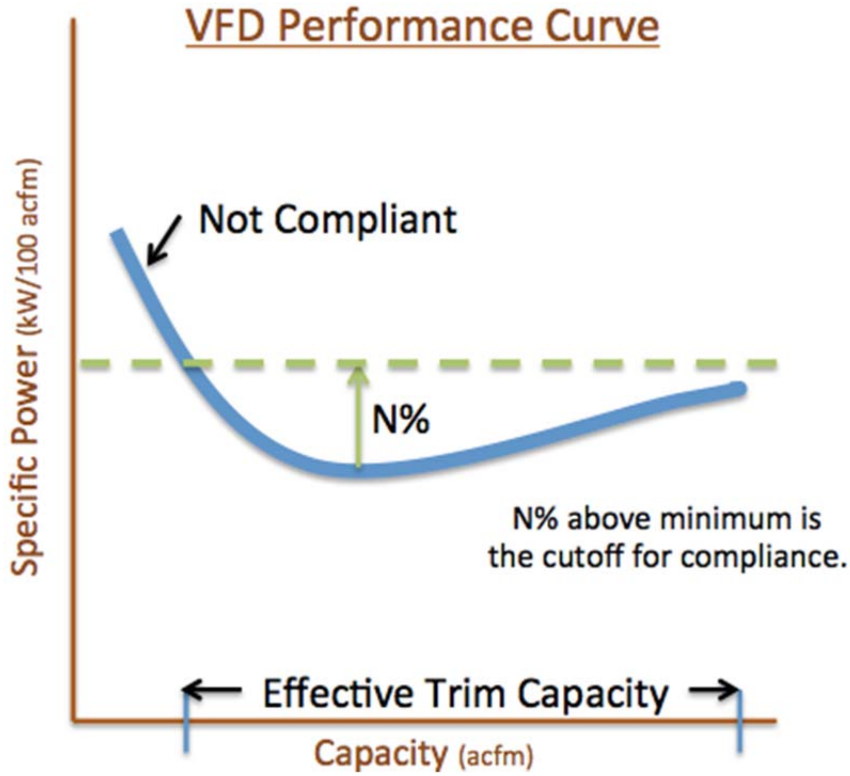

Figure 8: The effective trim capacity of a compressor is the size of the continuous range of outputs for which the specific power of the compressor is within a specified tolerance from its most efficient point.

There are several advantages to this methodology. It does not prescribe or proscribe the use of a particular technology, just a performance requirement. It acknowledges and accounts for the fact that all compressors have some trimming faculty. It evaluates the relative efficiency and 'flatness' of the efficiency curve rather than an absolute efficiency so that it can be applied equally well and without prejudice in cases where the end uses demand inherently less efficient compressor technologies (such as applications that require very high pressures or very low impurity levels). It allows the stringency of the requirement to be updated over time by reducing the threshold value, but without changing the underlying structure of the methodology.

One possible disadvantage to this methodology is its reliance on published efficiency curves. Efficiency curves of this type are currently published for many variable speed drive compressors, but not typically for other compressor types. Additionally the efficiency curves for some compressor types such as load/unload are highly dependent on the amount of primary storage available. For these compressors the storage used in the test would have to be published as well. This is a reasonable tradeoff because compressors that meet the requirements can currently be found on the market without difficulty, the barrier to entry for compressors that do not currently publish their efficiency curves is relatively low, and the increase in published efficiency data will benefit the users.

To determine the threshold value to use in this round of regulation, current market data for variable speed drive compressors was examined, as well as standard model for a load/unload compressor at several storage levels. VSDs appear to be becoming a standard solution for trim requirements and load/unload compressors with adequate storage represent a possible alternative when a moderate amount of trim capacity is needed. The CASE Team proposes that a performance threshold of 15% above the minimum specific power will best meet the goals of the measure.

Figure 9 displays the published efficiency curves for typical VSD compressors from three different manufacturers normalized relative to their total capacity and minimum specific power. Several sizes are included, as are both oil flooded and oil free compressors and both air-cooled and water-cooled models. The 15% threshold is called out to show the cutoff point for effective trim.

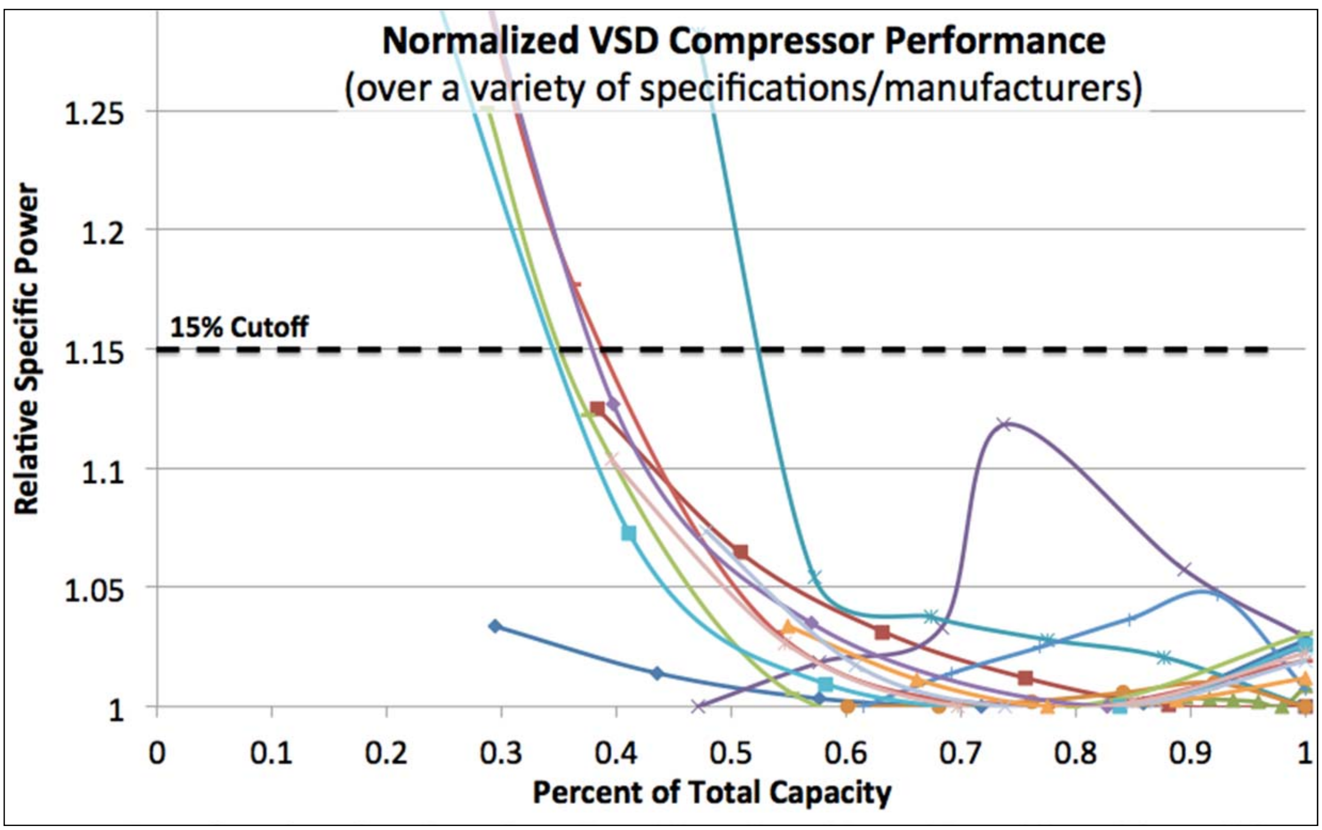

Figure 9: VSD performance curves for a number of models in the market. The curves have been normalized against the rated max capacity and minimum specific power for each compressor.

At this cutoff point all of the VSDs sampled are effective trim compressors for at least 40% of their total range, and some are efficient for 60% or more. It is likely that several of the VSDs effectively trim beyond the data points currently provided by the manufacturer. If this measure is adopted, the manufacturers could publish more of the curves to demonstrate the full potential of their compressors.

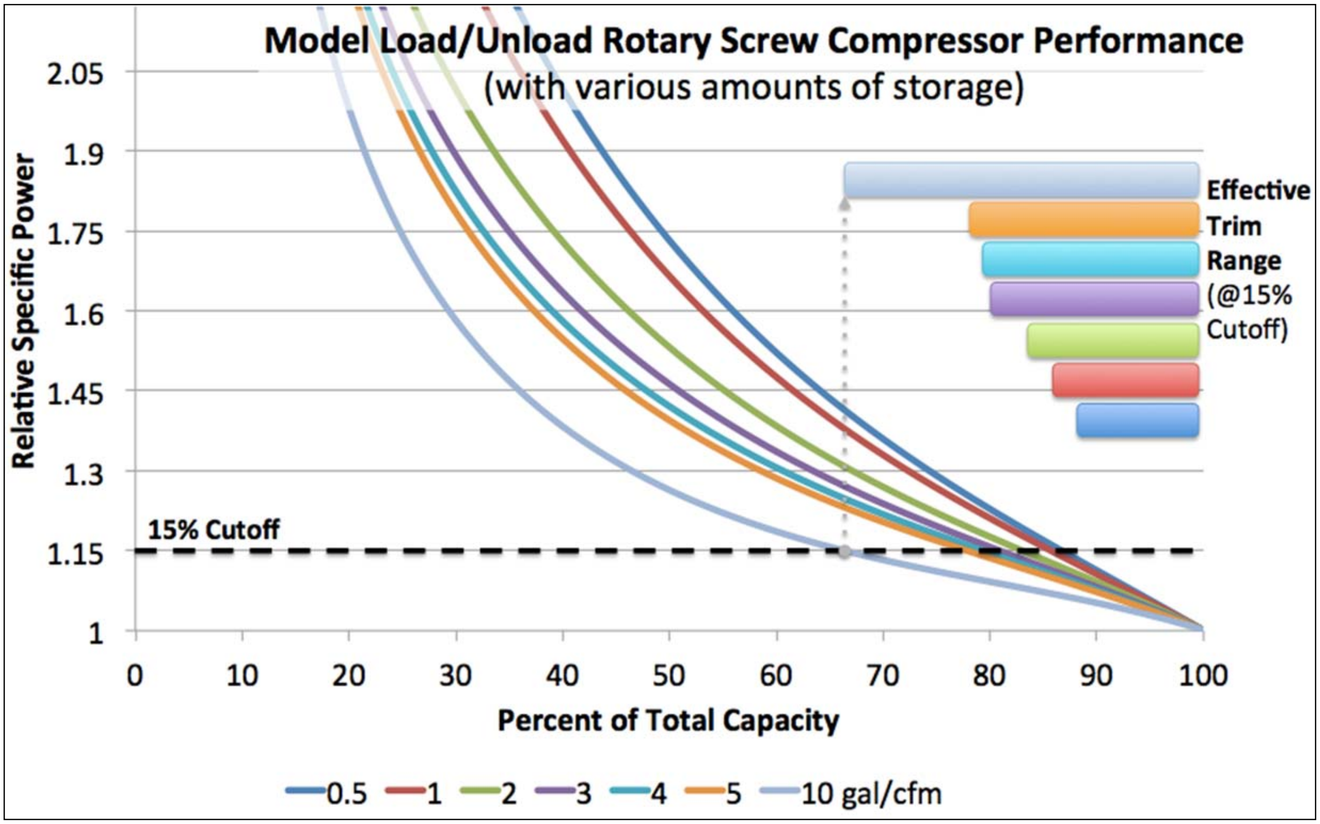

Figure 10: The normalized efficiency curves for a model (CAC Sourcebook, 2003) load/unload compressor at varying storage levels.

The same data for a model load/unload compressor from the Compressed Air Challenge shown in Figure 4 can be redrawn in terms of specific power versus percent capacity, see Figure 10. The 15% is again shown to illustrate the effective trim cutoff. A manufacturer could publish data such as this to demonstrate the trim capabilities of other non-VSD compressors. This generic load/unload compressor could be an effective trim in some scenarios, particularly if ample storage is used. Manufacturers wishing to improve the trim capacity of such a compressor could utilize strategies such as including a shutdown timer with a short fuse or improving the unloaded power use, and republishing the curves.

Matching Trim Capacity to System Need

By selecting a trim compressor with an effective trim capacity at least the size of the largest net increment of the base compressor combination, a system designer can go a long way toward ensuring that a system will perform well across its full range.

An alternative considered for sizing trim would be to base it on the varying trim demand of the end uses of the system. However, this approach requires (currently quite uncommon) extensive long term system monitoring to establish an accurate picture of the varying demand for most systems. New systems can only be expected to accurately estimate their varying demand in practice if they are near identical copies of well characterized existing systems. Furthermore nearly every system changes significantly over the course of its useful life as equipment is added or removed, production levels change, leaks develop, etc. It is far better practice to design a robust system than to design to demand projections that are unlikely to be accurate from the beginning and highly likely to change in unexpected ways over time.

There does remain an unresolved issue of how to address single compressor systems. It is not feasible to require that a single compressor system have a flat efficiency curve across its entire range. At the same time, part load efficiency still has as great an impact on power consumption. Additionally, the CASE Team does not wish to unintentionally push the market toward large single compressor systems.

The question of single compressor system trim requirements requires continued consideration. One possible solution is as follows: For single compressor systems the trim requirement could simply be a set portion of the capacity of the compressor. Furthermore, the CASE Team proposes that portion be 30% of the rated compressor capacity. This trim requirement attempts to strike a balance between efficiency and availability and other practical considerations.

Storage Requirements

When presenting trim requirement proposals to industry, one of the most common pieces of feedback the CASE Team received was that in actual practice, even an effective trim compressor such as a VSD requires a reasonable amount of primary storage to function well. A common industry standard is a bare minimum of 2 gallons per acfm of trim load. In the case of these requirements that would be 2 gallons per acfm of the trim compressor's largest net increment.

It is recommended that minimum storage be included as part of the trim requirement. Additional savings and costs for this storage are not included in the savings calculations because this is taken to be the current industry standard and included as part of the base case. It is, however, still important to include in the requirements because the industry standards are not always followed. The storage requirement does not improve expected trim performance significantly, but is in place to ensure that the system is not highly compromised.

Existing Systems

For retrofits of existing systems, stakeholders have raised concerns that because of possible physical factory floor constraints, the potential significant space requirements needed for one or more new compressors and especially for added storage tanks may prove an undue burden.

The CASE Team proposes a compromise granting exceptions to existing systems provided they are altering less than 50% of the total capacity of their system. That is to say, adding or replacing compressors with total combined capacity less than 50% the total combined capacity of the existing compressors. Systems undergoing more substantial alterations will already require extensive modifications to the space and are more certain to be able to accommodate these requirements.

3.4 Statewide Energy Savings

The statewide energy savings associated with the proposed measures will be calculated by multiplying the per unit estimate for each scenario (from the controls measure) by the new construction rate for each scenario in 2014. Once stakeholder input is incorporated, the details on the method and data source of the new construction forecast will be presented here.

4. Analysis and Results

4.1 Smart Controls

4.1.1 Energy Savings

Savings analyses were performed on the four baseline systems both with and without the assumption of auto-shutdown timers on the individual compressors. When a compressor with an auto-shutdown timer has been in the unloaded state for a preset period of time, the compressor is fully shut down. In this case the auto-shutdown timers were assumed to be set for a relatively short period of time (half an hour or less), though longer times are common. In the end, assuming systems without auto-shutdown timers was judged not sufficiently conservative, and only the cases including them were used for the final analysis. The results from the cases without auto-shutdown timers do, however, provide a good example of the markedly greater savings that can be realized with a single deviation from the most conservative case. As detailed in Section 3.2.1, the results presented below are the most conservative savings estimates that could be expected from compressed air systems.

By comparing the energy use found from AirMaster+, the annual savings (in kWh) were found for each baseline. These annual savings were multiplied out over 15 years. This was then weighted to find the 15 year benefit to society (both in kBtu and monetary benefit).

Table 4: Energy savings for implementing smart controls on 4 baseline systems. Italicized values will be used in cost-effective analysis.

	Baseline 1 2 compressors 125 hp total		Baseline 2 2 compressors 200 hp total		Baseline 3 2 compressors 450 hp total		Baseline 4 3 compressors 800 hp total	
Auto-shutdown Timer in Base Case?	no	yes	no	yes	no	yes	no	yes
Total Annual Savings (kWh)	31,738	8,788	27,890	4,940	74,048	7,025	197,733	25,812
Total 15 Year Savings (kWh)	476,072	131,817	418,355	74,100	1,110,725	105,380	2,965,991	387,180
Total 15 Year TDV ($) Savings	$67,941	$18,812	$57,523	$8,395	$155,499	$12,026	$418,515	$48,832

4.1.2 Costs

The incremental costs for each baseline system are summarized in Table 5. As mentioned in the previous section, these costs are based on estimates from controls manufacturers and averaged.

Because incremental costs are driven by the number of components within a system, the first three baselines (all 2 compressor systems) have the same incremental costs.

Table 5: Incremental costs for smart controls, averaged.

	Baseline 1	Baseline 2	Baseline 3	Baseline 4
Incremental Costs	$6,173	$6,173	$6,173	$10,159

4.1.3 Cost Effectiveness

By comparing the incremental costs and energy savings, the 15-year life-cycle cost savings were found. Table 6 shows that all 4 baseline systems are found to be cost-effective.

Table 6: Cost Effectiveness analysis.

Baseline	Incremental Costs	Energy Cost Savings (TDV$)	LCC Savings	Benefit/Cost Ratio
System 1	$6,173	$18,812	$12,639	3.05
System 2	$6,173	$8,395	$2,222	1.36
System 3	$6,173	$12,026	$5,836	1.95
System 4	$10,159	$48,832	$38,673	4.81

4.2 Trim Compressor Requirements

4.2.1 Energy Savings

By comparing the energy use found from modeling runs in AirMaster+, the annual savings (in kWh) were found for a variety of trim compressor configurations and three different demand profiles. These annual savings were multiplied out over 15 years, then weighted to find the present value 15 year benefit (both in kBtu and monetized benefit to society), using the CEC-approved Time Dependent Valuation (TDV) methodology. This is graphed in Figure 11 and Figure 12 for both VSD compressors and increased storage.

For the smallest compressed air system, the annual energy savings range from 8,293 kWh to 19,669 kWh, which is dependent on how variable the trim load is. The minimum savings assumes a 25 hp compressed air system with a fairly constant load operating below 10% of full load of the trim compressor. The fairly constant load is a conservative assumption and the savings are likely closer to the mid and high end of the energy savings range (>13,000 kWh/yr). These savings scale proportionally as the size of the trim compressor increases.

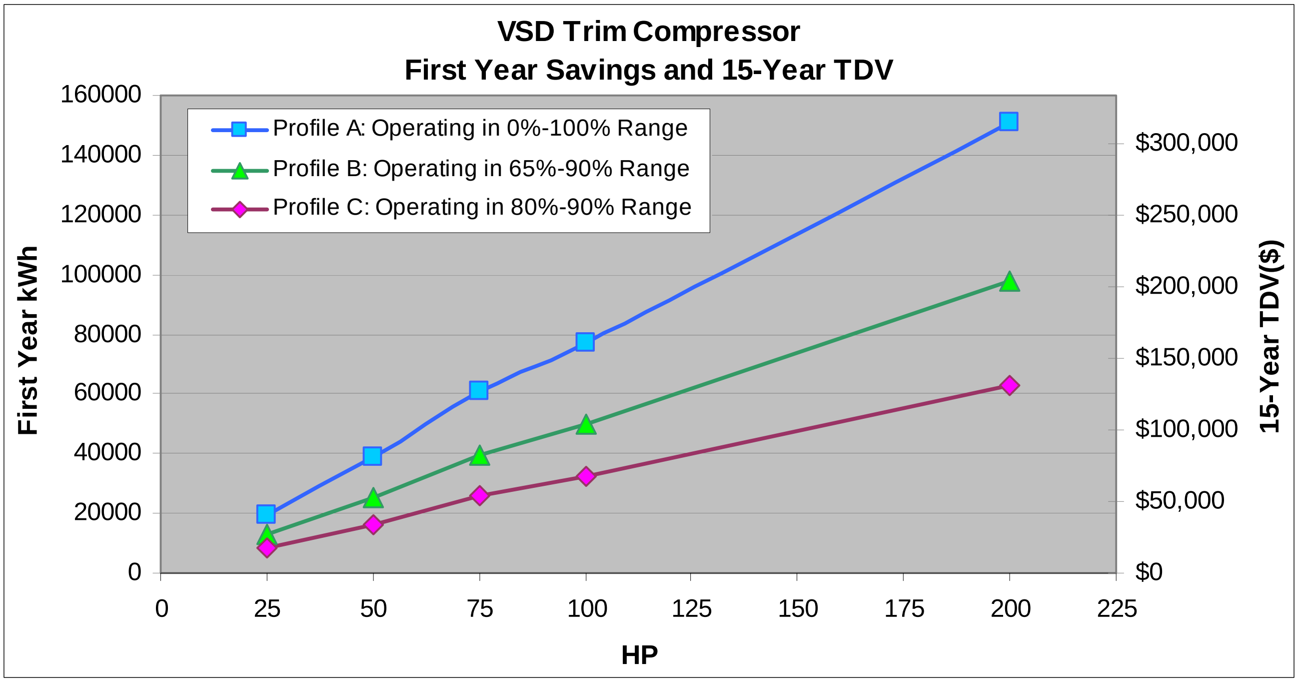

Figure 11: First-year energy savings and 15-year TDV $ savings from replacing the constant speed trim compressor with a VSD compressor.

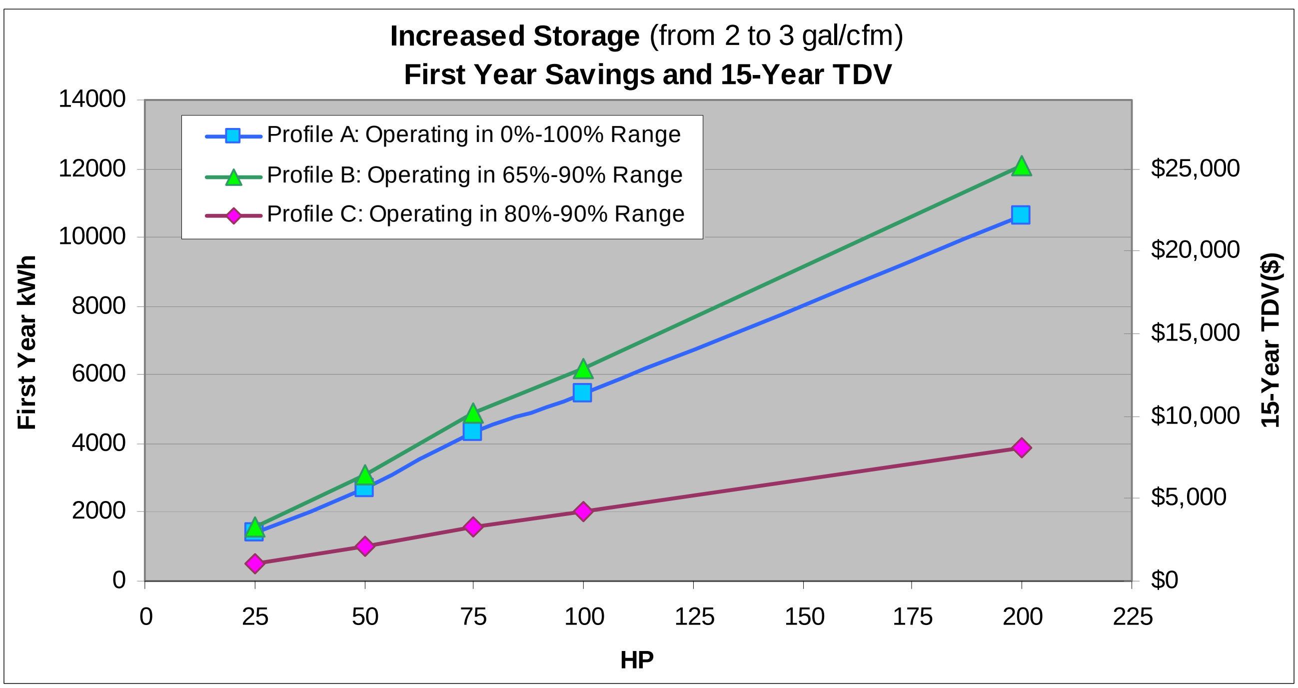

Figure 12: First-year energy savings and 15-year TDV $ savings from increasing storage (2 gal/cfm to 3 gal/cfm).

4.2.2 Costs and Cost Savings

Using the trend-line equations formulated from the incremental costs gathered, the following shows the incremental costs used for the cost effectiveness analysis.

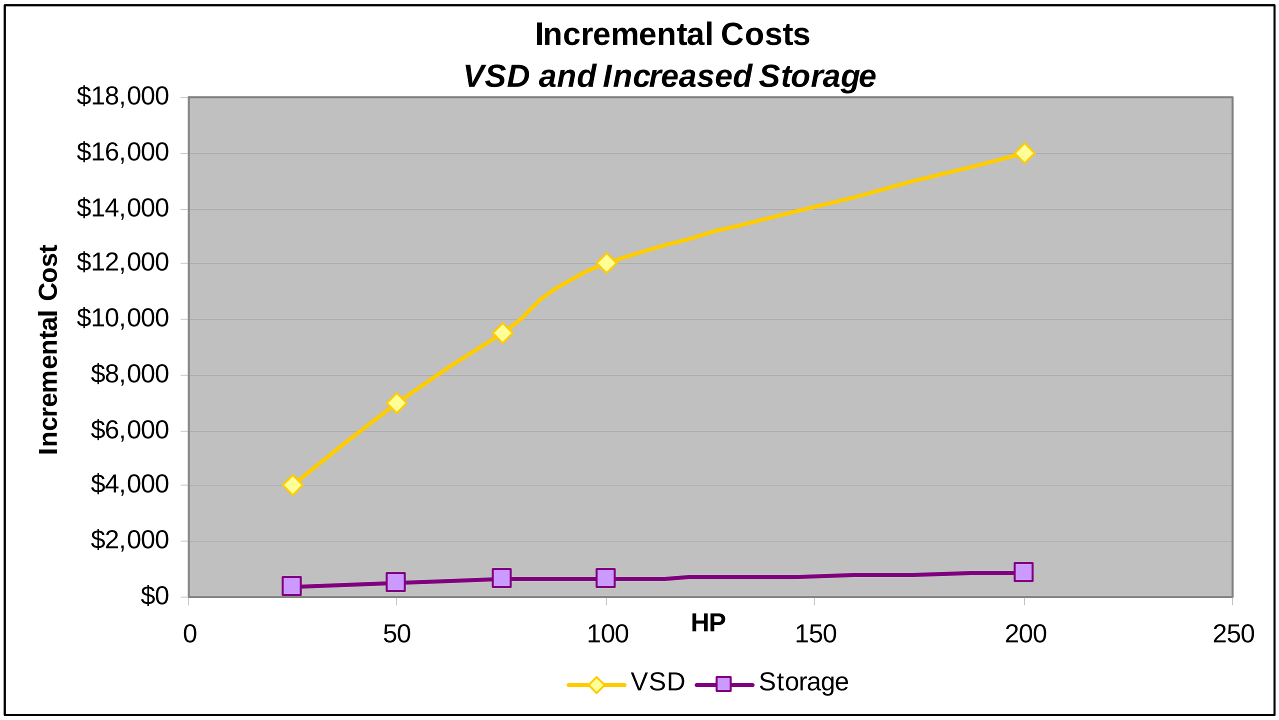

Figure 13: Incremental costs for VSD compressors and increased storage.

4.2.3 Cost Effectiveness

The life cycle cost savings are shown below, comparing the incremental cost of each system and the TDV savings. This shows both options to be cost-effective, though the savings resulting from the VSD option is an order of magnitude higher than increased storage. Based on the results of this analysis and stakeholder feedback, the CASE Team is proposing to require part load performance comparable with expected VSD levels. Other mechanisms such as increased storage may be used, but only to the extent that they can provide comparable part load efficiencies.

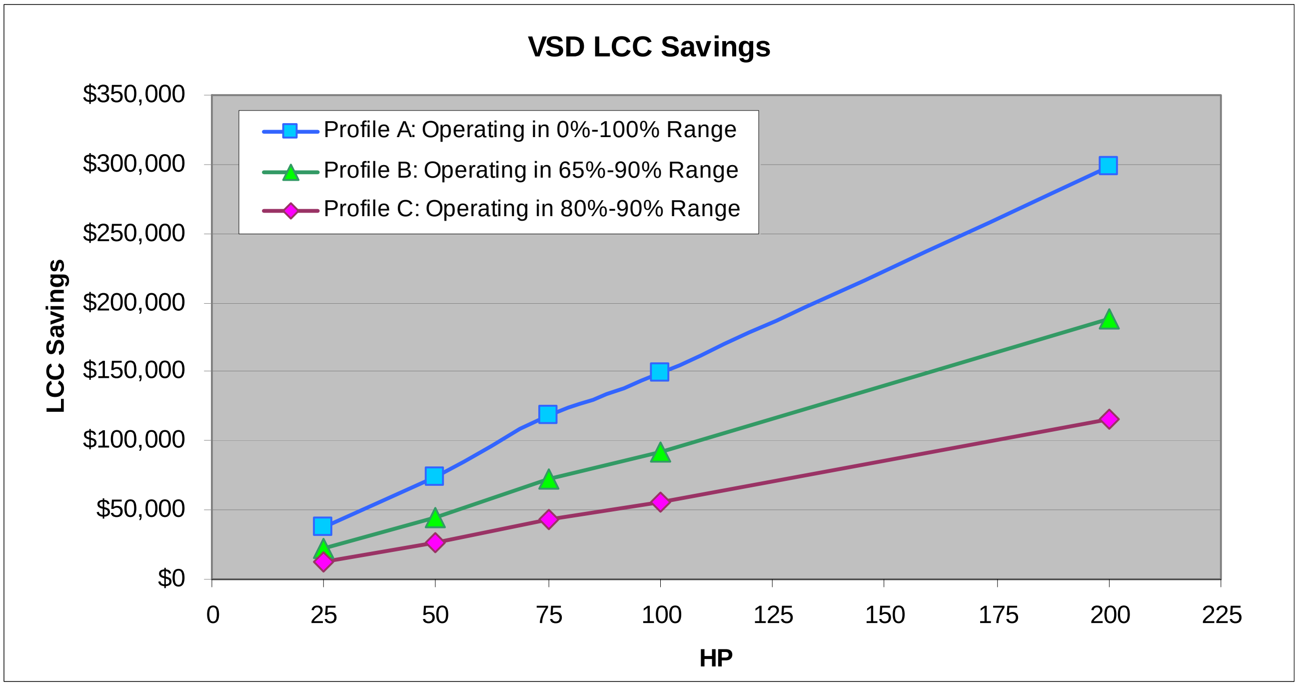

Figure 14: LCC Savings for VSD Trim Compressor

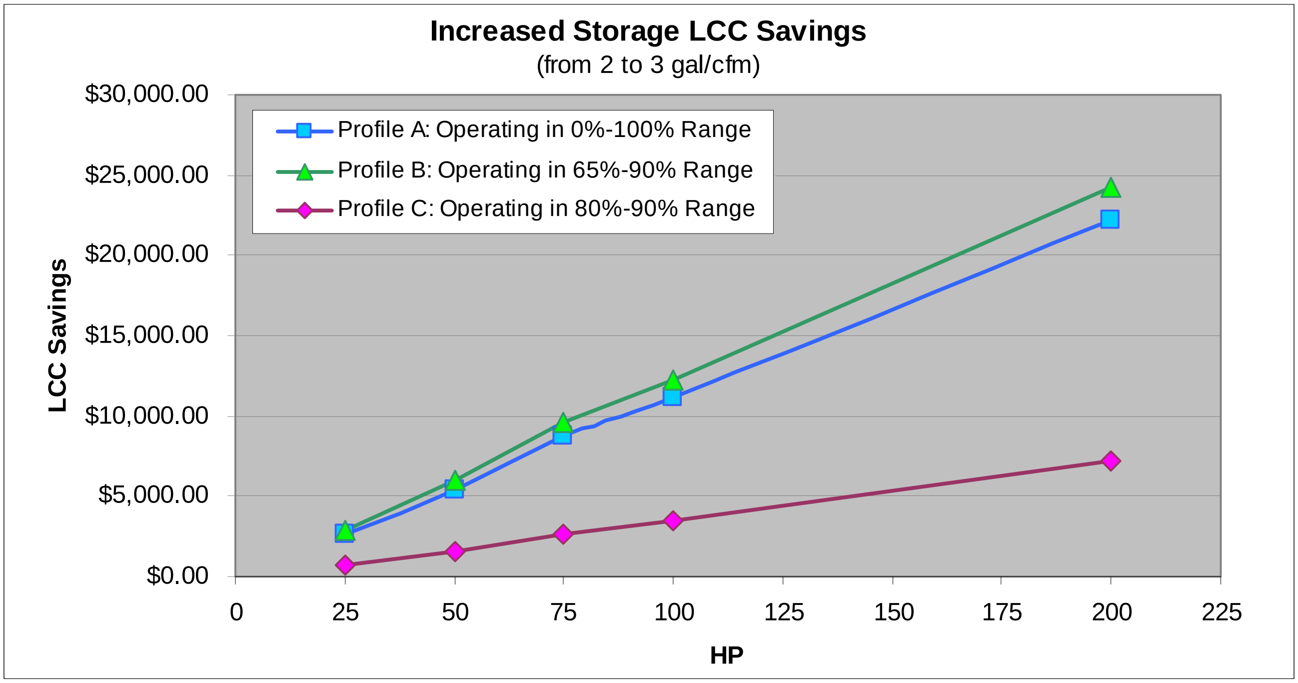

Figure 15: LCC Savings for Increased Storage

4.3 Statewide Savings Estimates

As mentioned in section 3.4, the statewide savings still require further investigation. This section will be updated once a method and data sources are finalized.

5. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

As this is a new area of Title 24, the majority of the recommended language will be new code rather than a code change. To address the measures noted in the previous section, the CASE Team is recommending the following language in the standards document.

5.1 NR Mandatory Equipment

SECTION 120.6 (e)– MANDATORY REQUIREMENTS FOR COMPRESSED AIR SYSTEMS

All new compressed air systems where the total combined horsepower (hp) of the online compressor(s) is 25 hp or more shall meet the requirements of this Section.

(1) **Trim Compressor and Storage Requirements**. Compressed air systems with more than one compressor shall include a compressor or set of compressors with total effective trim capacity at least the size of the largest net increment between combinations of base compressors. Single-compressor systems shall have a total effective trim capacity of at least 30% of the rated compressor capacity. The systems shall also include primary storage of at least 2 gallons per actual cubic feet per minute (acfm) of the required trim capacity.

(2) **Controls Requirements**. Compressed air systems with more than one compressor and having a combined horsepower rating of more than 100 hp, must operate with an approved controller that is able to choose the most energy efficient combination of compressors within the system based on the current air demand as measured by a sensor. The approved controller shall pass acceptance testing specified in NA7.9.1.

(3) **Compressed Air System Acceptance.** Before an occupancy permit is granted for a compressed air system subject to 120.6(e), the following equipment and systems shall be certified as meeting the Acceptance Requirements for Code Compliance, as specified by the Reference Nonresidential Appendix NA7. A Certificate of Acceptance shall be submitted to the enforcement agency that certifies that the equipment and systems meet the acceptance requirements specified in NA 7.13.

5.2 NR Additions Alterations Repairs

SECTION 141.x (x)– MANDATORY REQUIREMENTS FOR COMPRESSED AIR SYSTEMS

All supply side alterations (excluding air treatment equipment and maintenance) in systems where the total combined horsepower (hp) of the online compressor(s) is 25 hp or more shall meet the requirements of this Section.

(1) **Trim Compressor and Storage Requirements**. Compressed air systems with more than one compressor shall include a compressor or set of compressors with total effective trim capacity at least

the size of the largest net increment between combinations of base compressors. Single-compressor systems shall have a total effective trim capacity of at least 30% of the rated compressor capacity. The systems shall also include primary storage of at least 2 gallons per actual cubic feet per minute (acfm) of the required trim capacity.

EXCEPTION to Section 120.6(e)(2): Compressed air systems in existing facilities that are altering less than 50% of the total online capacity of the system.

(2) **Controls Requirements**. Compressed air systems with more than one compressor and having a combined horsepower rating of more than 100 hp, must operate with an approved controller that is able to choose the most energy efficient combination of compressors within the system based on the current air demand as measured by a sensor. The approved controller shall pass acceptance testing specified in NA7.9.1.

(3) **Compressed Air System Acceptance.** Before an occupancy permit is granted for a compressed air system subject to 120.6(e), the following equipment and systems shall be certified as meeting the Acceptance Requirements for Code Compliance, as specified by the Reference Nonresidential Appendix NA7. A Certificate of Acceptance shall be submitted to the enforcement agency that certifies that the equipment and systems meet the acceptance requirements specified in NA 7.13.

5.3 Compliance

SECTION NA7.9.1 – COMPRESSED AIR SYSTEM CONTROLS ACCEPTANCE TEST

Construction Inspection

Prior to functional testing, compressed air system with 2 or more air compressors must verify and document the following:

- Rated horsepower, rated capacity, and control type of each air compressor
- Total online system capacity (the sum of the individual capacities)
- System operating pressure
- Compressor(s) designated as trim compressors
- Method and tools for observing and recording the states of each compressor in the system, which shall include at least the following mutually exclusive states:
    - Off
    - Unloaded
    - Partially loaded
    - Fully loaded

  and the presence of the following behaviors:
    - Short cycling (loading and unloading more often than once per minute)
    - Blow off (venting compressed air at the compressor itself)
- Method and tools for measuring the current air demand as a percentage of the total system capacity, including any necessary calibrations.

Functional Testing

Step 1: Per the test methods outlined in the Construction Inspection, verify that these methods have been employed, so that the states of the compressors and the current air demand can be observed and recoded during testing.

Step 2: Run the system steadily (at as close to a constant load as can be practically implemented) at a mid-range point, between 50% and 85% of total system capacity, for a duration of at least 10 minutes.

Step 3: Observe and record the states of each compressor and the current air demand during the test.

Step 4: Confirm that the combinations of compressors states meet the following criteria:

- No compressor exhibits short-cycling.
- No compressor exhibits blowoff.
- For new systems, the trim compressors shall be the only compressors partially loaded, while the base compressors will either be fully loaded or off by the end of the test.

In addition to the new code in these sections, the CASE Team recommends the following definitions be added to Section 101(b).

TRIM COMPRESSOR: compressor that is designated for part-load operation, handling the short term variable trim load of end uses, in addition to the fully loaded base compressors

SPECIFIC POWER: is the ratio of the power input into an air compressor to the 100 cubic feet per minute of air delivered at actual pressure (kW/100 acfm).

EFFECTIVE TRIM CAPACITY: is the (continuous) range for which the specific power is 115% of the minimum specific power or less of the trim compressor.

LARGEST NET INCREMENT: is the largest increase in capacity when switching between combinations of base compressors that is expected to occur under the system control scheme.

PRIMARY STORAGE: is compressed air storage located between the compressors and pressure regulating equipment, such as a pressure-flow controller.

6. Bibliography and Other Research

6.1 Annotated Bibliography

Compressed Air Challenge, and Tom Taranto. DOE - CAC Qualified AIRMaster+ Specialist Participant Workbook. Washington, D.C.: DOE, 2001.

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McKane, Aimee. "Creating a Standards Framework for Sustainable Industrial Energy Efficiency."*Energy Efficiency in Motor-Driven Systems* (2005).

Xenergy, Inc. Assessment of the market for compressed air efficiency services. Washington, D.C.: Office of Industrial Technologies, Office of Energy Efficiency and Renewable Energy, U.S. Dept. of Energy, 2001.

6.2 Stakeholder Feedback

The following table is a list of stakeholder feedback that was received throughout this process and the response from the CASE Team to address these concerns. Some of these concerns will require additional feedback throughout this process.

Stakeholder Feedback	CASE Team Response
1. There are numerous energy efficiency measures that can be implemented. Not all are applicable to every system.	The CASE Team listed out all the energy efficiency measures and took into consideration both energy savings potential (and cost effectiveness), and feasibility for Title 24 code compliance and enforcement.
2. The market is varied and a typical system does not exist. It will be difficult to model energy savings without a proper baseline.	Originally, the CASE Team addressed this concern by creating a number of baseline systems that were very different in an attempt to capture the majority of the market. In moving forward, the CASE Team decided to instead use systems that would have a conservative amount of savings for both measures. The CASE Team also shared the proposed baselines with stakeholders and incorporated significant feedback before proceeding with savings analysis.

<table>
<tr><td>3. Smart controls do not save energy for systems with a constant load profile.</td><td>From various sources, the CASE Team has determined that systems that have loads so constant that the system would not benefit from a smart controls measure would be extremely rare. Furthermore, even for systems that are sized exactly to the load when new, load profiles almost always change over time and having smart controls allows system operators to continue to maximize efficiency.</td></tr>
<tr><td>4. VSDs are not cost-effective for systems with a constant load profile.</td><td>As mentioned previously, there are few load profiles that are very constant. Furthermore, feedback from industry stakeholders suggests that compressors are almost always slightly oversized, to avoid system failure. As VSDs are more efficient during part load operation, there will be energy savings for the vast majority of systems. Finally, the CASE Team also considered adding an exception to the VSD requirement by giving the option of adding more storage in lieu of installing a VSD. In response to additional stakeholder input (addressed below), the CASE Team decided against allowing this option.</td></tr>
<tr><td>5. Leaks are a large opportunity for energy savings.</td><td>The CASE Team agrees that this is a large opportunity, but also that the largest energy savings are from fixing leaks in an existing system. It is difficult to assume more than a certain percentage of leakage will exist within a system at the time of new construction.</td></tr>
<tr><td>6. Increased storage should not be a comparable (or available) option in place of requiring a VSD compressor. There is also concern about this providing a loophole.</td><td rowspan="2">This feedback was taken into account and increased storage is no longer being proposed.</td></tr>
<tr><td>7. Increasing storage alone will not result in energy savings. Additional controls are needed for the system to actually utilize the storage. Sump unloading is more important.</td></tr>
</table>

8. Spiral Valve control is more efficient at a higher range as compared to VSDs. Why not require this as an option in place of VSDs?	Based on research done with major compressor manufacturers, it seems that this technology is not widely available from many manufacturers. However, requiring a set of specifications for a trim compressor in lieu of requiring a specific technology allows owners the flexibility to install a trim compressor that accomplishes the same thing as a VSD.
9. Definitions need to be explicit for a compressed air system, trim compressor, and standard automation protocol.	*Compressed air system* definition needs to incorporate the intricacies of what a system means. If the CASE Team is not careful about how this is defined, this could lead to undesirable system design. *Trim compressor* was equally important to define, when the storage option was being considered. This is not as important now. *Standard automation protocol* was included in the code language to address the requirement of having a controller that worked with compressors of various types and from various manufacturers. This was included so an owner was not tied to a specific vendor in the future for when an expansion would occur. Stakeholder feedback confirms that this is not a big issue and this has been dropped from the current code language.
10. How will this code change language affect booster compressors?	The CASE Team is investigating this issue, as the current code language would require controls on these booster compressors.

7. Appendices

7.1 Alternate Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

The following is alternate wording for the recommended language in 120.6 (e)(1). The intent behind this alternate wording is to show a different approach to presenting the same information. Instead of defining the effective trim capacity, the definition is laid out in 120.6 (e)(1).

(1) **Trim Compressor and Storage Requirements**. Compressed air systems with more than one compressor shall include a compressor or set of compressors that shall maintain a specific power of 115% of the minimum specific power or less for a continuous range of at least the size of the largest net increment between combinations of base compressors. Single-compressor systems shall maintain a specific power of 115% of the minimum specific power or less for all loads above 70% of full load. The systems shall also include primary storage of at least 2 gallons per actual cubic feet per minute (acfm) of the required trim capacity.

In addition to the new code in these sections, the CASE Team recommends the following definitions be added to Section 101(b).

TRIM COMPRESSOR: compressor that is designated for part-load operation, handling the short term variable trim load of end uses, in addition to the fully loaded base compressors

SPECIFIC POWER: is the ratio of the power input into an air compressor to the 100 cubic feet per minute of air delivered at actual pressure (kW/100 acfm).

LARGEST NET INCREMENT: is the largest increase in capacity when switching between combinations of base compressors that is expected to occur under the system control scheme.

PRIMARY STORAGE: is compressed air storage located between the compressors and pressure regulating equipment, such as a pressure-flow controller.

Appendix B. Nonresidential Compliance Manual and Compliance Forms

The Compliance Forms Language has been appended in the following pages.

2013

NONRESIDENTIAL COMPLIANCE MANUAL

FOR THE 2013 BUILDING ENERGY EFFICIENCY STANDARDS

TITLE 24, PART 6, AND ASSOCIATED ADMINISTRATIVE REGULATIONS IN PART 1

JUNE 2013
CEC-400-2013-002-SD

CALIFORNIA ENERGY COMMISSION
Edmund G. Brown Jr., Governor

10.8 Compressed Air Systems (§120.6(e))

10.8.1 Overview

§120.6(e) applies to all new compressed air systems with a total installed compressor capacity of ≥25 hp. It also applies to existing compressed air systems that are being altered on the supply side (equipment upstream of the distribution system). For alternations there is an exception for systems that include one or more centrifugal compressors.

As described in the following paragraphs, there are 3 main requirements in this section:

- Trim Compressor and Storage (§120.6(e)1)
- Controls (§120.6(e)2), and
- Acceptance (§120.6(e)3)

10.8.2 Mandatory Measures §120.6(e)

F. Trim Compressor and Storage (§120.6(e)1)

This requirement targets the performance of a compressed air system across its full range. This requirement excludes alterations that are not making a large change to the system. A large change is defined as adding or replacing more than 50% of the online capacity.

There are two alternate paths to comply with this requirement:

- Using a VSD controlled compressor(s) as the Trim Compressor (§120.6(e)1A)
- Using a compressor or set of compressors as the Trim Compressor (§120.6(e)1B)

Both of these paths aim to reduce the amount of cycling of fixed speed compressors by utilizing a better-suited compressor that operates well in part-load.

Compliance Option 1: VSD-controlled Trim Compressor (§120.6(e)1A)

In order to avoid control gaps - portions of the compressed air system range with poor performance - it's important to have a trim compressor sized to handle the gaps between base compressors. This minimum size is determined with the *Largest Net Capacity Increment* - the biggest step increase between combinations of base compressors.

With equally sized compressors this is fairly intuitive: in a system with two-100 hp (434 acfm) rotary screw compressor system, the largest step increase would be the size of one of the compressors (434 acfm). For systems with uneven compressor sizes, it requires going through the following steps:

a) Determine all combinations of base compressors (including all compressors off).

b) Order these combinations in increasing capacity.

c) Calculate the difference between every adjacent combination.

d) Choose the largest difference.

This largest difference is what must be covered by the trim compressor(s) in order to avoid a control gap.

Example 10-55

Question

Given a system with three base compressors with capacities of 200 acfm (Compressor A), 400 acfm (Compressor B) and 1,000 acfm (Compressor C), what is the *Largest Net Capacity Increment?*

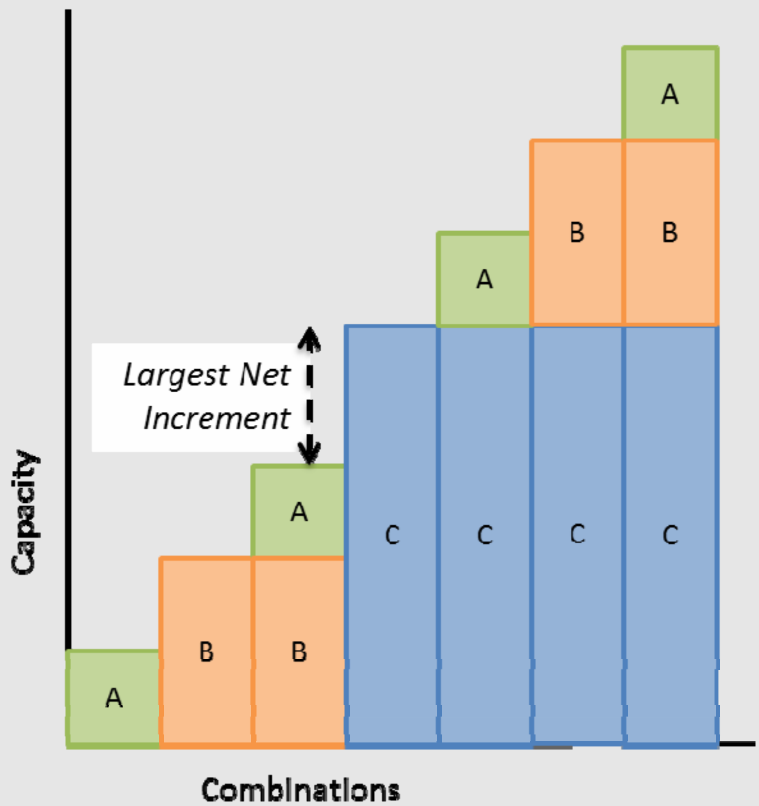
Answer

As shown in the image below there are 8 possible stages of capacity ranging from 0 acfm with no compressors to 1,600 acfm with all three compressors operating. The largest net increment is between stage 4 with compressors A and B operating (200+400=600acfm) to stage 5 with compressor C operating (1,000 acfm)

Combinations of Base Compressors

Base Compressors	
A	200
B	400
C	1000

Capacity	Combination
0	None
200	A
400	B
600	A + B
1000	C
1200	A + C
1400	B + C
1600	A + B + C



For this system the *Largest Net Capacity Increment* is 1,000 acfm-600 acfm = 400 acfm

Once the *Largest Net Capacity Increment* is calculated, this value can be used to satisfy the first compliance option. Option one mandates that the rated capacity of the VSD compressor(s) be at least 1.25 times the largest net increment.

Example 10-56

Question

Using the system from the previous example, what is the minimum rated capacity of VSD compressor(s) that are needed to comply with Option 1?

Answer

As previously shown, the *Largest Net Capacity Increment* is 1,000 acfm-600 acfm = 400 acfm. The minimum rated capacity for VSD compressor(s) is 400 acfm X 1.25 = 500 acfm.

For compliance option 1, the system must include primary storage that has a minimum capacity of 1 gallon for every acfm of capacity of the largest trim compressor.

Example 10-57

Question

What is the required minimum primary storage capacity for the trim compressor from the previous example to comply with Option 1?

Answer

Assuming there is a VSD compressor with a rated capacity of 500 acfm, per §120.6(e)1A it must have 1 gallon of storage per acfm of rated capacity or 500*1 = 500 gallons of storage.

Compliance Option 2: Other Compressors as Trim Compressor (§120.6(e)1.B)

The second compliance option offers more flexibility but requires looking at both the *Largest Net Capacity Increment* of the system, as well as the *Effective Trim Capacity* of the trim compressor(s).

The *Effective Trim Capacity* is the range across which a trim compressor has adequate part-load performance. Performance is measured in power input over air volume output or specific power (kw/100acfm). Many VSD compressors come with a compressor performance graph in a CAGI data sheet that looks similar to the graph in **Error! Reference source not found.**.

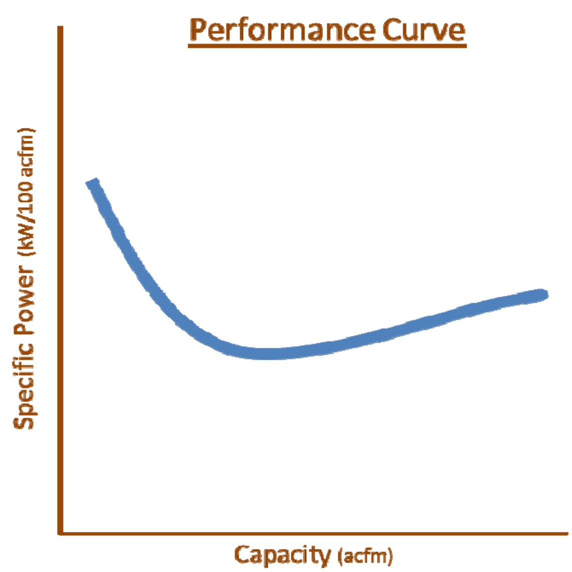


Figure 10-40 –Example Compressor Power vs. Capacity Curve

The capacity of the compressor is along the x-axis, while the power is on the y-axis. The curve in **Error! Reference source not found.** is a typical shape of a performance curve for a VSD compressor. The lower the specific power, the more energy efficient the compressor is at that condition.

The *Effective Trim Capacity* uses the minimum of the compressor power vs. capacity curve to determine the range of adequate part-load performance. This can be done in the following steps and is illustrated in the graph below.

a) Find the minimum specific power across the range.

b) Find the upper bound by calculating 1.15 times the minimum specific power.

c) Determine the endpoints of the capacity where the specific power is less than or equal to the upper bound.

d) The difference between these two endpoints is the effective trim capacity.

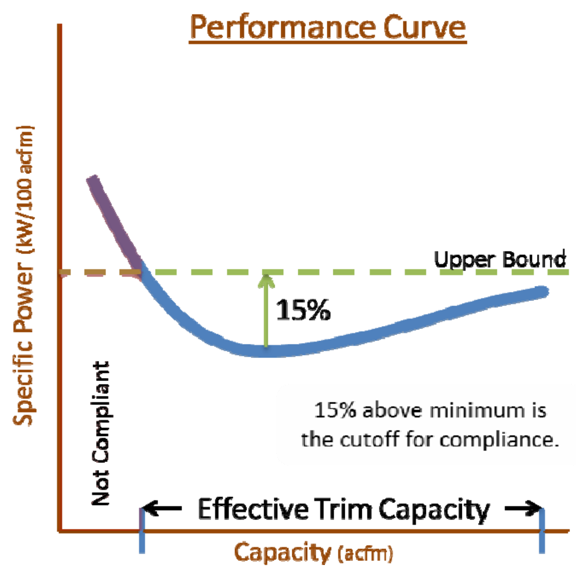


Figure 10-41 –Determination of Effective Trim Capacity from a Compressor Curve

This definition of *Effective Trim Capacity*, along with the *Largest Net Capacity Increment* of the system, will be used to assist in sizing the trim compressor appropriately in the next section.

Example 10-58

Question

Continuing with the system from the previous examples, what is the required minimum *Effective Trim Capacity* of the trim compressor(s) to comply with Option 2*?*

Answer

As previously shown, the *Largest Net Capacity Increment* is 1,000 acfm-600 acfm = 400 acfm. Per §120.6(e)1 the minimum *Effective Trim Capacity* is equal to the *Largest Net Capacity Increment* or 400 acfm.

Example 10-59

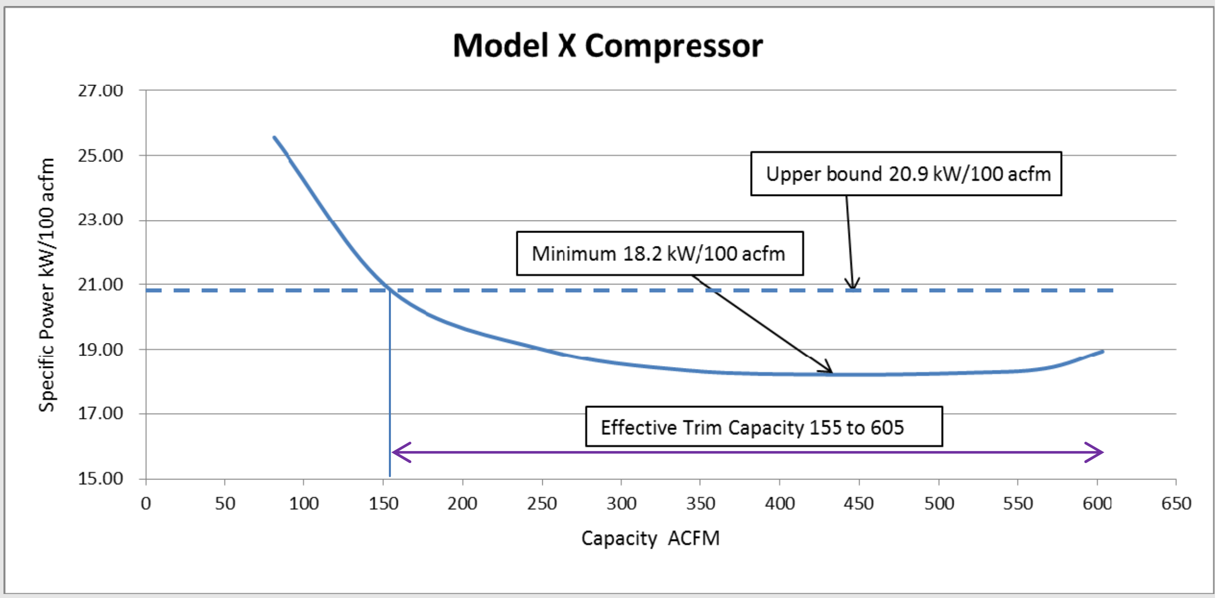
Question

A manufacturer provided the following data for their compressor; would this provide the minimum *Effective Trim Capacity* for this system to comply with Option 2?

Input Power (kW)	Capacity (acfm)[a,d]	Specific Power (kW/100 acfm)[d]
20.7	81.0	25.56
32.4	156.0	20.77
47.5	250.0	19.00
62.7	342.0	18.33
79.0	434.0	18.20
94.2	516.0	18.26
104.3	567.0	18.40
114.2	603.0	18.94

Answer

From the manufacturer's data the minimum specific power is 18.2 kW/100 acfm. The upper limit would be 18.2 * 1.15 = 20.9 kW/100 acfm. Interpolating from the manufacturer's data this appears to go from 155 acfm to 605 acfm for an Effective Trim Capacity of 605-155= 450 acfm. This is larger than the *Largest Net Capacity Increment* of 400 acfm so this compressor would comply as a trim compressor for this system.



For compliance option 2, the system must include primary storage that has a minimum capacity of 2 gallons for every acfm of capacity of the largest trim compressor.

Example 10-60

Question

What is the required minimum primary storage capacity for the trim compressor from the previous example to comply with Option 2?

Answer

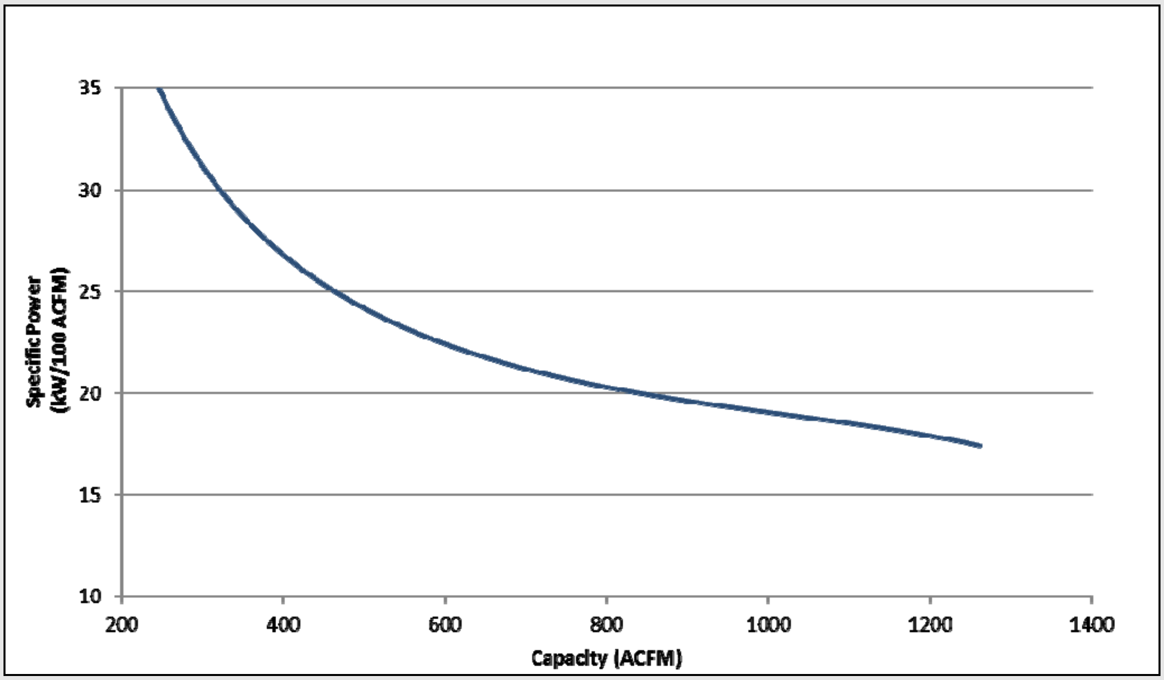
This compressor has a rated capacity of 603 acfm, per §120.6(e)1B it must have 2 gallons of storage per acfm of rated capacity or 603*2 = 1,206 gallons of storage.

The last example used a VSD compressor, but other technologies can be used for compliance option 2. The next example examines a 250-hp load-unload, single stage, rotary screw compressor coupled with 10 gallons/cfm of storage. Generally, higher levels of storage improve part-load performance and this combination was chosen to meet the part-load performance mandated by code. This data was generated from theoretical curves used in AirMaster+, a tool created by the U.S. Department of Energy.

Example 10-61

Question

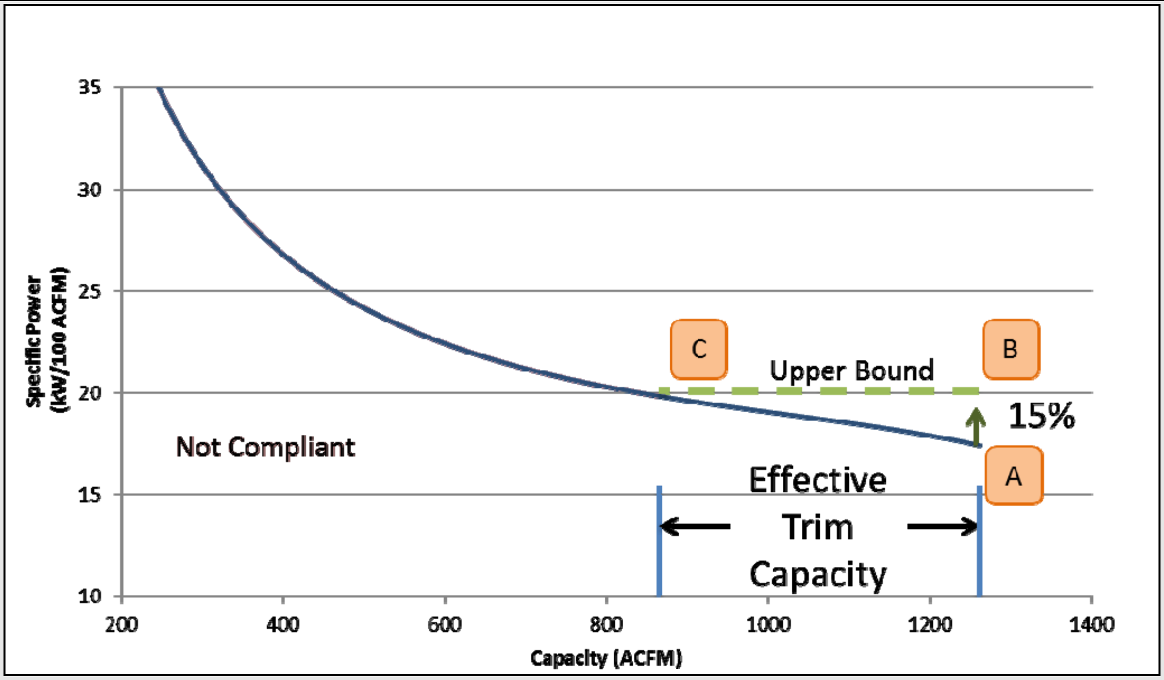
Part-load data was approximated below for a 250-hp load-unload, single stage, rotary screw compressor coupled with 10 gallons/cfm of storage; would this provide the minimum *Effective Trim Capacity* for this system to comply with Option 2?



Answer

Using the previous examples, a compressor with an effective trim capacity of at least 400 acfm is necessary.

Looking at the graph, the minimum specific power (labeled as A below) occurs at full load - a capacity of 1261 acfm, with a specific power of 17.4 kW/100acfm. Using this minimum specific power, the upper bound is 17.4 * 1.15 = 20.01 kW/100acfm or 15% higher than the minimum specific power. This puts the ends of the effective trim capacity at 1261 acfm (labeled as B) and 845 acfm (labeled as C), resulting in an effective trim capacity of 1261 – 845 = 416 acfm. This is larger than the Largest Net Capacity Increment of 400 acfm so this compressor would comply as a trim compressor for this system.



For compliance option 2, the system must include primary storage that has a minimum capacity of 2 gallons for every acfm of capacity of the largest trim compressor.

Example 10-62

Question

What is the required minimum primary storage capacity for the trim compressor from the previous example to comply with Option 2?

Answer

This compressor has a rated capacity of 1261 acfm, and per §120.6(e)1B it must have 2 gallons of storage per acfm of rated capacity or 1261 * 2 = 2,522 gallons of storage.

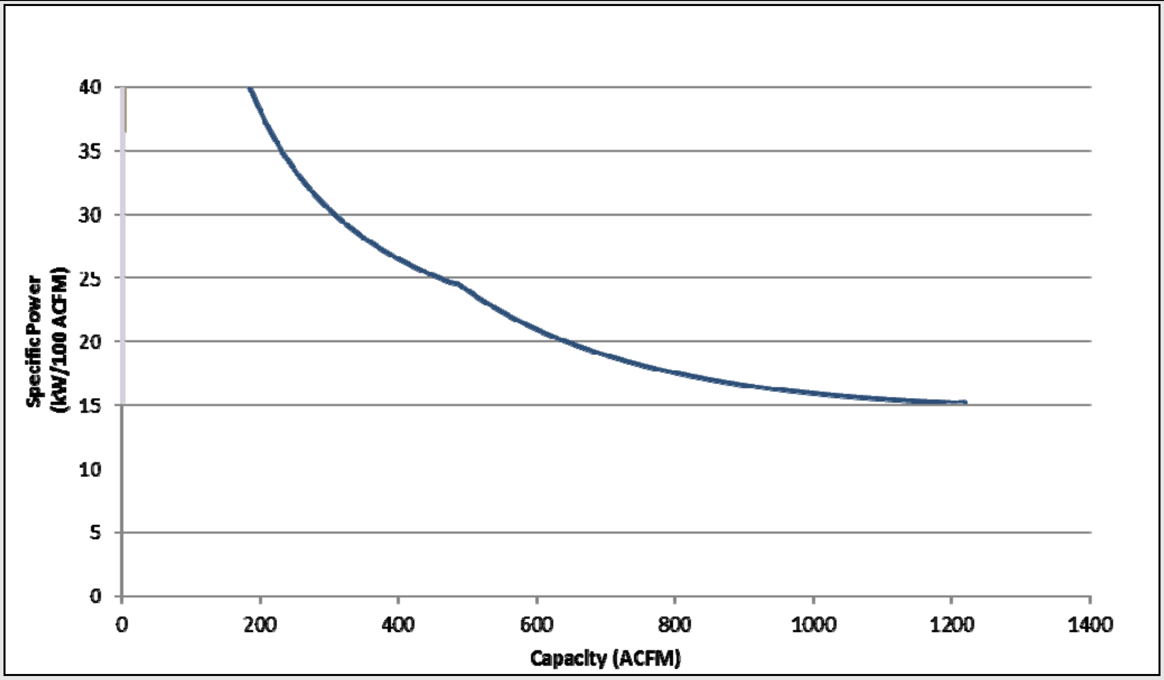
However, in order to meet the performance necessary for a large enough Effective Trim Capacity, there must be 10 gallons of storage per acfm of the rated capacity, or 1261 * 10 = 12,610 gallons.

The next example also utilizes option 2, but with a 250-hp Variable Capacity compressor, with part-load performance approximated by theoretical curves used in AirMaster+, similar to the last example.

Example 10-63

Question

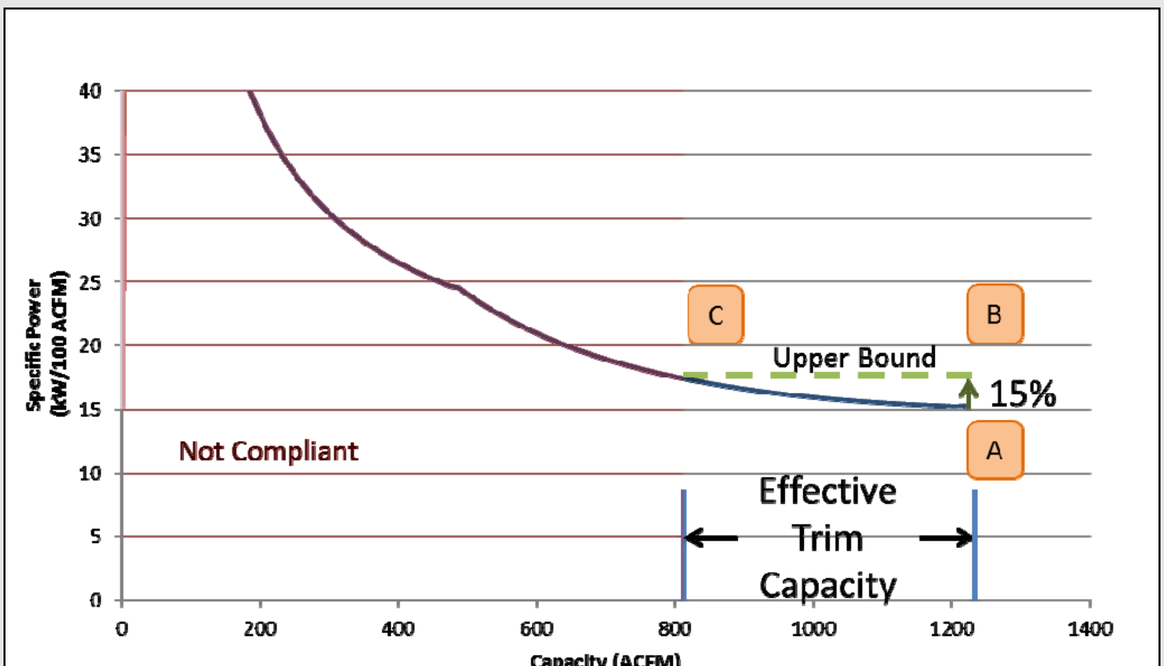
Part-load data was approximated below for a 250-hp variable capacity compressor; would this provide the minimum *Effective Trim Capacity* for this system to comply with Option 2?



Answer

Using the previous examples, a compressor with an effective trim capacity of at least 400 acfm is necessary.

Looking at the graph, the minimum specific power (labeled as A below) occurs at full load - a capacity of 1218 acfm, with a specific power of 15.3 kW/100acfm. Using this minimum specific power, the upper bound is 15.3 * 1.15 = 17.56 kW/100acfm or 15% higher than the minimum specific power. This puts the ends of the effective trim capacity at 1218 acfm (labeled as B) and 804 acfm (labeled as C), resulting in an effective trim capacity of 1218 – 804 = 414 acfm. This is larger than the Largest Net Capacity Increment of 400 acfm so this compressor would comply as a trim compressor for this system.



For compliance option 2, the system must include primary storage that has a minimum capacity of 2 gallons for every acfm of capacity of the largest trim compressor.

Example 10-64

Question

What is the required minimum primary storage capacity for the trim compressor from the previous example to comply with Option 2?

Answer

This compressor has a rated capacity of 1218 acfm, and per §120.6(e)1B it must have 2 gallons of storage per acfm of rated capacity or 1218 * 2 = 2,236 gallons of storage.

G. Controls (§120.6(e)2)

This requirement applies to new and existing facilities that are being altered with ≥100 hp of installed compressor capacity. The section requires an automated control system which will optimally stage the compressors to minimize energy for the given load. With new systems, this ideally means that at any given load, the only compressors running at part-load are the trim compressors. Because not all systems are required to upgrade the trim compressor, the installed controls must stage the compressors in the most efficient manner.

This requirement also mandates the measurement of air demand. The control system must be able to measure or calculate the current system demand (in terms of actual cubic feet per minute of airflow). There are a variety of ways to accomplish this, including but not limited to the following sensors:

- A flow meter
- Pressure transducers, or
- A combination of pressure transducers and power meters

H. Acceptance (§120.6(e)3)

New systems and altered systems must be tested per NA7.13.

13.9.1 NA7.13.1 Compressed Air Systems

At-A-Glance

NA7.13 Compressed Air System Acceptance
Use Form NRCA-PRC-01-A

Purpose of the Test

The purpose of functionally testing the controls of a compressed air system is to confirm that the controls are set up in a compliant manner. A compliant system will choose the most efficient combination of compressors, given the current air demand as measured by a sensor, according to Standards Section 120.6(e)2. This test is designed for flexibility, as this covers both newer compressed air systems designed for use with controls and older compressed air systems under direction of controls for the first time.

Instrumentation

Instrumentation to perform the test includes:

- Power meter(s) for each compressor
- Pressure transducer(s) for each compressor
- Sensor or set of sensors to measure or infer current air demand, including but not limited to:
    - Flow meter
    - Set of pressure transducers
    - Pressure transducers and power meters

Test Conditions

Equipment installation is complete (including compressors, storage, controls, and piping).

Compressed air system must be ready for system operation, including completion of all start-up procedures per manufacturer's recommendations.

For a new compressed air system, the trim compressor(s) must be identified prior to conducting the test.

Document the initial conditions before overrides or manipulation of the settings, if any. All systems must be returned to normal at the end of the test.

If using a valve to achieve a steady demand, ensure that this will not affect any equipment downstream.

Estimated Time to Complete

Construction Inspection: 1 to 1.5 hours (depending on complexity of the system)

Functional Testing: 1 to 3 hours (depending on familiarity with the controls and issues that arise during testing)

Acceptance Criteria

The states of each compressor will be observed throughout the duration of the test. By the end of the 10-minute duration, each compressor must not exhibit short-cycling or blowoff.

For new compressed air systems, the trim compressors are the only compressors that can be partially loaded. All base compressors must be either fully loaded or off by the end of the test.
Potential Issues and Cautions
For older systems, it may not be feasible to run at a steady demand for 10 minutes. In these cases, still observe the compressors to ensure that the controls are operating efficiently.

13.9.2 Test Procedure: NA7.13 Compressed Air Acceptance, Use Form NRCA-PRC-01-A

Purpose (Intent) of Test

The purpose of the installed controls is to choose the best combination of compressors for a given current demand. This test verifies that the installed controls have been set up to make these choices.

Ideally, the best combination of compressors keeps all base compressors either fully loaded or off with any given demand. The only compressors that should be partially-loaded are compressors that operate well partially-loaded, deemed as trim compressors.

This test is designed for flexibility, as this covers both older and newer compressed air systems. Older compressed air systems may be under direction of controls for the first time and may require compressors to be partially loaded.

Controls need to be able to determine real-time demand with a sensor (or calculate demand by a set of sensors). This is done directly with a flow sensor.

Construction Inspection

Prior to the functional test, the system and compressor specifications must be documented. In addition, the method for determining the current air demand and the state of each of the compressors must also be documented. Having this documented will assist in determining if the controls are working properly. The following sections provide instructions on the data that must be verified during the Construction Inspection and included on the Acceptance Form.

Compressor Specifications

Note the following data on the Acceptance Form. Most of this information can be identified from compressor specification sheets or the nameplate. This includes:

- Size (in rated horsepower)
- Rated Capacity (in actual cubic feet per minute)
- Control Type
  - Fixed Speed
  - Variable Speed
  - Variable Displacement
  - Inlet Modulation
  - Centrifugal
  - Other
- Designation as a Trim Compressor

If in doubt, contact the plant manager or controls designer, who should have this information readily available.

System Specifications

Note the online system capacity on the Acceptance Form. The online system capacity refers to the sum total capacity of all the compressors that will be in operation and connected to the control system. Once the compressor specifications are identified, taking the sum of every compressor's rated capacity should yield the online system capacity.

Note the operating system pressure on the Acceptance Form. The operating system pressure should match up with the rated operating pressure of each of the compressors, also found in the specification sheets.

Method for Determining Current Air Demand

Note the method for determining the current air demand on the Acceptance Form. There are a variety of ways to determine current air demand, which is the load required to safely run all downstream operating equipment. Since equipment operation is variable, the current air demand will also be variable. Tracking the real-time air demand is important to a well-functioning control system.

The controls designer should be aware of this method, as it is crucial to the operation of the controls.

It's important to document the following in this explanation of the method:

- Sensors and tools being used to determine the current air demand
- What each sensor is measuring
- Calculations (if necessary) used to determine the current air demand (in acfm)

Method for Determining the State of the Compressors

A compressor, at any given time, is operating in one of the following states:

- Off (0% of Rated Power)
- Unloaded (15-35% of Rated Power)
- Partially Loaded
- Fully Loaded (100% of Rated Power)

As with current air demand, there are a few ways you can determine the state of the compressor. All states, aside from the Partially Loaded state, can be easily determined with a power meter and the rated power of the compressor. For example, if a compressor is fully loaded, the power meter for this compressor should read near 100% of the rated power. If the compressor is unloaded, it will be approximately 15-35% of rated power. If the compressor is off, it should be near 0 kW of power.

Determining if a compressor is partially loaded would vary based on the compressor's control scheme. A fixed speed compressor would cycle between loaded and unloaded (or off and on) if it were partially loaded.

Both variable speed drive and variable displacement compressors match power and air output somewhat linearly. As air output decreases, then power also decreases in direct proportion. Thus, operating between 35-99% rated power may qualify as partially loaded.

The best way to determine if a compressor is Partially Loaded is to install a flowmeter at the discharge of the compressor. If the acfm output is less than the rated acfm of the compressor, it is running Partially Loaded. If there is no flow, but the motor is still running, the compressor is Unloaded. If there is no flow and the motor is not running (the power reading is near 0 kW), the motor is Off.

Note the method for determining the compressors' states on the Acceptance Form.

In addition to these states, it is important that none of the compressors exhibit the following behavior:

- Short-cycling (loading and unloading more often than once per minute)
- Blowoff (venting compressed air at the compressor itself)

Short-cycling is easily measured with a stopwatch and a power meter or flowmeter. Simply observe if any compressors are cycling between the loaded and unloaded state. If so, measure the frequency by counting how many cycles are achieved over the 10 minute duration of the test. If it is more than 10 on-off cycles, then the compressor is short-cycling.

Blowoff is a state that will need to be observed rather than measured. This is sometimes used to limit flow delivered to a compressed air system, where the air is vented to the atmosphere. This is usually noisy and obvious, though compressors can be outfitted with silencers. For Centrifugal compressors, this is sometimes necessary to prevent surge (and compressor damage) when running at partial load. The reason for exhibiting blowoff at a particular compressor should be noted during the Functional Testing.

Functional Testing

Step 1: Verify that the methods from the Construction Inspection have been employed by confirming the following:

- *Compressor states can be observed and recorded for every compressor.*
  As documented in the Construction Inspection, ensure that the proper tools are installed and operational. Confirm that if external sensors are needed to determine the state of each compressor, they are calibrated. The power meter and flow meter should read levels that are at or below the rated power input and air capacity, respectively (as recorded in Form NRCA-PRC-01-A).

- *The current air demand (in acfm) can be measured or inferred.*
  The easiest way to accomplish this is to install a flowmeter at the common header. This can be achieved by other methods, but this will need to be documented in the Notes section of Form NRCA-PRC-01-A.

Step 2: Run the compressed air supply system steadily at as close to the expected operational load range as can be practically implemented for a duration of at least 10 minutes. Verify the following:

- *System is running steadily for at least 10 minutes.*
  It is the intent to observe a system running normally and at steady state.

- *System is running near to the expected operational load range.*
  Confirm that the controls are operating as expected. Running the system in the typical operational range is one way to accomplish this intent, though will require

some communication with the plant manager to get an idea of this range. For example, does the system typically operate closer to 40-50% or 80-90% of the total online system capacity?

- *Downstream equipment is not affected by a test valve being open, if applicable.* Running a system steadily may be difficult without a valve installed near a common header (in the distribution system upstream of the demand side of the system) that will release air to the atmosphere. If a test valve is not used, it's recommended that the plant manager be contacted to determine a good time during the day when the system will be running steadily for a period longer than 10 minutes. For the case with a test valve, the pressure may drop below what is safe for some equipment. If there is equipment that must be running during the time of the test, take this into account when deciding how to perform the test.

If it is not possible to achieve a steady air demand for a 10 minute period of time, document the reason why and observe the state of the compressors during the 10 minute test. Observe any anomalies and document this in the Notes section.

Step 3: Observe and record the states of each compressor and the current air demand during the test.

Fill out the table for Step 3 in Form NRCA-PRC-01-A. If any state is difficult to determine, then document your specific observations and measurements in the Notes section.

Step 4: Confirm that the system exhibits the following behavior following the test:

- *No compressor exhibits short-cycling*
  If any compressor was cycling between loaded and unloaded during the test, and if the number of on-off cycles exceeds 10, this portion of the test fails. Circle N in Form NRCA-PRC-01-A.

- *No compressor exhibits blowoff*
  If any compressor is venting pressurized air to the atmosphere, this portion of the test fails. Circle N in Form NRCA-PRC-01-A

- *The trim compressors are the only compressors partially loaded, while the base compressors will either be fully loaded or off by the end of the test. (only applicable for new systems)*
  This is a requirement for new systems because these systems are required to have properly sized trim compressors. If the new systems are designed properly, the controls should operate in a manner that has the trim compressors responsible for the trim load on top of fully loaded base compressors.

  If any compressor is in the Partially Loaded state that is not a trim compressor, this portion of the test fails. Circle N in Form NRCA-PRC-01-A.

  If this is not a new system, Circle NA in Form NRCA-PRC-01-A.

Step 5: Return system to initial operating conditions.

CERTIFICATE OF ACCEPTANCE		NRCA-PRC-01-F
Compressed Air System Acceptance		(Page 1 of 3)
Project Name:	Enforcement Agency:	Permit Number:
Project Address:	City:	Zip Code:

Note: Submit one Certificate of Acceptance for each system that must demonstrate compliance.	Enforcement Agency Use: Checked by/Date:

Intent:	Verify that compressed air system controls are installed and operating correctly.

Construction Inspection

1. Supporting documentation needed to perform test includes:
   a. 2013 Building Energy Efficiency Standards Nonresidential Compliance Manual *(NA7.13 Compressed Air Systems Acceptance At-A-Glance).*
   b. 2013 Building Energy Efficiency Standards (*Section 120.6(e)*).
2. Instrumentation to perform test may include, but is not limited to:
   a. Power meter(s) for every compressor
   b. Pressure transducer(s) for every compressor
   c. Flow meter(s) for every compressor
3. Installation: (**all** of the following boxes must be checked)
   - ☐ Equipment installation is complete (including compressors, storage, controls, conditioning equipment, piping, etc.)
   - ☐ Compressed air system is ready for system operation, including completion of all start-up procedures per manufacturer's recommendations.
4. Prior to functional testing, fill out the System Specifications Table. If the number of compressors exceeds the number in this list, please list additional compressors and specifications in the Notes section.
5. Prior to functional testing, document below the method and tools for observing and recording the states of each compressor in the system, as seen in Step 3 of Functional Testing.

Method for Observing and Recording Compressor States:

System Specifications Table

Total Online System Capacity (acfm): | **Operating Pressure (psi):**

Compressor Specifications:

Compressor	**Size (hp)**	**Rated Capacity (acfm)**	**Control Type (check one or fill-in for 'Other')**					**Acting as Trim Compressor?**
			Fixed Speed	***Variable Displacement***	***Variable Speed***	***Centrifugal***	***Other***	
1								Y / N
2								Y / N
3								Y / N
4								Y / N
5								Y / N
6								Y / N
7								Y / N
8								Y / N
9								Y / N
10								Y / N

If number of compressors exceeds 10, please list the additional compressors with specifications in the following Notes section.

Notes:

CERTIFICATE OF ACCEPTANCE		NRCA-PRC-01-F
Compressed Air System Acceptance		(Page 2 of 3)
Project Name:	Enforcement Agency:	Permit Number:
Project Address:	City:	Zip Code:

A.	**Functional Testing**	**Results**
Step 1: Verify that the methods from the Construction Inspection have been employed by confirming the following:		
a.	Compressor states can be observed and recorded for every compressor.	Y / N
b.	The current air demand (in acfm) can be measured or inferred.	Y / N
Step 2: Run the compressed air supply system steadily at a load within (or close to) the expected operational load range as can be practically implemented for a duration of at least 10 minutes. Verify the following:		
a.	System is running steadily for at least 10 minutes.	Y / N
b.	System is running within (or close to) the expected operational load range.	Y / N
c.	Downstream equipment is not affected by test valve being open (if applicable).	Y / N / NA

Step 3: Observe and record the operating states of each compressor and the current air demand during the test.							
				Current Air Demand (acfm)			
	Compressor States *(Check one)*				**Compressor States** *(Check all that apply)*		
Compressor	***Off***	***Unloaded***	***Partially Loaded***	***Fully Loaded***	***Blowoff***	***Short Cycling***	**Notes:**
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
If number of compressors exceeds 10, please list the additional compressors with specifications in the Notes section.							

Step 4: Confirm that the system exhibits the following behavior following the test:		
a.	No compressor exhibits short-cycling (loading and unloading more often than once per minute).	Y / N
b.	No compressor exhibits blowoff (venting compressed air at the compressor itself).	Y / N
c.	The trim compressors shall be the only compressors partially loaded, while the base compressors will either be fully loaded or off by the end of the test. (only applicable for new systems)	Y / N / NA
Step 5: Return system to initial operating conditions.		Y / N

B. Testing Results	**PASS**	**FAIL**
Step 1: Verify construction inspection steps are complete (all answers are Y).		
Step 2: Run system steadily at operational load range for 10 minutes (all answers are Y or NA).		
Step 3: Record all observed states of the compressors and system demand (Table is filled out).		
Step 4: System exhibits expected behavior (all answers are Y or NA).		

CERTIFICATE OF ACCEPTANCE		NRCA-PRC-01-F
Compressed Air System Acceptance		(Page 3 of 3)
Project Name:	Enforcement Agency:	Permit Number:
Project Address:	City:	Zip Code:

C.	Evaluation:
☐	PASS: All **Construction Inspection** responses are complete and all **Testing Results** responses are "Pass"
Notes:	