CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Draft Measure Information Template – Compressed Air Systems

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team, April 2011

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1. Purpose

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 load (like a variable-speed drive (VSD) compressor) to serve as a relatively efficient trim (ie part load) compressor. 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 building departments, contractors organizations, and other related industries and the California Energy Commission (CEC) into account.

This is a preliminary draft version of the CASE Report. A final version will be completed by Summer/Fall 2011.

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. 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 a 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 redress 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 those compressors is for the system operators to base those individual 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 avoid this by ensuring that at any given time the most appropriate set of compressors is being used to meet the current demand. At most a single compressor will be operating in an inefficient regime (and if paired with the trim compressor measure 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 of this 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. Compressed air systems are not currently covered by Title 24.

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.

Statewide savings estimates are still being refined and could depend strongly on several points still being negotiated with stakeholders. 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. 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.

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 fifteen year expected lifespan would not be unreasonable. Control performance is not expected to decrease with age. The impact 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 and with proper maintenance compressors can last decades.

2.8 Performance Verification of the Proposed Measure

At this time no specific acceptance test is recommended beyond simple verification that the compressor and control models installed match the submitted forms.

2.9 Cost Effectiveness

Smart controls (in multi-compressor systems) and efficient trim compressors are cost effective in the vast majority of practical scenarios. In order to be not cost effective a system in regular use would need to have a very constant rate of flow demand. Furthermore, that demand would need to be very accurately predicted before system installation, the system would need to be precisely sized with very little extra capacity, and the system demand would need to remain unchanged over the course of several years. 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. Furthermore, 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 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 is expected to be released in late 2011. The standard will provide guidance and best practices, 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, and cycling dryers, to 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;

As this would be the very first time many of the users and manufacturers would be required to take into consideration and comply with Title 24 requirements, it was deemed very important to emphasize simplicity. This point was raised repeatedly by stakeholders from the very beginning of this process. As such 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 steady efficiency across an expansive load range. This analysis considered the option of increasing storage as a way of achieving this. After the analysis was done and review from stakeholders, it was determined that this option does not achieve the same scale of savings as VSD compressors and is not applicable to every compressor. The results of this analysis, however, are still presented in this draft. To allow for flexibility, the code change language was updated to require a trim compressor with a relatively constant specific power across a broad load range rather than limiting the options to one or two types of technology.

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 each individual system and there exists no ‘typical’ system to use as a model. In order to address this, a set of conservative systems were 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 which greatly outweigh this cost. If cost effectiveness can be shown for the conservative cases, then the measure is cost effective in the vast majority of 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 the two configurations.

The Team used AirMaster+ to model energy savings because it is the industry-accepted standard modeling tool and it is 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.

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.

Furthermore, auto-shutdown timers, which turn a compressor off after it has been unloaded for a certain amount of time, 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.

However, 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 1 describes the representative systems used in the energy savings analysis, including compressor models and other hardware. Figure 1 presents the load profiles that were modeled.

	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

Table 1: Specifications of Representative Systems

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 on the weekend, this slight variation is a very small proxy for any deviation from expectations: 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.

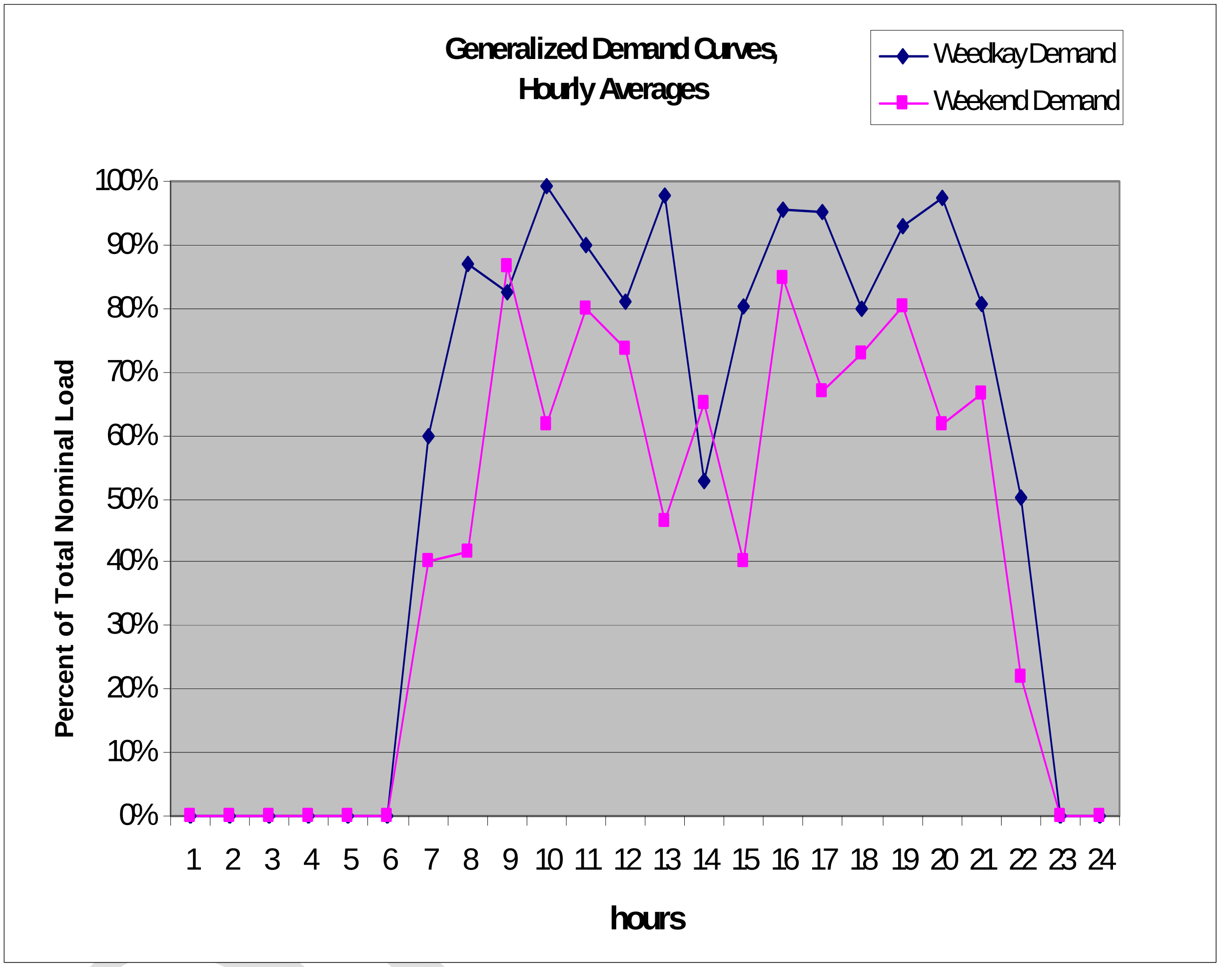

Figure 1: Modeled load profiles

3.2.2 Costs

Measure Costs

The incremental cost to add smart controls is the full cost to install a control system. Costs 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 (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.

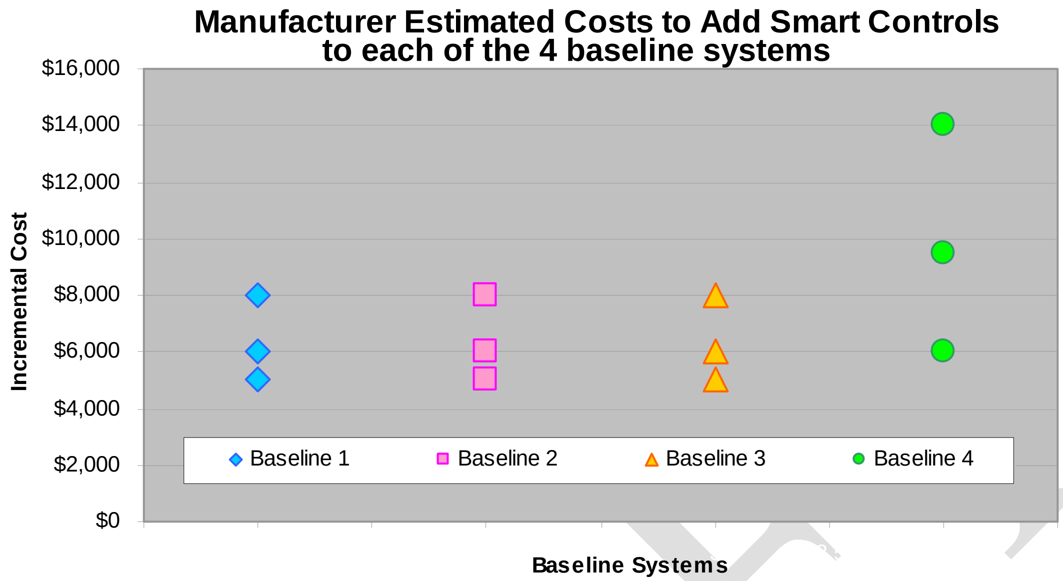

Figure 2: Cost to install a system to meet the minimum requirements of the smart controls measure for the 4 baseline systems as estimated by three manufacturers.

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.

3.3 Trim Compressor Requirements

This analysis focuses on the requirement for compressed air systems to include a compressor with a relatively constant specific power across a broad range of load to serve as a relatively efficient trim compressor. There are a variety of ways of achieve this, but this analysis looked at two: first, with a VSD compressor and second, by increasing the storage for a constant speed load/unload compressor.

3.3.1 Energy Savings

To determine the energy savings of requiring 1) a VSD motor driven compressor as the trim compressor or 2) 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.

Profile 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.

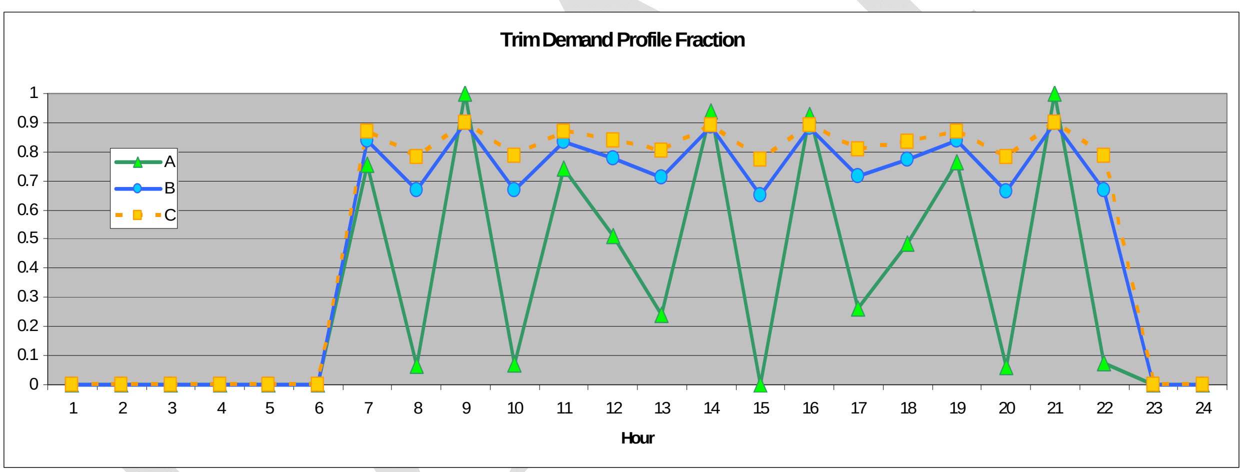

Figure 3: Trim Load Profiles (scaled) for use in energy analysis of trim compressor measures.

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. This is determined to also be a conservative assumption, as typical practice is 1 gal/cfm of storage without intervention from an energy auditor.

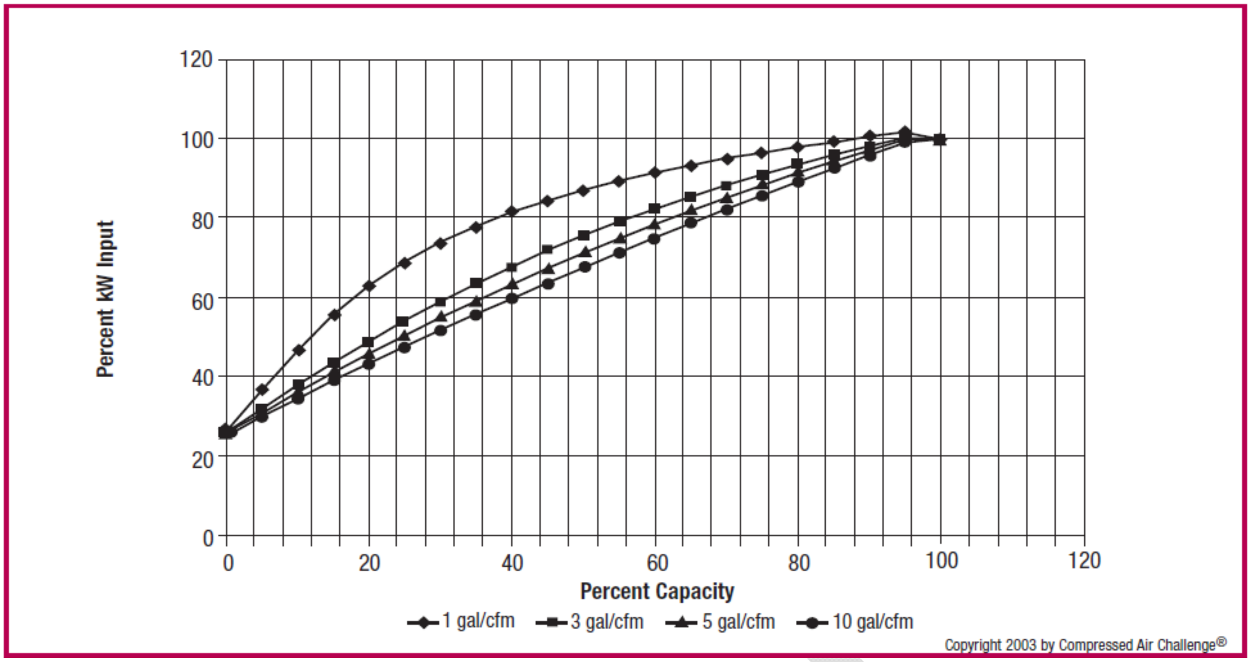

Figure 4: Percentage of energy input vs. capacity for lubricant-injected rotary screw compressors with varying amounts of storage. (CAC Sourcebook, 2003)

Given the expected load and the performance curves, the power (kW) input required by either a rotary screw 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 is needed to find time-dependent valuation savings, as described earlier in this section.

3.3.2 Costs

Based on the methodology for energy savings, the CASE team compared the average cost of a rotary screw compressor with the average cost of a similarly sized VFD 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.

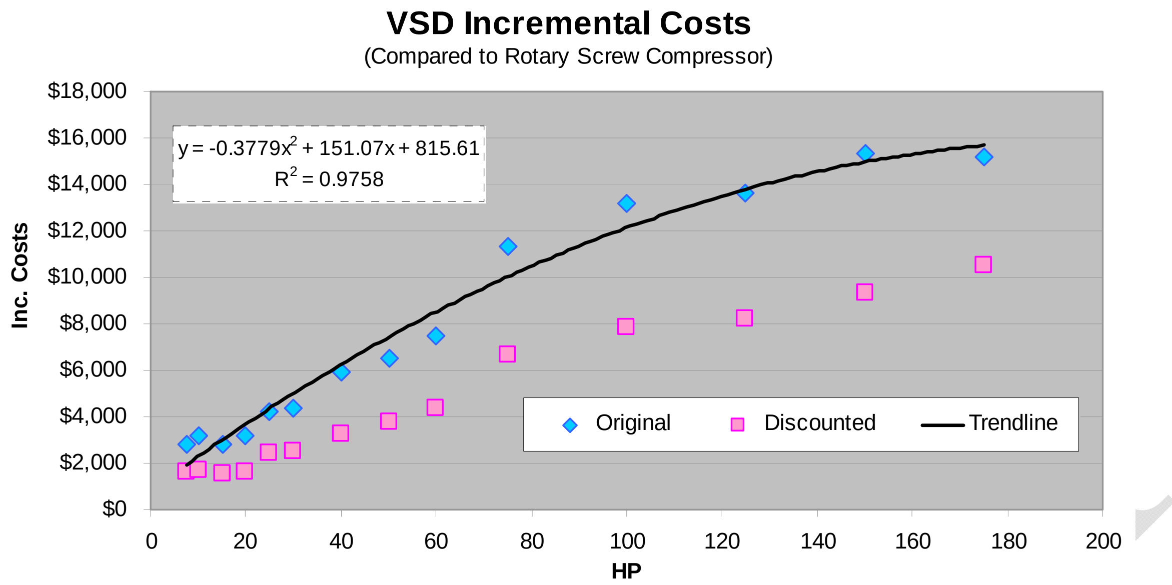

Figure 5: Incremental costs between a VSD compressor and a lubricant injected rotary screw compressor.

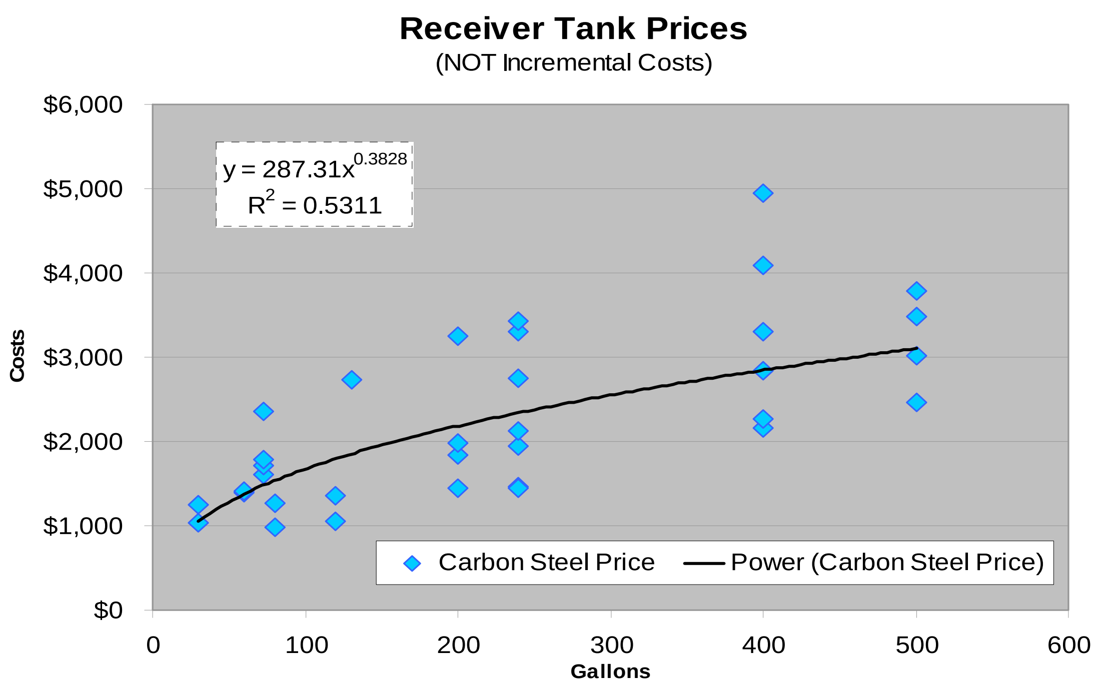

Figure 6: Costs for various carbon steel receiver tanks.

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 a receiver tank. 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.

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 too aggressive 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 considerably greater savings that can be realized with a single deviation from the conservative case.

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).

	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)	47,6072	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*

Table 2: Energy savings for implementing smart controls on 4 baseline systems. Italicized values will be used in cost-effective analysis.

4.1.2 Costs

The incremental costs for each baseline system are summarized in Table 3. 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 (which are 2 compressor systems) have the same incremental costs.

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

Table 3: Incremental costs for smart controls, averaged.

4.1.3 Cost Effectiveness

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

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

Table 4: Cost Effectiveness analysis.

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 7 and Figure 8 for both VSD compressors and increased storage.

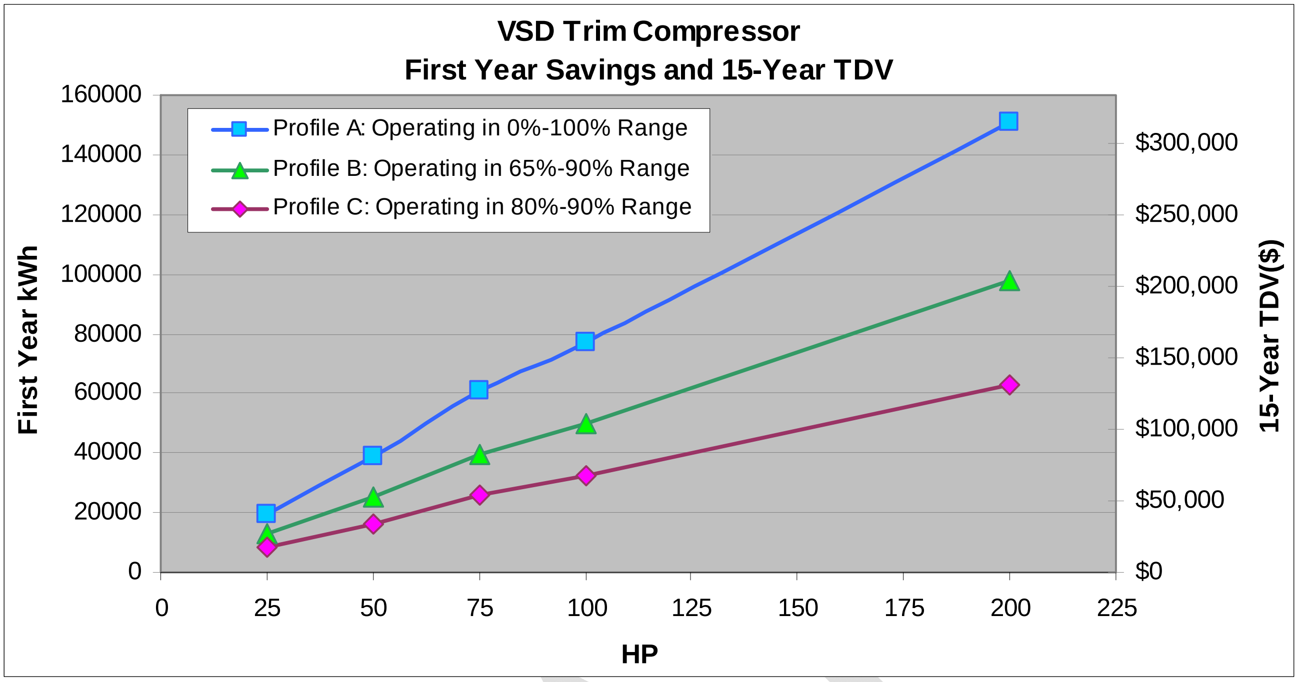

Figure 7: First-year energy savings and 15-year TDV $ savings from replacing the constant speed trim compressor with a VSD compressor.

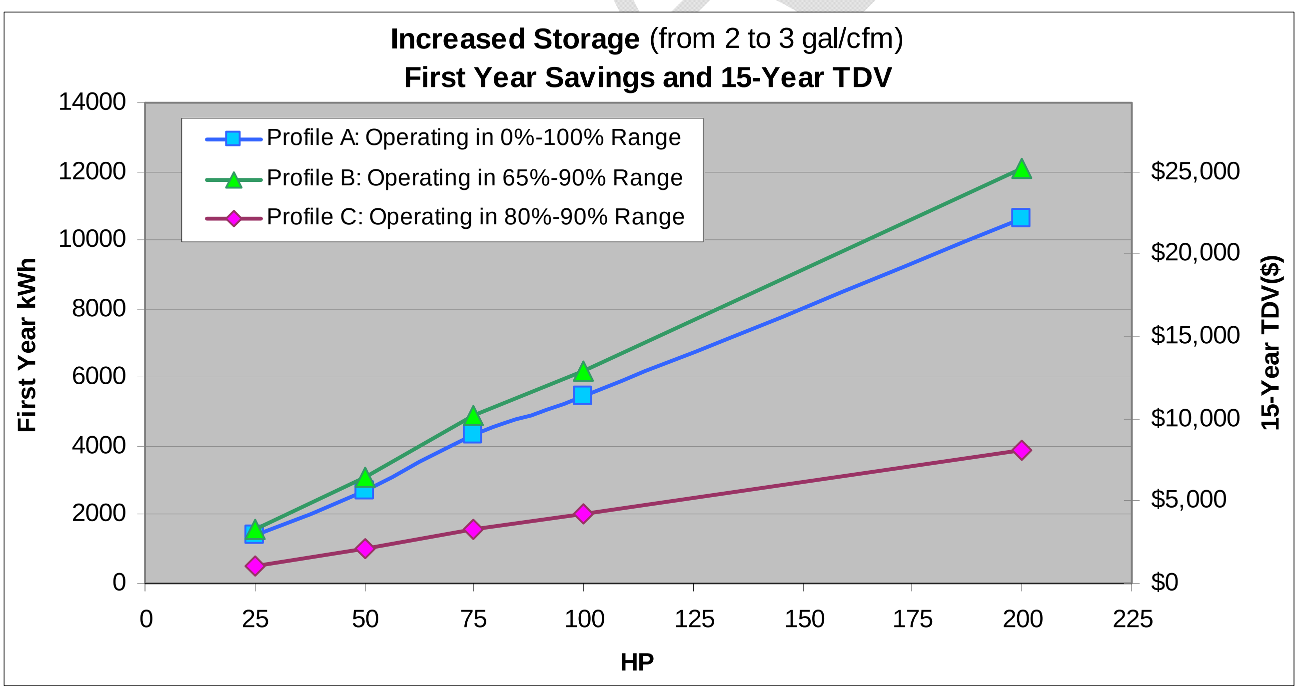

Figure 8: First-year energy savings and 15-year TDV $ savings from increasing storage (2 gal/cfm to 3 gal/cfm).

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.

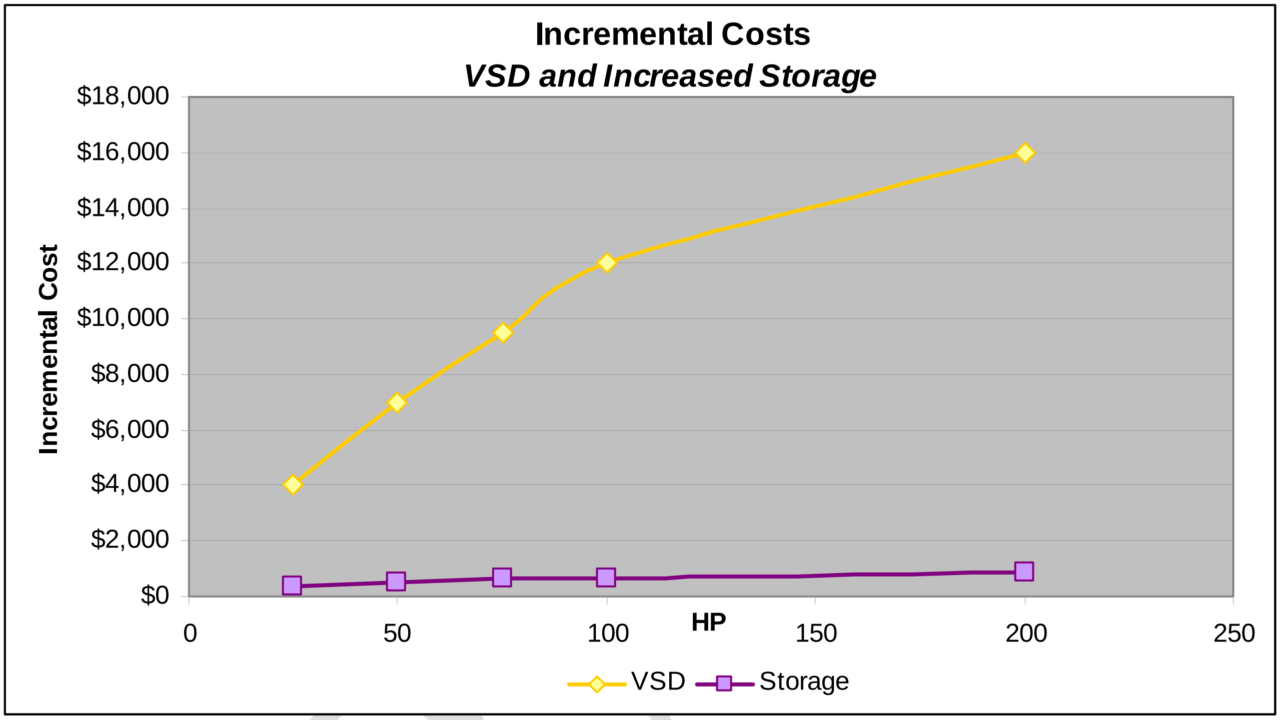

Figure 9: Incremental costs for VSD compressors and increased storage.

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 after weighing considerable stakeholder feedback, the CASE team is proposing to require high part load performance (easily achieved by VSD compressors) and to not provide an exception for systems with increased storage.

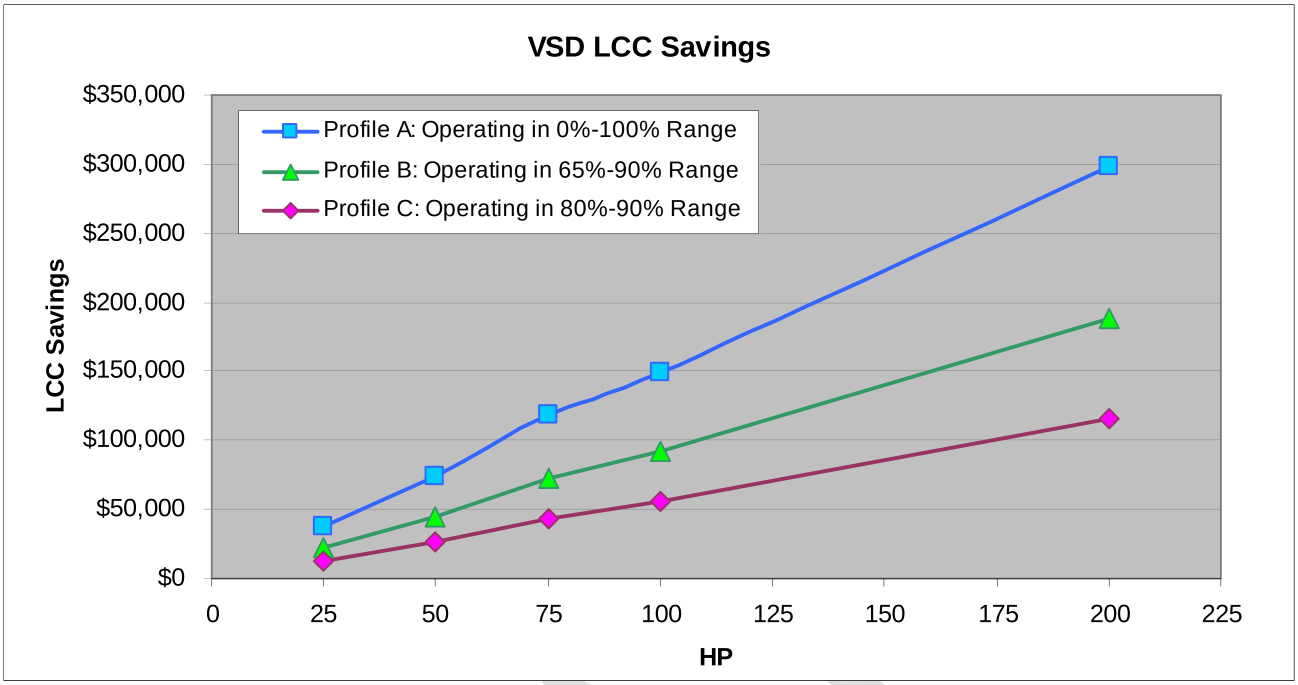

Figure 10: LCC Savings for VSD Trim Compressor

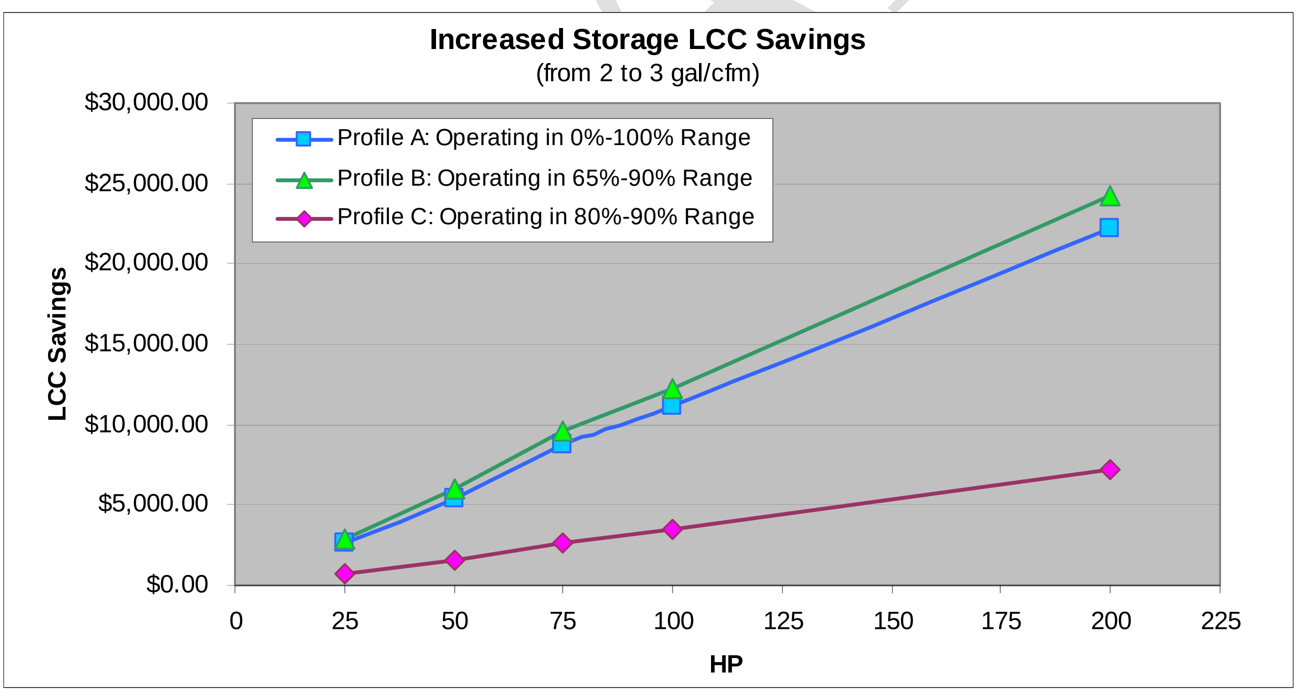

Figure 11: LCC Savings for Increased Storage

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.

SECTION 127 – MANDATORY REQUIREMENTS FOR COMPRESSED AIR SYSTEMS

A compressed air system with a total system power of 25 horsepower (hp) or larger shall meet the requirements of this section. This section applies to construction projects for which an application for a building permit or renewal of an existing permit is filed (or is required by law to be filed), and where the total combined horsepower of the compressors is increased.

(a) **Controls Requirements**. Compressed air systems with more than one compressor must operate with a 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.

EXCEPTION to Section 127(a): Compressed air systems with a total system horsepower of 100 hp or less.

(b) **Trim Compressor Requirements**. Compressed air systems shall include at least one compressor capable of maintaining 22 kW or less of input per 100 acfm of output throughout the usable trim load of the system.

EXCEPTION to Section 127(b): Compressed air systems in existing facilities.

In addition to the new code in this section, we also propose the following definitions be added to Section 101(b).

CURRENT AIR DEMAND refers to a measurement of total airflow necessary for end use in a compressed air system at the current instance in time, usually measured in actual cubic feet of air per minute (acfm).

PART-LOAD OPERATION occurs when a loaded air compressor is not functioning at maximum rated capacity, where constant speed compressors are the most efficient.

TRIM COMPRESSOR is ideally the only compressor that is at part-load operation, handling the variable trim load of end uses. The trim load is the variable portion on top of the base load (which is handled by base load compressors in a compressed air system with more than one compressor).

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.
3. Smart controls do not save energy for systems with a constant load profile.	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.
4. VFDs are not cost-effective for systems with a constant load profile.	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 VFDs 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 VFD. In response to additional stakeholder input (addressed below), the CASE team decided against allowing this option.
5. Leaks are a large opportunity for energy savings.	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.

6. Increased storage should not be a comparable (or available) option in place of requiring a VFD compressor. There is also concern about this providing a loophole.	This feedback was taken into account and increased storage is no longer being proposed.
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.	
8. Spiral Valve control is more efficient at a higher range as compared to VFDs. Why not require this as an option in place of VFDs?	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

To be completed…